Preface

This volume contains the papers presented at the ASC2022: 58th Annual Associated Schools of Construction International Conference held on April 20-23, 2022 in Atlanta, Georgia hosted by Georgia Institute of Technology and Kennesaw State University.

There were 147 submissions. Each submission went through a double-blind review process and was reviewed by an average of 2.4 external reviewers and 2 program committee members. Based on the review process 93 papers were accepted for an acceptance rate of 63%. Publication in the ASC proceedings represents an important milestone of accomplishment for the authors due to the rigorous review process.

The *ASC International Proceedings of the Annual Conference* provides for the dissemination of research that enhances and improves teaching and learning processes within construction education and construction practice. Papers submitted to the Annual Proceedings contribute to understanding of the issues, problems, and research associated with the construction industry and construction education. The *Proceedings* is published once each year for the international conference.

The editor would like to thank the ASC Board of Directors, Associate Proceedings Editors, the ASC Webmaster Carlos Sterling, and especially the External Reviewers that graciuosly volunteered their time to provide constructive reviews of the submitted papers. It is the efforts of all these individuals that make these proceedings possible.

April 7, 2022
Auburn

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Impacts of Covid-19 on Construction Industry 4.0 adoption and implementation within Southeastern US - An exploratory study

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The exploratory research assessed the Covid-19 impacts on Construction Industry 4.0 implementation during the first year of pandemic restrictions. The research used a case study approach with industry professionals as the unit of analysis geographically located in the southeast United States. Data was collected through a survey of industry professionals, capturing their views of individual and company competencies before and during the pandemic. The survey indicates the perceptions about the application of Industry 4.0 in construction have changed during Covid-19, from March of 2020 to March of 2021, and views on expected future utilization. The industry professionals were asked to describe their opinions of Industry 4.0 abilities and how they changed during the pandemic. That data was then assessed through qualitative and quantitative analysis and supported the research aim. BIM, Big Data, and Analytics were shown to be where most professionals felt company reliance increased during the pandemic. The analysis also indicates that most participants expect a future increase in their company's support on Industry 4.0. The response to Covid-19 has changed the perceptions and implementation of these methods within construction.

Key Words: Construction Industry 4.0, Covid-19 Impact, Construction Pandemic, Industry 4.0 (I4.0), Construction after Covid-19

Introduction

The construction industry is the fourth most significant contributor to the country's Gross Domestic Product (GDP) (Trading Economics, 2021). In the fourth quarter of 2020, United States GDP from Construction reached $673B (Trading Economics, 2021). Construction companies have experienced the effects of Covid-19 restrictions in ways that could be unforeseen, such as shortages in labor, increased material cost, and others (BLS 2020). The pandemic caused the industry to analyze these new risks/uncertainties while developing real-time responses. Industry 4.0 offers several solutions to combat the risks associated with project scheduling and delivering projects, considering the workforce shortage before Covid-19 (AGC 2021). Industry 4.0 technology's connection to Construction and Manufacturing results in it being an essential component to the future development of the US economy. "*The growth of the construction industry subset of the universal set of the gross domestic product value; thus, Industry 4.0 has a spillover effect on the engineering and construction industry*." (Maskuriy et al., 2019).

Traditionally, the construction industry has been slow to respond to technology (Cao et al., 2014; Eagan 1998). The engineering and construction sector has not kept pace in terms of technological opportunities that can help improve production and in the stagnation of labor productivity (Maskuriy et al., 2019). Various external pressures (coercive and mimetic) impact the adoption and implementation of technologies supporting Industry 4.0 (Cao et al., 2014, Maskuriy et al., 2019). New restrictions with pandemics changed the operational paradigm for construction companies and professionals, and integration among project teams became more than an ever-important part of operations.

Schönbeck et al. (2020) describe Construction Industry 4.0 as the inclusion of new technologies in the design, engineering, and construction industry, similar to Industry 4.0 (I4.0) for the manufacturing industry. The fourth revolution evolved with the maturity and interaction of automation, electrification, and digitization to improve the industry with more benefits (Schönbeck et al., 2020). Osunsanmi et al. (2020) also discovered that some of the outdated methods for information sharing among construction professionals are elements that cause a building project to be delayed. Video conferencing, cloud, and automation, among other tools, fall under Industry 4.0 (Maskuriy et al., 2019). Adopting current techniques of I4.0 will improve the effectiveness of information sharing during the construction phase.

Background

Construction entails many people with a wide range of interests, skills, and backgrounds. The essential construction stakeholder includes owners, designers, contractors, subcontractors, material suppliers, bankers, insurance and bonding agencies, attorneys, and the general public (Maskuriy et al., 2019). When Covid-19 restrictions arose in March of 2020, the construction industry was exposed to increased health and safety risks because of new social distancing laws that addressed site outbreaks and related labor shortages (AGC 2021).

Thus the global pandemic has brought into focus the need to assess previous, present, and future Industry 4.0 implementation and competencies. Industry 4.0 (I4.0) is a term that describes the fourth iteration of the Industrial Revolution. I4.0 introduces disruptive digital technologies that may help overcome traditional barriers in operations management (Tortorella et al., 2021). Construction industry 4.0 is defined as "*the application of Industry 4.0 to the construction sector*." (Construction 4.0, NAC Executive Insights) https://www.researchgate.net/publication/348690890_Construction-40 Construction Industry 4.0, at its core, describes the increased use of integrated cyber technology to improve construction project delivery. The technology is meant to enhance the activities required for construction, from manufacturing goods to team communication, and how information is shared at all stages of a construction project. In this regard, Construction Industry 4.0 can create more integrated site construction activities and improve communication among team members. Increased cloud computing focuses on better-centralized data sharing and applications while people work remotely. Furthermore, implementing site management in a virtual construction site can help enhance supply chain management by adequately tracking and monitoring personnel, equipment, and materials (Li and Yang, 2017).

The digital transformation is crucial to the construction industry's current challenge and includes such as automation, connectivity, digital data, digital access, Augmented Reality, Virtual Reality, BIM technology, and Artificial intelligence (Dallasega et al., 2018). Some of these components can add digital information of physical components, allowing sharing informations among stakeholders (project managers, owners, contractors, and designers). All the information needed for construction operations and model components may be simulated and retrieved in a real-world context, making site activities considerably easier to manage. With the digital information modeling platform's real-time cloud services, users can obtain real-time feedback on their future design decisions and plans via mobile applications such as smartphone applications. Further, Artificial Intelligence can analyze building, construction, and operational data and improve knowledge transfer, decision-making, and efficiency.

Furthermore, the implementation of Industry 4.0 in the construction industry is projected to boost productivity and profitability while also contributing to the development of the industry (Nowotarski and Paslawski, 2017). However, the historical lack of the construction industry’s adoption of innovation and technology is a concern. Thus, the exploratory research provided the perspective of construction industry support professionals on I4.0 into the pandemic restrictions. The objectives of this research include: 1) determine perceptions of construction professionals about the adoption and implementation of technologies supporting I4.0 and 2) determine the impact of Covid-19 on the adoption and implementation of technologies supporting I4.0.

Research Method

The exploratory study used an online survey method to determine the industry professionals' perception in the southeastern US for I4.0. Survey design can provide a snapshot at a particular point in time.The online survey was selected as it allowed for the best value to the research team, especially during a pandemic. The general population of the study was construction professionals, the supporting staff, and researchers associated with the construction industry. The sample of the population was geographically constrained to the southeastern United States. The instrument had questions covering four areas, including 1) perceptions of employer-organization use of Industry 4.0 technologies; 2) reliance on I4.0 methods changed during the first year of the Covid-19 pandemic (March 2020 to March 2021); 3) determine the changes knowledge changes in I4.0; 4) perceptions of professionals about their organization’s reliance on Industry 4.0 for future and benefits. The instrument consisted primarily of multiple-choice, multiple selections, and Likert scaled questions. Further, the instrument was designed so that respondents could complete the entire survey in approximately 5 minutes provided the respondent possessed all the information. The online instrument was distributed in April 2021. The survey was distributed via interpersonal channels such as LinkedIn. A total of 18 survey responses was received by April 20, 2021.

Data Analysis and Results

A series of filters were utilized, which included: 1) respondent geographical location (southeastern United States), 2) Respondent role; 3) Survey Completion. Based on the application of the filters, the number of respondents for the study decreased to thirteen. There was an almost equal distribution of respondents, with seven identifying as male and six as female. In addition, most of the respondents were born in the 1970s (Table 1).

Table 1: Respondent year of birth

Year of birth (Decade)	Response (No.)
1950s	1
1960s	2
1970s	4
1980s	3
1990s	3

Of the thirteen respondents, 2 had roles in Engineering, 4 in Sales, and 3 in Project Management. The remaining respondents were in Executive roles (2), Academic and researcher roles (1), or Finance (1).

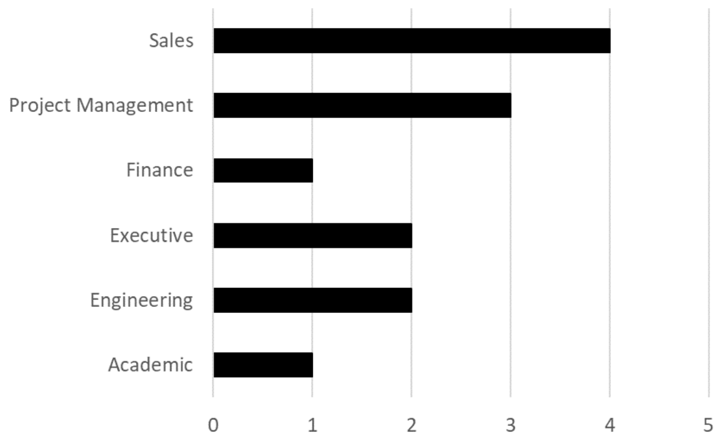

Figure 1: Respondent Industry Representation

From the perspective of respondent company size, the majority of the respondents have employed companies having 501-1000 employees and 1001-5000 employees (Figure 2).

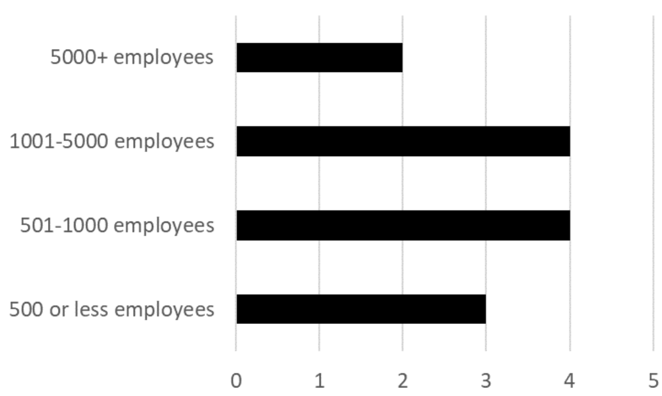

Figure 2: Respondent Company Size

Figure 3 indicates that all professionals who did not know I4.0 as of March 2020 would consider themselves a “Novice” after March 2021. Based on their knowledge of Construction Industry 4.0, respondents were asked to describe the aspects of Industry 4.0 that impacted their roles the most. Respondents identified seven aspects impacting their profession, including 1) Big Data and Analytics, 2) BIM, 3) Building Materials, 4) Customer Communications, 5) Employee Communications, 6) Manufacturing, and 7) Site Construction. As a result of Industry 4.0 impacts, respondents were also asked to select the areas of their business where reliance changed during pandemic restrictions. The same even areas of activities were provided as possible responses.

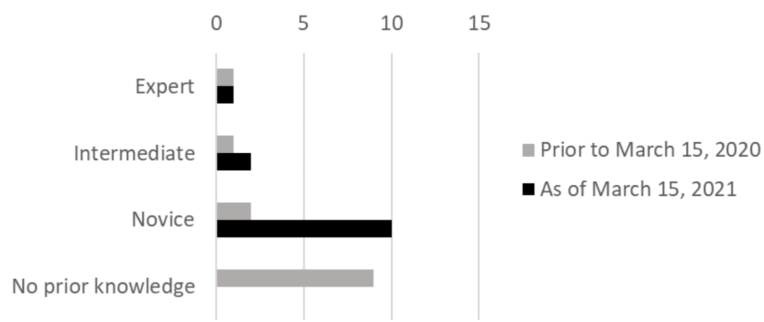

Figure 3: Respondent knowledge of Construction Industry 4.0 applications

The respondents were asked to assess their organization’s awareness of Industry 4.0 in construction before the pandemic restrictions that began in March of 2020. About half of the respondents felt that the company was unaware of any I4.0 methods (Figure 4). Of the participants who felt their company had some awareness, half felt their company had slightly integrated Industry 4.0 methods, and the other half felt that their company was “very integrated.” The next set of questions asked for opinions about how participants felt their company utilized construction I4.0 to respond to the pandemic restrictions. Also shown in Figure 4, participants were asked to describe whether their company’s reliance on I4.0 changed as of March 2021.

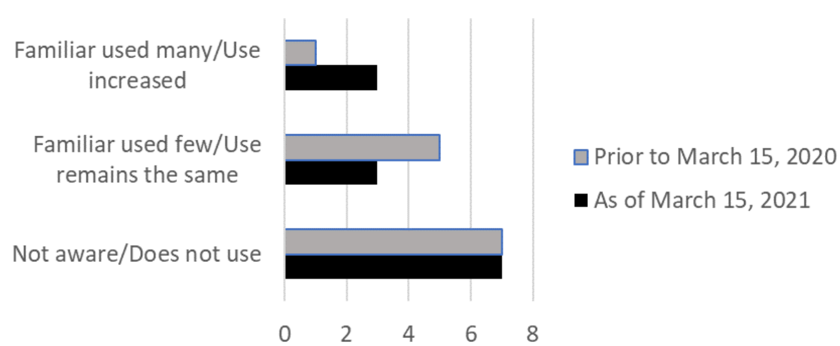

Figure 4: Integration and Reliance on construction I4.0 methods

Figure 5 shows the responses regarding Construction Industry 4.0 technologies selected in response to Covid-19. Use of Cloud applications was the most selected technology, with 9 of 14 respondents.

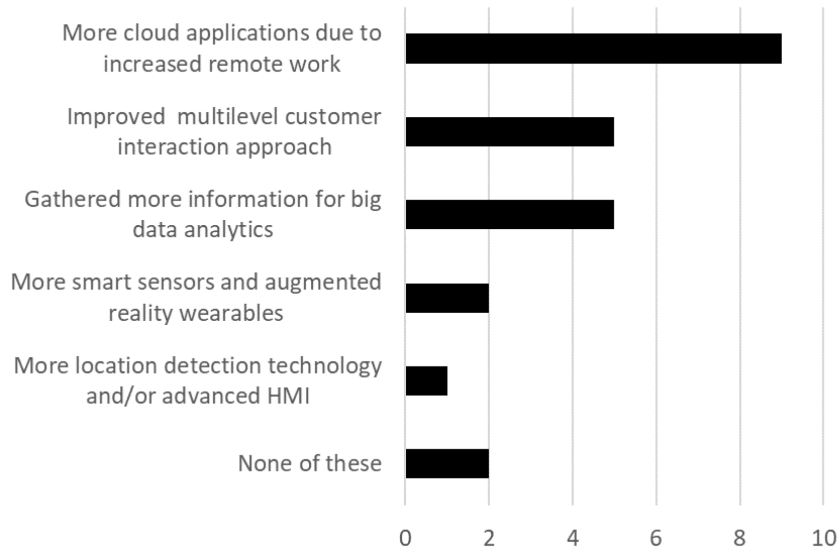

Figure 5: Construction Industry 4.0 technologies selected in response to Covid-19

Construction professionals felt that their employer's attitude changed toward I4.0 following one year of pandemic restrictions (Figure 6). More than half the respondents felt that their company did not make any attitude changes to I4.0 due to Covid-19, although they may be monitoring developments. Two respondents felt their company made changes in attitude towards I4.0 due to Covid-19.

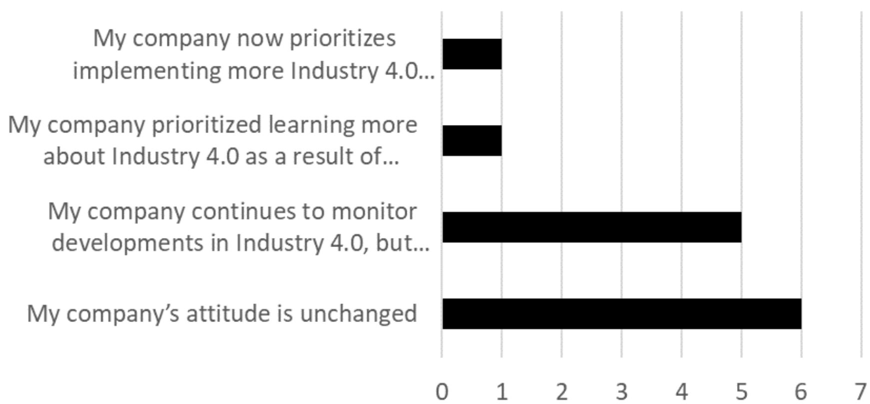

Figure 6: How has Covid-19 affected your company's attitude toward Industry 4.0?

In terms of the areas that would benefit from I4.0 integration in construction, most respondents felt that during the construction phase, the use of the cloud for Data Management would benefit from improved I4.0 competencies (Figure 7). Regarding changes in outcomes with a better understanding of construction I4.0, most respondents (61.5%) indicated a higher probability of a potential increase of I4.0 implementation (Table 2).

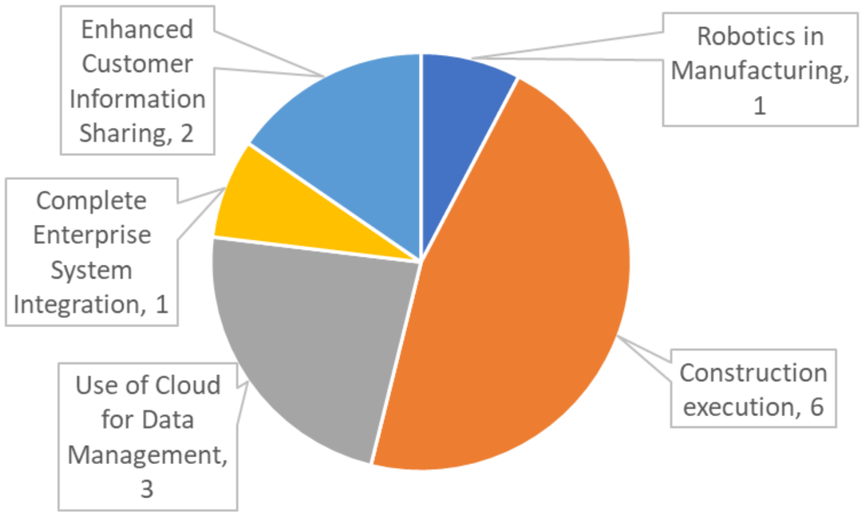

Figure 7: Areas where companies would benefit from improved I4.0 competencies based on survey respondents

Table 2: Potential Increase of Construction I4.0 Implementation (Respondent Number)

Definitely will	2
Probably will	8
Might or might not	2
Probably will not	1

Conclusion

The findings of the exploratory study are limited by the number of respondents that participated in the study, and arguments for generalizability cannot be made even for the Southeastern region of the United States. However, based on the responses, one can articulate and further investigate that the competencies of construction professionals have enhanced over the past year, which resulted in higher awareness of I4.0. One of the significant challenges with technology adoption could be a lack of awareness, as half of the respondents felt that the company was unaware of any I4.0 methods. Of the participants who felt their company had some awareness, half felt their company had slightly integrated Industry 4.0 methods, and the other half felt that their company was “very integrated.” Due to limited knowledge, it can be hypothesized company-wide competencies did not grow as expected because 50% of the companies continue not to utilize the available tools. However, the hypothesis that the lack of knowledge about I4.0 needs to be tested in future studies.

Nearly half of respondents did not see a change in their company’s attitude since March of 2020. Pandemic has increased reliance on the I4.0 methodologies out of necessity. Site construction and digital technologies (BIM/Data Analytics) saw substantial increases in focus, regardless of company size. The construction industry responded to Covid-19 was “use of more Cloud applications,” with 9 of 13 respondents. However, some respondents did not identify any I4.0 methods used to respond to

Covid-19. The use of the cloud for data management and site construction is recognized as an area that would benefit companies the most.

As the economic recovery begins, it will be interesting to see how much digital integration becomes a priority instead of a short-term response to Covid-19. The most positive sign of change was about Industry 4.0 in the future. A combined 75% of the participants felt they would see more I4.0 in the coming years. Based on the age demographics, which showed that 38.10% of the respondents were born in the 1990s, there is a high likelihood that future leaders will share this positive outlook. The power to change the trend of industry competencies will be within their control.

Limitations and Future Studies

The initial exploratory research findings are limited to institutional and commercial professionals, mainly in the Southeastern region of the US. This study can also be expanded to the entire US to determine the national patterns for adoption and implementation. Further, the data collected only reflects the opinions of professionals one calendar year after restrictions. Therefore, it would be beneficial to determine the adoption and implementation patterns among the construction companies post-return to normalcy. Since construction, in general, has been slow to adapt, monitoring the progress in the areas of construction site robotics, manufacturing robotics, big data and analytics, and intelligent sensors is imperitive. The top concern from the survey was “Site Construction,” “Customer Communications,” and “Big Data and Analytics”; however, the participants did not describe seeing changes in this area of implementation. Future studies need to depict how the industry has dealt with this concern.

References

Association of General Contractors (AGC). (2021). Construction workforce shortages reach pre-pandemic levels. Building Design & Construction. https://www.proquest.com/trade-journals/construction-workforce-shortages-reach-pre/docview/2569058082/se-2?accountid=4117

Buehler, M; Buffet, P; Castagnino, S. (2018) “ The Fourth Industrial Revolution is about to hit the construction industry. Here’s how it can thrive” June 2018. https://www.weforum.org/agenda/2018/06/construction-industry-future-scenarios-labour-technology/

Bureau of Labor Statistics (BLS). (2020). “Construction Sector - Workforce Statistics.” <https://www.bls.gov/iag/tgs/iag23.htm> Retrieved June 15, 2020.

Dallasega, P., Rauch, E. and Linder, C. (2018) ‘Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review’, Computers in Industry, 99(April), pp. 205–225.

Guilherme Luz Tortorella, Paulo A. Cauchick-Miguel, Wen Li, Jo Staines & Duncan McFarlane (2021) “What does operational excellence mean in the Fourth Industrial Revolution era?”, International Journal of Production Research, DOI: 10.1080/00207543.2021.1905903

Li, J. and Yang, H. (2017) ‘A research on development of construction industrialization based on BIM technology under the background of industry 4.0’, MATEC Web of Conferences, 100.

Liao, L., Teo Ai Lin, E. and Low, S.P. (2020), "Assessing building information modeling implementation readiness in building projects in Singapore: A fuzzy synthetic evaluation approach", Engineering, Construction and Architectural Management, Vol. 27 No. 3, pp. 700-724. https://doi.org/10.1108/ECAM-01-2019-0028

Livotov, P.; Sekaran, A.P.C.; Law, R.; Reay, D.; Sarsenova, A.; Sayyareh, S. "Eco-Innovation in Process Engineering: Contradictions, Inventive Principles and Methods"; Elsevier Ltd.: Amsterdam, The Netherlands, 2019; Volume 9.

Maskuriy, R.; Selamat, A.; Ali, K.; Maresova, P. and Krejcar, O. "Industry 4.0 for the Construction Industry—How Ready Is the Industry?" Appl. Sci. 2019, 9(14), 2819; https://doi.org/10.3390/app9142819

NAC Executive Insights, 2021 https://www.researchgate.net/publication/348690890_Construction-40

Nowotarski, P. and Paslawski, J. (2017) 'Industry 4.0 Concept Introduction into Construction SMEs', IOP Conference Series: Materials Science and Engineering, 245(5), pp. 0–10.

Osunsanmi, T. O. et al. (2020) 'Appraisal of stakeholders' willingness to adopt construction 4.0 technologies for construction projects', Built Environment Project and Asset Management, 10(4), pp. 547–565.

Schönbeck, P., Löfsjögård, M. and Ansell, A. (2020) 'Quantitative review of construction 4.0 technology presence in construction project research', Buildings, 10(10), pp. 1–15.

Trading Economics. "United States GDP From Construction." Int. https://tradingeconomics.com/united-states/gdp-from-construction.

Cao, D., Li, H., and Wang, G. (2014). "Impacts of Isomorphic Pressures on BIM Adoption in Construction Projects," *Journal of Construction Engineering and Management*, 140 (12), doi: 10.1061/(ASCE)CO.1943-7862.0000903.

Egan, J. (1998). *Rethinking construction*, Department of Trade and Industry, London.

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Effects of COVID-19 on the Safety Procedures Implemented in the Construction Industry: A Survey

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COVID-19 has significantly impacted the construction industry when it comes to the safety of workers. While the Occupational Safety and Health Administration (OSHA) has come up with some requirements for improving workplace safety for COVID, no study has been done on its effects on construction companies. The guide provided by OSHA talks about topics such as which workers are more at risk, how to stop the spread, and what Personal Protective Equipment (PPE) to use, but not about the overall effect it could have on workers. Also, as it is still quite a recent problem, there is not enough data for it. The purpose of the study is to assess the effects of COVID-19 on safety procedures in the construction industry. In this study, a questionnaire survey was used to collect important data about the safety-related issues faced by workers in the construction industry during COVID-19. The study mainly focused on the impacts of the virus on the safety of construction workers in the U.S. The collected data regarding the safety practices during COVID-19 provides some useful information that could be used to improve workers' safety in construction while keeping the business running.

Key Words: COVID-19, Construction Safety, OSHA Regulations

Introduction

COVID-19 has plunged the construction industry into the most challenging times. OSHA has been dealing with the safety of construction workers on one hand and coming up with protocols for COVID-19 on the other hand. This has somehow abetted the construction companies in curbing the spread of the COVID-19 virus. However, the current turbulent times can be an opportunity for companies to come up with a model that curtails the spread of the virus and be a benchmark for future challenges. Although OSHA recommendations have been relatively adopted as recommended by the CDC for the construction companies, little research has been done to address the impact of these recommendations.

The recommendations need to be assessed and evaluated, followed by a rational plan of action. To address this nominal gap, this study has analyzed data gathered using a survey questionnaire from 450 different construction-related companies in the U.S. This will give us an in-depth analysis of the best practices during COVID-19 and benchmark for other companies across the globe who are struggling with the safety of their employees during this unprecedented time. Moreover, this study is expected to help competent authorities in making prudent decisions for developing new protocols on construction sites.

Literature review

Although the overall construction industry took a plunge at the height of the COVID-19 pandemic, very little research is available on the effects of COVID-19 on the safety of construction workers. According to Amoah and Simpeh (2020), the COVID-19 epidemic has drastically changed safety protocols in the construction industry, better yet, every industry. In response, the construction industry has implemented rigorous safety measures the construction sites to slow the diseases spread among the construction industry. The researchers examine the construction workforce's challenges due to the unforeseen onset of the COVID-19 pandemic. Cates and Swanek (2020) find out that 87% of contractors report delays in projects at the onset of the COVID-19 pandemic. However, contractors are less concerned about delays in the future. Index results say that one in three contractors plan to hire more workers soon. The researchers state that the pandemic is also acting as a spark for technological change in the construction industry. While the industry took a hit at first, it seems as if it will bounce back in the end.

Gamil and Alhagar (2020) stated that many countries had declared a lockdown since the World Health Organization announced the Coronavirus pandemic. These decisions resulted in business shutdowns, including the construction industry. Their study investigates the effect of COVID-19 on the construction industry's survival. The study found the most prominent impacts of COVID-19 are the suspension of projects, labor impact and job loss, time overrun, cost overrun, and financial implications. According to Ogunnusi et al. (2020), the effect of this pandemic in these unusual times posed both positive and negative impacts in the Architecture, Engineering, and Construction (AEC) industry. Its effect has brought supply chain disruption, new policy issues, and worker anxiety. Its effect has also brought about innovative and diverse use of technology in an ideal manner which may change the course of construction even after the extinction of coronavirus.

Pasco et al. (2020), the decision of resuming construction work during shelter-in-place orders was associated with increased hospitalization risks in the construction workforce and increased transmission in the surrounding community. According to the study, the allowing of unrestricted construction work was associated with an increase in COVID-19 hospitalization rates. Clark (2020) stated that communicating with your employees during COVID-19 is essential to keeping them safe, informed, and productive as they adapt to sudden and unexpected changes. According to Clark, with things changing rapidly, it can be hard to know what to say when things will return to business-as-usual. Clark suggested nine ways to communicate: communicate early and often, stay focused, be clear, reinforce your values, establish a single source of truth, assign authority, involve people managers, show care, and provide two-way communication.

D'Auria and DeSmet (2020) stated that COVID-19 had posed challenges in communicating with all people of interest. The researchers go into five behaviors to help leaders navigate the pandemic and recovery: organization, remaining calm, making decisions with optimization, demonstrating empathy, and communicating effectively.

Goodman (2020) stated that the coronavirus crisis changed the construction industry immediately, and some of the implementations put in place will be around even after the pandemic decreases in magnitude. As the industry prepares to hit the ground running, they will be faced with new challenges because of COVID-19. This article goes into eight ways that the coronavirus has changed the construction industry. According to Associated General Contractors (AGC) of America (2020), construction employment has declined by 975,000 jobs in April of 2020. AGC stated that the construction industry is not immune to the economic impact being caused by COVID-19. Without Federal funding, it is hard to predict when and if the industry will be able to recover anytime soon.

Alsharef et al. (2021) believe that the COVID-19 pandemic had been the largest global health crisis in decades. Apart from the unprecedented number of deaths and hospitalizations, the pandemic has resulted in economic slowdowns, widespread business disruptions, and significant hardships. The safety measures adopted to mitigate COVID-19 included: requiring employees to wear cloth face masks, social distancing protocols, staggering of construction operations, offering COVID-19-related training, administering temperature checks prior to entry into the workplace. Belingheri et al. (2020) stated that healthcare workers have an increased risk of contracting COVID-19, but a recent study has reported that other workers may also be exposed to the coronavirus, including staff in tourism, retail and hospitality industries, transport and security workers, and construction site workers. Considering the current situation and the ongoing spread of COVID-19, action needs to be taken for all work fields. Physicians and other Health Care Workers are generally used to implementations regarding the containment of a disease. While generally, people in other fields of work are less accustomed to these practices. This research looks to provide information to assist in slowing or stopping the spread of COVID-19 in non-health care-related fields.

Stiles et al. (2021) stated that construction has been significantly affected by COVID-19 and is critical to economic recovery. The construction industry needs to be diligent in safety and risk mitigation in pair with timely project delivery. Therefore, an ordinance for COVID-19 must be implemented so that the industry can keep running while keeping people safe. There is not a lot of knowledge on this issue, though. The researchers stated that some safety implementations are more difficult to follow because of projects' temporary duration and phases. Pamidimukkala et al. (2021) indicated that COVID-19 has completely shifted how people work. These shifts have been in the form of distance. Most office workers are able to work remotely. Factors such as isolation, home situations, and job stability often contribute to anxiety and depression. This study looks to identify the challenges accompanied by COVID-19 in the workplace and how to mitigate these challenges to positively impact the health and safety of workers.

Simpeh and Amoah (2021) find that most construction companies have instituted measures to curb the spread of COVID-19 on-site. Additionally, some companies have implemented extra protocols to mitigate the spread of COVID-19 on the jobsite. Few construction companies were lacking in these preventive measures. Data shows that points of weakness for COVID-19 mitigation on the jobsite were jobsite screening, handling of materials and equipment, and jobsite deliveries. These are areas where improvement is necessary to help curb the spread. Olukolajo et al. (2021) indicated that construction workers' outlook on COVID-19 could be the key to mitigation or another lockdown. The researchers surveyed onsite construction workers. The findings show that the preventive measures to mitigate COVID- 19 can be classified into the groups as follows: personal protective measures, etiquette, contact precautions, and prompt actions. The workers taking the survey stated to be aware of the pandemic. However, their temperament towards the preventative measures implemented on constructions sites is daunting.

Bsisu (2021) stated that the lockdown resulting from the COVID-19 pandemic has caused Civil Engineering design offices to work remotely. The pandemic has also caused continuing construction projects to come to a halt. An online questionnaire was posed to Jordanian personnel about their perception of the lockdown. Those design engineers were able to work from home with efficiency, while site engineers and construction workers could not say the same. Site engineers do not believe that construction workers will adhere to the guidelines implemented to mitigate the virus after the lockdown is lifted. Dennerlein et al. (2020) conducted a study to create an integrated work approach to support worker safety, health, and well-being during the COVID-19 pandemic. Emerging workplace recommendations were investigated for reducing workers' exposure to COVID-19 and the challenges posed to workers in protecting their health. The recommended approach includes six characteristics: focusing on work conditions for infection control; identifying daily challenges; collaborative efforts to increase efficiencies; committing as leaders to supporting workers; adhering to ethical standards, and using data to evaluate progress.

Araya (2021) indicated that as the spread of COVID-19 has continued, stay-at-home orders have been placed around the globe. While some jobs can be completed virtually with little to no change, this is not the case for all. Construction cannot be easily completed virtually. The construction industry makes up approximately 13% of the Global GDP. Therefore, having the ability to perform construction tasks while minimizing the spread of COVID-19 will help with the financial response of the pandemic. This study aims to understand the potential impact of COVID-19 on construction workers using an agent-based modeling approach. Activities are classified as being low, medium, and high risks for workers. The simulation found that the workforce may be reduced from 30%-90% on a given construction project due to the spread of COVID-19. Understanding how COVID-19 may spread among construction workers may help project managers to create adequate mitigation techniques to reduce the chances of infection. Bushman et al. (2021) investigated COVID-19 outbreaks at two separate construction sites. Difficulty in following the Interim COVID-19 Guidance for Construction set in place by the New York State Department of Health was reported. To minimize outbreaks, the researcher concluded that jurisdictions should increase specific implementations, emphasizing infection prevention.

The literature review reveals that there is no information about business support programs such as the Payback Protection Program. Payback Protection Program is a loan that helps businesses keep their workforce employed during the COVID-19 crisis. This loan is provided by the US Small Business Administration. This study will survey safety measures during COVID-19 in the U.S. construction industry, including the effect of the Payback Protection Program to keep businesses operating during COVID-19. The next section will discuss the survey process and results.

Safety Practices Survey

The survey targeted people from various age groups, different experiences, and different job titles. Survey Monkey was used to distribute the survey. The first set of questions was demographic (3 questions). The second set of questions was technical and targeted best practices used in the construction industry (11 questions). The survey was distributed to the construction industry in the U.S., and 450 responses were collected. The survey results are shared below.

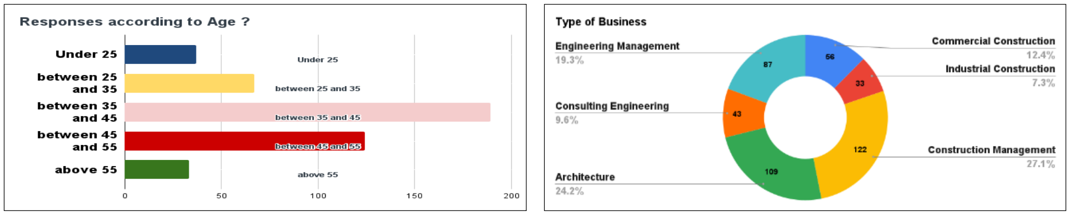


Figure 1.A (left) & 1.B (right). Respondents' age and business types

Figure 1.A illustrates that most of the survey questions were answered by mid-age people (34-45); the next group who contributed to the questionnaire were people between 45 and 55 years old. Figure 1.B shows the type of business of the people who took part in the survey. Construction management took the lead in the survey with 27.1%. Architecture companies come next for 24.2%.

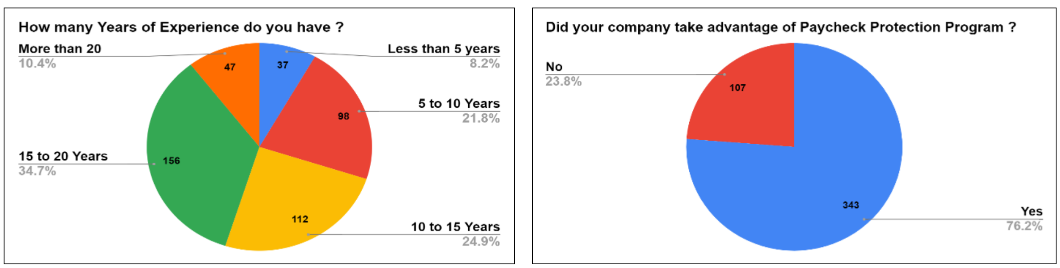


Figure 2.A (left) & 2.B (right). Respondents' experience and Paycheck Protection Program (PPP) awareness

Figure 2.A shows that 34.7% of the respondents have 15-20 years of experience, followed by 24.9% who have 10-15 years of experience. 21.8% of the participants have 5-10 years of experience. Figure 2.B depicts the response of people when asked if their company took advantage of Paycheck Protection Program. 76.2% of the participants responded positively, while 23.8% answered that their company did not take part in PPP.

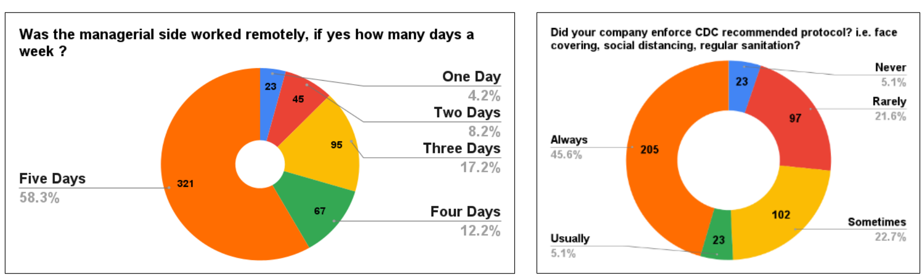
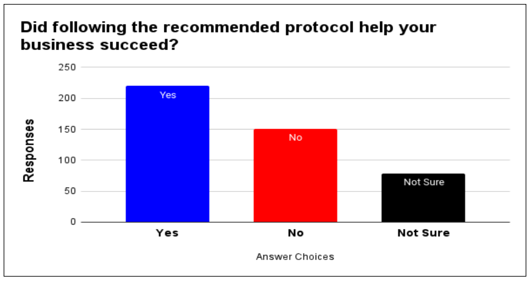


Figure 3.A (left) & 3.B (right). Remote work and CDC protocol

Figure 3.A represents the response of the people about the frequency of remote working. Out of 450 responses, 58.3% said the managerial side worked from home completely (5 days). Meanwhile, only 4.2% said they had one day of working remotely. In general, most companies implemented a policy of working from home. Figure 3.B shows that responders have diverse views when asked about the implementation of CDC protocols. 45.6% of the responders always enforce CDC recommendations, while 21.6% enforce it rarely.



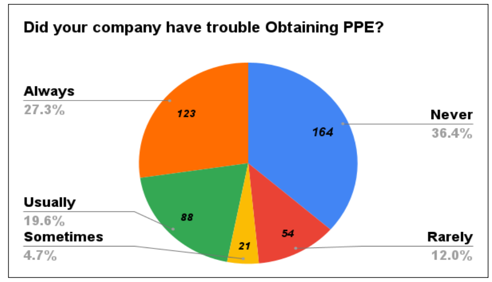
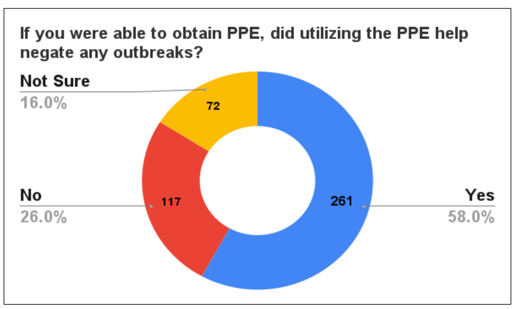


Figure 4.A (left) & 4.B (right). The benefits of following protocol and the PPE availability

Figure 4.A illustrates that the majority of the responders in the survey answered positively about the benefits of the recommended protocols. However, less than half of the participants responded negatively about protocols and some of them were not sure about it. Figure 4.B shows that 27.3% had a constant problem getting PPE, however, 36.4% of responders showed their satisfaction about getting PPE. Other responders had issued sometime while getting PPE.



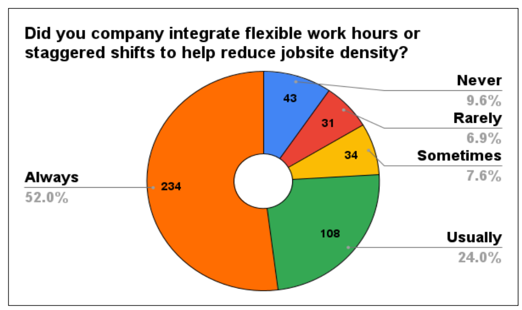
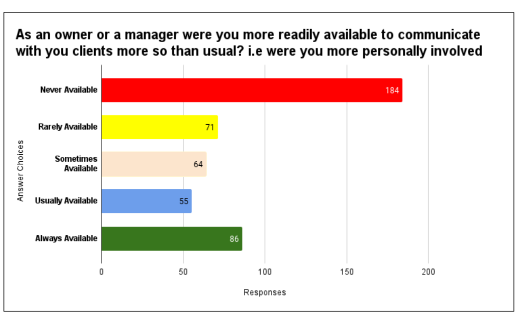


Figure 5.A (left) & 5.B (right). Utilizing PPE and the benefits of flexible work hours.

Figure 5.A depicts that the majority of responders believe that PPE utilization helps them mitigate the risk of COVID-19. Only 26% responded negatively to the effect of PPE. Figure 5.B shows that the majority of responders have flexible working hours during COVID-19, however, some people answered that they were unable to work in shifts.



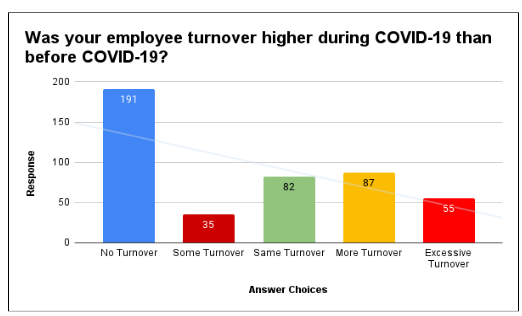


Figure 6.A (left) & 6.B (right). Communications and turnover questions

Figure 6.A shows that during COVID-19 most managers were not available for communication with clients, although 86 people answered that managers were able to communicate during the pandemic.

Other responders answered that managers were rarely available. Figure 6.B illustrates that during COVID-19 majority of organizations had more turnover, although 191 of the 450 responders answered that they had no turnover.

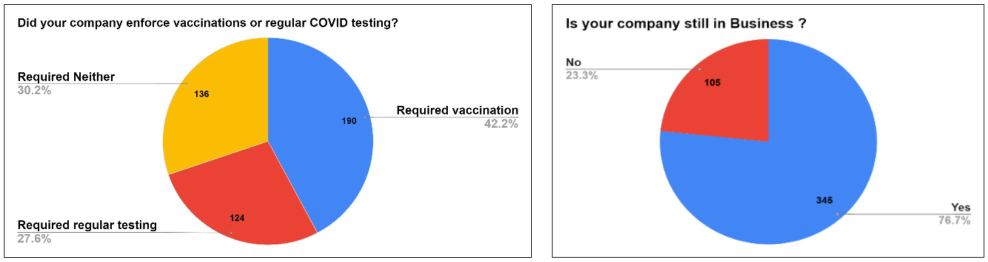


Figure 7.A (left) & 7.B (right). Vaccination enforcement and business status

Figure 7.A illustrates that the company of 42.2% of the responders required vaccination while 27.6% required regular testing and 30.2% required neither. Figure 7.B shows that majority of companies are still in business while only 23.3% went out of business due to COVID-19.

Conclusion

This research conducted a survey to collect important information about construction safety practices during COVID-19. The research provided some insight into the impact of COVID-19 on construction companies. As determined in this study and stated earlier, relatively many companies enforced vaccination or regular testing. This practice allows the company to have a feeling of security knowing that their staff is not viral. Also, many companies opted for remote work (for office or offsite work) during the pandemic and engaged in job shifts to reduce job density on the site. The ability to telework and or work various shifts ultimately slowed the spread due to people not being together as often. All companies followed the recommended protocol when able, but half of them were not sure if the practices implemented were helpful to their business success. About 76.2% of the survey participants took advantage of the Paycheck Protection Program, while 23.8% were not aware of the program.

This is pertinent information that companies must be aware of. There needs to be more education, statistically showing how the recommended procedure works. This will ultimately convince more people to follow the recommended protocol and help mitigate the spread of COVID-19. Fortunately, all the businesses that participated in our research are still in business which shows the resilience of their respective businesses and the effectiveness of the recommended practices. In a nutshell, this study has provided the construction industry with significant data about the overall impact of the recommended practices, and it can be concluded that the recommended practices have been fruitful when it comes to curbing the spread of the virus.

References

Amoah, C., Simpeh, F. (2020). Implementation challenges of COVID-19 safety measures at construction sites in South Africa, *Journal of Facilities Management*, 19(1), 111-128. https://doi.org/10.1108/JFM-08-2020-0061

AGC (2020). Construction Industry Loses 975,000 Jobs in April as New Association Survey Shows Deteriorating Demand for Construction Projects. (n.d.). Retrieved February 18, 2021, https://www.agc.org/news/2020/05/08/construction-industry-loses-975000-jobs-april-newassociation-survey-shows

Alsharef, A., Banerjee, S., Uddin, S.M.J., Albert, A., & Jaselskis, E. (2021). Early Impacts of the COVID-19 Pandemic on the United States Construction Industry. *International Journal of Environmental Research and Public Health*, 18(4), 1559. doi:10.3390/ijerph18041559

Bsisu, K.A. (2020). The Impact of COVID-19 Pandemic on Jordanian Civil Engineers and Construction Industry. *International Journal of Engineering Research and Technology. 13(5),* 828-830.

Araya, F. (2021) Modeling the spread of COVID-19 on construction workers: An agent-based approach*, Safety Science,* 133(5), 1-8, https://doi.org/10.1016/j.ssci.2020.105022.

Belingheri, M., Paladino, M.E., Riva, M.A. (2020) COVID-19: Health prevention and control in non- healthcare settings, *Occupational Medicine, 70(2),* 82–83 https://doi.org/10.1093/occmed/kqaa048

Bushman, D., Sekaran, J., Jeffery, N. (2021). Facility Notifications Team, Coronavirus Disease 2019 (COVID-19) Outbreaks at 2 Construction Sites-New York City, *Clinical Infectious Diseases*, *73(1),* S81–S83, https://doi.org/10.1093/cid/ciab

Dennerlein, J.T., Burke, L., Sabbath, E.L., et al. (2020). An Integrative Total Worker Health Framework for Keeping Workers Safe and Healthy During the COVID-19 Pandemic, *SAGE Journals.* 5(2), 75-94. https://journals.sagepub.com/doi/full/10.1177/0018720820932699

D'Auria, G; DeSmet, A, (2020, March 16). *Leadership in crisis: responding to the coronavirus outbreak and future challenges*, McKinsey and Company, https://www.mckinsey.com/business-functions/people-and-organizational-performance/our-insights/leadership-in-a-crisis-responding-to-the-coronavirus-outbreak-and-future-challenges

Goodman, J. (2020, April 30). *The New Normal: 8 Ways The Coronavirus Crisis is Changing Construction,* Construction Dive, https://www.constructiondive.com/news/the-new-normal-8-ways-the-coronavirus-crisis-is-changing-construction/576681/

Clark, K. (2020, December 31). *9 steps for communicating with employees during the COVID-19 crisis*, Ragan, https://www.ragan.com/9-steps-for-communicating-with-employees-during-the-covid-19-crisis/

Cates, L., Swanek, T. (2020, June 23). *Chamber Study Shows Commercial Construction Industry Poised for Recovery After Covid- 19*, U.S. Chamber Of Commerce, https://www.uschamber.com/series/above-the-fold/us-chamber-study-shows-commercial-construction-industry-poised-recovery-after

Ogunnusi, M., Hamma-Adama, M., Salman, H., & Kouider, T. (2020). COVID-19 pandemic: the effects and prospects in the construction industry. *14(2),* 120-128.

Olukolajo, M.A., Oyetunji, A.K. & Oluleye, I.B. (2021), Covid-19 protocols: assessing construction site workers compliance, *Journal of Engineering, Design and Technology*, 17(2), 1-18.

Pamidimukkala, A., Kermanshachi, S., & Nipa, T. (2021, June 8-10), *Impacts of COVID-19 on Health and Safety of Workforce in Construction Industry*, International Conference on Transportation and Development, Virtual Conference

Pasco R.F., Fox, S.J., Johnston, S.C., Pignone, M., Meyers, L.A. (2020). Estimated Association of Construction Work with Risks of COVID-19 Infection and Hospitalization in Texas, *JAMA Network Open*, 3(10), 1-11.

Stiles, S., Golightly, D., Ryan, B. (2021). Impact of COVID-19 on health and safety in the construction sector. Hum Factors Man, *Human Factors and Ergonomics in Manufacturing & Service Industries*, 31(1), 425-437.

Simpeh, F., Amoah C. (2021). Assessment of measures instituted to curb the spread of COVID-19 on construction site, *International Journal of Construction Management*, 1(1), 1-9.

Gamil, Y., Alhagar, A. (2020). The Impact of Pandemic Crisis on the Survival of Construction Industry: A Case of COVID-19. *Mediterranean Journal of Social Sciences*, 11(4), 122-128

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Construction Worker-Drone Safety Training in a 360 Virtual Reality Environment: A Pilot Study

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Integrating drones into construction sites can introduce new risks to workers who already work in hazardous environments. Consequently, several recent studies have investigated the safety challenges and solutions associated with this technology integration in construction. However, there is a knowledge gap about effectively communicating such safety challenges to construction professionals and students who may work alongside drones on job sites. In this study, a 360-degree virtual reality (VR) environment was created as a training platform to communicate the safety challenges of worker-drone interactions on construction jobsites. This pilot study assesses the learning effectiveness and user experience of the developed 360 VR worker-drone safety training, which provides an immersive device-agnostic learning experience. The result indicates that such 360 VR learning material could significantly increase the safety knowledge of users while delivering an acceptable user experience in most of its assessment criteria. The outcomes of this study will serve as a valuable resource for improving future worker-drone safety training materials.

Key Words: Drones, Construction Safety, 360 Virtual Reality (VR), Immersive Training, Training Assessment

Introduction

The use of Unmanned Aerial Vehicles (UAV), also known as drones, in the construction industry has grown dramatically in recent years. However, along with several benefits, the integration of any novel technology such as UAVs can also bring in new challenges. As a result, more and more research and practice specialists have gradually focused on the challenges that drones may bring to the industry (Albeaino and Gheisari 2021; Khalid et al. 2021; Yahya et al. 2021). Among these challenges, the rise of new safety concerns triggered by such robotic technologies is the most prominent (Bademosi and Issa 2021; Gheisari and Esmaeili 2019). As such, construction workers, who already work in a relatively dangerous industry that accounts for 20% of fatal occupational injuries in the United States (Bureau of Labor Statistics 2019) , will face additional and unknown risks on their job site when it is shared with drones. Consequently, researchers have started investigating the potential risks and creating countermeasures for such challenges (Jeelani and Gheisari 2021). These potential hazards have been identified and categorized as physical risks, attentional costs, and psychological impacts, and several countermeasures have also been proposed to address these risks accordingly (Jeelani and Gheisari 2021). Previous research regards safety training as an essential and urgently needed intervention to aid construction workers in coping with safety challenges, but there is a research gap on creating effective safety training content and delivery strategies for construction workers and professionals who work in a drone-populated work environment (Albeaino and Gheisari 2021; Khalid et al. 2021; Yahya et al. 2021). Currently, there is no similar training that educates construction workers about the safety challenges when working with drones on their jobsites. Therefore, this paper aims to create an effective training material to educate construction workers about the safety challenges that drones could pose on construction jobsites. The outline of the training program will be designed based on the previous studies that have discussed the specific hazards of drone application at construction sites.

Research Methodology

The objectives of this study are to (1) develop a construction worker-drone safety training and (2) conduct assessments of the learning effects and user experience. Considering the known effectiveness of learning experiences through immersive training, the training material was created in a virtual reality (VR) environment and exported as a 360 video, providing an immersive device-agnostic experience that can be easily disseminated. The assessment in this study aims to provide an understanding of the effectiveness and user experience of the proposed training material. A knowledge test about the basic knowledge of drones and the relative safety challenges was performed by the participants before and after training to understand the users' learning effectiveness, and a validated user experience survey was also adopted followed by a discussion on users' qualitative feedback to provide useful insights for improving future training material.

Drones Application and Safety Challenges in Construction

Drones are defined as aerial vehicles that are controlled remotely and do not have a human pilot onboard (Gheisari et al. 2014). This type of robot has since been widely embraced by a variety of industries, including construction. According to DroneDeploy's 2018 commercial drone trends report, the use of drones in construction surged by more than 200 percent in a year, making the construction industry the quickest commercial drone adopter (DroneDeploy 2018). Drones have become increasingly significant in construction because they can execute several construction-related tasks more effectively, swiftly, safely, and at a reduced cost, especially in difficult-to-reach places (Patel et al. 2021). However, according to literature, drone adoption in the construction industry has been hampered by liability and legal concerns, technical concerns, weather condition, and safety concerns (Albeaino and Gheisari 2021; Gheisari and Esmaeili 2019; Yahya et al. 2021). These issues could not only be a deterrent to the construction sector adopting drones, but they could also have significant ramifications, especially given the safety concerns, when more drones enter the construction job site in the future. As a result, studies have begun to investigate these issues and potential solutions (Albeaino and Gheisari 2021; Khalid et al. 2021; Yahya et al. 2021). In a very recent study, Jeelani and Gheisari (Jeelani and Gheisari 2021) categorized the possible health and safety challenges of drones on construction sites into three groups: (1) physical risks, (2) attentional costs, and (3) psychological impacts; and proposed several interventions-based research directions for ensuring safe integration of drones, including human-drone interaction, cyber-security, and privacy, as well as further research on regulatory, administrative, technological and training interventions. Further research on training intervention has been consistently emphasized in the literature to mitigate the hazards of using drones in construction (Albeaino and Gheisari 2021; Khalid et al. 2021; Yahya et al. 2021). However, limited research has been conducted to design an effective training material that focuses on the safety challenges of drone integration in construction for those who may work alongside drones. In this study, a 360 VR environment was created as a training platform to communicate the safety challenges of construction worker-drone interactions.

VR Training in Construction Safety

Safety training has been considered an important and effective measure to address safety risks in construction industry (Sacks et al. 2013). Lack of training has also been shown to have a strong correlation with construction fatalities (Eteifa and El-adaway 2018). Notably, traditional training methods have been proven to have a lower level of engagement and, therefore, could only provide minimal efficiency in conveying safety-related knowledge (Eiris et al. 2018; Jeelani et al. 2020; Sacks et al. 2013). Compared to traditional safety training methods, VR training, which could provide a sense of presence without exposing construction workers to real risk, has been shown to have better learning effectiveness, engagement, and motivation among learners (Eiris et al. 2021; Jeelani et al. 2020). VR is a technology that involves a computer-generated 3D environment to allow users to control items, move around and see the environment from various angles, immerse and navigate in real-time (Eiris et al. 2021; Wen and Gheisari 2020). Among the various forms of VR technology, 360 VR is thought to have great potential for widespread adoption because it can provide an immersive device-agnostic experience and be accessed on the most popular social media and video sharing platforms that support 360-degree video content (e.g., YouTube, Facebook) (Pham et al. 2018; Wen and Gheisari 2021). Therefore, 360 VR is considered to present new opportunities for improving construction safety education (Pham et al. 2018). In this study, 360 VR video was chosen as the medium for construction worker-drone safety training material to take advantage of its operating system independence and device-capability adaption.

360 VR Training Video Development

In this study, 360 VR training content was developed in two phases: training content development and 360 VR development. The two phases will be described further in the coming sections.

Training Content Development

This phase focused on developing the training content targeted for construction workers, who are most exposed to the risks posed by drones. According to the data, fall accidents are the leading cause of injuries and fatalities in the construction industry, accounting for 34.7% of fatalities in the past decade (CPWR 2021). Furthermore, according to literature, falls from roofs, ladders, and scaffolds are the major scenarios of fall-related accidents in construction, accounting for 71.9% of fall fatalities in the construction industry from 2011 to 2018 (Samantha Brown et al. 2020). Workers on heights are among the workers who are most exposed to drones because their work environment overlaps with the flightpath of drones. Thus, the content of this training was developed based on the potential incidents that could happen when working with or near drones in these "working on heights" scenarios. The scenarios were mainly located on roofs, ladders, and scaffolds, and the safety challenge categories were based on the newly published study by Jeelani and Gheisari (Jeelani and Gheisari 2021). The structure of the training content was based on the following learning objectives: (1) train users about the basic operation and uses of various types of drones used on construction sites; and (2) train users about the health and safety risks associated with drones (see Figure 1).

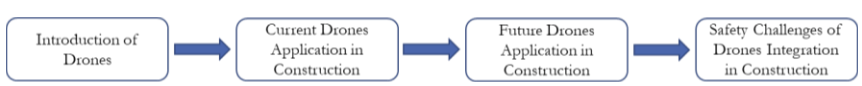

Figure 1. Structure of training video

360 VR Development

Following the design of the content structure, the 360 VR training material was developed using the Unity game engine with design and scripting capabilities. The process of 360 VR development (see Figure 2) consists of three steps: (1) Development of virtual construction site; (2) Development of training content; and (3) Dissemination of 360 VR video.

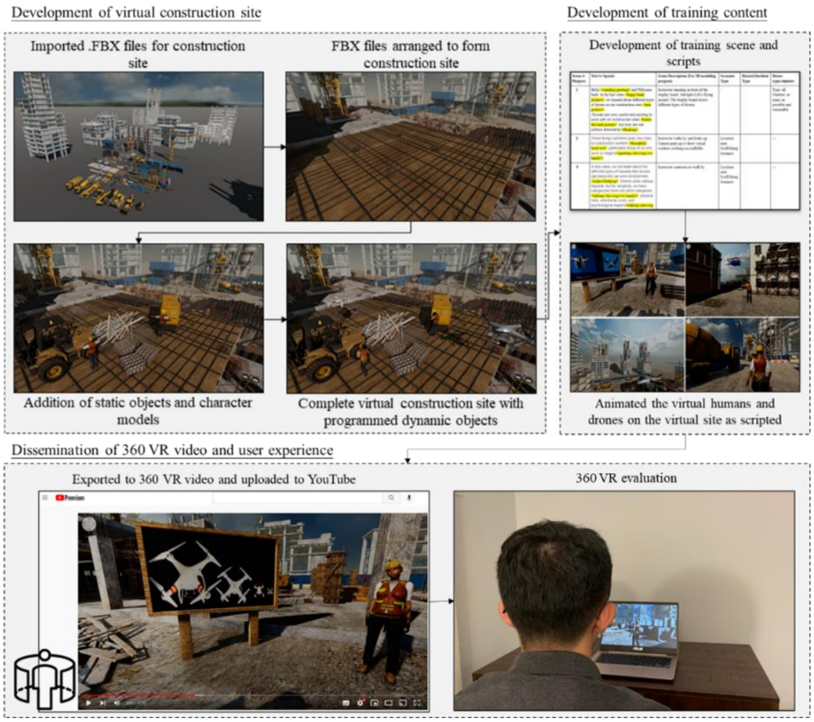

Figure 2. 360 Development of 360 video

In the first step, we developed a virtual-drone dominant construction site with virtual drones and virtual workers to simulate construction jobsites with multiple drones. We imported the construction-related assets into Unity, and virtual workers and drones were added to the virtual site and programmed to operate as they would in a real construction site. In the second step, the video content structure was defined in a more detailed script, including scene purpose, narration text, and scene descriptions. Following the script, the animation of virtual humans and drones was generated in the Unity game engine. The animations included a virtual instructor that would guide users through the process of learning about drones and construction worker-drone safety (see Figure 3). The VR content was then exported as 360 video to enable users to explore the construction environment better and enhance their sense of presence, which improves understanding and user engagement. The viewers' perspectives switch to attract their attention to specific areas within the 360 video. For instance, when presenting related topics, the users' viewing angle would shift to follow the flying drone, aiding users in understanding the content presented in the video.

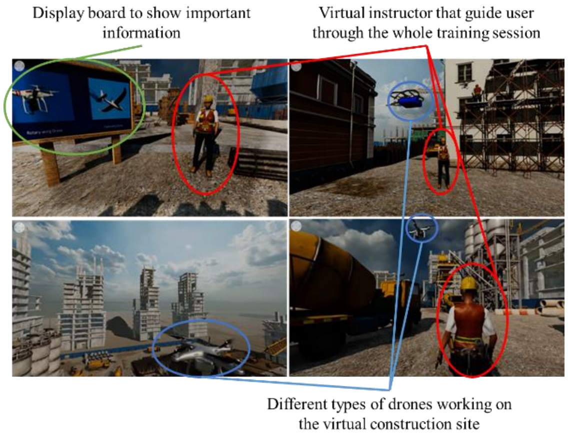

Figure 3. Different perspectives and details in the 360 VR training video

Training Assessment

The assessment of the developed training material is divided into two parts: learning outcomes assessment and user experience assessment. More than 50 subjects were recruited to evaluate the training video, and 43 effective data sets were collected and analyzed. The survey was primarily aimed at Architecture, Engineering, and Construction (AEC) students with varying professional experience and prior knowledge of construction safety or drones (see Table 1). Besides the quantitative results of learning outcomes and user experience, qualitative feedback from users were also collected. The result of the collected data will be discussed in the following subsections.

Table 1

Demographics and backgrounds

Variables	Category	Count	Percentage
Age	18-20	13	30%
	21-23	24	56%
	24-26	4	9%
	Older than 27	2	5%
AEC Professional Experience	None	6	14%
	0 to 6 months	14	33%
	6 to 12 months	11	26%
	1 to 2 years	8	19%
	More than 2 years	4	9%
Have taken a course or attended a workshop about Construction Safety	Yes	28	65%
	No	15	35%
Understanding of Construction Safety	None	3	7%
	Fair	22	51%
	Some knowledge of	9	21%
	Competent	9	21%
Understanding of drones	None	11	26%
	Fair	9	21%

Some knowledge of	22	51%
Competent	1	2%

Learning Outcomes Assessment

A pre- and post-training knowledge evaluation survey was used to evaluate the users' learning outcomes during the training session. Before beginning the training video, users were requested to complete a survey in which they answered questions about drones, their application in construction, and worker-drone safety. Following training, participants were asked to answer the same questions to determine whether the video effectively improved their knowledge level. The result of the learning outcomes assessment shows that the participants' knowledge level increased by 13%, while the P-value of the two sample T-test is 0.013 < 0.05, which indicates a statistically significant increase after going through the training (see Table 2). This result reveals that the training video provided some valuable information for the participants.

Table 2

Assessment result of learning outcomes

	Pre-training Mean (SD)	Post-training Mean (SD)	P-value
Learning Outcome	0.490 (0.126)	0.556 (0.188)	0.013

User Experience Assessment

The framework of the Tcha-Tokey et al. (2016) questionnaire was adopted in this study to evaluate user experience during the training session. This questionnaire adopts six criteria to measure user experience: engagement, immersion, emotion, experience consequence, judgment, and technology adoption. The definition of criteria is as follows (Tcha-Tokey et al. 2016):

- Engagement: Energy in action, the connection between a person and its activity, consisting of a behavioral, emotional, and cognitive form.
- Immersion: The illusion that the virtual environment technology replaces the user's sensory stimuli with virtual sensory stimuli.
- Emotion: The feelings (of joy, pleasure, satisfaction, frustration, disappointment, anxiety) of the user in a virtual environment.
- Judgment: The overall judgment of the experience in the virtual environment.
- Experience Consequence: The symptoms (e.g., simulator sickness, stress, dizziness, headache) that user can experience in the virtual environment.
- Technology Adoption: The actions and decisions taken by the user for future use or the intention to use the virtual environment.

The user experience results indicate that five criteria with at least acceptable reliability are better than average (2.5/5 or higher). Among these criteria, user engagement obtains the highest score (3.76/5), showing that the training video allows viewers to engage in the situation. In contrast, the experience consequence (measured negatively in the survey) is slightly better (2.34/5) than average, suggesting that video quality should be improved. Notably, the "Technology Adoption" result did not achieve an acceptable degree of reliability, indicating that the questionnaire should be modified to obtain more precise findings for this criterion. Overall, the user experience assessment results demonstrate that the proposed 360 VR training video has great potential to be used as an effective training tool. In addition, users' qualitative feedback was also collected to provide a more precise direction for improving the training video.

Table 3

Assessment result of user experience

	Mean (out of 5)	SD	Cronbach's Alpha	Items
Engagement	3.76	0.85	0.838	2
Immersion	3.27	0.85	0.655	2
Emotion	3.31	0.93	0.660	2
Judgment	3.65	0.72	0.742	3
Experience Consequence*	2.34	0.94	0.943	4
Technology Adoption	3.53	0.80	0.485	2

**Experience Consequence items are negatively expressed*

Qualitative Feedback from Users

In the open-ended section of this survey, the users also provided feedback about the system and how it could be enhanced. The feedback can be divided into five categories. The categories and examples are shown as Table 4. First. some users brought up the low video quality. Limited by state-of-the-art display information, spatial resolution, angular resolution, and viewing angle have become critical trade-offs in 3D displays (Hua et al. 2021). The high-resolution 360 videos also consume more bandwidth (Afzal et al. 2017), which could also influence the user experience since users' internet connections could vary. As such, the technical trade-off should be considered when generating 360 videos in the future. However, some users also mentioned the possibility that the low quality of the video could have been caused by their own settings. So, a brief instruction should be added to ensure users can set the video setting correctly. Another similar feedback is about the poor quality of animations. To provide a better user experience, it was also suggested that the animation quality be improved, notably by animating the virtual characters with enhanced natural movements. Moreover, the instructor's voice was generated using a "text-to-speech" system. Related comments show that using a real human voice could help create a more natural training experience. Furthermore, several users reflected on 360 video's limited interactivity capability and the limited level of immersion of desktop-based VR. It should be noted that the desktop-based 360 VR video has a limited interactive capability with a low sense of realism, but it is device-agnostic and easy to access. To address the interactivity issue, a VR game with a more interactive user interface could be developed in the future. Moreover, future efforts could be made to evaluate if the limitation of immersion could significantly influence learning outcomes. Finally, some users reported cybersickness and exhaustion. A few suggestions were also provided about increasing the speaking pace to finish the training faster. To address this, one solution could be to break the training into several parts and arrange a short break between each part of the training.

Table 4

Qualitative feedbacks from users

Categories	Examples of users' feedbacks

Low video quality	*"Video was very bad quality"*, "*The only complaint was the quality of video - but that could have been user error on my part.*"
Poor quality of animations	"*The animation is far behind the best of what we have today. The woman's legs bent the wrong way when she walked*"
Use real human voice	"*The voice made it hard to really immerse myself"*
Limited interactivity capability	"*If there was clicking/interaction, I think the experience would be more memorable"*
Limited level of immersion	"*I believe the immersion would increase with something like this if I was wearing a VR headset*"
Cybersickness and exhaustion	"*When I moved it too much it made me feel a tiny bit motion sick"* "*I definitely would not want to do it for more than 30 minutes"*

Conclusion and Future Work

The research aimed to develop a drone safety training video in a 360 VR environment and understand the learning effects and user experience of the proposed video, which is intended to fill a research gap concerning a lack of training interventions to mitigate the risks that construction workers may face when co-working with drones on construction job sites. To accomplish the research goals, a virtual construction job site with several virtual drones was created. The structure of the training material was designed to assist users in grasping the fundamentals of drone operation in construction and educate them about the safety challenges of working near drones. A small sample pilot evaluation with 43 effective data points was conducted to evaluate the learning effects and user experience of the developed training content. The training was delivered via YouTube and offered the web-based and device-independent benefits of 360 VR video. The results reveal that users' knowledge level can be enhanced by 13% after training, and five out of six criteria for evaluating user experience received acceptable reliability. The outcome demonstrates the high potential of the designed training content to serve as an effective training tool. Furthermore, several suggestions were derived from the qualitative comments from users, providing valuable feedback to improve the training video. Future research should collect a larger sample size and reexamine the questionnaire to analyze user replies using in-depth statistical analysis. In addition, only AEC-related students were recruited for this pilot study. To evaluate the learning impacts and user experience of different groups of users, a diverse range of backgrounds and professions connected to the AEC industry should be included. Furthermore, the qualitative responses from this study should be considered to improve the development of training videos in future studies.

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References

Afzal, S., Chen, J., and Ramakrishnan, K. "Characterization of 360-degree videos." *Proc., Proceedings of the Workshop on Virtual Reality and Augmented Reality Network*, 1-6.
Albeaino, G., and Gheisari, M. (2021). "Trends, benefits, and barriers of unmanned aerial systems in the construction industry: a survey study in the United States." *J. Inf. Technol. Constr.*, 26, 84-111.

Bademosi, F., and Issa, R. R. A. (2021). "Factors Influencing Adoption and Integration of Construction Robotics and Automation Technology in the US." *Journal of Construction Engineering and Management*, 147(8), 04021075.
Bureau of Labor Statistics (2019). "Fatal occupational injuries by event or exposure for all fatal injuries and major private industry sector, all United States, 2019."
CPWR (2021). "Construction Fatality Map Dashboard." <https://bit.ly/3HDowQx>. (November 6, 2021).
DroneDeploy (2018). "The Rise of Drones in Construction." <https://bit.ly/3sotmwk>.
Eiris, R., Gheisari, M., and Esmaeili, B. (2018). "PARS: Using Augmented 360-Degree Panoramas of Reality for Construction Safety Training." *International Journal of Environmental Research and Public Health*, 15(11), 2452.
Eiris, R., Wen, J., and Gheisari, M. (2021). "Influence of Virtual Human Appearance Fidelity within Building Science Storytelling Educational Applications." *Journal of Architectural Engineering*, 27(4), 04021036.
Eteifa, S. O., and El-adaway, I. H. (2018). "Using Social Network Analysis to Model the Interaction between Root Causes of Fatalities in the Construction Industry." *Journal of Management in Engineering*, 34(1), 04017045.
Gheisari, M., and Esmaeili, B. (2019). "Applications and requirements of unmanned aerial systems (UASs) for construction safety." *Safety Science*, 118, 230-240.
Gheisari, M., Irizarry, J., and Walker, B. N. "UAS4SAFETY: The potential of unmanned aerial systems for construction safety applications." *Proc., Construction Research Congress 2014: Construction in a Global Network*, 1801-1810.
Hua, J., Hua, E., Zhou, F., Shi, J., Wang, C., Duan, H., Hu, Y., Qiao, W., and Chen, L. (2021). "Foveated glasses-free 3D display with ultrawide field of view via a large-scale 2D-metagrating complex." *Light: Science & Applications*, 10(1), 1-9.
Jeelani, I., and Gheisari, M. (2021). "Safety challenges of UAV integration in construction: conceptual analysis and future research roadmap." *Safety science*, 144, 105473.
Jeelani, I., Han, K., and Albert, A. (2020). "Development of virtual reality and stereo-panoramic environments for construction safety training." *Eng. Constr. Archit. Manag.* .
Khalid, M., Namian, M., and Massarra, C. (2021). "The Dark Side of the Drones: A Review of Emerging Safety Implications in Construction." *EPiC Series in Built Environment*, 2, 18-27.
Patel, T., Suthar, V., and Bhatt, N. "Application of Remotely Piloted Unmanned Aerial Vehicle in Construction Management." Springer Singapore, 319-329.
Pham, H. C., Dao, N., Pedro, A., Le, Q. T., Hussain, R., Cho, S., and Park, C. (2018). "Virtual field trip for mobile construction safety education using 360-degree panoramic virtual reality." *International Journal of Engineering Education*, 34(4), 1174-1191.
Sacks, R., Perlman, A., and Barak, R. (2013). "Construction safety training using immersive virtual reality." *Construction Management and Economics*, 31(9), 1005-1017.
Samantha Brown, Raina D. Brooks, and Xiuwen Sue Dong (2020). "New Trends of Fatal Falls in the Construction Industry." CPWR - The Center for Construction Research and Training.
Tcha-Tokey, K., Christmann, O., Loup-Escande, E., and Richir, S. (2016). "Proposition and validation of a questionnaire to measure the user experience in immersive virtual environments."
Wen, J., and Gheisari, M. (2020). "Using virtual reality to facilitate communication in the AEC domain: A systematic review." *Construction Innovation*.
Wen, J., and Gheisari, M. (2021). "VR-Electricians: Immersive storytelling for attracting students to the electrical construction industry." *Advanced Engineering Informatics*, 50, 101411.
Yahya, M. Y., Shun, W. P., Yassin, A. M., and Omar, R. (2021). "The Challenges of Drone Application in the Construction Industry." *Journal of Technology Management and Business*, 8(1), 20-27.

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Analysis of U.S. Construction "Fatal Four" Fatalities investigated by OSHA in 2019

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Due to the dangerous nature of construction work, thousands of U.S. construction workers are injured and hundreds are killed on American worksites each year. In 2019, the U.S. construction industry accounted for one thousand and sixty-one (1,061) work-related fatalities, which amounts to a five percent (5%) increase from the previous year and the largest total number of annual worker deaths since 2007. This research study examined the Occupational Safety & Heath Administration (OSHA) construction fatality investigation findings during 2019 and organized these data points into four (4) major fatality-type categories and forty-nine (49) detailed types of events to identify potential trends for these fatal incidents.

Key Words: Fatal Four, OSHA, construction, safety, accidents

Introduction

Construction is an inherently dangerous industry that comprises a wide range of activities where workers are exposed to a variety of occupational hazards (OSHA, 2021). Data obtained from the U.S. Bureau of Labor Statistics (BLS) indicate that close to five thousand (5,000) U.S. construction workers died on-the-job between 2015 to 2019, which averages to nearly three (3) construction fatalities per day (BLS, 2020). During this same time period, OSHA states the U.S. construction industry accounted for approximately twenty percent (20%) of all workplace fatalities in the United States, but only employed roughly five percent (5%) of the workforce (OSHA, 2021). One thousand and sixty-one (1,067) of those construction deaths occurred in 2019. This 2019 number depicts a 5 percent (5%) increase from the previous year and represents the largest total number of U.S. construction fatalities since 2007 (BLS, 2020). Incidents involving 'falls to a lower level' and 'caught-in/between collapsing materials' were largely responsible for the increase in construction fatalities in 2019 (Brown, et.al, 2021).

Table 1. OSHA fatal four hazards

Hazard Type	Example Situations
Caught-in/Between Hazards	trench cave-in, run-over/roll-over by equipment, caught-in equipment, crushed by material/equipment, asphyxiation, inhalation of toxic vapor

Electrocution Hazards	Shock by touching exposed wires, shock by equipment/tool contacting power source
Fall Hazards	fall from ladder, fall from roof, fall through skylight, fall through unguarded floor opening, fall from structure
Struck-by Hazards	struck-by highway vehicle/construction equipment/falling material, power saw kick-back

The Occupational Safety & Health Administration (OSHA) has identified the four leading causes of fatalities in the construction industry (OSHA, 2011). They are referred to as either OSHA's "Fatal Four Hazards" or the "OSHA Focus Four Hazards". These top-4 hazards are listed in Table 1.

According to calculations conducted by the Center to Protect Workers' Rights (CPWR), the "Fatal Four" caused roughly sixty four percent (64.3%) of all construction fatalities for the year 2019. Falls historically remain the leading cause of all deaths in construction (Brown, et.al, 2021). Workers often work from heights, such as ladders, scaffolding, roofs, and aerial lifts. Falls, however, are not the only hazard to construction workers. Other potential hazards include:

- Crushed by motorized construction equipment
- Struck by falling tools or material
- Exposure to energized wires
- Trench cave-ins
- Fires/explosions
- Exposure to chemicals/low-oxygen atmospheres

Before hazards can be eliminated or reduced, they must be first identified. The data analysis of the study in this paper will review the trends of fatal construction accidents investigated by OSHA in 2019 into four (4) major fatality-type categories and forty-nine (49) detailed types of events to help identify potential trends of common hazards found in "Fatal Four" incidents for various work activities. Supervisors and workers can then use this information to help address hazards in similar current or future work.

Research Methodology

The Occupational Safety & Heath Administration (OSHA) conducts an inspection for most work-related fatalities and records a descriptive narrative of each investigated incident through the use of an *OSHA 170- Fatality and Catastrophe Investigation Summaries* form. The author submitted a request under the *Freedom of Information Act* in September 2020 for the dataset of OSHA inspections of construction fatalities conducted between 2015 to 2019. The information dataset was sent as a Microsoft Excel spreadsheet file by Gretta Jameson, OSHA Directorate of Construction, to the author via email in May 2021. Microsoft Excel was used by the author to sort and organize this information. Data received for this five-year time period was comprised of two thousand nine hundred and thirty-nine (2,939) lines of data. This information was reorganized and sorted by the author in order to group and analyze the information. Only the 2019 information from this dataset was used for this paper.

The OSHA inspection report dataset included the following elements:

- OSHA Inspection number for each fatality investigation
- North American Industry Classification System (NAICS) number of companies/industries
- Incident date and time
- Total number of fatalities for the incident
- Description of event with keywords

The 2019 data were provided by OSHA in six hundred and eleven (611) lines of data and represented five hundred and eighty-one (581) of the one thousand and sixty-one (1,061) U.S. construction fatalities in 2019. The author reviewed the detailed descriptions of each incident provided on each *OSHA 170 form* by inputting the inspection number provided in the OSHA dataset into the *OSHA Inspection Information* website found at https://www.osha.gov/pls/imis/inspectionNr.html.

All OSHA investigated construction fatality incidents in 2019 were classified by the author into one of the four major “Fatal Four” fatality categories of either *Falls*, *Struck-By*, *Caught-in/Between*, or *Electric shock.* Afterwards, the incidents were then separated into one of forty-nine (49) detailed fatality event descriptions. This event list of fatality was initially based on the twenty-nine event types presented in the Banik (2010) paper. This ‘list’ increased to forty-nine detailed events by the author based on review of the 2015-2019 OSHA Inspection Data. These forty-nine detailed event types allow a clearer analysis of the events related to the “Fatal Four” fatalities.

Once all *OSHA 170 Fatality and Catastrophe Investigation Summaries* were reviewed and data points were sorted by the author, the following initial information was found:

- Thirty-seven (37) of the incidents in the dataset had multiple inspection reports. These inspection numbers for these spreadsheet lines were still used to help determine the cause of the referenced fatality.
- Three (3) incidents were deemed not construction work-related incidents and therefore not included by the author in the final total of five hundred and eighty-one (581) fatalities. For example, a family of four was killed in their new home by carbon monoxide poisoning due to faulty workmanship and, therefore, not considered work-related.
- A total of five hundred and seventy-one (571) investigations were conducted for the five hundred and eighty-one (581) construction-related fatalities. The author organized the inspection report information by event type and fall height (if applicable/given).
- A majority of the 2019 OSHA construction fatality investigations (559 out of 571 investigations, or 98%) involved a single victim. The remaining twelve investigations (2%) involved 2 to 3 victims, which includes the infamous Hard Rock Casino collapse in New Orleans that killed three construction workers in a single event.

Study Results

As previously mentioned, the five hundred eighty-one (581) construction fatalities investigated by OSHA in 2019 were categorized by the author as either a *Fall* (44%, or 257 out of 581), *Struck-By* (16%, or 93 out of 581), *Caught-in/Between* (20%, or 114 out of 581), *Electric Shock* (11%, or 63 out of 581), or *Other* (9%, or 54 out of 581) event based on the descriptive narrative provided in each of the *OSHA Form 170* inspection reports. Note that the fifty-four (54) fatalities grouped into the “Other” category and are not discussed in this particular paper. The detailed events for the ‘Fatal Four “incidents are, however, discussed further in the following sections of this paper.

Caught-In/Between Fatalities

The “Caught-in/Between” fatalities were divided into thirteen (13) of the sixty (60) different events and are shown in Table 2. It should be noted that the ‘caught-in/between’ category experienced a total of seven (7) multiple fatalities within the same event. These multiple fatalities include three (3) trench collapses (with two fatalities each), one (1) tower crane collapse with two (2) fatalities, one (1) event where two workers were fatally crushed by a falling utility pole, another single (1) event where two (2) workers were asphyxiated by vapors in a tank, and the one (1) *Hard Rock Casino* building collapse event in New Orleans that resulted in the deaths of three (3) workers. The detailed 'caught-in/between' construction worker fatality incidents in 2019 are listed in Table 2.

Table 2. Detailed events for caught-in/between fatalities

Item #	Description of caught-in/between events
1.1	Asphyxiation/inhalation of toxic vapor/poison
1.2	Caught-in stationary equipment
1.3	Crushed from collapse of structure
1.4	Crushed/run over of non-operator by operating construction equipment
1.5	Crushed/run over/trapped operator by operating construction equipment
1.6	Crushed/trapped operator between manlift controls and structure/material
1.7	Crushed/run over by construction equipment during maintenance/modification
1.8	Crushed while unloading/loading equipment or material
1.9	Crushed/run-over by highway vehicle
1.10	Struck or crushed by elevator/counter-weights
1.11	Caught-in/crushed/suffocation by trench collapse
1.12	Caught-in/between unknown source/other/not listed
1.13	Crushed by falling material/non-motorized equipment

Overall, there were one hundred and fourteen (114) 'caught-in/between' fatality events investigated by OSHA in 2019. The detailed 'caught-in/between' construction worker fatality incidents in 2019 are shown in Figure 1.

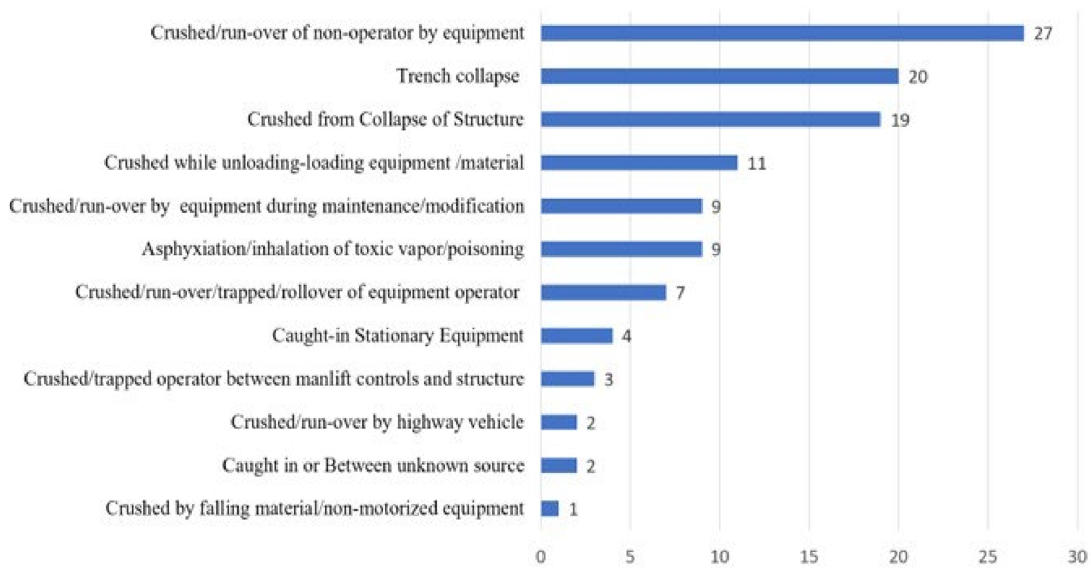

Figure 1. OSHA inspected 'caught-in/between' construction fatalities in 2019

Being 'crushed or run-over by a non-operator' accounted for the highest percentage (23.6%, or 27 out of 114) in this category. These particular events occurred when the victims worked in close proximity of construction equipment. There were sixteen different types of construction equipment involved the 'crushed/run over' events. The top-three types of equipment involved in these fatality incidents were dump trucks (8 incidents or 29.6%), front-end loaders (3 incidents, or 11.1%), and skid-steer equipment (2 incidents, or 7.4%). Being killed in a trench collapse (17.5%, or 20 out of 114) and getting crushed by the collapse of a structure (16.7%, or 19 out of 114) were respectively the second and third leading causes of construction worker fatalities in the 'caught-in/between' category.

Electrical Shock Fatalities

There were there were sixty-three (63) 'electrical shock' fatality events investigated by OSHA in 2019. The 'electrical shock' fatalities were divided into nine different events as shown in Table 3.

Table 3. Detailed events for electrical shock fatalities

Item #	Description of electrical shock events
2.1	Electrical shock by touching exposed wire
2.2	Electrical shock by arc to the ground
2.3	Electrical shock by ladder contacting power source
2.4	Electrical shock by scaffolding contacting power source
2.5	Electrical shock by crane/boom truck/drum truck contacting power source
2.6	Electrical shock by contacting power source while handing materials
2.7	Electrical shock from equipment installation/tool use
2.8	Shock/burn from flashback/lightning
2.9	Electrical shock, other

The 'electrical shock' category was responsible for one multiple fatality event. This occurred when two workers were electrocuted when the 35-foot aluminum extension ladder they were moving contacted the overhead power service line. The detailed 'electrical shock' events that resulted in construction worker fatalities in 2019 are listed in Figure 2.

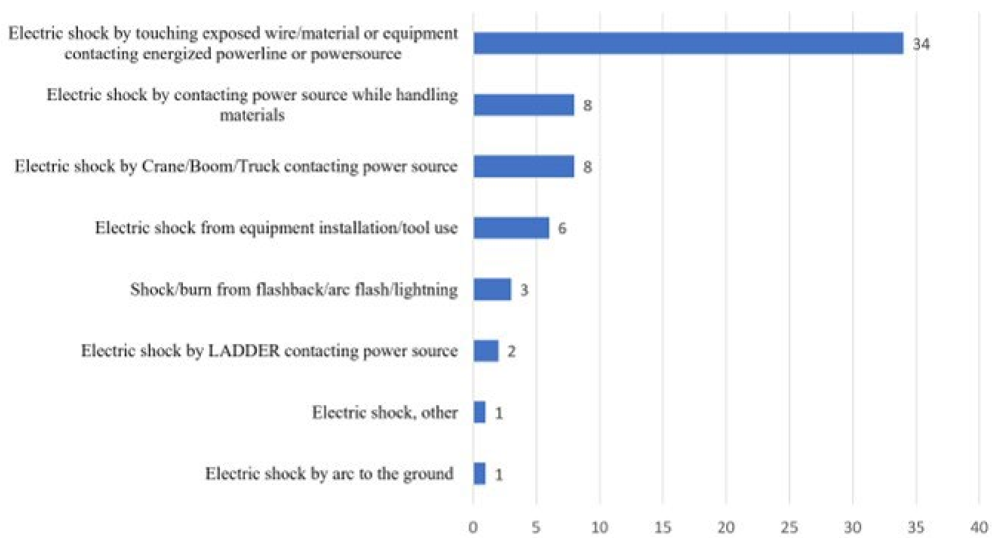

Figure 2. OSHA inspected 'electrical' construction fatalities in 2019

Overall, the 'electrical shock' fatalities investigated by OSHA accounted for almost eleven percent (10.8%, or 63 out of 581) of the fatalities investigated by OSHA in 2019. The incidents responsible for the most electrical shock fatalities were by far the thirty-four (34) 'touching an exposed wire' events, which included *working on electrical equipment/electrical panels* (32.2%, or 11 out of 34 incidents), *personal contact with the overhead power line* (29.4%, or 10 out of 34 incidents), and *light installation* (also 29.4%, or 10 out of 34 incidents). It appears that working with energized components and the lack of lock-out/tag-out procedures led to most of the ‘electrical shock’ fatalities. This also includes contacting the overhead power line due to being in close proximity to an active electrical line. Working in manlifts, bucket trucks, aerial lifts and on the roof caused most of the *contact with overhead power line* events.

Fall Fatalities

Fall events accounted for the majority of the fatality incidents (44.2%, or 257 out of 581) inspected by OSHA. Overall, there were twenty (20) detailed events related to fall fatalities. The ‘fall’ fatality incidents investigated by OSHA in 2019 were primarily one victim incidents. The exception was the one aerial lift tip over event caused by operating the equipment on uneven ground (no height was provided on the report) that killed two workers. The detailed ‘fall’ events that resulted in construction worker fatalities in 2019 are listed in Table 4.

Table 4. Detailed events for fall fatalities

Item #	Description of fall events
3.1	Fall from/with ladder (includes collapse of ladder)
3.2	Fall from ladder/equipment due to electric shock
3.3	Fall from roof
3.4	Fall through skylight
3.5	Fall through roof other than skylight
3.6	Fall from trusses/bar joists
3.7	Fall from highway vehicle/construction equipment/crane
3.8	Fall from scaffold
3.9	Fall from aerial lift basket
3.10	Ejected from aerial lift basket
3.11	Fall from aerial lift tip over
312	Fall from structure (other than roof or trusses/bar joists
3.13	Fall by collapse or failure of structure
3.14	Fall from platform or catwalk
3.15	Fall from unguarded wall opening/elevator shaft
3.16	Fall through floor opening
3.17	Fall through ceiling
3.18	Fall, same level (slip/trip)
3.19	Fall down stairs
3.20	Fall, other or unknown

It should be noted that item *3.18–Fall, same level (slip/trip)* did not apply in the 2019 data. OSHA provided heights for one hundred ninety-three (193) of the two hundred and fifty-seven fatality cases investigated in 2019. These fall heights ranged from two feet (2’) where a worker stepped out of the back of a box truck and fell two feet to the ground up to two hundred feet (200’) where the victim was killed during a floor collapse during the demolition of a building. The average height for falls that resulted in a construction worker fatality was around twenty-seven (27) feet. As shown in Figure 3, ‘falls from roof’ accounted for the most fatalities (26%, or 67 out of 257) in this category. Ten (10) of the sixty-seven (67) OSHA inspection reports for the ‘fall off roof’ fatalities did not provide the height that the victim fell. For the remaining fifty-seven (57) 'fall from roof' fatalities, the height ranged between 6 feet (transferring from roof to ladder) to 120 feet (twelve stories) and averaged a fatal fall height around twelve feet (12'). Eighty percent (80.7%, or 46 out of 57) of the 'fall from roof' incidents involved falls of 30 feet high or lower.

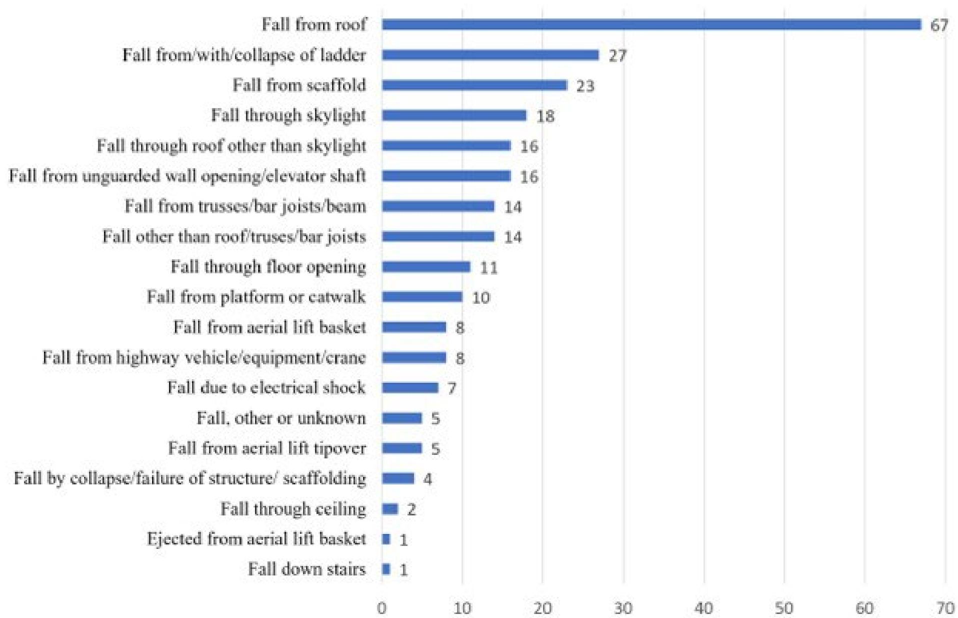

Figure 3. OSHA inspected 'fall' construction fatalities in 2019

Four (4) of the 'fall from roof' victims were wearing a harness and lanyard when they fell. In these four cases, one victim unhooked his lanyard to egress from the roof via ladder while the remaining three victims wore a harness and lanyard, but were not attached to an anchor point. Forty-six (46) of the fifty-seven (57) 'fall from roof' fatalities were roofing contractors (NAICS code 238160).

'Falls from ladder' (10.5%, or 27 out of 257) and 'falls from scaffolding' (8.9%, or 23 out of 257) were the second and third most causes of construction worker fall fatalities. There is no mention as to the type of ladder used or any factors that resulted in the 'fall from ladder' incidents. Fall heights for the 'fall from ladder' fatal incidents ranged from three feet (3') to thirty feet (30'). Fall heights for the 'fall from scaffolding' fatalities ranged from three feet (3') on a mobile Baker-type scaffolding to forty-five feet (45') scaffolding (type not given).

Roof-related fatalities also included 'fall through skylight' (18 out of 257 fall fatalities) and 'fall through roof other than skylight' (16 out of 257) incidents. If these two types of incidents were added together with the 'fall from roof' fatalities discussed earlier, then "roof-related" incidents actually accounted for one hundred and one (101) or thirty-nine percent (39%) of all fall fatalities investigated by OSHA in 2019.

Struck-by Fatalities

There were three (3) multiple fatality incidents in this category. Two (2) of those incidents involved road construction workers getting hit by motor vehicles in work zones and one incident involved a gable truss collapse. Overall, there were seven (7) detailed events related to 'struck-by' fatalities as shown in Table 5.

Table 5. Detailed events for struck-by fatalities

Item #	Description of struck-by events
4.1	Struck-by highway vehicle
4.2	Struck-by of non-operator by construction equipment
4.3	Struck-by of operator by construction equipment
4.4	Struck-by falling object/material/equipment
4.5	Struck-by, unknown/other
4.6	Power tool amputation/saw kick back
4.7	Struck-by structure collapse

Struck-by events accounted for sixteen percent (16%, or 93 out of 581) of the fatality incidents inspected by OSHA. The distribution of construction worker fatalities due to ‘stuck-by’ incidents is shown in Figure 5. Note that items *4.6–Power tool amputation* and *4.7–Stuck-by structure collapse* did not apply in the 2019 data.

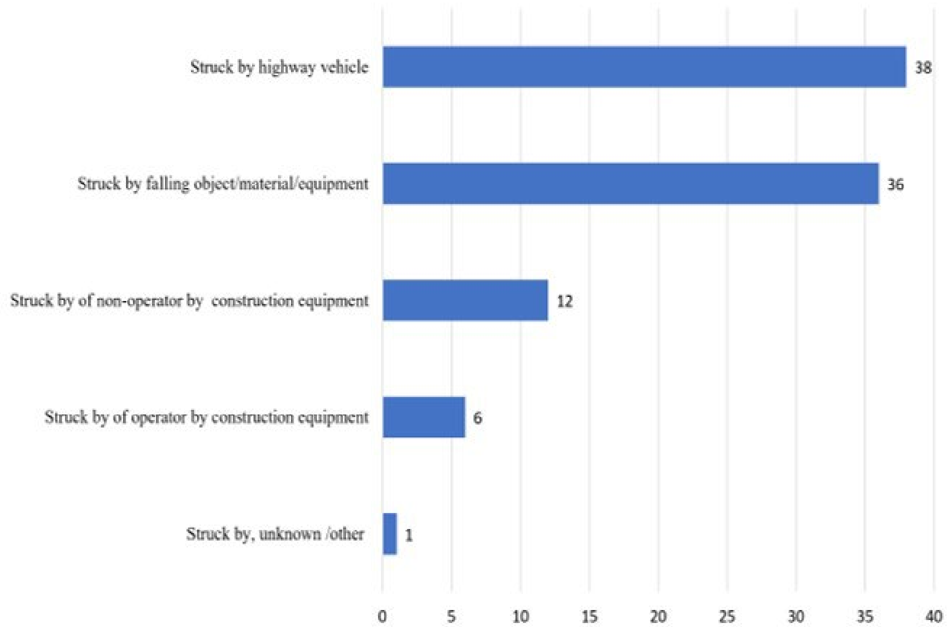

Figure 4. OSHA inspected ‘struck-by’ construction fatalities in 2019

As shown in Figure 4, thirty-eight (38) construction workers were killed after being struck-by a highway vehicle. Twenty-one (21, 55%) of these fatalities were related to roadwork. One (1) worker was killed while removing traffic cones, eight (8) workers were killed will working as a flagger/traffic control (one of these incidents involved a drunk driver), and twelve (12) workers were killed by motorists in roadway work-zones (one of these incidents also involved a drunk driver). Workers getting ‘struck-by falling objects/material/equipment’ (which included a non-operator being struck-by construction equipment tip over) was the second deadliest event for construction workers accounting for thirty-six worker deaths, or thirty-eight percent (38.7%, or 36 out of 93) ‘struck-by’ fatality events.

Summary of Study Findings/Conclusion

OSHA investigated 581 of the 1,061 U.S. construction workers fatalities in 2019. While events within the 'Falls" category were responsible for the majority of construction worker deaths in 2019, workers were also being killed by caught-in/between, electrical shock, and struck-by incidents. Note that the remaining fifty-four (54) fatalities in 2019 investigated by OSHA were categorized as "Other" by the author. These events, which include drownings and heart attacks, included eleven (11) detailed events, but were not discussed due to page limitations. Based on the results of this study, the top-5 fatality "Fatal Four" incidents are as shown in Table 6. These top-5 fatality events accounted for thirty-five percent (35%, or 202 out of 581) of the construction worker deaths investigated by OSHA in 2019.

Table 6. Top-5 construction worker fatality events investigated by OSHA in 2019

Ranking	Fatality Event	No. of Fatalities	Percentage (out of 581 fatalities)
1	Fall from roof	67	11.5%
2	Struck-by highway vehicle	38	6.5%
3	Struck-by falling objects/material/equipment	36	6.2%
4	Electrical shock by touching exposed wire	34	5.8%
5	Fall from/with ladder	27	4.6%

The analysis of the forty-nine (49) fatality events presented in this paper provide trend information on how construction workers are getting killed on the jobsite. Supervisors and and their employees can use this information to plan safe work practices by proactively addressing these potential hazards in current or future work and can also be used as discussion points for worker safety training.

References

Banik, G. (2010). Trend and causes of fatal accidents in the U.S. construction industry. Proceedings of the 46th ASC Annual International Conference. Accessed April 11, 2021 from http://ascpro0.ascweb.org/archives/2010/CPRT235002010.pdf

Brown S., Harris, W., Brooks, R., Dong, X. (2021, February). Fatal injury trends in the construction industry. CPWR Center for Construction Research and Training. Accessed November 7, 2021. from https://www.cpwr.com/wp-content/uploads/DataBulletin-February-2021.pdf

Bureau of Labor Statistics news release (2020, December 16). Accessed July 2, 2021 from https://www.bls.gov/news.release/pdf/cfoi.pdf

Occupational Safety and Health Administration (2012, January). Injury and Illness Prevention Programs White Paper. Accessed October 26, 2021 from https://www.osha.gov/sites/default/files /OSHAwhite-paperjanuary2012sm.pdf

Occupational Safety and Health Administration (2021). Construction industry. Website accessed October 26, 2021 from https://www.osha.gov/construction

OSHA Directorate of Training and Education (2011, April). Construction focus four: Outreach training packet. Accessed April 22, 2021 from https://www.osha.gov/sites/default /files/constrfocusfour_introduction.pdf

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Safety Considerations to Operate Drones on Construction Sites

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A range of new safety implications is emerging with the integration of Unmanned Aerial Vehicles (UAVs) in construction, necessitating the development of adaptable guidelines to sustain satisfactory safety performance. Construction is one of the fastest-growing industries to use UAVs on a grand scale to achieve a high degree of productivity, efficiency, and safety. However, owing to the limitations of regulatory specifications and safety considerations for the specific industry, new drone technologies may drive workers into a state of flux. Construction is already filled with numerous hazards, so adding another source might increase construction employees' cognitive and physical demands. Despite the Federal Aviation Administration's establishment of regulatory criteria to promote general public safety, construction critically requires specific safety guidelines to manage the complex interaction between construction operations and UAVs. As a result, this study aims to provide insights into the dynamic interactions between UAVs and construction processes while also taking into account the human variables involved. The researchers obtained first-hand information from construction and UAV professionals through a questionnaire survey. The obtained data were analyzed to address safety concerns that add to the body of knowledge about the safe integration of drones in construction.

Keywords: Drone; UAV; Safety; Risk; Construction.

Introduction

Despite significant technological advancements, the construction industry continues to face high rates of occupational fatalities and non-fatal injuries year after year. Construction is one of the industrial sectors where workers constantly have to tackle complex operational environments. UAVs, commonly known as drones, are finding widespread use in construction because of their inherent benefits in mobility, affordability, and productivity (Figure 1). The construction industry is quickly adopting drones' technological benefits, but they also pose many unexpected safety risks and operational issues. Proper safety training is required to limit the safety concerns of UAVs in construction. UAV safety training programs tailored to construction contexts must be integrated into modern safety management processes to achieve exemplar safety performance. The purpose of this study is to emphasize the safety aspects for construction workers in order to provide critical safety information concerning the use of UAVs in construction. This study lays the groundwork in identifying these safety strategies according to the existing practice in actual construction job sites. Furthermore, the results benefit researchers, construction professionals, regulatory agencies, experts, and practitioners by revealing essential safety measures to limit the risks associated with drone-based applications.

Figure 1: Pilot and crew member controlling drone on a construction job site. Image credit: Gorodenkoff/Shutterstock.com

Literature Review

Drones represent a leap forward in technology that has recently piqued the attention of a wide variety of businesses. Significantly, construction operations are increasingly adopting UAVs as a reliable source of data collection purposes. UAVs can allow construction professionals to conduct remote surveillance by reaching dangerous sites, tracing resources, and assessing safety concerns, reducing the need for personnel to work in hazardous environments (Kas & Johnson, 2020). UAVs can capture large amounts of data with real-time transmission for building information modeling (BIM), surveying, and mapping applications because of the enhanced features of photogrammetry and remote sensing technologies (Wang et al., 2016). The capabilities of UAVs make applications safer and more manageable in situations when human intervention is required (Petrlík et al., 2020). UAVs take a firm stance as an efficient option, mainly when human lives are at risk. Contrarily, UAVs also bring in a series of unwarranted challenges that the entire construction industry does not fully recognize (Namian, Khalid, Wang, & Kermanshachi, 2021).

Although a considerable collection of research has been developed to address the safety concerns of construction workplaces, there is a lack of focus on technology integration challenges. The deployment of UAVs in the construction environment, in particular, offers a slew of new safety challenges that the discipline of construction science has yet to address. Drones on construction sites, according to researchers, pose significant safety hazards owing to the chance of collisions with people and property, distraction, violation of privacy, or trespassing (Namian, Khalid, Wang, & Turkan, 2021). Furthermore, researchers have noted how swiftly drones can be integrated into the construction environment in the absence of applicable safety and privacy management programs to safeguard personnel from physical and mental challenges (Khalid, Namian, & Massarra, 2021).

Construction workers' functional capacity requires both cognitive and physical features to be at their disposal and readily utilized in the assigned construction task (Khalid, Namian, & Behm, 2021). The intensity of construction work necessitates ongoing physiological and psychological exertion and unobstructed cognitive capacities to appraise the situation and take necessary actions (Craik, 2014). On the other side, drones have been acknowledged as a key cause of occupational distraction, capable of capturing a worker's concentration during the construction process (Li & Liu, 2019). Distraction at the construction workplace can directly affect their hazard recognition and risk perception attributes, ultimately leading to compromised safety management (Namian, Albert, & Feng, 2018). Therefore, the administration needs to understand the safety demands required by each project and diverse workforce to facilitate progress with mitigated risks. For example, a specialist such as a manager, engineer, or safety personnel may be actively involved with the UAV operation and planning at the job site, aided by their specialized experiences and abilities to interpret the drone's specific behaviors. On the other hand, a general worker may only be accustomed to watching a drone fly without the opportunity to obtain any detailed understanding and training of how it functions and its accompanying features. The limits in acquiring extensive familiarity with drone technology may cause construction workers to be fearful, producing discomfort and anxiety in their working environment (Xu, Turkan, Karakhan, & Liu, 2020).

The Federal Aviation Administration (FAA) has issued rules to safely control the use of drones in order to protect the general public. Still, it overlooks the actual realities of drone-related safety implications (Calandrillo, Oh, & Webb, 2020). The numerous existing hazards already heighten the safety risks of the workforce, and the consequences can become much more severe if timely preparation is not implemented. FAA has a set of qualification-based requirements for the pilots to obtain their operating license. It provides the right to operate small UAVs by ensuring the pilots understand the relevant rules and guidelines through passing the aeronautical knowledge exam and the basic physical and mental competency. Also, another essential aspect of the pilot license ensures their aeronautical knowledge recency by requiring pilots to complete online recurrent training every two years ("Become a Drone Pilot," 2021). The FAA's final rule alters 14 CFR Part 107 to broaden the authority to undertake operations above people if the activity fits the conditions of one of four operational categories. FAA does not explicitly necessitate the drone pilots to undertake any specific measures that would encompass the dynamic complexities of construction job sites. On the other hand, OSHA indicates to abide by the flight plan and checklist as required under FAA Part 107.49 in the stages of UAV's pre-deployment and post-flight office procedures. Although it provides a fundamental safety viewpoint of working with drones for inspection at workplaces, it is overly generic (Occupational Safety and Health Administration, 2018). It fails to recognize the construction industry as a sector that requires delicate attention due to its complex safety dynamics.

Research Methodology

Construction is a complicated system that undergoes constant changes. Workers and UAV operators face a variety of safety and operational issues resulting from these complex and dynamic transitions in construction. They must be adequately prepared and knowledgeable to anticipate possible risks on the working sites. A five-step research methodology was devised and applied for this research (shown in Figure 2). The first two steps were to perform a thorough literature study to identify the safety risks of

UAVs in construction. Then, a questionnaire survey was developed to collect information on existing practices linked to safety initiatives to avoid such risks. The study was facilitated by the use of the snowball sampling technique to transmit the online survey due to the scarcity of UAV-related information in the construction sector. This is a prevalent strategy employed by construction-related research studies (Loosemore & Malouf, 2019; Öney-Yazıcı & Dulaimi, 2015). Followed by that, an array of data was logically organized and descriptively analyzed to observe the critical safety considerations and the frequency of responses for each of them. Descriptive analysis was adopted for this study to represent the essential safety concerns associated with drones. Finally, the safety strategies that are critical to UAV-construction operations were identified, and the results were discussed.

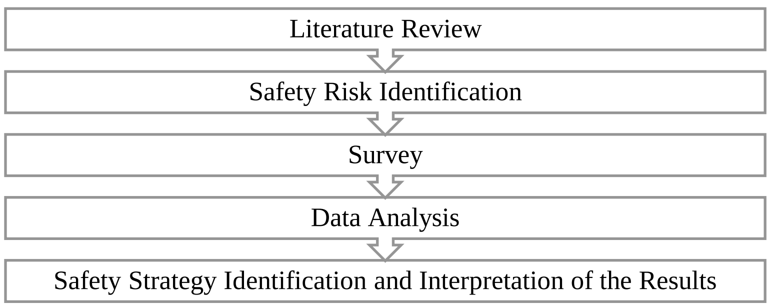

Figure 2: Research framework.

Interviews and Questionnaire Survey

To accomplish the research goals, this study involves the perception of industry professionals through the development of a questionnaire survey and data collection via in-person and online channels. After receiving Institutional Review Board (IRB) permission, data on UAV-construction safety management measures were collected using in-person and online surveys. Construction companies having a connection to UAV activities on the job sites were chosen for data collection purposes, primarily across the United States. The participants ranged from various job roles, including directors, project managers, engineers, surveyors, safety personnel, drone pilot, research, etc., spread across multiple construction projects and locations. The content acquired from the participants was treated with confidentiality. The study's participants provided a transparent assessment of the obstacles and potential solutions linked with the emergence of construction safety issues when deploying UAVs on the job sites. The questionnaire survey yielded 63 complete responses, excluding the incomplete and partially completed responses.

Data Analysis and Results

Relevant literature, including peer-reviewed journal papers, conference papers, and technical reports, were evaluated for this study to extract the safety risk-related information and the preventive countermeasures. A total of 18 safety strategies were examined for relevance to UAV construction operations, and they were presented in the questionnaire survey. One hundred eight individuals from various construction organizations and their UAV solution providers took part in the survey with a survey response rate of 58.34%. Since 45 participants only offered partial input, their replies were discarded as incomplete and were not included in the final data analysis. The remaining 63 participants, which is the sample size of this study, shared remarks about their safety concerns and encounters with UAV-related events. The participants were asked to rate each of these safety countermeasures, and their responses are shown in Figure 3.

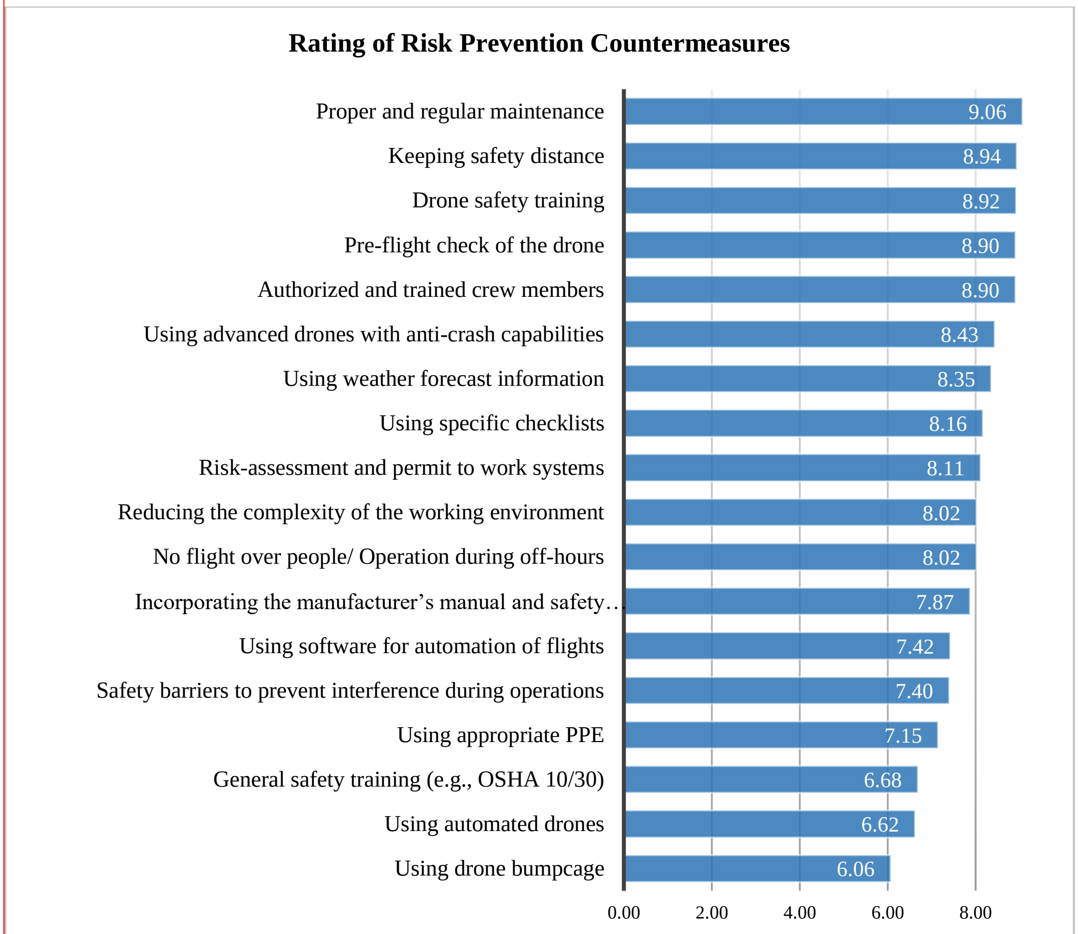

Figure 3: Safety Countermeasures Rated by Participants.

The questionnaire involved questions to evaluate the effectiveness of the "Unmanned Aircraft General – Small (UAG) Knowledge Test" administered by the FAA. The first question asked the participants if that test helped them understand drones' safety implications effectively. The following question directed towards the participants sought to evaluate if the knowledge-based test covered all the aspects to ensure the safety of the surroundings of the drones. Both of the responses were descriptively analyzed based on the frequency of their responses, as shown in Figure 4.

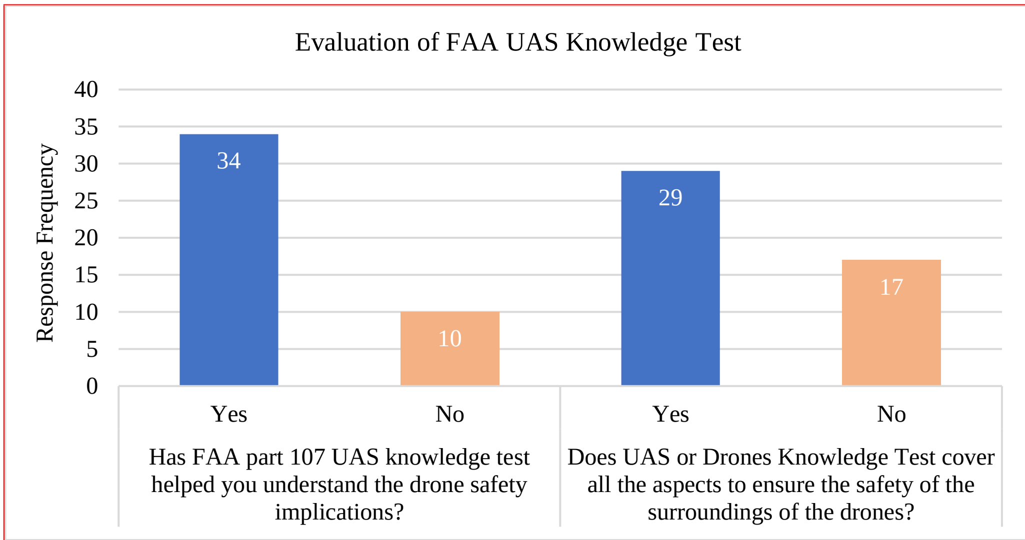

Figure 4: Evaluation of FAA's Unmanned Aerial Systems (UAS) Knowledge Test.

In addition to the rated safety countermeasures and evaluation of the knowledge test applicability, the participants were also asked about several safety consideration factors related to flight reliability, emergency plans, and personal data and privacy-related questions to better understand the current practice within their job sites. Table 1 represents the list of specific safety considerations with the sample size for each response and the number and percentage of respondents who have implemented or not implemented these in their respective job sites.

Table 1: Safety Considerations for UAV Flights in Construction.

Category	Safety Considerations for UAV Flights in Construction	Surveyed Responses	Implemented	Not Implemented
Flight Reliability	Risk assessment or Job Hazard Analysis before UAV flight	58	47 (81%)	11 (19%)
	Barricade to avoid distraction or interference	59	25 (42%)	34 (58%)
Emergency Preparations	Emergency Medical and Rescue Plan	58	34 (59%)	24 (41%)
	Emergency Contingency Plan	57	35 (61%)	22 (39%)
Personal Data and Privacy	Ethical Code of Conduct	54	44 (81%)	10 (19%)
	Management Strategy for Unauthorized Trespassing and Collection of Sensitive Information	55	32 (58%)	23 (42%)

Discussion

An expanding body of research has concentrated on the positive aspects of UAV technology and has made significant progress in developing disruptive innovations. Research on the operational complexity of drone integration, on the other hand, is inadequate. This study investigates and identifies the safety strategies and considerations to address the inherent safety risks presented by UAVs in construction. This study aimed to emphasize the practical problems of UAV deployments so that construction researchers and practitioners could better comprehend the variety of safety elements associated with UAV applications. The results indicate that the questionnaire extracted the construction workforce's current understanding based on the on-site safety prevention measures. For instance, Figure 3 represents the list of safety countermeasures shared with the construction and drone professionals to obtain their perceptions and selections when it comes to controlling the safety performance of construction and drone operations. The results show that "proper and regular maintenance," "keeping safe distance," and "drone safety training" were selected as the top three safety countermeasures in addition to others. The research examined the general perception of individuals who took the drone-based knowledge exam and whether they were effectively supported by it on the actual job site. More than 20% of the participants expressed that the test had not helped them understand the safety implications of drones sufficiently. Similarly, a more significant percentage of the participants, almost one-third, reported that the knowledge exam did not cover all areas necessary to ensure the safety of the drones' surroundings. Further, the focus was directed towards obtaining information regarding the effectiveness of the current regulatory requirement of competency in the form of the "Unmanned Aircraft General – Small (UAG) Knowledge Test." Participants were questioned about existing practices and procedures at their respective employment locations regarding flight reliability, emergency preparations, and personal data and privacy issues. For maintaining safe flight operations and unhindered flight reliability, 81% of the participants reported that they had conducted Risk Assessment or Job Hazard Analysis before conducting the flight.

Fifty-eight percent of the participants reported not utilizing measures to barricade themselves during flight operations in the construction environment. Similarly, more than a third of respondents expressed that there were no "emergency medical and rescue" and "emergency contingency" plans in place to deal with any unprecedented scenarios resulting from drone-related mishaps. Further analysis of the data indicates that 81% of the respondents reported that they followed the ethical code of conduct when dealing with the personal information collected through drone-based applications. However, 42% of the participants expressed that they did not have any management strategy to deal with the unauthorized trespassing of drones and the collection of personal information of people or properties surrounding the target job site. In this regard, establishing safety countermeasures and procedures is critical to UAVs' safe integration and operation in the construction environment. The literature review presents an array of safety risks of UAVs that are still not adequately comprehended by the majority of the construction workforce; therefore, following the federally imposed rules and standard processes designed for generalized UAV operations will not guarantee continued progress since they do not address all the potential safety risks of UAVs. As a result, construction organizations with UAV integrated operations should consider construction-specific UAV safety training programs to enable diverse types of projects to fulfill their particular needs with comparable safety objectives.

Conclusions

The rising safety issues associated with the deployment of UAVs are undervalued until the frequency of construction workplace mishaps increases, jeopardizing workers' normalcy and halting regular productivity. As a result, the emphasis of this research was on potential safety countermeasures associated with the use of drones on construction sites for the protection of the public and property. Pilots and crew members may be subjected to physical and mental stress due to severe weather, construction disruption, worker interference, auditory-visual distraction, and psychological pressures if suitable barricading procedures are not implemented. Results of the study reveal that a significant portion of the employees does not utilize such measures to avoid interferences. The workforce and the safety management of the typical construction job sites still lack an understanding of the drone-related implications. The majority do not consider establishing emergency procedures in case of medical or any other contingencies. Working in an environment where workers' privacy is threatened and exploiting personal information might negatively impact their safety performance. The legal ramifications of unauthorized trespassing and the unpermitted acquisition of private information can hinder construction progress and productivity. There is also a lack of understanding provided by the UAV knowledge test, which does not adequately cover all the related aspects to properly identify and reduce associated risks of drone-based hazards. Construction has gained significant attention as a leading industry for adopting UAVs in their job sites in the recent decade. In order to utilize the beneficial offerings of this technology, the end-users must do their homework and learn what to expect in terms of operational performance and UAV application development, particularly on construction sites, which are prevalent for being hazardous. The study's findings are intended to aid the construction practitioners, particularly project managers, engineers, safety personnel, pilots, and supervisors who are primarily responsible for designing and executing UAV-based construction applications. The following research approach will concentrate on the identified safety problems in real-world scenarios by creating a virtual reality environment to illustrate the enhanced benefits. This can lead to the collection of data on worker behavior and the development of predictive algorithms. Furthermore, after efficiently resolving the rapidly growing safety issues associated with UAV use, a quantitative risk assessment based on work hazard analysis approaches may be produced.

References

Become a Drone Pilot (2021). Retrieved November 13, 2021, from https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot/

Calandrillo, S., Oh, J., & Webb, A. (2020). Deadly Drones? Why FAA Regulations Miss the Mark on Drone Safety. *Stanford Technology Law Review*, *23*, 182.

Craik, F. I. (2014). Effects of distraction on memory and cognition: A commentary. *Frontiers in Psychology*, *5*, 841. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001459

Kas, K. A., & Johnson, G. K. (2020). Using unmanned aerial vehicles and robotics in hazardous locations safely. *Process Safety Progress*, *39*(1), e12066. https://doi.org/10.1002/prs.12066

Khalid, M., Namian, M., & Behm, M. (2021). *Safety Implications of Using UAVs in Construction: An Ethical Perspective*. Proceedings of the Joint CIB WO99 & W123 Annual International Conference, Glasgow, UK. Retrieved from https://www.w099tg592020.com/uploads/1/3/0/5/130510093/cib_proceedings_2021_final.pdf

Khalid, M., Namian, M., & Massarra, C. (2021). The Dark Side of the Drones: A Review of Emerging Safety Implications in Construction. *EPiC Series in Built Environment*, 18–27. Chico, California.

Li, Y., & Liu, C. (2019). Applications of multirotor drone technologies in construction management. *International Journal of Construction Management*, *19*(5), 401–412. https://doi.org/10.1080/15623599.2018.1452101

Loosemore, M., & Malouf, N. (2019). Safety training and positive safety attitude formation in the Australian construction industry. *Safety Science*, *113*, 233–243. https://doi.org/10.1016/j.ssci.2018.11.029

Namian, M., Albert, A., & Feng, J. (2018). Effect of distraction on hazard recognition and safety risk perception. *Journal of Construction Engineering and Management*, *144*(4), 04018008.

Namian, M., Khalid, M., Wang, G., & Kermanshachi, S. (2021). Ascending Drones' Safety Risks in Construction. *Proceedings of the Joint CIB W099 & W123 International Conference 2021*. Retrieved from https://www.w099tg592020.com/uploads/1/3/0/5/130510093/cib_proceedings_2021_final.pdf

Namian, M., Khalid, M., Wang, G., & Turkan, Y. (2021). Revealing Safety Risks of Unmanned Aerial Vehicles in Construction. *Transportation Research Record*, 03611981211017134. https://doi.org/10.1177/03611981211017134

Occupational Safety and Health Administration. (2018). *OSHA's use of Unmanned Aircraft Systems in Inspections*. Retrieved from https://www.osha.gov/memos/2018-05-18/oshas-use-unmanned-aircraft-systems-inspections

Öney-Yazıcı, E., & Dulaimi, M. F. (2015). Understanding designing for construction safety: The interaction between confidence and attitude of designers and safety culture. *Architectural Engineering and Design Management*, *11*(5), 325–337. https://doi.org/10.1080/17452007.2014.895697

Petrlík, M., Báča, T., Heřt, D., Vrba, M., Krajník, T., & Saska, M. (2020). A Robust UAV System for Operations in a Constrained Environment. *IEEE Robotics and Automation Letters*, *5*(2), 2169–2176. https://doi.org/10.1109/LRA.2020.2970980

Wang, G., Hollar, D., Sayger, S., Zhu, Z., Buckeridge, J. S., Li, J., … Hu, W. (2016). *Risk Considerations in the Use of Unmanned Aerial Vehicles in the Construction Industry*. Retrieved from https://thescholarship.ecu.edu/handle/10342/6067

Xu, Y., Turkan, Y., Karakhan, A. A., & Liu, D. (2020). *Exploratory Study of Potential Negative Safety Outcomes Associated with UAV-Assisted Construction Management*. 1223–1232. https://doi.org/10.1061/9780784482865.129

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Perceptions for Natural Disaster Preparedness among Historic Houses of Worship

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Historic houses of worship have traditionally been cornerstones for society and have the potential to become resilience hubs for the community in response to the increasing impacts of natural disasters. However, given that most historic houses of worship are decades or centuries old, the maintenance paradigm for such buildings is unknown and should be investigated before they can be considered resilience hubs. Therefore, the research investigated the building maintenance paradigm of historic houses of worship in coastal Texas counties impacted by Hurricane Harvey. The study also determined the role played by the historic houses of worship in response to a natural disaster. The study utilized an online survey method in which the instrument was shared with historic houses of worship stakeholders. Pre-established criteria were used as parameters to determine respondents. About 17 out of 40 historic houses of worship in 16 counties responded to the study. The study found considerable vulnerabilities in building maintenance protocols, maintenance budget, and the lack of professionals to maintain the historic houses of worship. Most respondents also indicated the need for standard guidelines to support historic houses of worship's maintenance. The study also found that historic houses of worship volunteer in response to natural disasters.

Key Words: Natural disasters, building maintenance, disaster resilience, resilience hubs, historic places of worship

Introduction and Background

Natural disasters severely impact societies across the globe from the perspective of loss of lives, economic loss, and population displacement (Kreft et al., 2016; Stapleton et al., 2017; Guha-Sapir et al., 2016). Historically, the U.S. is among the top five countries globally most hit by reported natural disasters and sustaining most economic damages from natural disasters each year (Guha-Sapir et al., 2016; CRED 2019; CRED 2020). As a result of natural disasters, more than 15,030 people have died within the U.S., and economic losses have been assessed to exceed two trillion USD since 2016 (NOAA-NCEI, 2021). At the same time, faith-based organizations operating from houses of worship have demonstrated they play a pivotal socio-cultural role within local communities, contributing to disaster risk reduction and disaster management (Gianisa & Le De, 2018). They also help reduce community vulnerability by raising awareness among community members and offering training. There have been multiple instances when faith-based organizations/religious institutions have helped communities during the disaster or the recovery phase within the U.S. and globally (Keller, 2017).

Historic houses of worship provide intimate and close interconnection between tangible (such as the building and its sub-components) and intangible (such as social practices, rituals, and festive events, oral traditions, performing arts, knowledge, and others) aspects of heritage (Aulet & Vidal, 2018). They are culturally significant because of the authenticity and integrity of the physical features of a site or building. The building is also a social interaction space, "loci" within which religious and cultural expressions are performed through rituals and festive events. Houses of worship can serve as refuges to the surrounding communities and have the potential to become resilience hubs, prepared for natural disasters and the threats posed by climate change.

Resilience hubs are facilities such as neighborhood or community centers used year-round for community-building activities but can also coordinate resource distribution before, during, or after a natural disaster (Baja, 2019). A key attribute of resilience hubs is that they are localized, created, and managed independently by the communities they serve (Baja, 2019; de Roode & Martinac, 2020), thereby reducing the burden on public resources while improving initiatives in public health and wellness. They can also act as a liaison to local government agencies, informing them of immediate issues affecting their specific communities. In the process, they can enhance organization, trust, and leadership within a community, foster neighborhood revitalization (Baja, 2019), and empower local communities to be more resilient (de Roode & Martinac, 2020). An ideal characteristic for a resilience hub is to be based out of an existing community-serving facility (de Roode & Martinac, 2020). Resilience hubs also lie at the intersection of community resilience—its intangible aspect—and resilient design, the physical facility. Both are applications of the concept of resilience, pioneered by C. S. Holling in his seminal study of stability in ecological systems (Folke, 2006). Holling's (1973) proposition that resilience measures the ability of "*systems to absorb changes of state variables, driving variables, and parameters, and still persist*" applies to both social systems in the form of communities and environmental systems in the form of buildings and infrastructure. For communities to be considered resilient, they must amass, attain, and enhance "*economic resources, infrastructure, assets, skills, information, knowledge, community networks, access to services, and shared values*" (Cramer et al., 2018). As for the built environment, resilience is at the heart of design, and any intervention should be designed to the highest standard, exceeding code-compliance minimums, to best protect public health, safety, and welfare (AIA, 2021). Resilience hubs can also engender a culture of preparedness by providing guidance and resources. Without them, individuals may not understand how best to prepare for disasters or, worse, may mistakenly believe they are prepared, exacerbating damages. Overall, "*the vulnerability of a community to the impacts of a disaster depends as much on social and cultural elements of the community as on the natural hazard itself*" (Cramer et al., 2018).

For historic houses of worship to play a vital role as resilience hubs and build community resilience towards natural disasters, the resilience of the historic building itself must first be enhanced. One substantial way to improve resilience of historic houses is by ensuring they are maintained consistently. The definition for maintenance of historic buildings has been operationalized in numerous ways (Forster & Kayan 2009; Seeley 1993; Feilden & Jokilehto 1993). Forster and Kayan (2009) further state that there is no consensus on the definition for maintenance of historic structures. More recent approaches propose that historic building resilience can be enhanced through a preventive conservation approach, an innovative 'systemic' method that uses maintenance protocols

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based on building conditions and user needs. Preventive conservation, developed initially for museums, has recently broadened to include the built environment, emphasizing historic buildings and contexts (Della Torre, 2020) to reduce building vulnerability and enhance resilience. A combination of condition-based and scheduled cyclical building maintenance is a critical element of this process to ensure the good health of the historic building. The resilience of historic houses of worship can be assessed through cyclical maintenance protocols and interlinking them with dynamic external factors (such as infrastructural, environmental, and others) (Van Balen & Vandesande, 2013). The maintenance process may include treatments that respond to climate change based on minimal interventions to reduce risk, increase the building's resilience, and build capacity to respond to the community's growing needs and social role. Building maintenance is an essential tool for preventive conservation that moves the paradigm from an expert-centered to a user-centered model, based on the active involvement of users to improve awareness of what is needed to effectively respond as a community resilience hub towards natural disasters (Della Torre, 2020). Although some resources for maintaining historic houses of worship exist within the U.S. and abroad (Prieto et al. 2019; Partners for Sacred Places, 2019), limited studies exist that document the building maintenance paradigm for historic houses of worship within the U.S. Therefore, there are performance/prescriptive recommendations for optimal maintenance of historic houses of worship, but limited studies documenting the existing maintenance paradigm followed by houses of worship within the U.S. In addition, the problem is exacerbated by the fact that the historic building's maintenance is complex due to a confluence of considerations, including the users' perceptions, needs, expectations, and devoted funds (Prieto et al., 2019).

Therefore, given the potential for these buildings to become resilience hubs, the research assessed the building maintenance paradigm for historic houses of worship in coastal Texas, U.S. Texas was purposively selected because it has been impacted by 139 billion-dollar weather and climate disasters in the last twenty-one years, making it the state within the U.S. with the highest disaster incident rate (NOAA-NCEI, 2021). Historic houses of worship accounted as the general population for the study are existing community-serving institutions based in historic buildings, listed on the National Register of Historic Places (NRHP), or determined eligible for inclusion on the NRHP. These institutions manifest the Texas region's rich and complex diversity, linking communities to ancestral traditions and cultures and serving as places of education, cultural centers, and supporting citizens in need. Since the analyzed buildings were constructed decades or, in some cases, centuries ago using various construction methods and have undergone numerous generations of maintenance, understanding the building maintenance paradigm is crucial.

Method

An online survey method was determined to be optimal to determine the building maintenance paradigm among historic houses of worship and their preparedness for natural disasters in 2021. The selected research method allowed for identifying trends and perceptions (Gable, 1994). An online method for data collection was used as most people in the U.S. have internet access (Sheehan, 2001). In addition, online data collection allows for quick response generation (Flaherty et al., 1998), and the value generated by the method outweighed other survey methods (Sheehan, 2001), especially as the research was conducted during the COVID-19 pandemic. After identifying the research method, the instrument was developed on Qualtrics and consisted of multiple choice and essay question types. The developed instrument was pilot tested for validity and reliability by historic houses of worship representatives. The general population for the study was historic faith-based organizations geographically located in Texas coastal counties (Figure 1). A comprehensive listserv of faith-based organizations was developed with Philadelphia-based nonprofit Partners for Sacred Places. The

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instrument was then emailed to representatives of historic houses of worship located on the Texas Gulf Coast. The respondents were asked to share the instrument with decision-makers or people associated with the maintenance of the historic building. Only one response from each historic house of worship was used. Two reminders were emailed, and the survey was closed two weeks after the second reminder. Approximately twenty-nine faith-based organization representatives responded to the survey. All collected data were subjected to the following filters: 1) Presence on the NRHP or determined eligible for inclusion on the NRHP; 2) Geographic location in counties deemed as most impacted by the U.S. Department of Housing and Urban Development (HUD) (Figure 1); 3) Survey completion. Based on the applied filters, the final respondent size was 17. All compiled quantitative data was downloaded and subjected to descriptive analysis. All textual data was subjected to thematic analysis to determine the commonly identifiable themes representing the areas of support provided by historic houses of worship in response to a natural disaster.

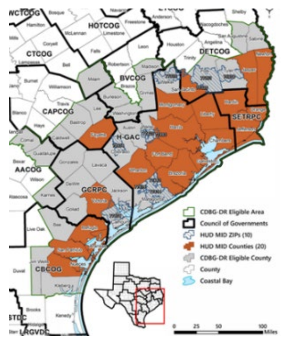

Figure 1: Most impacted counties analyzed in the study (Source: TxGLO, 2020)

Results

Approximately 17 out of 40 historic faith-based organizations in HUD-identified Texas counties most impacted by Hurricane Harvey (TxGLO, 2020) responded to the study. The majority of the respondents (70.6%) identified themselves as clergy, 17.6% as staff (non-clergy), and 11.8% as volunteer/lay leaders. Harris (41.2%), Galveston (23.5%), and Victoria (11.8%) were the top three counties from which responses were received. Further, most respondents (41.2%) identified their congregation size as less than 75 members (Figure 2). Most of the respondents (41.2%) indicated to have last experienced a natural disaster 4 – 5 years back (Figure 3). In addition, all respondents had experienced a natural disaster, indicating the severity of the problem. The majority also stated that they were a part of the current congregation when they encountered the last natural disaster.

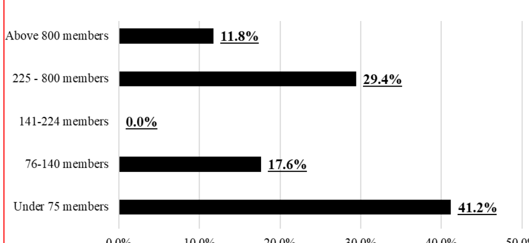

Figure 2: Respondent congregation size (n=17)

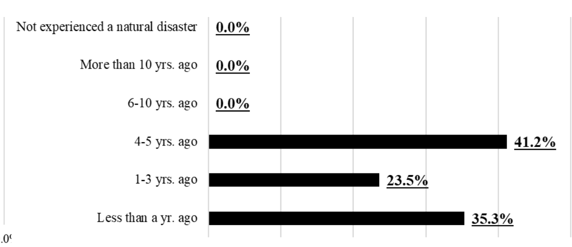

Figure 3: Respondent's last experience to a natural disaster (n = 17)

Disaster Recovery

The research also investigated if the analyzed historic houses of worship supported the response/recovery efforts to recent natural disasters. Although only 35.3% of the historic houses of worship indicated having a longstanding/permanent disaster response recovery program, the majority did indicate their congregation volunteered in the recovery efforts in response to recent natural disasters (Figure 4). The thematic analysis enabled the determination of areas where the volunteer efforts of the historic house of worship were focused (Figure 5). The top three themes for voluntary support in response to a natural disaster included: 1) Distribution (food and water); 2) Offering shelter; 3) Home repairs.

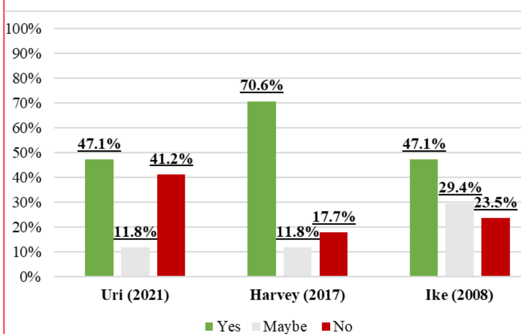

Figure 4: Volunteer recovery efforts for recent natural disasters (n=17)

Figure 5: Theme identifying the support offered by the historic houses of worship

Building Maintenance Paradigm

Historic houses of worship support recovery efforts (Figures 4 & 5) post-natural disaster. The critical question that emerges is if the houses of worship themselves were maintained to be resilient and contribute effectively to the recovery efforts post-disaster. Such a query becomes vital, especially when the buildings were constructed decades or, in some cases, centuries before the potential event. Further, given their role in the post-disaster recovery, they must be maintained to absorb external shocks and stresses imposed by the natural disaster, especially when the building is used to shelter affected people or distribute goods and volunteer for recovery. Therefore, part of the survey investigated maintenance standards for the historical place of worship.

Most respondents (35.3%) indicated having an annual operating budget of up to $99,000 (Figure 6). Further, about 35.3% of the respondents indicated a separate budget for building maintenance and capital improvements. About 70.6% of the respondents indicated that the house of worship implemented a significant capital improvement project (significant repairs or renovations) in the past 15 years, indicating that a substantial portion of the respondents (about 29.4%) had not made any significant improvement to the historic building. For the houses of worship that had implemented a significant capital improvement project, only 58.3% of the respondents invested in capital improvements specifically for disaster response/recovery efforts, whereas 25.0% did not, and the remainder were categorized as unsure.

About 76.5% of the respondents indicated they were involved in the maintenance of their historic house of worship. At the same time, only 23.5% of the respondents had received any formal training for the maintenance of buildings. When asked about their proficiency to make decisions for maintaining historic houses of worship that are resilient to natural disasters, most (41.2%) identified their confidence levels as "fairly confident" (Figure 7).

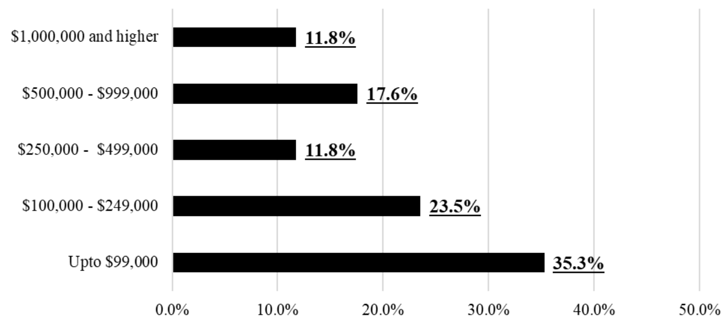

Figure 6: Respondent annual operating budget for the historic house of worship (n=17)

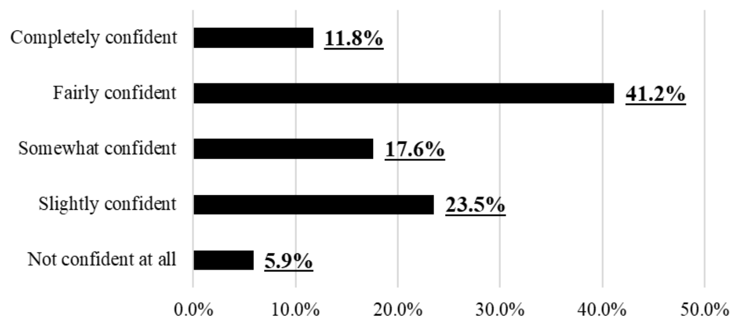

Figure 7: Confidence in making decisions for maintaining the building

About 52.9% of the respondents identified protocols for building maintenance in the historic house of worship. At the same time, a significant majority (70.6%) of the respondents also indicated that they had either no knowledge (35.3%) or were unsure (35.3%) of anyone in the congregation having any formal training regarding the maintenance of buildings. Only 43.8% of the respondents indicated having a dedicated staff person for the historic house of worship maintenance. The research also identified that most respondents had someone within the congregation who possessed the ability to design or construct non-residential buildings (Figure 8). However, only a tiny percentage indicated the existence of someone in the congregation who could maintain the historic house of worship and thereby an area of concern (figure 8). The majority of the respondents (76.5%) also indicated the existence of a committee dedicated to the historic house of worship's maintenance.

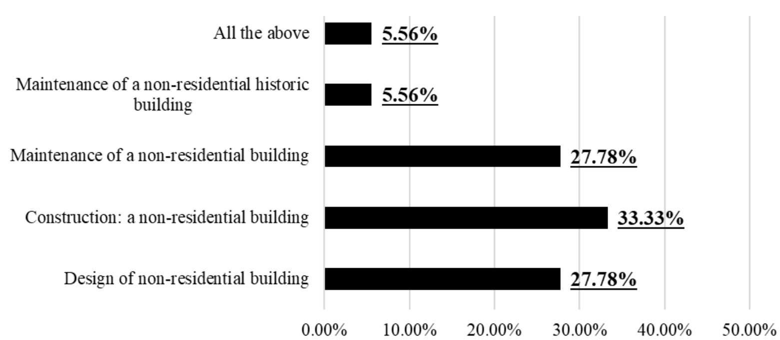

Figure 8: Response for anyone within the congregation having a building design, construction, or maintenance background

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From the perspective of building improvements that are a priority for the historic houses of worship to enhance the resilience, the top five building components (based on scores) were: 1) Air-Conditioning System; 2) Roof; 3) Exterior Windows; 4) Exterior Doors; 5) Fire Protection Systems. Most respondents (82.4%) indicated a need for “Standard Guidelines” to make historic houses of worship resilient to natural disasters. At the same time, the opinions were reversed when asked about the need for “Regulatory Guidelines” to make historic houses of worship resilient to natural disasters. The majority of the respondents (52.9%) indicated that they did not want regulatory guidelines. Thus, the results also indicate a need for guidelines to enhance the resilience of historic houses of worship in the form of supporting information rather than regulations or enforceable mandates.

Conclusion

This research is one of the first few studies within the U.S. that identified the building maintenance paradigm for historic houses of worship. The historic characteristics of these buildings can intrinsically transmit and preserve culture, heritage, and communities, creating the potential to be resilience hubs, although their age and construction techniques can leave them vulnerable to natural disasters. With future intense natural disasters, these buildings become more vulnerable, and the losses can be irreparable or irreplaceable to the communities and future generations in terms of heritage, culture, and values that bring the communities together.

The study found that over two-thirds of the respondents did not have a dedicated budget for building maintenance. Of those with a dedicated budget, only 58.3% invested in disaster response. The findings are concerning, as the historic buildings need dedicated funds to address maintenance requirements to be resilient to natural disasters and serve the communities in disaster recovery efforts. Along with dedicated funds, there is also a need for building maintenance protocols, dedicated staff for building maintenance, and people trained in its maintenance to alleviate occupant-driven vulnerabilities. Within these, developing building maintenance protocols is vital as the protocols can support maintenance through minimal interventions to retain the significance and integrity of the historical buildings. The findings are significant because coastal areas will become more prone to intense natural disasters in the future due to climate change (Miller Hesed et al., 2020).

As historic buildings are complex and houses of worship can have a pivotal role as resilience hubs, formalized training for specific congregation members in building maintenance of historic houses of worship is needed and at the core of the preventive conservation approach. The study also found that most historic houses of worship participated actively in the recovery efforts that impacted the region. Most of the recovery efforts focused on resource distribution (such as food, water, and supplies), post-disaster cleanup, and shelter for the affected in their buildings. Some of the historic houses of worship indicated they already perform some of the services that resilience hubs would undertake. At the same time, they have the potential to improve their role as resilience hubs but need to offer more services (such as natural disaster-resilient shelters) and/or become a part of a network of resilience hubs at the regional level.

Future Research

This research assessed the building maintenance paradigm for historic houses of worship in hurricane-prone counties of Texas. The researchers aim to expand the study to other disaster-prone areas of the U.S. to determine if a pattern emerges that could facilitate the identification of weaknesses and

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strengths of similar historic houses of worship. This identification would help congregations protect their structures and explore the possibility of potential resilience hubs through a possible resilience network. Results also indicated a need for "standard guidelines" that help users maintain historic buildings. Future research could also investigate the best tools for preventive maintenance plans that will help to increase the resilience of the historic houses of worship, allowing them to best perform as resilience hubs.

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References

American Institute of Architects (AIA). (2021). *Disaster Assistance Handbook* (4th ed.). https://content.aia.org/sites/default/files/2021-09/AIA_Disaster_Assistance_Handbook_4th_Edition_2021-0927.pdf

Aulet, S., & Vidal, D. (2018). Tourism and religion: Sacred spaces as transmitters of heritage values. *Church, Communication and Culture, 3*(3), 237–259.

Baja, K. (2019). *Resilience Hubs: Shifting Power to Communities and Increasing Community Capacity*. Urban Sustainability Directors Network. https://www.usdn.org/uploads/cms/documents/usdn_resiliencehubs_2018.pdf

Cramer, L. A., Cox, D., & Wang, H. (2018). Enhancing a culture of preparedness for the next Cascadia subduction zone tsunami. In L. L. Price, & N. E. Narchi (Eds.), *Coastal Heritage and Cultural Resilience*, Ethnobiology (pp. 243–264). Springer Nature Switzerland.

Centre for Research on the Epidemiology of Disasters (CRED). (2019). *Natural Disasters 2019*. https://cred.be/sites/default/files/adsr_2019.pdf

Centre for Research on the Epidemiology of Disasters (CRED). (2020). *Natural Disasters 2020*. https://cred.be/sites/default/files/CRED-NaturalDisaster2020-v06-2.pdf

de Roode, A. F., & Martinac, I. (2020). Resilience hubs: A Maui case study to inform strategies for upscaling to resilience hub networks across island, coastal, and remote communities. *IOP Conference Series Earth and Environmental Science.* 588(1).

Della Torre, S. (2020). A coevolutionary approach as the theoretical foundation of planned conservation of built cultural heritage. In A. Vandesande, E. Verstrynge, & K. van Balen (Eds.), *Preventive Conservation - From Climate and Damage Monitoring to a Systemic and Integrated Approach* (pp. 11–18). CRC Press.

Flaherty, T. B., Honeycutt, E. D., Jr., & Powers, D. (1998). Exploring text-based electronic mail

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surveys as a means of primary data collection. In J. Ford, & E. Honeycutt, Jr. (Eds.), *Proceedings of the 1998 Academy of Marketing Science Annual Conference*. (pp. 260–264). Springer, Cham.

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems of analyses. *Global Environmental Change*. 16(3), 253–267.

Forster, A.M. & Kayan, B. (2009). Maintenance for historic buildings: a current perspective. *Structural Survey*. 27(3), 210–229.

Gable, G. G. (1994). Integrating case study and survey research methods: an example in information systems, *European Journal of Information Systems*. 3(2), 112–126.

Gianisa, A., & Le De, L. (2018). The role of religious beliefs and practices in disaster: The case study of 2009 earthquake in Padang city, Indonesia. *Disaster Prevention and Management,* 27(1), 74–86.

Guha-Sapir, D., Hoyois, P., Wallemacq, P., & Below, R. (2016). *Annual Disaster Statistical Review 2016: The numbers and trends.* (p. 91). Centre for Research on the Epidemiology of Disasters (CRED). https://www.emdat.be/sites/default/files/adsr_2016.pdf

Feilden, B. M. & Jokilehto J. (1993). *Management Guidelines for World Cultural Heritage Sites*. Rome: ICCROM

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics,* 4(1), 1–23.

Keller, J. (2017). The complicated role churches play in disaster relief. *Pacific Standard*. https://psmag.com/news/the-complicated-role-churches-play-in-disaster-relief

Kreft, S., Eckstein, D., & Melchior, I. (2016). *Global Climate Risk Index 2017: Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2015 and 1996 to 2015*. https://germanwatch.org/sites/default/files/publication/16411.pdf

Miller Hesed, C. D., Van Dolah, E. R., & Paolisso, M. (2020). Engaging faith-based communities for rural coastal resilience: lessons from collaborative learning on the Chesapeake Bay. *Climatic Change, 159*(1), 37–57.

NOAA National Centers for Environmental Information (NOAA-NCEI). (2021). *U.S. Billion-Dollar Weather and Climate Disasters*. https://www.ncdc.noaa.gov/billions/

Prieto, A. J., Macías-Bernal, J. M., Chávez, M. J., Alejandre, F. J., & Silva, A. (2019). Impact of maintenance, rehabilitation, and other interventions on functionality of heritage buildings. *Journal of Performance of Constructed Facilities,* 33(2).

Partners for Sacred Places. (2019). *Repair & Maintenance Guide*. https://sacredplaces.org/info/publications/repair-maintenance/

Seeley, I. H. (1993). *Building Maintenance* (2nd ed.). Macmillan, London, UK.

Sheehan, K. B. (2001). Email survey response rates: A review. *Journal of Computer-Mediated Communication,* 6(2).

Stapleton, S. O., Nadin, R., Watson, C., & Kellett, J. (2017). *Climate change, migration, and displacement.* (p. 36). Overseas Development Institute, & United Nations Development Programme. http://www.undp.org/content/dam/undp/library/Climate%20and%20Disaster%20Resilience/MIgration_Report.pdf

Texas General Land Office (TxGLO). (2020). *Hurricane Harvey State Action Plan: Based on Amendment 7*. https://recovery.texas.gov/documents/action-plans/2017-hurricane-harvey/harvey-state-action-plan-overview.pdf

Van Balen K. & Vandesande A. (Eds.) (2013). *Reflections on Preventive Conservation*, Maintenance and Monitoring, Leuven: Acco

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Risk Analysis of Occupational Heat-Related Illness

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Heat-related illness (HRI) has become a particular concern in recent years. Many industry workers are affected by HRI due to prolonged exposure to heat and humidity. HRI is a well-known health threat that can lead to serious morbidity and mortality. This study aimed to recognize HRIs characteristics and risk factors by reviewing the HRI incident report between 1984 and 2020. Data cleaning and text mining methods were used to derive incident features and relevant risk factors. The results showed that trucks and roofs are the highest incidence locations and the main symptoms of HRI are collapse, dehydration, dizziness, and vomit. In the 1,406 incident cases, 43.8% of HRIs were fatal. The findings revealed that 89.7% of HRI patients were male with an average age of 41.4. Besides, HRIs were highly influenced by season and time of day, with 77% of incidents in the summer months and 64.1% between 11 am and 5 pm. Furthermore, between 1984 and 2020, HRI demonstrated a considerable upward tendency. The findings will assist employers and safety professionals to take appropriate actions to eliminate or reduce the identified risk factors.

Key Words: Heat-related Illness, Risk Factors, Workers, Text Mining

Introduction

Among all weather-related mishaps, heat is the leading cause of mortality. Due to climate change, extreme heat events become more frequent with an increased number of HRI cases in recent years (Coates et al., 2014; Jones et al., 2015). Working in hot environments can increase mortality and morbidity. Physical activity in a hot environment increases the risk of HRI, some of which can be fatal, such as heat exhaustion and heat stroke (Xiang et al., 2014). Occupations such as workers are more susceptible to HRI because of their frequent exposure to heat. In 2021, the United States is seeing record-breaking hot weather, putting millions of employees at risk of heat sickness or injury in both indoor and outdoor work situations (OSHA, 2021a). Thousands of employees suffer from HRI each year as a result of occupational heat exposure, even when underreported (EPA, 2021; OSHA, 2021b). Between 1992 and 2019, 907 employees died from heat stress, according to the Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (BLS, 2021). HRI not only creates substantial health difficulties to employees but also leads to considerable productivity and financial losses (Flouris et al., 2018; Takakura et al., 2017).

However, HRIs are preventable and can be readily reduced by low-cost interventions (Casa et al., 2015; Lundgren et al., 2013; Payel et al., 2018). The Occupational Safety and Health Administration (OSHA) has suggested a few measurements to prevent repeat accidents, such as monitoring heat conditions, training supervisors and workers to control and recognize heat hazards, and providing sufficient shade, fluids, and breaks (OSHA, 2021c). However, the increasing number of HRI cases in recent years indicates that reducing the occurrence of heat illnesses is still challenging. Nowadays, OSHA is seeking additional efforts or measures to improve workplace safety and protect indoor and outdoor workers from hazardous heat (OSHA, 2021d). OSHA does not have a specific regulation related to heat, and it is looking for additional information and interventions on HRI and initiating rulemaking to protect workers from harmful heat (OSHA, 2021d).

In order to prevent repeat accidents and promote workplace safety, it is essential to understand the causes of HRI accidents. OSHA gathered the accidents inspection reports from the local federal or state office and provided as a complete description as possible of how the accident occurred. The reports are crucial materials for the incidents factors analysis. The purpose of this study is to investigate the essential factors influencing HRI and other key elements by analyzing OSHA HRI accidents data from 1984 to 2020. Based on the results of the characteristics and risk factors of HRI accidents analysis, safety professionals can take appropriate actions to eliminate or reduce the identified risk factors.

Literature review

Risk Factors and Prevention of HRI

HRI is a syndrome that occurs when people are exposed to an extreme heat environment when their thermoregulatory functions are disrupted. HRI symptoms include heat rashes, heat cramps, heat exhaustion, and heat stroke (Lugo-Amador et al., 2004; Gauer et al., 2019). Risk factors of HRI include both environmental and human factors. These factors vary greatly with the workplace, occupation, and human factors (Zhang et al., 2014). The environmental factors include high temperature, high humidity, and direct sunlight (Wang et al., 2021). The human factors include age, physical exertion, mental illness, drugs, and pregnancy (Becker et al., 2011). Physicians and authorities can give preventive interventions by identifying high-risk populations and workplaces (Becker, et al., 2011). OSHA has taken a variety of approaches to address dangerous heat for both indoor and outdoor workers (OSHA, 2021c). These include requiring employers to provide workers with readily accessible drinking water, adequate rest, and shade (OSHA, 2021c). Employers in the construction industry are recommended to provide heat safety training to their employees (NIOSH, 2016). First aid actions will be taken when workers experience heat-related illnesses, such as hydration, taking rest, and accessing to an air-conditional area (Becker, 2011; Lugo-Amador et al., 2004).

A study concluded that HRI was associated with workers' age, maximum skin temperature, post-warm-up heart rate, and work area (Kakamu, et al., 2021). The study also found that simple actions can help to prevent HRIs, such as knowing the physical fatigue of workers in the morning was effective in preventing the occurrence of HRI. (Kakamu, et al., 2021). Researchers also found that workers with insufficient rest are less productive and have a higher risk of getting HRIs (Ebi et al., 2021). Many studies have shown that the HRI prevention measures being implemented by OSHA are effective. Studies found that taking extra precautions to protect new workers is essential. For example, an assessment of workplace deaths indicates that about 70% of deaths occurred during the first few days of work, and upwards of 50% occur on the first day of work (Arbury et al., 2014; Tustin et al., 2018). Additionally, it is also found that training supervisors and workers are an effective method to reduce HRIs. A study conducted training for farmworker crew leaders on OSHA's Heat Safety Tool application and evaluated the training effectiveness (Luque et al., 2020). The results showed that conducting heat safety training reduced the risk of HRI, especially among less experienced farmworkers (Luque et al., 2020). Another effective HRI prevention method is to introduce an HRI prevention program, which includes training, acclimatization, and medical care (McCarthy et al., 2019). In this program, the rate of HRI experienced by Texas outdoor workers declined each year from 2009 to 2017, and no HRI case was reported to occur over the hot season during the last two years (McCarthy et al., 2019). However, more HRI accidents still occurred because many companies or employers fail to effectively implement these preventive methods (Arbury et al., 2014). According to a questionnaire survey of military personnel, it is suggested that establishing educational programs and improving systematic educational materials are critical to raising awareness of HRI (Wang et al., 2021). Knowledge, attitude, and practice were recognized as the three most significant strategies for avoiding HRIs (Wang et al., 2021).

Occupational Safety and Health Data Collection and Analysis

The OSHA Integrated Management Information System (IMIS) provides a list of enforcement cases, including HRI cases. This database is updated daily from over 120 OSHA Area and State 18b plan offices (OSHA, n.d.). Additionally, many companies have developed incident reporting systems to identify hazards and actively prevent repeat incidents (Song et al., 2020). According to a steel manufacturing company, all incidents are required to be reported by the employees and workers and then organized by safety managers into company-specific categories (Song et al., 2018). Moreover, an electricity generation company documents accidents and incidents using different IT systems, and existing data gathering approaches are being continuously improved, such as the usage of risk registers (Leva et al., 2017). After an accident occurs, an inspection summary with a complete description of the accident process is significantly important for risk analysis. It is crucial to classify and analyze the risk factors and causes of accidents, as prevention strategies should be developed accordingly to different causes. However, natural language narratives are ambiguous and vague, unstructured textual data that require a lot of time and effort to retrieve and analyze (Soleimani et al., 2019). Currently, techniques such as Natural Language Processing (NLP), text mining, and machine learning are applied to text analysis.

Text mining is the process of extracting previously unseen and non-obvious information from textual data (Miner et al., 2012). The current researches mainly focus on optimizing text mining models and identifying and classifying risk factors (Zhang et al., 2019; Song et al., 2020). According to Song et al. (2020), to prevent the recurrence of similar accidents, an energy source recognition approach was applied to identify and evaluate hazards, and text mining was used to analyze the causal factors of past accidents. Before performing the classification process, NLP techniques were used by the researchers to pre-process the text data, then a hybrid supervised machine learning model was proposed for construction site accident classification (Cheng et al., 2020). For the classification of large injury accidents dataset, the Human-machine learning method was implemented to improve the accuracy of text mining (Marucci-Wellman et al., 2017). For example, a study combined techniques including machine learning to implement automatic coding and aid in extracting the causes of workers' injuries and compensation (Bertke et al., 2012).

Methodology

In this study, data collection, data cleaning, and text mining were used to identify the risk factors and features of HRI. The first step was to pre-process the unstructured narrative data from OSHA inspection summaries to extract the main elements of HRI such as demographic characteristics, time trending, location distribution, accident summary, etc. Then the study contributed the text mining technique to extract keywords of each HRI incident.

Data Collection

OSHA gathers occupational enforcement cases data and makes them publicly available on its website. This study obtained the HRI incident reports from the inspection summary of IMIS (OSHA, 2021e) between 1984 and 2020. Each report provides a complete description of each incident including the demographic characteristics and occupations of the workers, the event degree, the course of the accident, etc. A total of 2,418 relevant event records were identified under all heat-related keywords. The dataset was made up with a short one-sentence incident description. The detailed incident description text data were then acquired from the Summary ID of each incident. A complete dataset was finalized in an excel spreadsheet.

Data Cleaning

Due to the ambiguity and vagueness of natural language description, a few data cleaning methods were used to correct and remove inaccurate information. As a result, 1,406 valid data were identified by the HRI keyword search such as "heat-related illness", "heat stroke", and "heat exhaustion". The most significant and independent columns in the excel file were designated using feature selection analysis, including Date, Time, City, State, Accident degree, Age, Sex, Occupation and Incident description, while the less important ones were removed (Table 1).

This study used a TM package in R-language to discover the characteristics and key factors of HRI from investigation summaries (Feinerer, 2008). Before starting to mine the text data, several spelling problems and unnecessary characters had to be fixed or eliminated. For example, removing all punctuations, stop words, and numbers, and converting uppercase letters to lowercase letters. Furthermore, the number of possible keywords was reduced by combining words with different tenses and similar meanings. For example, the combination of "fall" and "fell" is classified as "fall", and the combination of "roofing" and "roof" is classified as "roof".

Table 1

A sample dataset of the collected HRI incident data

Event number	1	2	3
Summary number	129395.01	129284.01	128851.01
Age	23	39	45
Sex	M	M	M
Date	9/4/20	9/3/20	8/20/20
Time	5:00 PM	2:15 PM	11:00 AM
City	Oklahoma City	Hampton	Englewood
State	OK	VA	CO
Accident Degree	Fatality	Fatality	Fatality

Occupation	Construction Laborers	Carpenter	Construction Laborers
Investigation Summary	At 5:00 p.m. on September 4, 2020, an employee was working to break concrete and separate rebar. At some point, the employee requested a break and upon returning from the break showed signs of disorientation and was stumbling. The employee was taken to a local hospital, where the employee died of suspected heat stroke.	At 2:15 p.m. on September 3, 2020, an employee worked outdoors performing various labor tasks such as site cleanup and demolition of roof materials. After approximately six to seven hours of working in the heat, the employee went to the work vehicle to take a break. The employee was later discovered unresponsive in the driver's seat of the vehicle. Coworkers called for emergency services and at tempted first aid. The employee was transported, by ambulance, to a local hospital, where the employee was pronounced dead of heat stroke.	At 11:00 a.m. on August 20, 2020, Employee #1, employed by a specialty construct ion company, was setting rebar for a new commercial building, a multi-employer construction project. He was placing and tying the rebar when he showed signs of heat-related illness. Employee #1 walked to a shaded area, collapse, and died. His death was attributed to an apparent heat stroke.

Results

Demographics and HRI Characteristics

Of these 1406 HRI incidents, 616 were fatalities, 535 were hospitalized and 256 were non-hospitalized. The average age (standard deviation) was 41.4 with a maximum of 25% of young workers aged 25-34 (Figure 1). Besides, the majorities were males 89.7% and females were 10.3%.

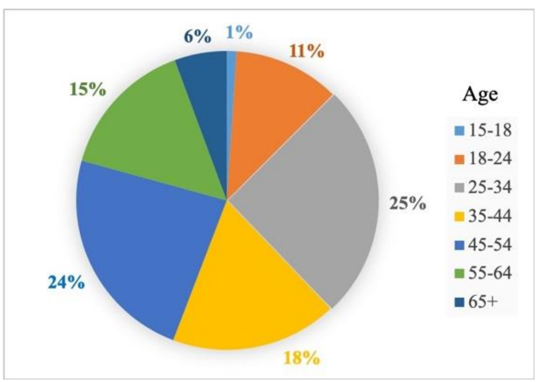

Figure 1. The age distribution of HRI workers

HRI accidents were unevenly distributed by month and time of day, with the majority of HRIs (77%) occurring in the summer months: June, July, and August. The largest proportion (36%) occurred in July. During the day, the most HRI occurred between 11 am and 5 pm, making up 64.1% of the total accidents during the day (Figure 2). In Figure 3, HRI has shown an increasing trend over the past thirty years. Especially in the last five years, the number of HRI accidents has a significant and rapid increase. The most significant increase is in hospitalized accidents, where the number of HRI accidents has increased by 257% over the last five years.

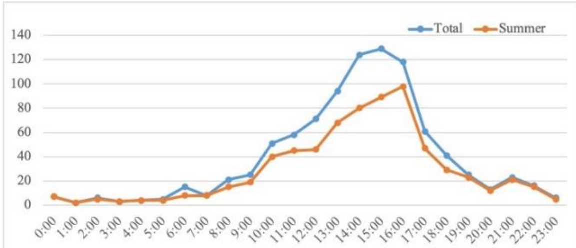

Figure 2. The whole year and summer time distribution of HRI accidents

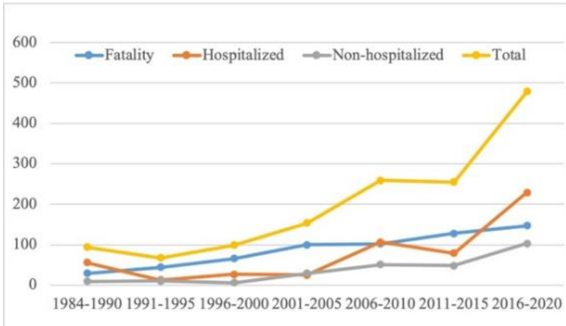

Figure 3. Trends of the number HRI incidents in 1984-2020

The US Census Bureau divides the US into four regions, including Northeast, Midwest, South, and West. According to Figure 4, the West region had the highest number of HRI cases at 47%, with California accounting for 42% of all regions and 90% of the West. Then followed by the South region, which accounted for 33% of all HRI accidents in the US. The Northeast and Midwest had fewer HRI cases, with 9% and 11% respectively.

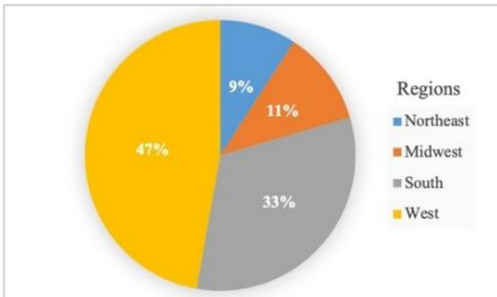

Figure 4. The geographic distribution of HRI accidents

Key Risk Factors

According to the text mining results, several keywords showed up as the most significant factors of the HRI accidents (Figure 5). The top twenty were "July", "August", "June", "Collapse", "Truck", " Dehydration", "Training", "Roof", "Humidity", "Fall", "Dizzy", "Lunch", "Weather", "Concrete", "September", " Vomit", "Firefighters", "Cramp", and "Vehicle". These factors also indicated that the HRI accidents occurred mainly in the summer, and that trucks, roofs, etc. were the main locations of accidents. It can also be seen that the main symptoms of HRI are collapse, dehydration, dizziness, vomit, etc.

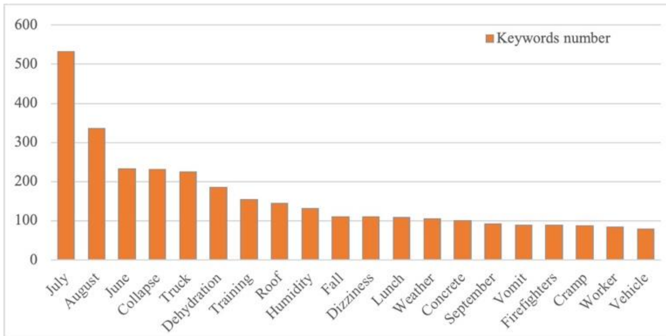

Figure 5. The keywords of the HRI accidents description text data

Conclusion

This study analyzed 1,406 HRI incident reports between 1984 and 2020. Through the methods of data cleaning and text mining, descriptive text data were used to identify characteristics and key risk factors of HRI accidents. The demographic characteristics indicated that middle-aged male workers were more frequently injured by heat stress. The temporal and spatial distribution revealed that time and location have a strong influence on HRI. In addition, “roof” is a location-based keyword with a high number of occurrences. Workers should minimize long-time work on the roof during hot seasons and periods. It is also suggested that more protective and effective measurements should be implemented when working on the roof. The results of the study can help with developing more explicit risk control plans for specific populations and dangerous workplaces.

This study analyzed the spatial and temporal characteristics of the number of HRI in recent years, and the next step will analyze the ratio of HRI to total workers to derive a more comprehensive understanding of the spatial and temporal variation of HRI. Future research also can explore the potential correlations between HRI factors and provide more effective HRI prevention strategies. In addition, root cause analysis can be conducted on HRI accidents, such as global warming, to seek more effective hazard control measures.

References

Arbury, S., Jacklitsch, B., Farquah, O., Hodgson, M., Lamson, G., Martin, H. & Profitt, A. (2014). Heat illness and death among workers - United States. *Morbidity and mortality weekly report*, 63(31), 661–665.

Becker, J.A. & Stewart, L.K. (2011). Heat-related illness. *American Family Physician*. 83(11), 1325-30.

Bertke, S.J., Meyers, A.R., Wurzelbacher, S.J., Bell, J., Lampl, M.L. & Robins, D. (2012). Development and evaluation of a Naïve Bayesian model for coding causation of workers’ compensation claims. *Journal of Safety Research*, 43(5–6), 327-332.

Bureau of Labor Statistics (BLS). (2021). Survey of occupational injuries and illnesses data.

Casa, D.J., DeMartini, J.K., Bergeron, M.F., Csillan, D., Eichner, E.R., Lopez, R.M., Ferrara, M.S., Miller, K.C., O'Connor, F., Sawka, M.N., & Yeargin S.W. (2015). National athletic trainers' association position statement: Exertional heat illnesses. *Journal of athletic training*, 50(9), 986–1000.

Cheng, M.-Y., Kusoemo, D. & Gosno, R.A. (2020). Text mining-based construction site accident classification using hybrid supervised machine learning. *Automation in Construction*, 118,103265.

Coates, L., Haynes, K., O'Brien, J., McAneney, J., & de Oliveira, F. D. (2014). Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844–2010. *Environmental Science & Policy*, 42, 33–44.

Ebi, K.L., Capon, A., Berry, P., Broderick, C., Dear, R.D., Havenith, G., Honda, Y., Kovats, R.S., Ma, W., Malik, A., Morris, N.B., Nybo, L., Seneviratne, S.I., Vanos, J. & Jay, O. (2021). Hot weather and heat extremes: health risks. *The Lancet*, 398, 698-708.

Environmental Protection Agency (EPA). (2021). Climate change indicators: heat-related deaths. https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths.

Feinerer, I., Hornik, K., & Meyer, D. (2008). Text mining infrastructure in R. *Journal of Statistical Software*, 25(5), 1–54.

Flouris, A.D., Dinas, P.C., Ioannou, L.G., Nybo, L., Havenith, G., Kenny, G.P. & Kjellstrom, T. (2018). Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. *Lancet Planetary Health*, 2 (12): e521-531.

Gauer, R. & Meyers, B.K. (2019) Heat-related illness. *American Family Physician*, 15;99(8), 482-489.

Jones, B., O'Neill, B.C., McDaniel, L., McGinnis, S., Mearns, L.O. & Tebaldi, C. (2015). Future population exposure to US heat extremes. *Nature Climate Change*, 5, 652–655.

Kakamu, T., Endo, S., Hidaka, T., Masuishi, Y., Kasuga, H. & Fukushima, T. (2021). Heat-related illness risk and associated personal and environmental factors of construction workers during work in summer. *Science Report*, 11, 1119.

Leva, M.C., Balfe, N., McAleer, B. & Rocke, M. (2017). Risk registers: Structuring data collection to develop risk intelligence. *Safety Science*, 100, 143-156.

Lundgren, K., Kuklane, K., Gao, C. & Holmer, I. (2013). Effects of heat stress on working populations when facing climate change. *Industrial Health*, 51(1), 3–15.

Lugo-Amador, N.M., Rothenhaus, T. & Moyer, P. (2004) Heat-related illness. *Emergency Medicine Clinics of North America*, 22(2), 315-27.

Luque, J. S., Becker, A., Bossak, B. H., Grzywacz, J. G., Tovar-Aguilar, J. A., & Guo, Y. (2020). Knowledge and practices to avoid heat-related illness among hispanic farmworkers along the Florida-Georgia line. *Journal of Agromedicine*, 25(2), 190–200.

Marucci-Wellman, H.R., Corns, H.L. & Lehto, M.R. (2017). Classifying injury narratives of large administrative databases for surveillance—A practical approach combining machine learning ensembles and human review. *Accident Analysis & Prevention*, 98, 359-371.

McCarthy, R.B., Shofer, F.S. & Green-McKenzie, J. (2019). Outcomes of a heat stress awareness program on heat-related illness in municipal outdoor workers. *Journal of Occupational and Environmental Medicine*, 61 (9), 724-728.

Miner, G., Elder, J., Hill, T. & Delen, D. (2012). Practical text mining and statistical analysis for non-structured text data applications academic press.

National Institute for Occupational Safety and Health (NIOSH). (2016). Criteria for a recommended standard: occupational exposure to hot environments. https://www.cdc.gov/niosh/docs/2016-106/.

Occupational Safety and Health Administration (OSHA). (2021a). US Department of Labor announces enhanced, expanded measures to protect workers from hazards of extreme heat, indoors and out. https://www.osha.gov/news/newsreleases/national/09202021.

Occupational Safety and Health Administration (OSHA). (2021b). Safety and health topics-heat exposure. https://www.osha.gov/heat-exposure.

Occupational Safety and Health Administration (OSHA). (2021c). Safety and health topics-heat prevention. https://www.osha.gov/heat-exposure/prevention.

Occupational Safety and Health Administration (OSHA). (2021d). Heat injury and illness prevention in outdoor and indoor work settings rulemaking. https://www.osha.gov/heat-exposure/rulemaking.

Occupational Safety and Health Administration (OSHA). (2021e). Investigation summary keywords. https://www.osha.gov/pls/imis/accidentsearch.display_keyword?v_keywordletter=H.

Occupational Safety and Health Administration (OSHA). (n.d.). Inspections within industry search. https://www.osha.gov/help/industry-search.

Payel, A., Boggess, B., & Zhang, K. (2018). Assessing heat stress and health among construction workers in a changing climate: A review. *International Journal of Environmental Research and Public Health*, 15, 247.

Soleimani, S., Mohammadi, A., Chen, J. & Leitner, M. (2019). Mining the highway-rail grade crossing crash data: A text mining approach. *2019 18th IEEE International Conference on Machine Learning and Applications (ICMLA)*, 1063-1068.

Song, S., Lyu, Q., Marks, E. & Hainen, A. (2018). Steel manufacturing incident analysis and prediction. *Journal of Safety, Health and Environmental Research*, 14 (1), 331-336.

Song, S., & Awolusi, I. (2020). Industrial Safety Management Using Innovative and Proactive Strategies. In *Concepts, Applications and Emerging Opportunities in Industrial Engineering*. Intechopen.

Song, S., Awolusi, I., & Jiang, Z. (2020). Work-related fatalities analysis through energy source recognition. *Construction Research Congress 2020*, 279-288.

Takakura, J., Fujimori, S., Takahashi, K., Hijioka, Y., Hasegawa, T., Honda, Y. & Masui, T. (2017). Cost of preventing workplace heat-related illness through worker breaks and the benefit of climate-change mitigation. *Environmental Research Letters*, 12, 064010.

Tustin, A.W., Cannon, D.L., Arbury, S.B., Thomas, R.J. & Hodgson, M.J. (2018). Risk factors for heat-related illness in U.S. workers. *Journal of Occupational and Environmental Medicine*, 60 (8), e383-e389.

Wang, X., Xia, D., Long, X., Wang, Y., Wu, K., Xu, S., & Gui, L. (2021). Knowledge, attitudes, and practices of military personnel regarding heat-related illness risk factors: results of a Chinese cross-sectional study. *Frontiers in Public Health*, 9, 707264.

Xiang, J., Bi, P., Pisaniello, D. & Hansen, A. (2014). Health impacts of workplace heat exposure: an epidemiological review. *Industrial Health*, 52,91-101.

Zhang, K., Li, Y., Schwartz, J. & O'Neill, M. (2014). What weather parameters are important in predicting heat-related mortality? A new application of statistical learning methods. *Environmental Research*, 132, 350–359.

Zhang, F., Fleyeh, H., Wang, X. & Lu, M. (2019). Construction site accident analysis using text mining and natural language processing techniques. *Automation in Construction*, 99, 238-248.

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Physiological Metrics Across Construction Activity

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Safety management and occupational health are essential for construction work. Several studies examine the extent to which physical activity impacts the health and safety of construction workers. To date, however, few studies directly assess the impact of construction activities. This research analyzes physiological and environmental data to explore the impact of construction activity on individual workers, under a range of ambient conditions. Vital signs and physical indicators including heart rate, breathing rate, core temperature, physiological load, mechanical load and posture were collected from a relatively homogeneous set of US Air Force Academy cadets while performing four different construction activities. Results suggest average physiological measures (i.e. mean Heart Rate, Breathing Rate etc.) statistically vary by individual even for individuals similar in age, health, and fitness. Despite individual distinctions, statistical trends and patterns are observable across construction activities. Specifically, the results demonstrate that concrete and asphalt placement are generally more physically demanding, followed by, heavy equipment operation and surveying activities respectively. In addition, the ambient variable, Heat Index, plays a significant role and merits future research. The primary contribution of the research is to demonstrate a method for monitoring and assessing discrete physiological metrics across individuals as well as construction activity.

Key Words: Construction Worker Health, Physiological Metrics, Safety, Physiological status monitoring technology

Introduction

Many construction activities require extensive physical labor over extended periods, sometimes with exposure to adverse weather conditions. Construction, in general, is a labor intensive process where workers are subjected to unusual work postures, heavy weight lifting, and a range of work postures (Hartmann and Fleischer 2005). Injuries from construction activity can be immediate or cumulative over time. Physical stress and strain can lead to decreased work productivity, inattentiveness, or inability to make wise decisions. Construction productivity is generally measured as the number of hours of work required to complete a specified work product (Jang et al., 2011). While productivity is not directly measured in this research, it is well-documented that the typical, demanding workload of construction can take a toll on both the mental and physical health of a worker. Furthermore, continuous depression and dissatisfaction from a worksite can result in unwanted accidents and more injuries (Abdelhamid and Everett 2002). Construction workers are exposed to ergonomic hazards, which include dynamic movement, various unusual postures, pulling and lifting loads (Hartmann and Fleischer 2005). They are at risk to develop musculoskeletal disorders (Engholm and Holmström 2005).

A number of studies focused on analyzing the impact of construction work on workers using physiological indicators such as heart rate, body temperature, and blood oxygen level (Abdelhamid and Everett 2002; Buller et al. 2010; Kirk and Sullman 2001). For example, Abdelhamid and Everett (2002) collected oxygen consumption and heart rate data to determine the performance of 100 construction workers doing moderate to heavy work. The data showed that the average oxygen uptake was 0.82 L/min (± 0.22 L/min) and the average heartbeat was 108 beats/min (± 17 beat) min). Measurements were compared to standard guidelines for acceptable levels of physical performance for specific industrial environments. Results indicated that 20-40% of the workers regularly exceeded recommended thresholds for manual work, thereby making the workers more prone to inattentiveness, decreased productivity, poor judgment, accidents, and injuries. Several research works studied the factors affecting heat stress (Rowlinson et al. 2014; Yi et al. 2016; Yi and Chan 2015). For example, Rowlinson et al. (2014) studied factors affecting climatic heat stress and identified three ways of reducing heat stress in construction sites: (1) control of climatic heat stress exposure through the use of an action-triggering threshold system, (2) control of continuous work time with mandatory work-rest routine, and (3) allow workers to follow self-pace regimes. Other studies considered additional indicators such as posture to evaluate the health hazards among construction workers (Roja et al. 2006; Tak et al. 2011). For example, Roja et al. (2006) conducted a study on workers from the heavy civil industry which included ten road construction and maintenance workers and ten pavers who belonged from the age group 20-60 years. The study measured the physical demands of road construction work and estimated muscle fatigue. Average metabolic energy consumption for road construction and repair work was recorded as 8.1± 1.5 kcal/min, and 7.2 ± 1.1 kcal/min for paving respectively. Their findings documented that road construction work requires extreme manual labor, compulsive working posture, and continuous arm and leg movements. In the same study, they monitored the workers' heart rate, posture and muscle tone for a week and suggested that work-related musculoskeletal problems could be likely for these workers. Several studies applied physical monitoring systems (PMS) for the purpose of physiological monitoring, environmental sensing, proximity detection and location tracking analysis on construction workers (Aryal, Ghahramani, and Becerik-Gerber 2017; Awolusi, Marks, and Hallowell 2018; Lee and Migliaccio 2016; Wang et al. 2017; Yu et al. 2017). For example, Gatti et al. (2014) investigated the validation of PMSs for construction based on two physiological parameters including heart rate and breathing rate. Results indicated that PMS data can be used to identify and correlate physical strain, task level, productivity, and safe-unsafe behavior of construction workers.

Although the aforementioned studies had significant contributions in examining the extent to which physical activity impacts the health and safety of construction workers, there are limited studies that focused on monitoring and collecting physiological data of workers across different construction activities under a range of ambient conditions. Moreover, former studies have primarily been limited to one or more physical indicators of the construction workers. The present research focuses on the analysis of multiple physical indicators across four construction activities.

Research Objectives and Methodology

The objective of this research is to develop and advance a system that analyzes physiological and environmental data to explore the impact of construction activity on individual workers, under a range of ambient conditions. For this research, the system was applied to a relatively homogenous set of workers, in this case, a set of ten US Air Force Academy (USAFA) cadets comprised of 8 males and 2 females, who each performed four distinct construction activities under similar, relatively controlled, conditions. International Review Board protocols for research involving humans were completed under the supervision of USAFA. During the study period, volunteers were following similar food and sleep regimens. All the volunteers were within the age range of 20-22. The following metrics were analyzed: heart rate, breathing rate, core temperature, mechanical load, physiological load, and posture. Metric descriptions are provided in Table 1, based on research and available manufacturer information (Zephyr 2013).

Table 1

Metrics

Metric	Description	Units	Notes
Heart Rate	It is measured as the number of heart beats per minute.	Heartbeats per minute	The measure of Heart rate is analyzed from the 250Hz Echocardiogram (ECG) data
Breathing Rate	It is measured as the number of breaths per minute.	Breathing per minute	The sensors inside the zephyr puck detect breathing by the expansion and contraction of our torso.
Posture	It is measured as the change of angle of any individual in comparison with gravity.	Degree from the vertical position.	When an individual is standing straight the measurement is zero. Forward and backward leaning accounts for positive and negative values.
Core Temperature	The core temperature is estimated based on the heart rate.	Degree Centigrade	The accuracy of this estimate and have also demonstrated that such a computational measurement can indicate physical stress before an individual reaches an unhealthy state (Buller and Hoyt 2008).

Volunteers' physiological characteristics were monitored during four construction activities. Table 2 defines these activities based on USAFA's FERL handbook descriptions ("Civil Engineering Practices - Field Engineering Cadet Handbook," 2017).

Table 2

Construction Activities

Activity	Description
Concrete Placement (C)	Prepare a site, set framework and reinforcement, place concrete, and take samples and perform slump test.
Heavy Equipment (HE)	Operate construction equipment including an excavator, scraper, bulldozer, loader, and paving machine.
Surveying (S)	Use total station to measure distance and horizontal/vertical angles. Layout a calculated location for concrete slab pour and use measuring techniques to plot land data.

Asphalt Paving (A)	Place a section of road using approximately 20 tons of asphalt.

The PMS device used for this study was the Zephyr BioHarness, an off-the-shelf product capable of remote physiological monitoring and location tracer without hindering the flexibility and freedom of the individual (Zephyr 2013, 2016). To retrieve the recorded data from PMS devices, and to analyze the physiological status for each volunteer, "Omnisense" software was used (Zephyr 2016). To this end, individual weight, height, age, and fitness levels of the volunteers were entered into the software. Based on the collected data, the software generated spreadsheets including, heart rate, breathing rate, posture, core temperature, and Heart Rate Confidence (HRC) for each of the volunteers. HRC is calculated based on electrocardiogram noise and worn detection. The threshold for accepting data was based on HRC of 80% or higher, based on the recommendation of Zephyr's representative. Lower HRC levels suggest the data is unreliable based on the faulty collection. This indicator is then used to remove the noisy data. After the data collection phase, software R was used to perform statistical analyses in 5 steps: (1) filter the noisy data based on HRC; (2) aggregate one-second interval data to one-minute interval data; (3) add morning and afternoon weather, temperature, humidity level, and heat index using local station data; (4) apply a Linear Mixed Effect Model (LMM) to analyze the effect and statistical significance of the independent variables including heat index and activity on the physiological metrics such as heart rate, breathing rate, posture, and core temperature per individual and construction activity; and (5) compare data and identify general and observable patterns.

Model Development

Multivariable linear regression is predominantly used to model the relationships among two or more explanatory variables and a response variable by fitting a linear equation to the observed data. For the collected data, there are repeated observations over time for an individual which cannot be assumed to be independent. An appropriate way to model such repeated measures data across time is the use of the linear mixed-effects model. The Linear Mixed Effect Model (LMM) comprises both fixed effects and random effects. The random-effects take care of the correlation between the repeated observations. For this study, the goal was to determine the effect of the independent variables such as gender, heat index, activity level and activity on the metrics. The LMM, therefore, can be written as shown in Equation 1.

$$Y_{ij} = \beta_0 + \beta_1 gender + \beta_2 H.I + \beta_3 A.L + \beta_4 A1 + \beta_5 A2 + \beta_6 A3 + \beta_7 A4 + b_i + \epsilon_{ij} \qquad (1)$$

Where: Y_{ij} is the value of the response for the jth replication for ith individual; A1, A2, A3, and A4 are activity 1 to 4, respectively, and can have the value of 1 if the volunteer does the corresponding activity, and otherwise 0; gender is 1 for male and 0 for female; H. I is Heat Index; A. L is Activity Level; b_i is individual specific random effect for the ith individual; and ϵ_{ij} is the error (residual).

Likelihood Ratio Test (LRT) was used to determine if an outcome was statistically different from other outcomes. If a significant difference between activity outcomes was found, a pairwise comparison (t-test) was then used. To adjust raw p-values when testing various hypotheses, a Bonferroni correction (Dunn 1961) was used.

Results and Discussion

This research analyzed unique data sets to explore statistical relationships and observable patterns for physiological metrics variables as measured in construction workers of similar in fitness, age, and experience, performing four distinct construction activities. Violin plots representing the distribution of heart rate, breathing rate, core temperature, and posture across the four activities are shown in Figure 1. Violin plots visualize the distribution of the data and present a vertically symmetric probability distribution of the response variable as estimated from the data. These results indicate that concrete placement is the most physically demanding activity for all volunteers.

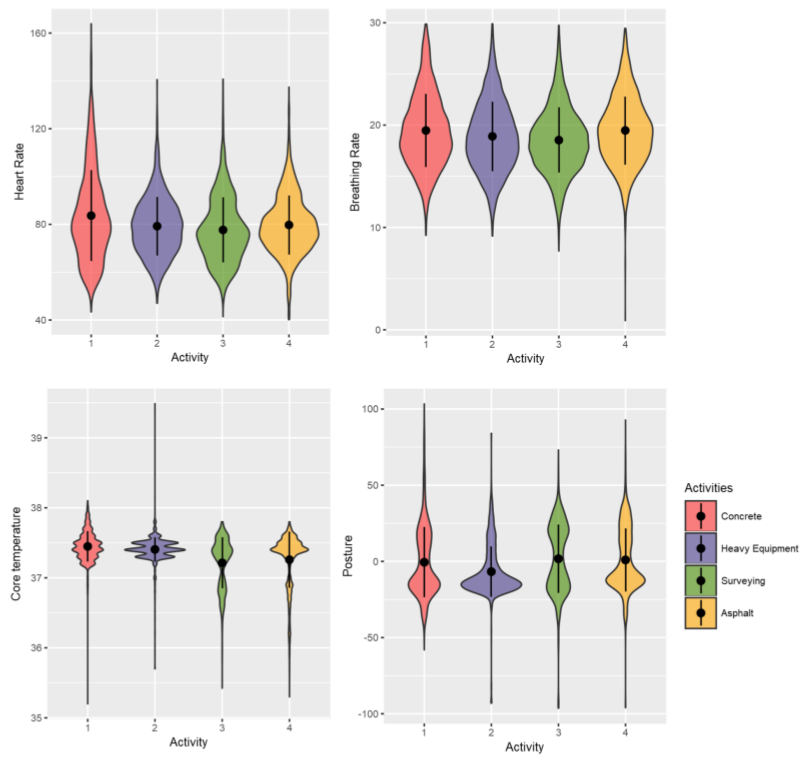

Figure 1. Violin plot showing the distribution of heart rate, breathing rate, core temperature, and posture across the four activities

To test for statistical differences t-test was performed for the heart rate, breathing rate, core temperature, and posture data across all 10 volunteers. The p-values indicate that: (1) heat index, activity level and activity are significantly associated with heart rate ($p \leq 0.05$), but gender is not significantly associated ($p > 0.05$). (2) heat index, activity level and activity are significantly associated with breathing rate ($p \leq 0.05$), but gender is not significantly associated ($p > 0.05$). (3) activity is significantly associated with core temperature ($p \leq 0.05$). (4) heat index, activity level and activity are significantly associated with posture ($p \leq 0.05$), but gender is not significantly associated ($p > 0.05$).

Pairwise comparisons between the different activities were performed to investigate which activities lead to significantly different heart rates, breathing rates, core temperature, and posture. The pairwise comparisons indicate that: (1) concrete-heavy equipment, concrete-surveying, heavy equipment-surveying, heavy equipment-asphalt result in statistically distinct heart rate profiles; (2) concrete-surveying, heavy equipment-surveying, surveying-asphalt result in statistically distinct breathing rate profiles from one another; (3) concrete- heavy equipment, concrete-surveying, concrete- asphalt, heavy equipment-surveying, and surveying-asphalt result in statistically distinct posture profiles; and (4) concrete-surveying, concrete-asphalt, heavy equipment-surveying, heavy equipment-asphalt, surveying-asphalt result in statistically distinct core temperature profiles from one another with the core temperature profiles during surveying and asphalt being the most distinct. Moreover, results suggest that heat index also affects the physiological metrics of individuals when performing construction activities.

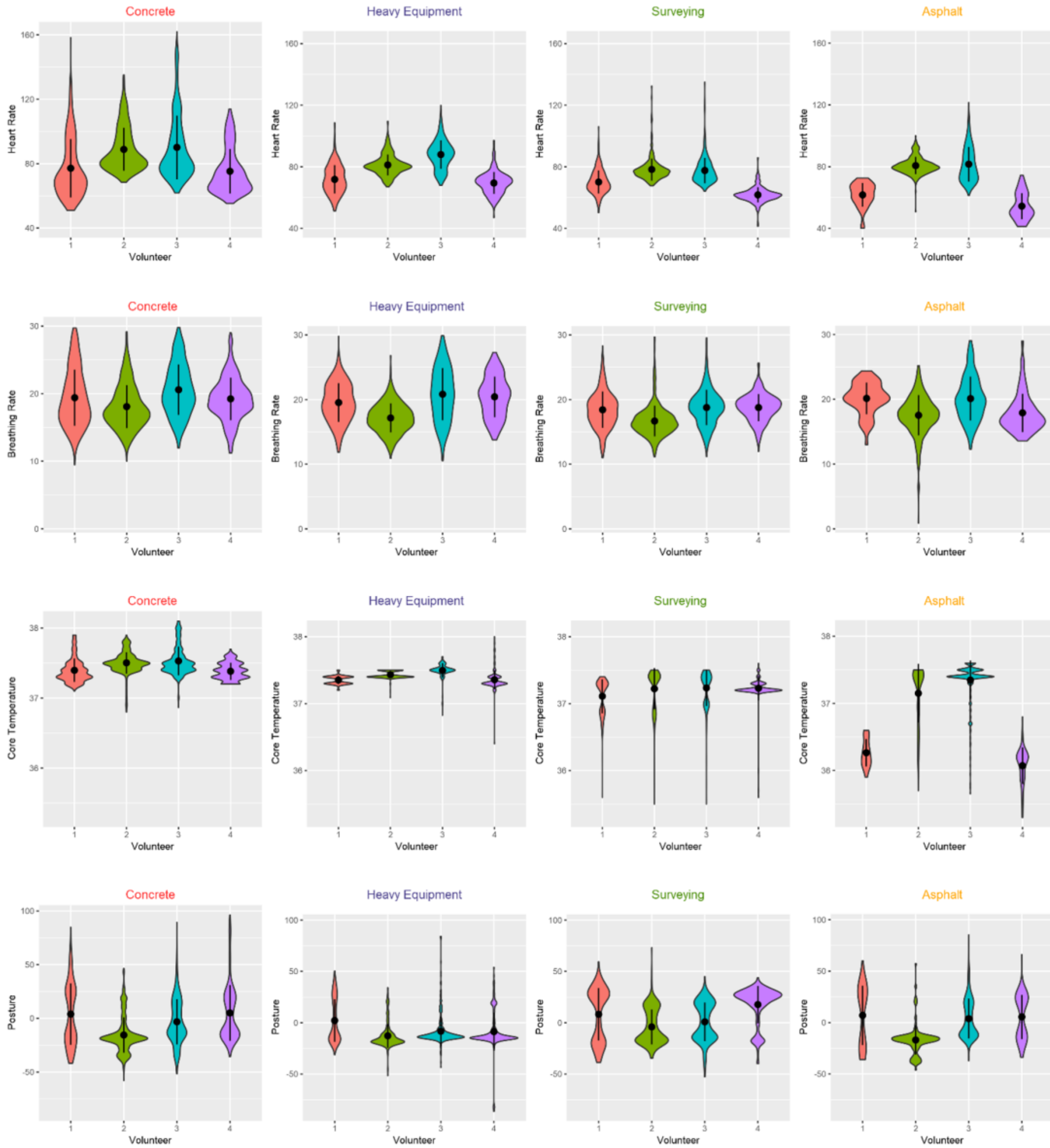

Figure 2. Violin plot showing the distribution of heart rate, breathing rate, core temperature, and posture for volunteers 1,2,3,4 across the four activities

In addition to the full analysis of the 10 volunteers, a focused analysis of the data from four volunteers who were in the same group was performed to minimize the role of external variables (such as weather, time of day, specific tasks performed etc.). Specifically, volunteers 1, 2, 3 and 4 were all working under the same climatic conditions and synchronously performing the same construction activities. Moreover, volunteers 1,2,3, and 4 were all male. Figure 2. shows the violin plots for each metric for the four volunteers performing concrete, heavy equipment, surveying, and asphalt activities to visually compare individual differences and patterns. A more in-depth look at the four volunteers performing construction activities concurrently confirms the results, suggesting that the research data collection and analysis method is capable of correctly identifying patterns for the impact of construction activities on construction workers. In particular, a general trend exists demonstrating that the mean heart rate for certain individuals (volunteers 2 and 3) is greater than others (volunteer 1 and 4) across all activities, but that patterns of the impacts of construction activity persist despite these individual differences. Similarly, Figure 2 shows that the mean posture metric for volunteers 1 and 4 is greater than volunteers 2 and 3 across all activities. In contrast, operating heavy equipment results in a posture that is the most reclined for nearly all volunteers.

Such results suggest that the studied metrics and methods are effective at assessing the impact of construction activities on individuals' physiological health. Furthermore, the study shows that it is possible to independently compare discrete physiological metrics across individuals performing activities under various weather conditions. In short, the research serves to highlight the significant opportunity to use the proposed research methods to study construction worker health and productivity in future studies.

While the longitudinal data from only four volunteers are based on a limited sample size, the similarity in conditions makes this data potential less confounded. Furthermore, the large number of data points collected for each volunteer still enables statistical comparison between and among metrics. In short, when heart rate is compared for the four volunteers (Figure 2), there is a clear pattern showing that heart rates for volunteers 1 and 4 are consistently lesser, on average, compared to volunteers 2 and 3. We can conclude that heart rate, in general, is higher for volunteers 2 and 3 irrespective of activity type. However, this general trend is shifted up or down based on the activity (although less so for Asphalt), suggesting that while individuals have different physiological norms, construction activities may impact distinct individuals in a similar manner, albeit, potentially, to differing extents. For example, the heart rates of all four volunteers are lower, on average, for surveying. Also, the heart rates reach a much higher value for concrete compared to other activities. Similar patterns are noticed for breathing rate and core temperature.

Finally, pairwise comparisons between the different activities were performed for the four volunteers to investigate which activities lead to significant differences. While perhaps not generalizable, results from pairwise comparisons p-values indicate: (1) all pairs of activities except asphalt and concrete yield significantly different heart rates; (2) all pairs of activities except surveying yield significantly different breathing rates. (3) all pairs of activities yield significantly different core temperatures. (4) asphalt-concrete and asphalt-surveying have similar posture and heavy equipment yields the most significant difference in posture.

The present research provides a potentially transformative model for supporting the occupational health of construction workers and motivates future research in the area. In future work, additional methods, such as mutual information from information theory, will be applied to evaluate the impact and influence of independent variables on physiological metrics to provide a more thorough analysis. Moreover, there is a need for future research on the impact of working environments on workers due to the variety in types of construction projects. For example, in highway infrastructure projects, workers are exposed to the risk of injury from the movement of construction vehicles and equipment within the work zones, as well as from passing motor vehicle traffic. Therefore, the working condition in this type of project is expected to increase the stress levels in workers. Finally, the current research can be expanded to collect more data on different activities from different types of construction projects. Using pattern recognition methods such as machine learning algorithms, the collected data can be used to predict or assess when health or performance thresholds are about to be reached or exceeded. In particular, such research will assist managers in scheduling workers to maximize productivity and minimize workplace injuries under extreme weather or working conditions. Moreover, these data can be used to establish indicators and real-time warning systems to help minimize potential physical harm to construction workers.

Summary & Conclusions

This study presented the development of a new system that uses physiological and environmental data to explore the impact of construction activities on individual workers, under a range of ambient conditions. The system was applied to a relatively homogenous set of workers, in this case, a set of ten US Air Force Academy (USAFA) cadets comprised of 8 males and 2 females, who each performed four distinct construction activities under similar, relatively controlled, conditions. Vital signs and physical indicators including heart rate, breathing rate, core temperature, physiological load, mechanical load and posture were collected and analyzed. To this end, software R was used to perform statistical analyses in 5 steps: (1) filter the noisy data based on HRC; (2) aggregate one-second interval data to one-minute interval data; (3) add morning and afternoon weather, temperature, humidity level, and heat index using local station data; (4) apply a Linear Mixed Effect Model (LMM) to analyze the effect and statistical significance of the independent variables on the physiological metrics; and (5) compare data and identify general and observable patterns. Research analysis suggests that heat index and construction activities have a measurable effect on the physiological metrics of individuals with similar physical characteristics. Specifically, results indicate that among the four different construction activities studied, concrete and asphalt paving are more physically demanding activities as compared to operating heavy equipment and surveying activities. Notably, looking at four volunteers working under similar climatic conditions revealed similar statistical and observable patterns for physiological metrics across construction activities. The results of this study suggest that such a research method yields statistically significant patterns and is capable of documenting the effects of construction activity as well as ambient conditions on individual construction worker health and performance. Such research will be critical in establishing physiological thresholds for construction workers while performing a range of activities under various climatic conditions.

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References

Abdelhamid, T. S., and J. G. Everett. 2002. "Physiological Demands during Construction Work." *Journal of Construction Engineering and Management* 128(5):427–37.

Anon. 2017. "Civil Engineering Practices - Field Engineering Cadet Handbook."

Aryal, Ashrant, Ali Ghahramani, and Burcin Becerik-Gerber. 2017. "Monitoring Fatigue in Construction Workers Using Physiological Measurements." *Automation in Construction* 82:154–65.

Awolusi, Ibukun, Eric Marks, and Matthew Hallowell. 2018. "Wearable Technology for Personalized

Construction Safety Monitoring and Trending: Review of Applicable Devices." *Automation in Construction* 85(July 2016):96–106.
Buller, M. J. .. B., W. J. .. Tharion, R. W. .. Hoyt, and O. .. Chadwicke Jenkins. 2010. "Estimation of Human Internal Temperature from Wearable Physiological Sensors." *Proceedings of the National Conference on Artificial Intelligence* 3:1763–68.
Buller, Mark J., and Reed W. Hoyt. 2008. "Estimation of Human Internal Temperature from Wearable Physiological Sensors." 1763–68.
Dunn, Olive Jean. 1961. "Multiple Comparisons among Means." *Journal of the American Statistical Association* 56(293):52–64.
Engholm, Göran, and Eva Holmström. 2005. "Dose-Response Associations between Musculoskeletal Disorders and Physical and Psychosocial Factors among Construction Workers." *Scandinavian Journal of Work, Environment and Health* 31(SUPPL. 2).
Gatti, Umberto C., Giovanni C. Migliaccio, Susan M. Bogus, and Suzanne Schneider. 2014. "An Exploratory Study of the Relationship between Construction Workforce Physical Strain and Task Level Productivity." *Construction Management and Economics* 32(6):548–64.
Hartmann, Bernd, and Andreas G. Fleischer. 2005. "Physical Load Exposure at Construction Sites." *Scandinavian Journal of Work, Environment & Health* 88–95.
Jang, H., Kim, K., Kim, J. and Kim, J. (2011), "Labour productivity model for reinforced concrete construction projects", Construction Innovation, 11(1): 92-113.
Kim, J. H., R. Roberge, J. B. Powell, A. B. Shafer, and W. Jon Williams. 2013. "Measurement Accuracy of Heart Rate and Respiratory Rate during Graded Exercise and Sustained Exercise in the Heat Using the Zephyr BioHarness™." *International Journal of Sports Medicine* 34(6):497.
Kirk, Patrick M., and Mark J. M. Sullman. 2001. "Heart Rate Strain in Cable Hauler Choker Setters in New Zealand Logging Operations." *Applied Ergonomics* 32(4):389–98.
Lee, Wonil, and Giovanni Ciro Migliaccio. 2016. "Physiological Cost of Concrete Construction Activities." *Construction Innovation* 16(3):281–306.
Roja, Zenija, Valdis Kalkis, Arved Vain, Henrijs Kalkis, and Maija Eglite. 2006. "Assessment of Skeletal Muscle Fatigue of Road Maintenance Workers Based on Heart Rate Monitoring and Myotonometry." *Journal of Occupational Medicine and Toxicology (London, England)* 1:20.
Rowlinson, Steve, Andrea Yunyanjia, Baizhan Li, and Carrie Chuanjingju. 2014. "Management of Climatic Heat Stress Risk in Construction: A Review of Practices, Methodologies, and Future Research." *Accident Analysis and Prevention* 66:187–98.
Tak, Sang Woo, Bryan Buchholz, Laura Punnett, Susan Moir, Victor Paquet, Scott Fulmer, Helen Marucci-Wellman, and David Wegman. 2011. "Physical Ergonomic Hazards in Highway Tunnel Construction: Overview from the Construction Occupational Health Program." *Applied Ergonomics* 42(5):665–71.
Wang, Di, Jiayu Chen, Dong Zhao, Fei Dai, Changjian Zheng, and Xiaobing Wu. 2017. "Monitoring Workers' Attention and Vigilance in Construction Activities through a Wireless and Wearable Electroencephalography System." *Automation in Construction* 82:122–37.
Yi, Wen, and Albert P. C. Chan. 2015. "Optimal Work Pattern for Construction Workers in Hot Weather: A Case Study in Hong Kong." *Journal of Computing in Civil Engineering* 29(5):05014009.
Yi, Wen, Albert P. C. Chan, Xiangyu Wang, and Jun Wang. 2016. "Development of an Early-Warning System for Site Work in Hot and Humid Environments: A Case Study." *Automation in Construction* 62:101–13.
Yu, Yantao, Hongling Guo, Qinghua Ding, Heng Li, and Martin Skitmore. 2017. "An Experimental Study of Real-Time Identification of Construction Workers' Unsafe Behaviors." *Automation in Construction* 82(July 2016):193–206.
Zephyr. 2013. "BioHarness BT User Guide."
Zephyr. 2016. "OmniSense Live Help." *Zephyr Technologies*.

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COVID-19 Vaccine Acceptance Among Construction Workers

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The COVID-19 pandemic has affected all industries, including the construction industry. In addition to being a hazard-prone environment, construction also has the highest number of occupational fatalities. Construction workers have been affected more severely by this disease than the general public. The availability of vaccines has fueled optimism, with vaccination considered the safest and most effective method of protecting against COVID-19. However, vaccinating the workforce to achieve herd immunity has been difficult as the acceptance rate appears to be a significant hurdle. The purpose of this study is to assess construction workers' acceptance of the COVID-19 vaccine after it became widely available. A two-step research methodology was used in this research that included: 1) a comprehensive literature review looked at COVID-19 vaccination rates in the U.S. and construction workers' unwillingness to get vaccinated and 2) a qualitative questionnaire survey to assess worker acceptance. Results showed 43% of construction workers have not received the COVID-19 vaccine, while 41% refused the vaccine. To increase vaccination acceptance among construction workers, construction stakeholders should supply safety training and improve the safety culture within their organizations.

Keywords: COVID-19, Construction Industry, COVID-19 vaccine, Hazard, Pandemic

Introduction

The construction industry has a substantial impact on the economic growth in the United States (Jeon et al., 2022). Approximately 4.3 % of the overall Gross Domestic Product (GDP) of the United States is contributed by this sector that accounts for approximately $1.87 trillion in the first quarter of 2021 (BEA, 2020). According to the U.S. Bureau of Labor Statistics, there are 7.41 million persons employed in the industry. Despite its importance, the construction industry is one of the most injury-prone industries (Agwu and Olele 2014). There have been over 1,061 confirmed fatalities in the U.S. construction industry in 2019, which translates into approximately one construction worker's death in an accident every eight hours (U.S. Bureau of Labor Statistics (BLS), 2021). Construction workers are already exposed to a considerable number of injuries, illnesses, and fatalities; however, the COVID-19 pandemic has further increased the level of safety concerns. COVID-19, or Coronavirus disease, is caused by SARS-CoV-2, or severe acute respiratory syndrome coronavirus (Acter et al. 2020). It is a highly infectious disease that can lead to symptoms such as fever, dry cough, fatigue, and shortness of breath (CDC 2021a). Unlike other industries, the construction industry could not adopt telecommuting to mitigate the safety challenges and productivity disruptions caused by the COVID-19 pandemic (Daniels et al., 2020). These difficulties compounded the maintenance of safety measures while delivering construction projects on time (Al-Mhdawi et al., 2022). The industry relies significantly on the ability of individuals rather than machines. Therefore, all employees, technicians, and engineers on the job site are essential to completing tasks and overseeing the job properly (Gamil & Alhagar, 2020). A recent analysis of COVID-19 tests results of 730,000 construction workers revealed that 5.7% were asymptomatic, and 10.1% were found to have symptoms (Allan-Blitz et al., 2020). COVID-19 has affected a substantial number of workers, and that number will invariably increase. Although the BLS and OHSA compiled some early statistics, they are not yet publicly available. It is uncertain how many construction workers have been affected by COVID-19 and their willingness to get vaccinated. This study aims to investigate the severity of COVID-19 experienced by construction workers, explore the workers' vaccination rate, and explore workers' COVID-19 vaccination attitude.

Research Methodology

A two-step approach was adopted in this research for data collection and analysis, as presented in Figure 1.

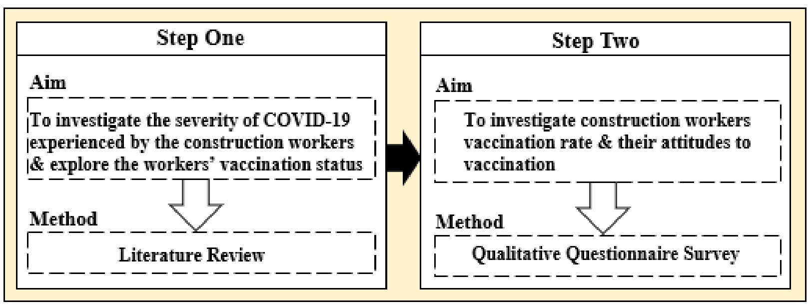

Figure 1. Adopted methodology

Step One: Literature Review

In this research, the authors conducted a literature review to gain a better understanding of COVID-19 (1) vaccination rate and (2) level of severity for the construction workforce. The approach used for the literature review for the study follows:

1) Database search engine: The database search was conducted using ASCE, Google Scholar, Tylor and Francis, Emerald Insight, and Science Direct.
2) Journal selection and keywords identification: the articles selected in the search included ASCE-Journal of Management in Engineering, ASCE-Journal of Construction Engineering and Management, Safety Science, and Analytic Methods in Accident Research. The keywords that were used for the search included COVID-19 pandemic, coronaviruses, workforce vaccination rate, and COVID-19 and construction safety. Preliminarily, 15 articles were qualified for literature review. Finally, 10 articles were reviewed in this literature. This study supplies an

overview of the COVID-19 immunization rate, severity, and hesitation among construction workers by presenting the facts in a descriptive way.

Step Two: Qualitative Questionnaire Survey

The authors developed a qualitative questionnaire survey (i.e., open-ended questionnaire) to investigate the construction workers' COVID-19 vaccination rate and attitude. The questionnaire was prepared and submitted to IRB for approval. This survey type did not supply predetermined answers as participants were asked to answer using their own responses. This helps keep the data exact by allowing the workers to respond in a genuine manner. The survey included nineteen questions and was grouped into two categories. No personal identifiers were used in the survey questionnaire. The category one of the survey was the demographic section, and the category two dealt with the COVID-19 contraction questionnaire. A sample of questions used in the survey is shown in Table 1.

Table 1.

Example questions for COVID-19 severity and vaccination acceptance.

Section	Example questions
COVID-19 contraction	"Q 2.15 Have you ever been tested positive with COVID-19?" "Q 2.16 How severe was your COVID-19 symptoms?" "Q 2.18 Have you received your COVID-19 vaccine?"

The survey was distributed to 44 construction workers in North Carolina state who were actively engaged in construction work during the COVID-19 pandemic. Participants were approached randomly at construction sites, and the study was conducted in person. The survey was conducted between the period of July 28, 2021, to October 15, 2021. Participants' demographic information age and years of experience are shown in Table 2.

Table 2

Demographic information of research participants.

Variable	Min	Max	Med	Avg
Age (years)	21	65	34.5	35.5
Experience (years)	0.25	36	10	11.6

Table 3 represents the type of projects where participants were actively engaged in and participants' work experience in another state. Participants worked on institutional and commercial buildings (39%) and residential buildings (32%).

Table 3

Surveyed projects' information

Type of Project	Number
Institutional and commercial building	17 (39%)
Residential building	14 (32%)

Other	6 (14%)
Infrastructure and heavy construction	4 (9%)
Specialized industrial construction	3 (7%)

Results and Discussion

The literature review and qualitative survey provided crucial information about Covid-19 severity, Vaccination status, and COVID-19 Vaccination attitude.

Literature Review

COVID-19 Severity Level

COVID-19 affects construction workers in a variety of ways. The experience is similar to being involved in a workplace accident. A worker who tests positive for COVID-19 may be absent from work for several days as part of the illness, and in some cases, recovery can take several months. The National Institutes of Health reported that patients with COVID-19 can have no symptoms of life-threatening illnesses (NIH, 2021). Table 4 illustrates how the severity of the disease is classified. COVID-19 cases and fatalities are reported throughout the country to the national surveillance network.

Nevertheless, there is a chance of underestimating the number of cases and deaths in the general population. Infections with COVID-19 disease symptoms, hospitalizations, and fatalities are likely to be underreported for assorted reasons. As an example, individuals with asymptomatic symptoms may not be detected. Furthermore, there is still no accurate assessment of the impacts of COVID-19 severity levels. As a result, COVID-19 may carry a more significant illness burden than reported due to underreporting (Angulo et al., 2021).

Table 4

COVID-19 Severity Classification adopted from (NIH, 2021).

Severity of Illness	Description of the Severity
Asymptomatic	People who are infected with COVID-19 yet do not show any
Mild Illness	People with COVID-19 symptoms such as fever, cough, sore throat, and malaise but no other signs or symptoms such as shortness of breath or dyspnea or abnormal chest x-rays, including loss of taste or smell.
Moderate Illness	People with oxygen saturation (SpO2) of 94% in room air at sea level and show lower respiratory ailment symptoms after a clinical evaluation or imaging.
Severe Illness	People who experienced an arterial partial pressure of oxygen to inspired oxygen fraction (PaO2/FiO2) ratios less than 94% on room air at sea level.
Critical Illness	People who have experienced Septic shock or multiple organ dysfunction with respiratory failure with COVID-19 symptoms.

The Centers for Disease Control and Prevention (CDC) uses statistical models to adjust for instances not captured by national surveillance networks, such as infections, hospitalizations, and fatalities (CDC, 2021b). Figure 2 illustrates the Percentage of COVID-19 conditions which the CDC reported across the U.S.

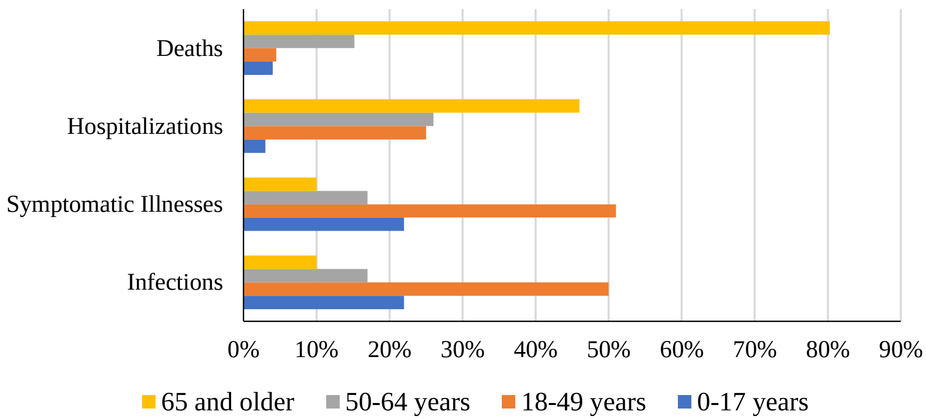

Figure 2. Percentage of reported COVID-19 infections, symptomatic illness, hospitalizations, and deaths, by age group from February 2020- May 2021(CDC, 2021b).

Vaccination Status

The COVID-19 vaccination is essential for ensuring safety and health in the construction industry. Unfortunately, only 53% of construction workers are vaccinated (CPWR, 2021). The United States has one of the lowest COVID-19 vaccination rates among the wealthiest nations (The New York Times, 2021). To encourage citizens to get vaccinated, some states have started to offer incentives such as gift cards or entries into a raffle (NGA, 2021). However, COVID-19 vaccination numbers remain lower than the government desires due to individual decisions by workers and employees. Superstitious beliefs are also traced back to a negative attitude towards safety (Namian et al., 2020). In addition, the Center for Construction Research and Training (CPWR) collects weekly information on the barriers to COVID-19 vaccination and vaccination hesitancy in all other occupations and construction (see Figures 3 and 4).

According to the COVID-19 vaccination dashboard, construction workers are not receiving the COVID-19 vaccine for three main reasons (CPWR, 2021a): distrust of government, vaccination inefficacy, and vaccination side effects. According to their data, as of September 2021, 60.1% of the workers distrust the government, 56% of workers are still hesitating about the vaccine's side effects, and 30.4% of workers think the vaccine is ineffective; the total percent of hesitant in construction was 41.8% which is 25.2% higher than all other occupations in the U.S. (CPWR, 2021a).

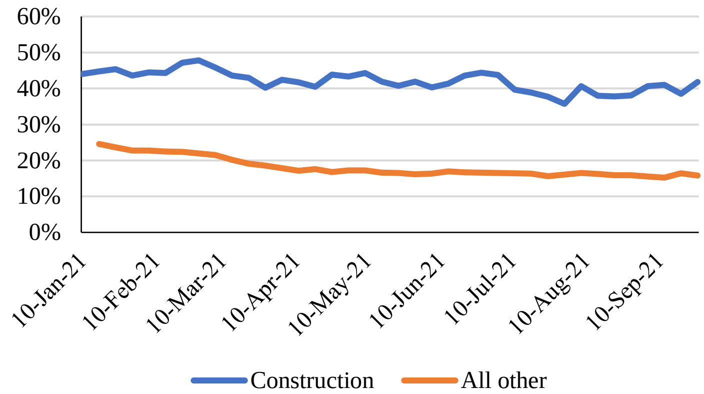

Figure 3. Vaccination hesitancy in construction and all other industries adopted from (CPWR, 2021a).

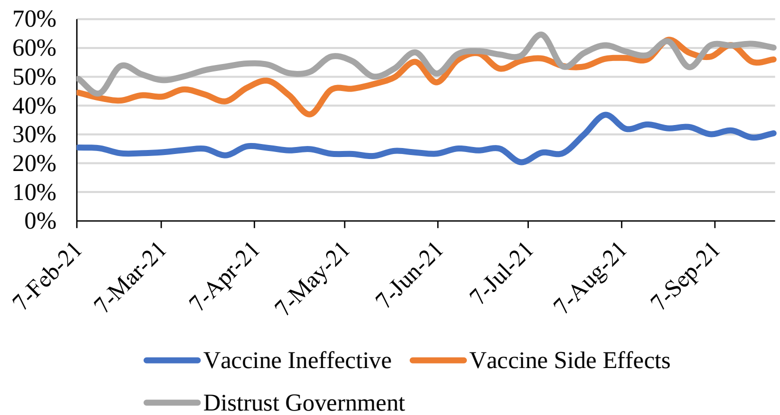

Figure 4 Common obstacles to immunization adopted from (CPWR, 2021a).

COVID-19 Vaccination Attitude

The results of this investigation showed that over half of the construction workers were already vaccinated. The study showed 57% of workers were vaccinated, and 43% of workers were unvaccinated. Additionally, participants who did not receive vaccinations were asked about their willingness to receive vaccinations. Of these participants, 41% expressed a refusal to get vaccinated, while only 2% expressed a willingness to get vaccinated (see Figure 5). Only 14% of the workers tested positive, despite other research studies suggesting a higher COVID-19 positivity rate among construction workers (see Figure 6). Furthermore, participants were asked to assess the severity of COVID-19 that they had experienced. There were 5% of workers who reported no symptoms, 2% reported mild symptoms, 5% reported moderate symptoms, and 2% reported severe symptoms (see Figure 6).

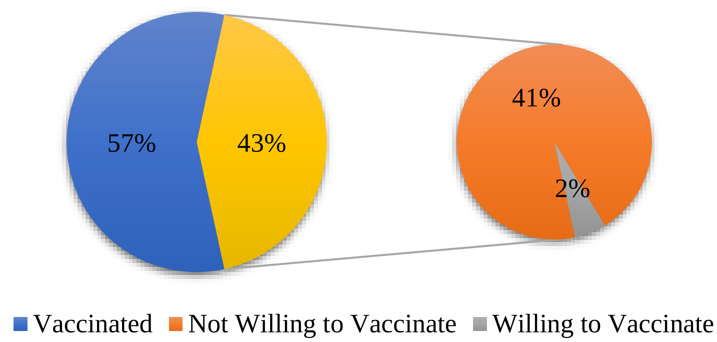

Figure 5. Vaccination and hesitancy status among construction workers.

Lack of safety training might be the reason behind the worker's unwillingness to get COVID-19 vaccine.

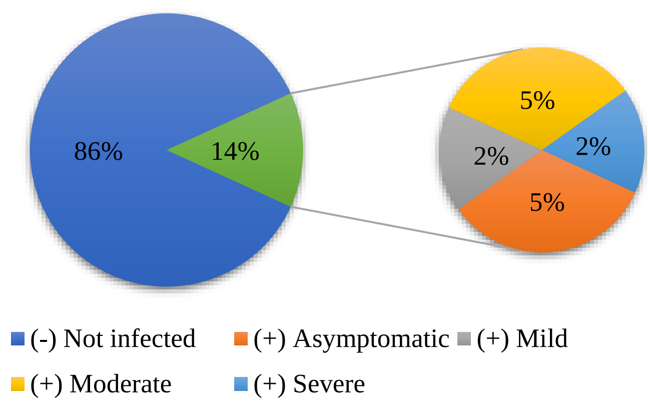

Figure 6. COVID-19 infection among construction workers.

Conclusions

The construction industry is a hazardous industry due to its unique nature. Injuries, sickness, and even death can happen to construction workers at any time. Unfortunately, COVID-19 has made construction workers more susceptible to injury, disease, and death due to the pandemic. The authors investigated the severity of COVID-19 experienced by the construction workers and explored the workers' vaccination rates. The authors used a two-step research method using literature review and qualitative questionnaire survey with 44 construction workers in North Carolina, United States. The results in our study showed that the vaccination rate in North Carolina is 4% higher than the national average reported vaccination rate for construction workers. 14% of the participants mentioned they had been COVID-19 positive during the pandemic. Our study implies that construction workers might have been cautious about COVID-19 at the workplace and followed preventive measures, which is why COVID-19 did not infect 86% of workers. On the other hand, the unwillingness of unvaccinated construction workers to receive vaccines is alarming for construction researchers and practitioners.

This study found that of the 43% of unvaccinated workers, 41% are not willing to get vaccinated. This may happen due to the disbelief about the COVID-19 vaccines or lack of knowledge about vaccines and their efficacy.

According to the OSHA COVID-19 Emergency Temporary Standard (ETS) on Vaccination and Testing, it is a requirement for employers to create, implement, and enforce a formal policy for mandatory vaccinations. Therefore, this study will help OHSA's mandatory vaccination policy implementers to get an idea about the worker's attitude towards the vaccination. The results show an urge to take practical actions to alter the construction workers' safety attitude to accept vaccines. This study illustrates the post-pandemic situation faced by workers in the construction industry. In addition, the findings of this study aim to provide government agencies and organizations with a clear picture of the post-pandemic COVID-19 vaccination scenario among unvaccinated construction workers.

Limitations

Despite its merits, this study has some limitations. Although the research collects crucial facts about the vaccination, acceptance rate, and severity of the COVID-19 pandemic in the construction industry, this study's sample size was small. The study may have missed a significant scenario of immunization, acceptability of vaccination, and severity of COVID-19 among construction workers due to various causes. In addition, because of the exploratory character of the study, the vaccination rate, acceptance rate, and severity of COVID-19 were only captured by the participants, who may not reflect the industry. Second, all surveyed workers were in North Carolina. Different states have different vaccination and acceptance rates. For example, the vaccination rate in North Carolina, published by the center for construction research and training, is 57% (CPWR, 2021a). In the study, the vaccination rate is the same as CPWR reported rate. It might happen due to the location we have conducted the study. Another reason for this could be the smaller sample size.

Reference

Acter, T., Uddin, N., Das, J., Akhter, A., Choudhury, T.R. and Kim, S., 2020. Evolution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as coronavirus disease 2019 (COVID-19) pandemic: A global health emergency. *Science of the Total Environment*, *730*, p.138996.

Allan-Blitz, L.-T., Turner, I., Hertlein, F., & Klausner, J. D. (2020). High Frequency and Prevalence of Community-Based Asymptomatic SARS-CoV-2 Infection. *medRxiv*, 2020.2012.2009.20246249. doi:10.1101/2020.12.09.20246249

Al-Mhdawi, M.K.S., Brito, M.P., Abdul Nabi, M., El-adaway, I.H. and Onggo, B.S., 2022. Capturing the Impact of COVID-19 on Construction Projects in Developing Countries: A Case Study of Iraq. *Journal of Management in Engineering*, *38*(1), p.05021015.

Agwu, M.O. and Olele, H.E., 2014. Fatalities in the Nigerian construction industry: a case of poor safety culture. *Journal of Economics, Management and Trade*, pp.431-452

Angulo, F. J., Finelli, L., & Swerdlow, D. L. (2021). Estimation of US SARS-CoV-2 infections, symptomatic infections, hospitalizations, and deaths using seroprevalence surveys. *JAMA network open*, *4*(1), e2033706-e2033706.

BEA. (2021). Bureau of Economic Analysis,U.S. Department of Commerce, Industry Economic Account Data: GDP by Industry. from https://apps.bea.gov/iTable/iTable.cfm?reqid=150&step=2&isuri=1&categories=gdpxind

CDC. (2021a). Center for Disease Control and Prevention:Benefits of Getting a COVID-19 Vaccine. Retrieved on November,02 2021 from https://www.cdc.gov/coronavirus/2019-ncov/vaccines/vaccine-benefits.html

CDC. (2021b). Centers for Disease Control and Prevention:Estimated COVID-19 Burden. Retrieved on November, 2 2021 from https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/burden.html

CPWR. (2021a). The Center for Construction:COVID-19 Vaccination Dashboard. Retrieved on November, 04 2021 from https://www.cpwr.com/research/data-center/data-dashboards/covid-19-vaccination-dashboard/

CWPR. (2021). The Center for Construction Research and Training :Why is it important that construction workers get vaccinated? Retrieved on November, 2 2021 from https://www.cpwr.com/wp-content/uploads/Construction-Sector-Vaccination-Absenteeism.pdf

Daniels, W., Griffith, M., & Shreve, R. (2020). The coronavirus effect on construction projects.

Fisher, K. A., Bloomstone, S. J., Walder, J., Crawford, S., Fouayzi, H., & Mazor, K. M. (2020). Attitudes toward a potential SARS-CoV-2 vaccine: a survey of US adults. *Annals of internal medicine*, *173*(12), 964-973.

Gamil, Y., & Alhagar, A. (2020). The impact of pandemic crisis on the survival of construction industry: a case of COVID-19. *Mediterranean Journal of Social Sciences*, *11*(4), 122-122.

Jeon, J., Padhye, S., Bhattacharyya, A., Cai, H., & Hastak, M. (2022). Impact of COVID-19 on the US Construction Industry as Revealed in the Purdue Index for Construction. *Journal of Management in Engineering*, *38*(1), 04021082.

Namian, M., Hollar, D., Taherpour, F., & Ghiasvand, E. (2020). Deciphering Why 'Cursed Construction Workers' are More Vulnerable to Occupational Accidents. *EPiC Series in Built Environment*, *1*, 491-498.

NGA. (2021). National Governors Association:COVID-19 Vaccine Incentives. Retrieved on November, 02 2021 from https://www.nga.org/center/publications/covid-19-vaccine-incentives/

NIH. (2021). National Institute of Health:Clinical Spectrum of SARS-CoV-2 Infection. Retrieved on November , 02 2021 from https://www.covid19treatmentguidelines.nih.gov/overview/clinical-spectrum/

The New York Times. (2021). The U.S. is falling to the lowest vaccination rates of the world's wealthiest democracies.. Retrieved on October , 09 2021 from https://www.nytimes.com/2021/09/11/world/asia/us-vaccination-rate-low.html

U.S. BLS. (2021). U.S. BUREAU OF LABOR STATISTICS,Number and rate of fatal work injuries, by industry sector. Retrieved on September, 29 2021 fromhttps://www.bls.gov/charts/census-of-fatal-occupational-injuries/number-and-rate-of-fatal-work-injuries-by-industry.htm

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Efficacies of Different Modes of Disseminating Construction Safety Training

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The construction industry continues to be plagued by a high rate of injuries and fatalities. The Occupational Safety and Health Administration requires that employers provide training for their employees on a regular basis to improve safety. Researchers for this study used a pretest-posttest evaluation method to investigate the effectiveness of different forms of construction safety training. The topics include warning lines, preferred fall protection systems, and harness inspection using videos, texts, and slides as training modes. The findings suggest that the training topic affects the training outcome. A more complex training topic like the preferred fall training topic will result in greater change in participants' posttest after the intervention while a simple topic like harness inspection will register minimal change in scores. The preliminary conclusion is that training was effective for all topics and all modes of instruction, but some are more effective.

Key Words: Construction safety, Safety training, Safety training videos, Fall protection, Training assessment

Introduction

The construction industry is hazardous globally, regardless of efforts that have been made by stakeholders in terms of policies, safety research and innovations (Loosemore, & Malouf, 2019). The Occupational Safety and Health Administration (OSHA) only has1850 inspectors for all worksites and so a low percentage of sites get inspected. As such, punishment as deterrent for safety infractions may have little effect on preventing accidents (Taylor, 2015). Education and training have been found to be more effective alternatives for accident prevention (Taylor, 2015).

Ideally, workers trained and educated in OSHA regulations significantly reduce their likelihood of injury. However, challenges exist in communicating the safety rules to the workers. Some challenges are literacy barriers (Loosemore & Andonakis 2007) and ethnic diversity (Brunette, 2005) which are notable given the culturally diverse workforce in the construction industry.

With various modes of disseminating safety training in use, the purpose of this study is to examine the efficacies of some common modes of construction safety training. Specifically, this study examines three different modes: text only, slides with text and graphics, and short videos. To examine the efficacies of each mode, this study was delimited to safety trainings for falls-from-height. The reason for selecting fall-from-height as the focus of the study is that it remains the leading cause of injuries and fatalities in the construction industry in the US accounting for 17% of fatalities in all industries in the US and 37% of fatalities in construction in 2020 (Bureau of Labor Statistics, 2020). Therefore, it is essential to train workers on safe methods of working at heights.

Literature Review

Efforts by constructions stakeholders and government agencies towards improving safety on construction sites have only yielded marginal improvements (Kaskutas, Dale, Lipscomb, & Evanoff, 2013). Effective training is essential to improving this situation and workers must be equipped with the technical skills and knowledge that will help them in performing their jobs in a safe and healthy manner (Goldenhar, Moran, & Colligan, 2001).

Construction Safety Training

Different training techniques have been developed over time to help increase worker safety awareness and improve overall safety performance in the construction sites. To improve safety performance, employers invest in developing safety training programs. Despite large investments in training, there is still a gap in workers' ability to recognize hazards (Albert, Hallowell, & Kleiner, 2014). There are several reasons for this, among them are faulty training delivery, methods, and materials (Wilkins, 2011). Additionally, language barriers, poor worker attitudes, and unqualified trainers present problems in effective training (Wang, Goodrum, Haas, & Glover, 2008). Nevertheless, training is still as important as ever to improve the poor safety performance of the construction workers.

Construction safety trainers need to focus on knowledge transfer to ensure a depth of learning from the training that is then practiced in the field (Blume, Ford, Baldwin, & Huang, 2009). Traditional classroom training is the most common mode of safety training, but its effectiveness is unclear.

Training Methods

Traditional training methods are not always effective for construction workers. Common instructor-led training techniques for adult learners are more fitting for standard classroom settings. To improve on this common pedagogical approach, learner-centric andragogic principles should be integrated into safety training programs (Tixier, Albert, & Hallowell, 2013). The Bureau of Labor Statistics (2020) estimates the median age of construction workers to be 43; the teaching principles usually used to teach much younger university students are applied in construction safety training when training adult learners (Bhandari et al., 2019).

Adult learner theory places the focus on self-directed learning in which the adult learner is in control of his/her own learning (Mitchell & Courtney, 2005) and offers guidance on ways to improve the effectiveness of safety training. Incorporating adult learning theories into health and safety training programs will produce better results and employees are more likely to retain what they learned (Wilkins, 2011). There is a need for safety training built on these principles for effective construction safety training (Fairchild, 2003; Kazis et al., 2007; Lundberg, 2003).

Research Method

For this study, one group pretest-posttest evaluation method was used to study the efficacies of the three different modes of construction safety training: text only in the form of electronic handouts, texts with graphics in the form of slides, and short videos. This one-group pretest-posttest design has been used for decades and is still being used today (Knapp, 2016). The study focused on three specific fall protection related trainings: preferred fall protection (such as guardrails and other basics), warning lines, and harness inspection. Data was collected using the online platform Qualtrics. Training was developed for each topic using all three training modes. Thus, each topic had three surveys giving nine unique surveys in total. The sample consisted of students at different levels and construction professionals. The trainings were connected so that when a participant received the link to one training, they would be redirected to the second training upon completion of the first, and the third upon completion of the second. In this way, each participant completed three total trainings, one of each topic and one of each mode without any duplication in topic or mode.

A total of approximately 500 potential participants were contacted to participate in the training. Each training began with a consent form and then the participant could proceed to take a pretest which was a short quiz on that topic. This was followed by the training intervention and then a posttest. The pretests and posttests were identical and consisted of a total of seven questions. Two of the questions were questions to test “base knowledge” that served as a sort of control. They were asked before and after the intervention and were generally related to the topic but were not covered in the trainings. These served as a check on the results as these should have remained stable since they were not covered. The remaining five questions were directly covered in the training material. Scores were on a 0-5 scale. The pretest and posttest scores were considered along with the change in score for analyses. Data were organized then analyzed using SPSS for descriptive analysis to summarize the data. Paired sample t-tests, and Analysis of Variance test (ANOVA) were used to compare means.

Safety Training Materials

The videos for all three topics were made in collaboration with the Gaylord College of Journalism and mass communication at The University of Oklahoma. All three videos had musical backdrops with narration and subtitles to keep the viewers fully engaged.

Screenshots from the videos were used to make slides that delivered relevant information as seen in the videos. Screenshots were taken at key moments in the video where an important information was being delivered. It was also imperative that the slides had the information needed to answer the pretest and posttest quizzes. In other words, the slides conveyed as much as possible the same amount of information that was shown in the videos, each one having between eight and 10 slides.

Texts in the form of a single page pdf with topical information and a single graphic were used for each training topic. The graphic is a screenshot of a frame from the corresponding video topic. They were designed to be like Toolbox Talks commonly used in the construction industry. The content of the text was a near transcription of the video to keep the information consistent.

Results

A total of 305 responses were received with 40 having missing data points which were discarded. The total number of complete responses therefore was 265. Among the responses included for analyses, most were students, 64 (24%) sophomores, 104 (39%) juniors, 22 (8%) seniors, 31(12%) graduate students, and 44 (17%) working professionals.

While there were 265 responses, the total number of unique participants was less since many completed more than one training and others completed fewer than three. Since the responses were anonymous the number of unique participants had to be estimated. The warning lines training was the first in each series of linked trainings sent so the number that completed this, a total of 115, was estimated as the number of unique participants. A breakout is shown in Table 1.

Table 1

Number of participants that completed each training

Training Topics	**Video**	**Slides**	**Text**
Warning Lines	31	34	50
Preferred Fall Protection	24	30	23
Harness Inspection	28	23	22

A total of 26 participants, representing only 9.8% of the total sample, had a reduction in score from pretest to posttest – a negative score change. This reduction in score from before to after the training could be due to respondents guessing the answers to the questions without relying on the contents of the training. Figure 1 shows frequency of pretest and posttest scores along with the frequency of score changes on the portion of the tests that measured knowledge related to information directly covered in the intervention. The chart shows the relatively even distribution of scores in the pretests and how the posttest scores are skewed to higher scores. There was no score change for 66 respondents representing 24.9% of the total sample. There was positive score change in 173 respondents representing 65.3% of the total sample.

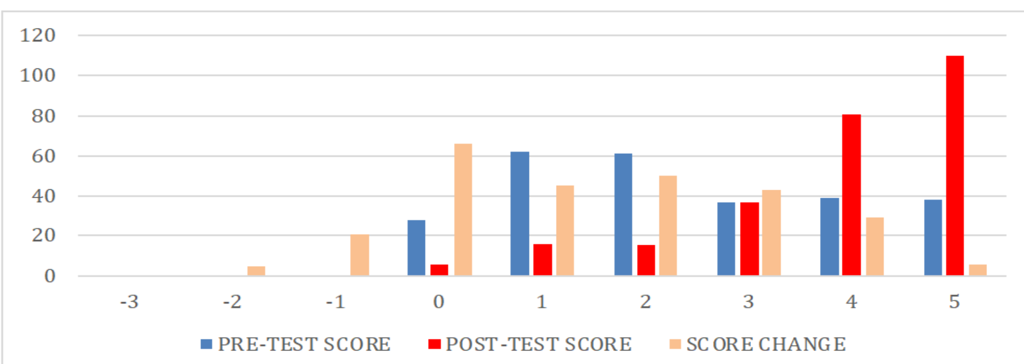

Figure 1: Comparison of score changes between Pretest and Posttest

To get a sense of whether there was large scale random guessing and to have a small set of control data, the scores on the two base knowledge questions (information not covered in the interventions) were analyzed in the same way using frequencies. Only three respondents had a drop in score of two points meaning that they got them both right the in the pretest and both wrong in the posttest. Conversely, there were only eight that got them both wrong then both right for a score change of positive two. These 11 responses may have been a result of random guessing but was a very small portion, 4.2%, of the sample. The majority of respondents scored the same on the base knowledge questions before and after the interventions which indicates two things. It indicates that respondents were likely reading the questions and answering them rather than giving a response set. Additionally, the minimal change from pretest to posttest indicates that the intervention had no effect on these questions which was expected as the information was not covered in the trainings. Figure 2 shows the number of participants associated with each possible change in the base score (between -2 and 2).

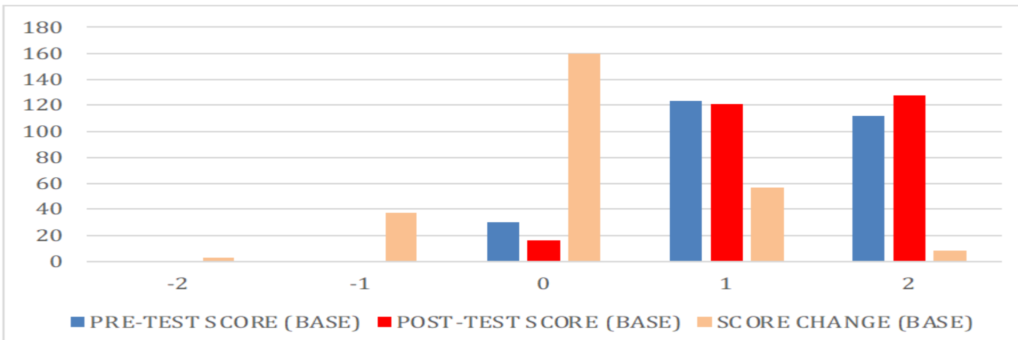

Figure 2: Comparison of base score changes

The first set of comparative statistical analyses done was to compare means of the score changes on the questions relevant to the interventions across participants, grouping them by student level, mode of instruction, and topic. The results showed there was no statistically significant difference in mean score change based on student level at the 0.05 confidence level [F (4,260) = 1.974, p = 0.099] meaning that the training intervention was equally effective for all participants, regardless of background. A summary of the results is in Table 2 below.

Table 2

Mean score change across modes of training, all topics

Topics	N	Mean (Std. Dev.)
Text/Toolbox Talk	95	1.40 (1.678)
Video	83	1.48 (1.603)
Slides	87	1.53 (1.669)

There was also no statistically significant difference in mean score change [F (2,262) =0.142, p=0.868] based on training mode, meaning that all modes of training (videos, slides, and text) were equally effective in enabling the participants to improve their scores. However, there was a statistically significant difference in the mean score change based on training topics [F (2,262) = 23.153, p < 0.001]. This shows the training topic was a significant factor in the effectiveness of the training. The mean score change for Preferred Fall Protection (M = 2.17, SD = 1.795) was statistically higher than the mean score changes for Warning Lines (M = 1.61, SD = 1.508), and the mean score change for Warning Lines was statistically higher than the mean score changes for Harness Inspection (M = 0.51, SD = 1.203) as seen below in Table 3.

Table 3

Mean score change across topics, all modes of training

Topics	N	Mean (Std. Dev.)
Harness Inspection	73	0.51 (1.203)
Warning Lines	115	1.61 (1.508)
Preferred Fall Protection	77	2.17 (1.795)

The next set of statistical analyses were also mean comparisons, but with pairs of variables rather than larger groups. These were done to ensure that the posttest scores were indeed statistically different from the pretest scores. Previously, only the mean score changes had been compared from one topic or mode to another. In this set of analyses, the pretest and posttest scores on the same topic were compared. Three paired sample t-tests were completed to compare the mean pretest and posttest scores separated by instructional mode and by training topic. The results show that the mean posttest scores were statistically higher than the mean pretest scores on all modes and topics. The results are shown in Table 4 below.

Table 4

Comparing pretest and posttest based on mode (all topics) and topic (all modes)

Mode	N	Pretest scores mean	Posttest scores mean	Score change
By Mode, All Topics				
Text	95	2.37	3.77	1.40*
Video	83	2.51	4.00	1.49*
Slides	87	2.39	3.92	1.53*
By Topic, All Modes				
Harness	73	3.96	4.47	0.51*
Warning Line	115	2.03	3.64	1.61*
Preferred Fall	77	1.53	3.71	2.18*
* Significant at $p < 0.001$				

The third and final set of analyses was also mean comparisons with pairs of variables rather than larger groups. But in this case, nine paired sample t-tests were completed to compare mean pretest and posttest scores based on topics across each mode. The results show that when the training mode is slides and the topic is Harness Inspection, there is no statistically significant difference between pretest and posttest score. However, when the same mode is used with either Preferred Fall or Warning Lines training topics, there is a statistically significant difference between pretest and posttest scores. The results further reveal that when the training mode is text and the topic is Harness Inspection, there is no statistically significant difference between pretest and posttest scores. But when the training topics are either Preferred Fall or Warning Lines, there is a statistically significant difference in the pretest and posttest scores even with the same mode of text. Finally, the results show that when video is the mode of training used for any of the three training topics, there is a statistically significant difference in pretest and posttest scores. The posttest score being the higher in all instances, details are in Table 5.

Table 5

Comparing pretest and posttest based on topics (Slides)

Topic	N	Pretest scores	Posttest scores	Score Change
Slides				
Harness	23	3.96	4.26	0.30
Warning Lines	34	2.26	3.79	1.53*
Preferred Fall	30	1.40	3.87	2.47*
Text				
Harness	21	4.14	4.36	0.22
Warning Lines	50	1.98	3.54	1.56*
Preferred Fall	23	1.52	3.70	2.18*
Video				
Harness	28	3.82	4.71	0.89**
Warning Line	31	1.87	3.65	1.78*
Preferred Fall	24	1.79	3.63	1.84*

* Significant at $p < 0.001$, ** Significant at $p<0.01$

Discussion

In Figure 1, the posttest scores are skewed to the right towards the high values which sets the tone for our analyses. This, even before any statistical analyses, suggests the intervention might be responsible for improvement in the scores of the trainees. Further statistical analyses show a connection between the instructional training topics and training modes, with improvement in scores.

The results from data analyses indicate that the training topic is crucial to the effectiveness of training delivered. All the analyses done seem to confirm this. The result of the analyses shows a trend that is consistent throughout, which identifies preferred Fall Training topic as being the topic with the most impact on training outcome, followed by Warning Lines, with Harness having the least effect on training outcome. The mean score changes when comparing means or difference in pretest and posttest scores of any combination of variables was always highest with preferred Fall Protection training topic.

The reason behind Preferred Fall being more impactful is fairly evident. The participants generally had very little previous knowledge, which is why they had low scores on the pretest (a mean score of 1.53 out of a possible 5 points), leaving room for improvement on the posttest. After the intervention there was knowledge gain leading to a significant score change across training modes and this topic. The Warning Lines topic follows closely behind in terms of score change for the same reason and was effective across all training modes. It is likely that there is a lower score change in Warning Lines topic compared to Preferred Fall topics because Warning Line topics are slightly less complex. The Harness Inspection topic has the least score change and this may be because it is the least complex topic. Most of the questions related to Harness Inspection only require a bit of common sense to answer.

There was a difference in score changes depending on whether the mode of training was text similar to a toolbox talk, slides, or video (1.40, 1.49, and 1.53, respectively). However, when looked at in aggregate, none of the differences in means was found to be statistically significant and so we cannot reliably conclude that one is more effective than the other. We can only conclude that each training topic has some positive effect on test scores. When all combined together (all modes and all topics), the total average score was improved from a pretest score of 2.42 to a posttest score of 3.89 which is a 61% increase.

Conclusion

The researchers used this study to set the tone for a more elaborate future study whose results can be widely adopted in the construction industry. The findings show some encouraging results and shed light on some options for training that is tailor-made for the construction industry.

Having seen the effectiveness of these training methods, we can say that this is a very cheap way to conduct safety trainings. With fewer resources, organizations or companies can deliver highly effective safety training that improves safety awareness of their workers. The cost and time of regular in-person training is drastically reduced and more options become available for regular interval training. The results of this study show significant improvement in scores even when the participants are not under any kind of pressure that made them to be fully invested in the training they received. In other words, some of them could not have been putting in their best effort, and yet we had significantly improved scores. Even better results are expected for mandatory training where workers apply what they have learned on the jobsites. It is particularly noteworthy as an alternative to traditional classroom training which is not always effective when it comes to the category of learners that make up the construction workforce.

Finally, there is the need to review how trainings are being delivered in the construction industry. A lot of effort is being put into improving construction safety statistics and yet the situation is not improving. Everyone agrees that training helps to improve safety, but we keep hearing of incidents every day. It shows the old ways are no longer working, new training methods are needed to face the current safety challenges in the construction industry. There is the need for a concerted effort by key players and stakeholders in the industry to explore and invest in new ways of training that can help improve the situation. We know smaller companies have the worst safety records; it is our recommendation therefore that the bigger companies not only work to protect themselves but also are mandated by law to invest in research on more effective training methods that makes learning and application of what is learned useful.

Limitations

There are a few limitations with this study. The 265 responses consisted of approximately 115 unique participants. While this seems to be an acceptable sample size, the fact that they were spread across several different interventions limited the size of each intervention group. A larger pool of participants would add more validity to these results. Secondly, the time gap allowed between the intervention and the posttest was not ideal. To capture the effect of the intervention, a longer time gap should be allowed between the intervention and the posttest.

References

Albert, A., Hallowell, M. R., & Kleiner, B. M. (2014). Enhancing construction hazard recognition and communication with energy-based cognitive mnemonics and safety meeting maturity model: Multiple baseline study. *Journal of Construction Engineering and Management*, *140*(2), 04013042. doi:10.1061/(asce)co.1943-7862.0000790

Bhandari, S., Hallowell, M. R., & Correll, J. (2019). Making construction safety training interesting: A field-based quasi-experiment to test the relationship between emotional arousal and situational interest among adult learners. Safety science, 117, 58-70.

Blume, B. D., Ford, J. K., Baldwin, T. T., & Huang, J. L. (2009). Transfer of training: A meta-analytic review. Journal of Management, 36(4), 1065-1105.

Bureau of Labor Statistics. (2020). *TABLE A-1. Fatal occupational injuries by industry and event or exposure, all United States, 2020.* https://www.bls.gov/iif/oshwc/cfoi/cftb0340.htm

Fairchild, E. E. (2003). Multiple roles of adult learners. New directions for student services, 2003(102), 11-16.

Goldenhar, L. M., Moran, S. K., & Colligan, M. (2001). Health and safety training in a sample of open-shop construction companies. *Journal of Safety Research*, *32*(2), 237-252. doi:10.1016/s0022-4375(01)00045-7

Huang, X., & Hinze, J. (2003). Analysis of construction worker fall accidents. *Journal of Construction Engineering and Management*, *129*(3), 262-271. doi:10.1061/(asce)0733-9364(2003)129:3(262)

Kazis, R., Callahan, A., Davidson, C., McLeod, A., Bosworth, B., Choitz, V., & Hoops, J. (2007). *Adult learners in higher education: Barriers to success and strategies to improve results*. Report Prepared for the Employment and Training Administration, Boston.

Knapp, T. R. (2016). Why is the one-group pretest–posttest design still used? *Clinical Nursing Research*, *25*(5), 467-472. doi:10.1177/1054773816666280

Kaskutas, V., Dale, A. M., Lipscomb, H., & Evanoff, B. (2013). Fall prevention and safety communication training for foremen: Report of a pilot project designed to improve residential construction safety. *Journal of Safety Research*, *44*, 111-118. doi:10.1016/j.jsr.2012.08.020

Loosemore, M., & Malouf, N. (2019). Safety training and positive safety attitude formation in the Australian construction industry. *Safety Science*, *113*, 233-243. doi:10.1016/j.ssci.2018.11.029

Lundberg, C. A. (2003). The influence of time-limitations, faculty, and peer relationships on adult student learning: A causal model. *The Journal of Higher Education*, *74*(6), 665-688. https://doi.org/10.1353/jhe.2003.0045

Mitchell, M. L., & Courtney, M. (2005). Improving transfer from the intensive care unit: The development, implementation and evaluation of a brochure based on Knowles' adult learning theory. *International Journal of Nursing Practice*, *11*(6), 257-268. https://doi.org/10.1111/j.1440-172x.2005.00533.x

Taylor, E. L. (2015). Safety benefits of mandatory OSHA 10h training. *Safety Science*, *77*, 66-71. doi:10.1016/j.ssci.2015.03.003

Tixier, A., Albert, A., & Hallowell, M. (2013). Teaching construction hazard recognition through high fidelity augmented reality. Proceedings of the 120th ASEE Conference & Exposition. Atlanta, GA, USA, June 2013.

Wang, Y., Goodrum, P. M., Haas, C. T., & Glover, R. W. (2008). Craft training issues in American industrial and commercial construction. *Journal of Construction Engineering and Management*, *134*(10), 795-803. doi:10.1061/(ASCE)0733-9364(2008)134:10(795)

Wilkins, J. R. (2011). Construction workers' perceptions of health and safety training programmes. *Construction Management and Economics*, *29*(10), 1017-1026. doi:10.1080/01446193.2011.633538

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Detection of Alkali-Silica Reactivity using Field Exposure Site Investigation

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The main objective of this research is to study the impact of supplementary cementitious materials (SCMs) on mitigating Alkali-Silica Reactivity (ASR) of hardened concrete. ASR is a deleterious reaction between alkali content within the cement and highly reactive silica content available in some aggregate sources across the United States. ASR results in the formation of an expansive white-like gel that adds internal tensile stresses within hardened concrete. Increased tensile stress results in the formation of cracks, dissipation of additional moisture, and reinforcement corrosion. In this research project, large scale concrete blocks, with aggregates from different sources, were poured using different percentages of SCMs. An exposure site was developed for the poured blocks to investigate ASR possible impact on concrete. ASR impact was measured by calculating concrete blocks expansion over a time span of two years. The outcomes of the research showed that different aggregates result in different rates of expansion. The use of SCMs resulted in mitigating ASR and limit concrete expansion. The replacement of 25% to 30% of cement weight with SCMs (fly ash) is sufficient to halt ASR, and improve the long-time performance of concrete structures.

Keywords: Alkali-silica reactivity, Expansion, Cracking, Concrete blocks, Supplementary cementitious materials

Introduction and Literature Review

Alkali-Aggregate Reaction (AAR) is an important parameter that partially or fully contribute to the deterioration of concrete structures, and results in poor serviceability, deterioration, and/or premature failure of infrastructure projects. Alkali-Silica Reactivity (ASR), discovered in the 1940s in California, is the main type of AAR that results in internal concrete cracking, surface cracking, and concrete spalling. ASR is a deleterious reaction between alkali content on cement and highly-reactive silica content available in some aggregates -source-dependent- within the United States. ASR is expedited in the presence of high moisture content. ASR results in the formation of expansive white gel-like material inside hardened concrete members (Figure 1). The expansion of developed gel material induces internal tensile stresses that could potentially result in concrete cracking. Crack location, number, and size depends on the amount of alkaline content, type, nature, and reactivity of silica content within aggregates, and the amount of free moisture available to catalyze the reaction.

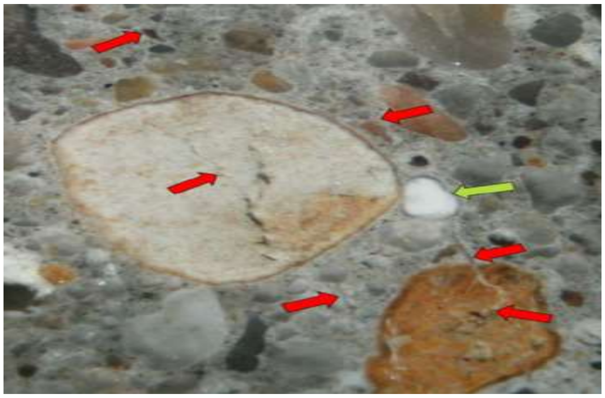

Figure 1. Expansive white gel-like material resulting from ASR

After initial ASR damage detection in the 1940s (Stanton, 1940), several research projects, funded by the Federal Highway Administration (FHWA) and Departments of Transportation (DOTs) studied ASR, parameters contributing to ASR activity, ASR damage magnitude, and how to mitigate, and possibly halt ASR. Typically, ASR damage is more noticeable in heavy construction projects due to the large concrete surface exposure to adverse environmental conditions, and moisture (Figure 2).

Figure 2. Infrastructure concrete cracking due to ASR

Due to the severity of losses caused by ASR, current research focuses on early detection of ASR in hardened concrete (Folliard et al., 2012; Deschenes and Hale, 2017a, 2017b). Alternative research programs target the detection of reactive aggregate sources to eliminate their use in future concrete construction projects, and/or proportion concrete mixes to mitigate the ASR deleterious effect, when reactive aggregates are used (Folliard et al, 2003, 2007). The main objectives of this research are: 1) Develop field exposure site for concrete specimens fabricated using aggregates obtained from different sources to investigate their potential reactivity by measuring samples expansion over time, and 2) Investigate the possibility of using supplementary cementitious materials, mainly class C and class F fly ash, to mitigate and/or halt the ASR damaging effect on hardened concrete.

Research Methodology and Experimental Investigation

ASR Standard Testing Procedures

Recent studies provided detailed explanation to ASR, and how it is initiated. During concrete mixing, the aggregate content including limestone, gravel, crushed granite, and fine sand is encapsulated with hydrated cement paste with high alkalinity (pH value may exceed 13.0). Once hydration process is concluded, free moisture within the hardened concrete dissipates through hardened concrete pores as a high-alkaline solution that reacts with specific silicious content within the aggregates (Folliard et al. 2012; Deschenes and Hale 2017a, 2017b; Akhnoukh et al. 2017) The alkali-silica reaction tends to form the expansive gel that results in the ASR damaging effect. Similarly, the alkaline solution may attack specific carbonates present in the aggregate to form a damaging alkali-carbonate reaction (ACR). Both ASR and ACR reactions are extremely damaging, and may cause premature failure to concrete structures. ASR and ACR damages are similar to other types of deterioration due to weathering, effect of de-icing salts on concrete structures, and the impact of freeze-thaw cycles. In order to differentiate between ASR and other types of concrete damages, a petrographic analysis of concrete specimens is required to identify the nature of the reaction causing deterioration. In a typical ASR petrographic testing, a concrete core is drilled in the structure, and the obtained sample is shipped to the lab (Figure 3), where reagents are applied on the concrete surface under consideration. Based on the reagent reaction outcome, ASR could be confirmed or denied.

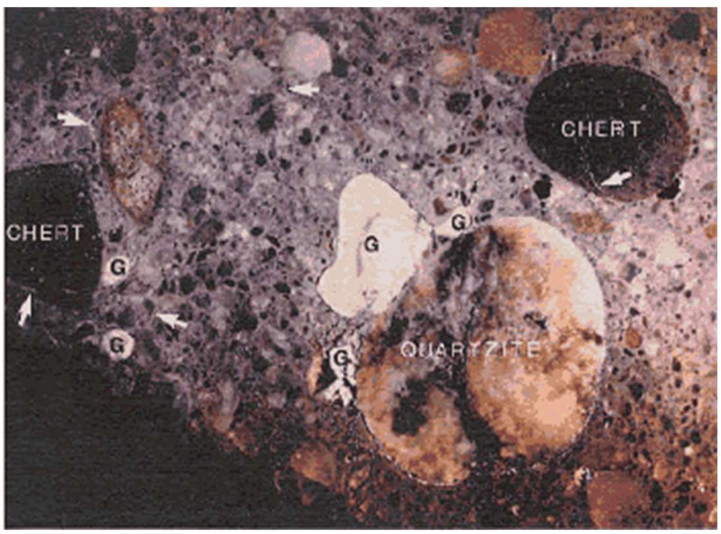

Figure 3. ASR petrographic scanning of hardened concrete (Fournier et al. 2010)

The detection of ASR depends on calculating the length changes (expansion) of concrete specimens over time. Due to the duration required for alkali-silica deleterious reaction detection, ASR is detected through the exposure of standard concrete bars to harsh/extreme laboratory conditions aiming to expedite potential ASR formation. Laboratory detection of ASR is done using Accelerated Mortar Bar Test (AMBT) according to ASTM C 1260. In the AMBT, precast bars are immersed in sodium hydroxide solution at 176 F (80ºC) to ensure harsh environmental exposure, and length changes are measured for 14 days (Figure 4). Expansion in excess of 0.1% of the original bar length indicates a potential reactivity for the used aggregates.

Figure 4. ASR measurement using AMBT (Akhnoukh et al., 2016)

Alternatively, ASR can be detected by exposing concrete specimens to normal environmental conditions, and measure concrete expansion due to ASR reaction over time (Thomas et al, 2011; Ideker et al., 2012). The process of concrete exposure to regular conditions is more accurate. However, several months of testing (up to 24 months) are required to detect ASR. In this research, concrete specimens of dimensions 13.8 in. x 13.8 in. x 35.4 in. (350 mm. x 350 mm. x 900 mm.) are poured, with different concrete mix designs to investigate the reactivity of different aggregates, obtained from different sources. In addition, different SCMs were incorporated in the mix to assess their ability to mitigate ASR by limiting concrete expansions. Exposure site soil was covered by large-sized limestone; and concrete specimens were placed on wooden logs to ensure consistent environmental exposure to all specimen sides (Figure 5)

Figure 5. Concrete specimens and field exposure site setup

Specimens Design for ASR Field Exposure Test

In this research, Type I/II Portland cement and a water-to-cement ratio of 0.5 is used in all concrete mixes. Three different types of aggregates were used including regular weight crushed limestone (CLS), lightweight expanded shales (ES), and light weight expanded clay (EC), and two types of fine aggregates including Arkansas River Sand (ARS), and Pine Bluff Sand (PBS). In addition, two different types of fly ash (Type C and Type F) were used in mix proportioning to investigate the SCM impact on block expansion. Fly ash percentage was kept at 25% by weight (of total cement). Eighteen different combinations for mix designs were used in pouring 54 exposure blocks (Table 1).

Table 1

Blocks combination for ASR exposure site investigation

Block #	Coarse Aggregate	Fine Aggregate	Fly Ash
1-3	CLS	PBS	No FA
4-6	CLS	PBS	C
7-9	CLS	PBS	F
10-12	CLS	ARS	No FA
13-15	CLS	ARS	C
16-18	CLS	ARS	F
19-21	ES	PBS	No FA
22-24	ES	PBS	C
25-27	ES	PBS	F
28-30	ES	ARS	No FA
31-33	ES	ARS	C
34-36	ES	ARS	F
37-39	EC	PBS	No FA
40-42	EC	PBS	C
43-45	EC	PBS	F
46-48	EC	ARS	No FA
49-51	EC	ARS	C
52-54	EC	ARS	F

Detached mechanical (DeMec) gages were installed on concrete blocks, and strain gage reader was used to record the developed expansion generated due to the exposure to environmental conditions DeMec gage readings were performed every 3-month, and results were recorded to develop strain profile for two-year of expansion. Average strain was generated for every combination using the results recorded from the three identical blocks poured for that specific combination. The following section provides the detailed results of the research.

Results and Discussions

The use of crushed limestone CLS with different combinations of fine sand did not result in significant expansion (expansion measured was less than 0.04%) which indicates no ASR. The incorporation of class C and class F fly ash resulted in a significant drop in the expansion, as compared to the sample with no-fly ash. Similar results were obtained when expansive clay EC was used as coarse aggregate in replacement of CLS. However, when expanded shales ES were used as coarse aggregate, higher expansion rates were measured for different specimen combinations. This is attributed to the higher tendency of ES to store moisture at initial specimen pouring. The excess moisture was dissipated to the hardened concrete during the project duration, which catalyzed the ASR, and resulted in higher expansion (Akhnoukh, 2018). It was noted that the use of class C and class F fly ash resulted in significant reduction of specimen expansion. Specimens poured with ARS had their expansion below 0.04% when both types of fly ash were used in specimen fabrication. Thus, potential ASR was halted (Table 2). SCMs results in ASR mitigation or halting due to the fine size of SCMs granular particles, which reduces the hardened concrete permeability (Akhnoukh 2013, 2019). Thus, it hinders the moisture dissipation to the inside of hardened concrete.

Table 2.
Expansion results for different concrete blocks

Block #	Coarse Aggregate	Fine Aggregate	Fly Ash	Expansion %
1-3	CLS	PBS	No FA	0.04
4-6	CLS	PBS	C	0.03
7-9	CLS	PBS	F	0.029
10-12	CLS	ARS	No FA	0.039
13-15	CLS	ARS	C	0.029
16-18	CLS	ARS	F	0.01
19-21	ES	PBS	No FA	0.07
22-24	ES	PBS	C	0.06
25-27	ES	PBS	F	0.058
28-30	ES	ARS	No FA	0.042
31-33	ES	ARS	C	0.031
34-36	ES	ARS	F	0.024
37-39	EC	PBS	No FA	0.04
40-42	EC	PBS	C	0.03
43-45	EC	PBS	F	0.03
46-48	EC	ARS	No FA	0.033
49-51	EC	ARS	C	0.03
52-54	EC	ARS	F	0.02

Conclusions

ASR is initiated when silica content within reactive aggregates reacts with alkaline content of the cement. The reaction is catalyzed by high moisture content. The ASR results in the formation of expansive gel that induce internal tensile stresses within hardened concrete. Increased tensile stresses results in concrete cracking, spalling, and reinforcement corrosion due to the increased moisture ingress in concrete structures. The magnitude of expansive reaction, hence concrete deterioration, is dependent on multiple parameters including the type of used aggregate, the type and quantity of used SCMs in partial replacement of cement. ASR investigation using field exposure site - though labor intensive, time-consuming, and requires an extended testing duration up to 2 years - is successfully used in ASR detection. ASR, measured by calculating concrete specimen expansion over time, shows that the incorporation of SCMs results in significant reduction in the concrete tendency to expand, hence, mitigate ASR. The incorporation of SCMs (class C and class F fly ash) with a 25% of cement content by weight is sufficient to halt ASR, prevent concrete cracking, improve the concrete project conditions, and minimize the need for maintenance and/or repair. Additional research to explore the impact of other types of SCMs as blast furnace slag, nano-silica, metakaolin, and multi-wall carbon nanotubes (MWCNTs) and the percentage of their incorporation in the concrete mix design on the mitigation of ASR in hardened concrete is needed. Different sample sizes should be considered in future research, and multiple samples per combination may be considered for improved statistical validation of results.

References

Akhnoukh, A.K., "Internal curing of concrete using lightweight aggregates," Particulate Science and Technology, Vol. 36, No. 3, pp. 362-367, 2018

Akhnoukh, A.K., "Overview of nanotechnology applications in construction industry in the United States," Micro and Nano-systems Journal, Vol. 5, No. 2, pp. 147-153, 2013

Akhnoukh, A.K., "The use of micro and nano-sized particles in increasing concrete durability," Particulate Science and Technology Journal, 2019

ASTM Standard C1260-05, "Standard test method for potential alkali-reactivity of aggregates (mortar bar test)," Annual Book of ASTM Standards 04.02. ASTM International, PA, 2008

Deschenes, Jr., R., and Hale, W., "Alkali-silica reaction (ASR) in concrete with previously inert aggregates," ASCE Journal of Performance of Constructed Facilities, 2017a

Deschenes, Jr., R., and Hale, W., "Alkali-silica reaction mitigation and prevention measures-phase I," Arkansas Department of Transportation and Mack Blackwell Rural Transportation Center, 86 pp., 2017b

Stanton, T.E., "Alkali-silica reaction mitigation & ," Proceedings, American Society of Civil Engineers, Vol. 66, pp. 1781-1811, 1940

Folliard, K. J., Thomas, M.D.A., & Kurtis, K. E., "Guidelines for the use of lithium to mitigate or prevent ASR," (Report No. FHWA-RD-03-047). Federal Highway Administration, U.S. Department of Transportation, Washington DC, 86 pp (2003)

Folliard, K. J., Barborak, R. C., Ideker, J. H., Fournier, B., & Thomas, M. D. A. Laboratory test methods for determining the dosage of lithium nitrate required to control ASR-induced expansion. Transportation Research Board (TRB) 86th Annual Meeting, Washington DC, 10 pp (2007)

Fournier, B., Berube, M., Folliard, K, and Thomas, M., "Report on the diagnosis Prognosis and Mitigation of Alkali-Silica Reaction (ASR) in Transportation Structure, FHWA-HIF-09-004, 2010
Ideker, J.H., Drimalas, T., Bentivegna, A.F., Folliard, K.J., Fournier, B., Thomas, M.D.A., Hooton, R.D., & Rogers, C.A., "The importance of outdoor exposure site testing," Proceeding of the 14th International Conference on Alkali Aggregate Reaction (ICAAR), Austin, Texas (2012)

Thomas, M.D.A., Fournier, B., Folliard, K.J., & Resendez, Y.A., "Alkali-silica reactivity field identification handbook," (Report No. FHWA-HIF-12-022). Federal Highway Administration, U.S. Department of Transportation, Washington DC, 80 pp (2011)

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The Effects of Partial Replacement of Sand by Recycled Plastic on Concrete Properties

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Plastic has become an essential part of our life. Unfortunately, it has a negative environmental impact due to its limited recycling rate. This study investigates the effect of replacing 10% of sand with recycled polyethylene terephthalate (PET) in concrete and the effect of particle size of PET used in the concrete mix. The impact of these two factors on the physical and mechanical properties of concrete was examined. Two types of PET particle sizes, 2.36 mm (sieve #8) and 4.75 mm (sieve #4), were investigated. Concrete was cast to determine the behavior of fresh and hardened concrete in terms of workability, unit weight, and compressive strength. The experimental results showed improvement in all three of these critical characteristics of concrete. Replacing 10% of the sand with 4.75 mm PET resulted in better properties than other mixes used in the trials. We think that using a specific size of PET particles rather than a randomly selected PET size combination is the reason behind this improvement. This study proved that utilizing plastic waste in specific ratios and specific particle sizes within concrete mixes can be effectively used in industrial applications. This is a pilot study to explore this specific topic.

Key Words: PET, Particle Size, Compression, Workability, Unit Weight

Introduction

Without a doubt, plastic waste is one of the most critical environmental problems. Five to thirteen million metric tons of plastic waste end up as debris in rivers and oceans every year (Jambeck et al, 2015). In the united states, the recycling rate of PET bottles and jars was 29.1%, while overall the amount of recycled plastics is relatively small three million tons for a 8.7% (EPA, 2018). Therefore, there is a persistent need to find different applications to utilize plastic waste.

Concrete manufacturing is one of the most suitable applications for using plastic waste since plastic preparation in the concrete mixture doesn't need a high purification process compared to other uses of plastic waste. With the increasing scarcity of space for landfilling and its ever-increasing cost, waste utilization has become an attractive and necessary alternative to disposal (Siddique et al, 2008).

Using plastic in concrete will help solve a critical environmental problem that the world faces with waste, especially its oceans, which are polluted faster than ever. Plastic pollution poses a great deal of risk to the environment and, by extension, human and animal health. The ecosystem is plagued with severe problems stemming from the indiscriminate disposal of plastic debris from post-consumer streams onto land and marine habitats.

Literature Review

Various forms of plastic such as high-density polyethylene (HDPE), polyethylene terephthalate (PET), low-density polyethylene (LDPE), polystyrene (PS), polypropylene (PP), polyvinyl chloride (PVC), and glass fiber reinforced plastic (GFRP), etc., are used in various essential products and applications. Plastic is extensively used as a waste disposal material. It is preferred for many more applications because it is flexible, durable, lightweight, moisture-resistant, and costs relatively less to produce compared to other materials (Babafemi et al, 2018). The utilization of waste plastic in concrete production has been reported as a cost and energy saver and potentially a viable alternative to burning or landfilling (Jacob-Vaillancourt & Sorelli, 2018).
Some researchers investigated the effect of replacing sand with PET at different levels (10-50)% by volume. They reported decreases in slump, unit weight, and compressive strength for all levels. For a replacement ratio of 10% of PET, the slump decreased by 12%, fresh unit weight reduced by 6.28%, and compressive strength dropped by 1.2% at age 28 days (Almeshal et al, 2020). Other researchers studied replacing fine and coarse aggregate with non-biodegradable plastic waste. They investigated replacement of fine aggregate weight by 10%, 15%, 20% with Plastic fine (PF) aggregate and for each replacement of fine aggregate 15%, 20%, 25% of coarse aggregate replacement also conducted with Plastic Coarse(PC) aggregate. They reported a reduction in mechanical properties of concrete due to replacement at all levels (Jaivignesh & Sofi, 2017).

Materials and Methods

Cement and Aggregates

The commercial-grade Portland cement No. 1124 was used for this research that complies with ASTM C150 Type II specifications. According to ASTM C-150, this type of cement is meant for general use, where moderate sulfate resistance is desired (ASTM C-150, 2021). The coarse aggregates used in the samples were crushed stones variably sized 1/2 inch or smaller. The aggregates were washed and already graded as all-purpose gravel, which complies with ASTM C33 standard specifications. The fine aggregates used for the study were the No. 1152 all-purpose sand, with a relative density of 154 Ib/ft^3. Cement, gravel, and sand were sourced from Home Depot. Grading of sand was done per ASTM C33, as shown in Figure 1.

Plastic

Crushed polyethylene terephthalate (PET) plastic (shown in Figure 2), sourced from a local materials recycling facility, was used as the plastic aggregates for this research. The relative density of the plastic grains used is 70.80 lb/ft3.

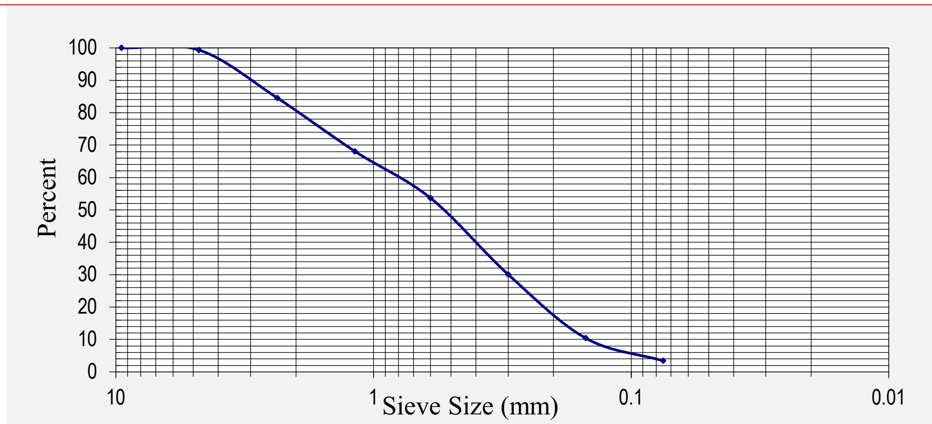

Figure 1. Particle size distribution curve of sand

Figure 2. Crushed polyethylene terephthalate (PET)

Specimens Preparing

A concrete mix proportion of 1:3:3 (Cement: Sand: Gravel), and water-cement ratio (w/c) of 0.55 were used to prepare the samples. Therefore, 33.33 Ib cement;100 Ib sand: 100 Ib gravel were mixed with 18.33 Ib of water in the reference case, against which the results from samples with PET were checked.

First, gravel was added to an electric mixer, and then sand was added gradually, followed by plastic and cement at sequent. The electric mixer kept operating for 5 to 10 minutes between adding the materials. Then water was added, and the mixer ran for 30 minutes before the samples were cast. That produced a homogenous blend of mixing. Poly-ethylene terephthalate (PET) grains size 2.36 mm (sieve #8), and 4.73 mm (sieve #4) were used to replace 10% by volume of the sand, particle size 2.36 mm (sieve #8).

Fresh Concrete Tests

The workability of each concrete mix was determined through a slump test according to ASTM C143 guidelines. The concrete was placed in the slump cone in three (3) approximately equal layers and then tamped 25 times for each layer.

The density of fresh concrete was measured according to ASTM C29. Three measurements were taken for each case, and the average was used for each case.

Specimens Casting and Curing

The casting and curing of test specimens were done following ASTM C31. Concrete cylinders were cast in 4" (diameter) x 8" (height) cylindrical plastic molds and used as compressive strength specimens. The molding was done in three (3) equal layers, each tapped 25 times with the 3/8 inch tapping rod. All concrete samples were removed from molds after 24 hours and remained fully submerged in the curing bath until the date compression testing, Figure 3 shows the specimens while curing in water.

Figure 3. Specimens cured in the container

Figure 4. Humboldt/compression machines

The compressive strength of cylindrical concrete specimens were tested in moist conditions after curing at 7, 14, and 28 days following the ASTM C39 standards. Steel retainer rings fitted with Neoprene pads were placed centered at both ends of the concrete specimen for unbonded capping. The capped specimen was placed in a power-operated machine (Figure 4) and continuously loaded axially at a constant loading rate until failure occurs. The maximum compressive loads are recorded. The compressive strength was determined in lb/in^2 to be the ratio of the maximum load attained and the area of the cross section of the test specimen.

$$\text{Compressive strength} = \frac{Maximum\ Load}{Cross\text{-}sectional\ Area\ of\ Specimen} = \frac{4P_{max}}{\pi D^2}$$

Where, P_{max} = Maximum load (lbf)

D = Average measured diameter (in.)

Results and Discussion

Slump

Figure 5 shows slump cone and base, and the measurement way. Replacing 10% of sand with PET produced a slight improvement in the workability of the concrete mix, as shown in Figure 6. In case 10% (A), in which 10% of sand is replaced with 2.36 mm (sieve #8) size of PET, the slump increased from 0.25 inches to 0.31 inches. While in case10% (B), in which 4.75 mm (sieve #4) size of PET is used instead, the slump is further increased to 0.708 inches. Even though the difference in slump measurements may seem small, these results suggest that using larger size plastic grain can improve the workability of concrete. Other researchers reported varying results regarding the effect of plastic grains on the workability of concrete. Many researchers reported decreasing in workability due to replacing sand with plastic aggregates (Albano et al, 2009), (Mustafa et al, 2019) and (Batayneh et al, 2007), while other researchers reported improvement in the workability of fresh concrete with increasing plastic content (Choi et al, 2009) and (Ghernouti et al, 2014). In addition to these two observations, some researchers claimed no significant impact on workability due to replacing sand with plastic aggregates (Kou et al, 2009) and (Tang et al, 2008). The variation in the recommendations in the literature may be attributed to several factors affecting slump results, such as water-cement ratio (w/c), substitution level of plastic aggregates, and the shape of the waste plastic grains (Gu & Ozbakkaloglu, 2016).

Figure 5. Slump measurement

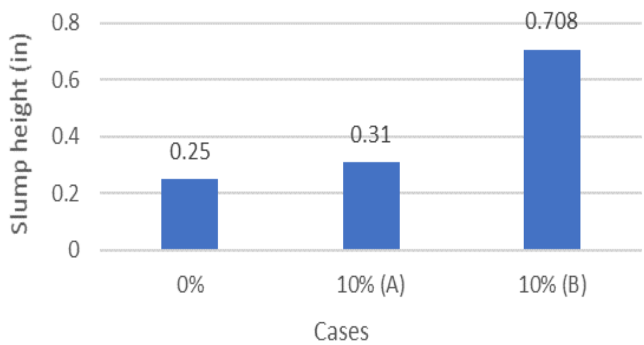

Figure 6. Slump results

Unit Weight of Fresh Concrete

Replacing 10% of sand by PET reduced the unit weight of fresh concrete, as shown in Table 1. The unit weight was reduced more in case 10% (B), where size 4.75 mm (sieve #4) plastic grains were used. The unit weight of concrete dropped from 148.90 Ib/ft^3 to 144.96 Ib/ft^3 and 138.37 Ib/ft^3 when PET sizes 2.36 mm and 4.75 mm, are used, respectively. These numbers correspond to 2.65% and 7.07% weight reduction, which is deemed reasonable since the density of PET size 4.75 mm (75.51 Ib/ft^3) is less than that for size 2.36 mm (76.46 Ib/ft^3).

Table 1

Unit weight of fresh concrete

Cases	Density (lb/ft^3)	PET size (sieve #)
0%	148.90	-
10% (A)	144.96	2.36 (#8)
10% (B)	138.37	4.75 (#4)

Compressive Strength

The compressive strengths of samples prepared with regular concrete and concrete containing PET are shown in Table 2 and Figure 7, which show replacing sand with PET improves the compressive strength of concrete. Using larger PET particles (case B) resulted in better improvements than smaller ones (case A) at each curing age; 7, 14, 28 days. The compressive strength values of regular concrete (0% PET) prepared for comparison were 3322.96, 4045.07 and 4743.61 psi at 7, 14, and 28 days. Compressive strength increased to 3501.61, 4060.84, and 4902.77 psi at 7, 14, and 28 days for Case 10% (A). That represents 5.38%, 0.17%, and 3.36% increase at the three curing ages used in the study. On the other hand, the compressive strengths increased to 4191.15, 4562.71, and 5640.85 psi at 7, 14, and 28 days for Case 10% (B), representing 26.13%, 12.55%, 18.91% increase in comparison to reference case at the same curing age. Also, the compressive strength increased with increasing curing age in all cases, as expected. All similar past research reported drops in compressive strength due to the replacement of sand with PET particles (Juki, et al , 2013), (Saxena, Siddique, Gupta, Sharma & Chaudhary, 2018) and (Frigione, 2010). Even though 10% sand replacement with PET may be considered a small amount in the overall concrete mix, consistently higher compressive strengths noted for samples with PET tested in this study is a significant finding. The authors' opinion that using a specific size of PET particles rather than a randomly selected PET size combination is the reason behind the improved compressive strengths. It should be noted that PET particles in this study had been separated according to ASTM C33 size classification, then the samples were prepared by using PET from a specific size category only, an approach unique to this study.

Table 2

Compressive strength of concrete (psi)

Case	7 Days	14 Days	28 Days
0%	3322.96	4054.07	4743.61
10% (A)	3501.61	4060.84	4902.77
10% (B)	4191.15	4562.71	5640.85

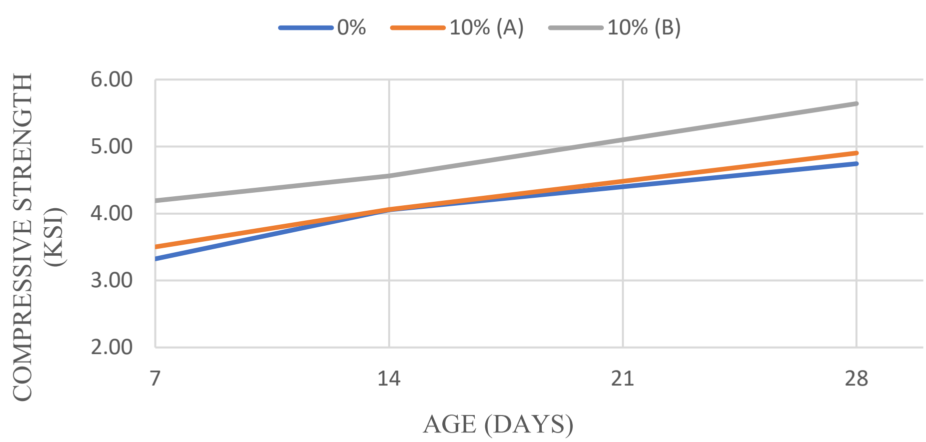

Figure 7. Compressive strength of concrete (ksi)

Conclusion

This research investigated the effect of replacing 10% of fine aggregate in the concrete mix with polyethylene terephthalate (PET) plastic and the impact of PET grain size used in the mixes. Regular concrete mix with cement:sand: gravel ratio of 1:3:3 was used to prepare the samples used as the base in comparisons. Then 10% of sand size 2.36 mm was replaced by PET size 2.36 mm (Case 10% A) and 4.75 mm (Case 10% B) in the trials. The results showed improved concrete properties due to replacing sand with PET. The workability of concrete increased by 24% and 183.2% when 10% sand was replaced by 2.36 mm and 4.75 mm PET grains, respectively. The improvement in workability is very likely attributed to the non-absorbent nature of PET. Since PET density is about 50% lower than sand density, unit weight was reduced by 2.65% (case 10%A) and 7.07% (case 10% B). The compressive strength increased by 5.38% (case 10%A) and 26.13% (case 10% B) after 7 days of curing, while the increases were 3.36% (10% A) and 18.91% (10% B) after 28 days of curing. Therefore, introducing plastic aggregates into fresh concrete mixes is a viable alternative to incineration or landfilling.

This is a pilot study, and the research is ongoing to explore the effect of other replacement ratios and other particle sizes. The limitations of the study is that a machine to grind the plastic was not available at the time of the testing therefore the sizes of the plastic waste had to be limited to what was available in the local market.

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References

Albano, C., Camacho, N., Hernandez, M., Matheus, A., Gutierrez, A., 2009. Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios. Waste Manage. 29, 2707–2716.

Almeshal, I., Tayeha, B., A., Rayed Alyousef, R., Alabduljabbar, H., Mohamed, A., M., 2020. Eco-friendly concrete containing recycled plastic as partial replacement for sand. J Mater Res Technol. 9(3) 4631-4643.

ASTM C-150/150M-21. Standard Specification fpr Portland Cement.

Babafemi, A., J., Šavija, B., Paul, S., C., & Anggraini, V., 2018. Engineering properties of concrete with waste recycled plastic: a review. *Sustainability, 10*(11), 3875.

Batayneh, M., Marie, I., Asi, I., 2007. Use of selected waste materials in concrete mixes. Waste Manage. 27, 1870–1876.

Choi, Y., W., Moon, D., J., Kim, Y., J., Lachemi, M., 2009. Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethyleneterephthalate bottles. Constr Build Mater. 23(8):2829–35.

EPA, United States Environmental Protection Agency, Facts and Figures about Materials, Waste and Recycling
https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data

Frigione, M., 2010. Recycling of PET bottles as fine aggregate inconcrete. Waste Manag. 30(6):1101-6.

Ghernouti, Y., Rabehi, B., Safi, B., Chaid, R., 2014. Use of recycled plastic bag waste in the concrete.

Gu, L., Ozbakkaloglu, T., 2016. Use of recycled plastics in concrete: A critical review. Waste Management 51, 19–42

Jacob-Vaillancourt, C., Sorelli, L., 2018. Characterization of concrete composites with recycled plastic aggregates from postconsumer material streams, Construction and Building Materials. 182, 561–572

Jaivignesh, B., Sofi, A., 2017. Study on Mechanical Properties of Concrete Using Plastic Waste as an Aggregate, IOP Conf. Series: Earth and Environmental Science 80, 012016

Jambeck, J., R., Geyer, R., Wilcox, C., Siegler, T., R., Perryman, M., Andrady, A., 2015. Plastic waste inputs from land into the ocean, Science. 347 (6223) 768– 771.

Juki, M., I., Awang, M., Mahamad, M., K., A., Boon, K., H., Othman, N., Aeslina Abdul Kadir, A., Roslan, M., A., Khalid, F., S., 2013. Relationship between compressive, splitting tensile and flexural strength of concrete containing granulated waste polyethylene terephthalate (PET) bottles as fine aggregate. Advanced Materials Research. 795:356–9.

Kou, S., Lee, G., Poon, C., Lai, W., 2009. Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes. Waste Manage. 29, 621–628.

Mustafa, M., Hanafi, I., Mahmoud, R., Tayeh B., 2019. Effect of partial replacement of sand by plastic waste on impact resistance of concrete: experiment and simulation. Structures. 20:519–26.

Siddique, R., Khatib, J., Kaur, I., 2008. Use of recycled plastic in concrete: A review, Waste Management. 28, 1835–1852.

Saxena R, Siddique S, Gupta T, Sharma RK, Chaudhary S., 2018. Impact resistance and energy absorption capacity ofconcrete containing plastic waste. Constr Build Mater. 176:415–21.

Tang, W., Lo, Y., Nadeem, A., 2008. Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete. Cement Concr. Compos. 30, 403–409.

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BIM for Fast-track Construction under COVID-19 Circumstances: A Comparative Case Study in the African Context

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Under COVID-19 circumstances, the majority of Architecture, Engineering, and Construction (AEC) contractors around the world found themselves handcuffed, facing the sudden restrictive measures to be mandatorily applied in worksites imposing a necessary shift in the typical practices for building. Building Information Modeling (BIM) technologies associated with fast-track construction were found to be an efficient solution for several countries to quickly build health care facilities to meet the rising number of COVID-19 cases. Based on a comparative study, this paper explores the applicability of BIM-based building operation for fast-track construction in the African context and discusses the associated challenges as well as needed elements for its implementation. The study reveals that to reach the full performances of BIM, the African AEC industry has to mainly handle the aspects related to skills, bidding, payment, infrastructure, and availability of local construction materials and technologies.

Key Words: Building Information Modeling, modular, prefabrication, Africa, Leishenshan hospital

Introduction and Context

The restrictive measures imposed against COVID-19 namely distancing, gathering avoidance, and wearing masks with constant hands sanitization carried several industries and economic sectors to firstly slow down or stop their activities, then readapt or shift their practices, strategies, or business models. Consequently, almost all economic sectors were heavily impacted, mainly those based on labor such as Architecture, Engineering, and Construction (AEC) industry. For instance, the African AEC industry experienced a 51% loss of sales value compared to 2019 (Arezki et al., 2021) and the construction backlog indicator decreased by 20.2% in the USA (Jeon et al., 2022). However, the pandemic circumstances have emphasized the automation and remote abilities provided by Building Information Modeling (BIM) at all stages of construction chain value (Meisels, 2020). Digital practices are becoming the essential key to future success in the AEC industry. Deloitte report (Meisels, 2020) revealed that 76% of AEC executives are likely to invest in at least one digital technology in 2021 and emphasized that BIM tops the list of digital initiatives allowing AEC companies to be differentiated. Indeed, BIM helped to keep the AEC field in activity (F. Lin & Howell-Jones, 2020) and enabled several contractors to effectively manage fast-track construction for the required health facilities to handle the sudden increasing number of people affected by the COVID-19 pandemic (Yang et al., 2020; Zhou et al., 2021).

This study aims to enlighten researchers and decision-makers on the strength of BIM-based building operation for fast-track construction in challenging conditions due to human aspects (distancing, contamination…etc.), explore its applicability in the African context, and identify the challenges as well as needed elements for its implementation. Thus, this paper could be a start point to develop further studies helping to create innovative approaches, strategies, or technological tools related to BIM-based fast-track construction. For this purpose, a comparative study between an already realized project in a BIM-expert environment and its analogy in the African context will be conducted. Case study 1 consists of Leishenshan hospital, in China, as a reference, and case study 2 is an analogic project to be built in the African context for which the focus group set a similar building environment in terms of climatic conditions and location features.

Literature Review

BIM Benefits to Overcome COVID-19 Impacts:

The COVID-19 crisis forced the AEC industry to migrate toward smart technologies headed by BIM, leading then to safer construction, smarter planning and design, faster and more predictable timelines, and more sustainable buildings (F. Lin & Howell-Jones, 2020). BIM market rose by 9.8% in 2020 compared to 2019 to reach US$5.71 billion and it is expected to grow to US$11.96 billion by 2027 at a compound annual growth rate of 11.1% (Fortune Business Insights, 2021). Actually, in 2020, remote practices and BIM gained wider spread among designers (architects and engineers) and contractors upheld by the additional and larger support provided by suppliers of digital AEC technologies to help AEC operators to accelerate digital transformation (Meisels, 2020).

BIM is an innovative technology allows the different stakeholders of a project to work simultaneously on a same 3D digital model. It enables real-time design modification, progress tracking, and visualization (Schimanski et al., 2021). Wang et al. (2021) showed that implementing a BIM-led coordination strategy can break through the economic dilemma of the AEC industry caused by the pandemic as it enables participants to coordinate and communicate on a unified information platform helping to effectively address problems and guarantee adequate supervision. Through its digital and automation features, BIM allowed working remotely, inclusively and collaboratively (C.-L. Lin et al., 2021) and demonstrated a big ability to share information among building participants, improve quality and optimize time and costs (Yang et al., 2020). Specifically, it helped to anticipate the contamination risks and build the facilities accordingly, manage the overlapped tasks planning and logistics, previously assess and prepare the needed resources for the project, and closely supervise and check the construction progress on a real-time basis (Yang et al., 2020; Zhou et al., 2021). Besides, it helped to automate area disinfection. Where, based on the already-stored information in the BIM model, a multidisciplinary team of researchers was able to develop specialized service robots capable of disinfecting potentially contaminated surfaces and automating the transport of essential items (Şahan, 2021, p. 19).

Fast-Track Construction

Fast-Track construction aims generally to accomplish a project in a shorter time than normal by applying diverse and innovative methods enabling in-parallel/overlapping on project completion (Lalu et al., 2019). The main principle of the Fast-Track method is well-founded and detailed early planning; Otherwise, it could result in significant delays and re-working (Lalu et al., 2019). Prefabrication and modular design are the most used technologies for fast-track construction. A recent report of Dodge Data & Analytics (Jones et al., 2020) affirmed that using BIM increases the schedule performance from 22% to 61% for prefabrication companies and from 21% to 46% for modular construction companies and showed that 82% of healthcare facilities are expected to use prefabrication and modular construction by 2023 among the surveyed companies.

Indeed, facing the significant spread of the COVID-19 pandemic in 2020, many countries associated prefabrication and modular technology with digital practices to accomplish the needed health facilities in a record time. For instance, in China, Huoshensham hospital was built in Wuhan on an area of 34000 m² in no more than 10 days (Zhou et al., 2021) and Leishenshan hospital was constructed in Jiangxia District, Wuhan in almost 12 days on a field of 21.87 ha with a building area of 79,900 m² (Chen et al., 2021). Similarly, in England, NHS Nightingale Hospital Birmingham was spanning the equivalent of 11 soccer fields and realized in only 4 weeks (Alderton, 2021). Likewise, in Mexico, the six CEMEX Hospitals were installed in 15 days (Alderton, 2021).

Research Design and Methodology

This study uses a 5-step process: First, based on the literature review, Leishenshan hospital was benchmarked as a reference (base) case study for BIM-based fast-track construction built during the restrictive measures related to COVID-19 as it has more available descriptive data. Then, the authors composed a focus group including experts that are knowledgeable of BIM technology and the African construction market. The focus group was composed of an Architect, two contractors, a civil engineer, and a BIM manager. Next, referring to the collected data related to shortlisted project, similar location features were defined for Case Study 2, and then its BIM model was built collaboratively with African engineering firms. Based on feedbacks of the focus group, the construction planning related to each case study was developed, the comparison was discussed, and inferences were drawn.

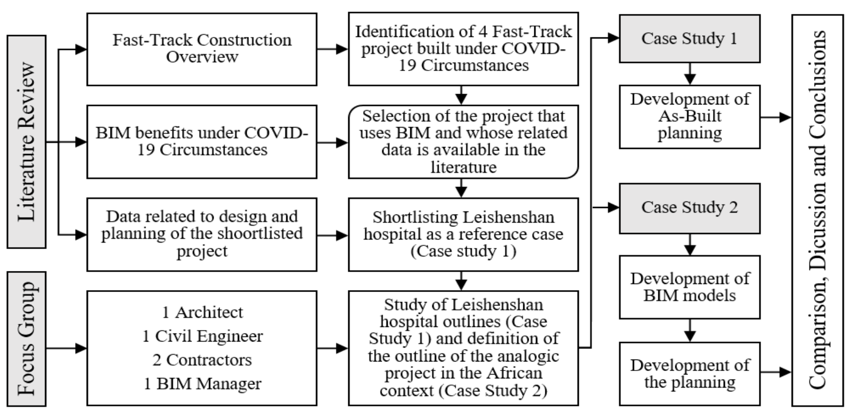

Figure 1. Methodology workflow

The literature review was conducted using Web-of-Science, Google, and Google Scholar based on three groups of keywords: (Fast-Track construction And BIM), (Fast-Track construction And COVID), and (COVID And BIM). As shown in Figure 1, four fast-track projects built under COVID-19 circumstances were identified in the literature. Among those using BIM, the Leishenshan hospital has the most available data related to planning and design. Hence, it was chosen as a reference case study (Case study 1). For comparative study, the focus group discussed building operation time, workforce qualification, needed materials and equipment, and administrative processes.

CASE STUDY 1: Leishenshan hospital, Wuhan-China

Project Outline

Wuhan Leishenshan hospital covers three main areas: 52,000m² for therapeutic isolation (1,600 beds), 9,000m² for accommodation, and 18,000m² for staff living and general logistics. Yet, for the case study, the authors will focus on the two buildings of medical area that, beside the incoming call bloc and mechanical technique Intensive Care Unit (ICU) bloc, contains almost 60,000m² for medical treatment rooms with 1,600 beds (Chen et al., 2021; Luo et al., 2020). The project was assigned to Central-south Architectural Design Institute (CSADI) as responsible for design and follow-up, and China Construction Third Engineering Bureau (CCTEB) Co., Ltd. as turnkey contractor (Luo et al., 2020). It was built based on repetitive modular prefabricated in manufactories and then assembled onsite. In order to respect the required timeline, BIM was used to design, plan and oversee the project (Chen et al., 2021).

The medical treatment area was arranged in repetitive lines of rooms. Each of them was structured in three zones, clean, semi-contaminated and contaminated zone, and two passages, one for medical staff and the other for patients. This area consists of 3,000 container-type prefabricated units.

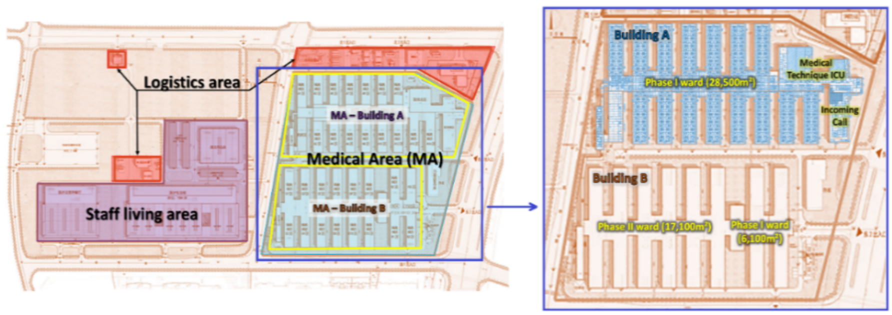

Figure 2. Master plan of Wuhan Leishenshan hospital and medical area (Chen et al., 2021; Luo et al., 2020)

Development of As-Built Planning of The Leishenshan Hospital

The project was built in lockdown period between 26 Jan. and 5 Feb. of 2020 (Chen et al., 2021) by about 1,025 building supervisors and 7,906 construction workers in nonstop 3-shift turn, and used almost 1,491 pieces of excavators, cranes, and other machinery and equipment (Luo et al., 2020). Based on the data collected from the literature (CGTN, 2020a, 2020b; Chen et al., 2021; CSCEC Pakistan, 2020; Luo et al., 2020). The as-built planning of the Leishenshan hospital construction was built during the focus group workshops as shown in figure 3.

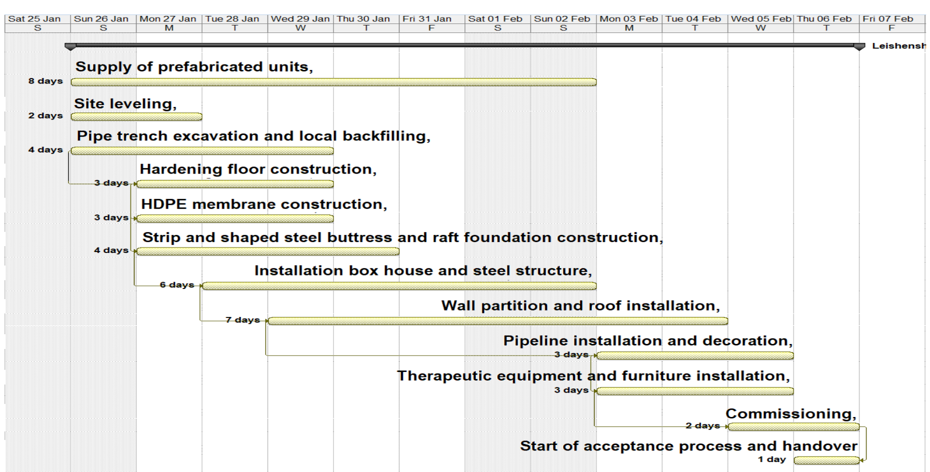

Figure 3. As-built schedule of Leishenshan hospital construction

CASE STUDY 2: Analogic Project in the African Context

Project Outline and Local Context

To well-define the features of the analogic project, firstly the experts participating in the focus group listed and analyzed the collected data about the benchmarked project "Leishenshan hospital" taken as a reference. Secondly, they defined a similar environment where it could be constructed. Therefore, a similar field in Casablanca – Morocco has been designated. In the same vein, since the construction of Leishenshan hospital started 3 days after the beginning of the lockdown, the start date of the analogic project construction was considered on 23 March 2020 (3 days after the beginning of the lockdown in Morocco). Likewise, to define the most optimistic scenario for BIM-based fast-track construction in the African context, the authors held workshops with the focus group. They revealed that the project planning should take into consideration the following constraints related to the local context:

- Since the project owner would be the public authority responsible for health, the project has to respect the conventional procedures imposed by public administrations leading then to long validation process, bureaucracy, important payment delays and so on,
- The construction workforce is mostly not accustomed to using technologies. Generally, only the supervisors could be graduated people, while the production laborers are mostly either handymen that learned by doing or temporary workers which makes investing in their training difficult. Moreover, the Moroccan construction workforce is commonly used to take 3 annual leaves of 2 or 3 weeks each (Aid el Fitr, Aid El Adha, and Aid El Mawlid),
- The majority of required equipment for the project is not produced locally and needs to be imported from industrial countries. Therefore, the planning should take into account the needed time for importation and the related administrative procedures,
- The local market is not used to that kind of fast-track project and needs to practice and validate the first sample as a reference before getting faster. This step should be considered in the planning including the validation process,
- Considering the long payment delays and the necessity of making an upstream payment of the imported equipment including panels, the expenses must be relatively balanced to the revenues with a tolerable margin, which will dependently affect the construction progress.

Development of BIM Models

Based on the plans of building A and the master plan of the medical area (Figure 2), the authors, in collaboration with the local firms, have simulated the remaining building B of the medical area of the hospital and then developed the BIM model as follows:

- Drawing the 2D plans of both building A and B using Autocad (Figure 4),
- Developing the BIM models of buildings A and B using Revit by nesting the modular units and based on the imported 2D-plan imported to the Revit file (Figure 5),

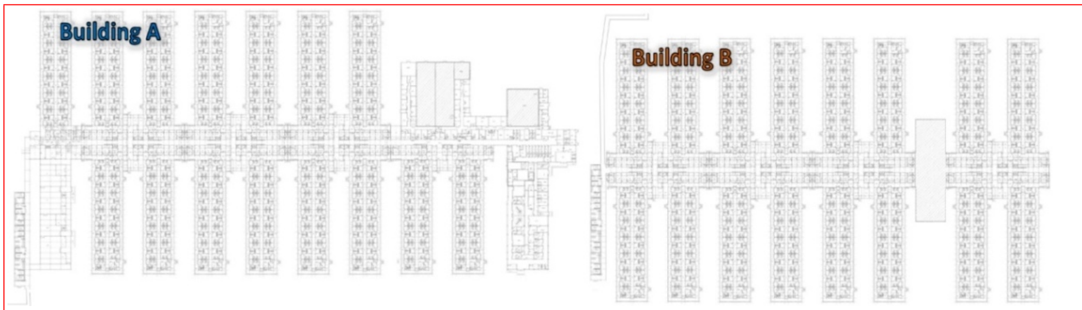

Figure 4. 2D plans of both Building A and Building B of medical area

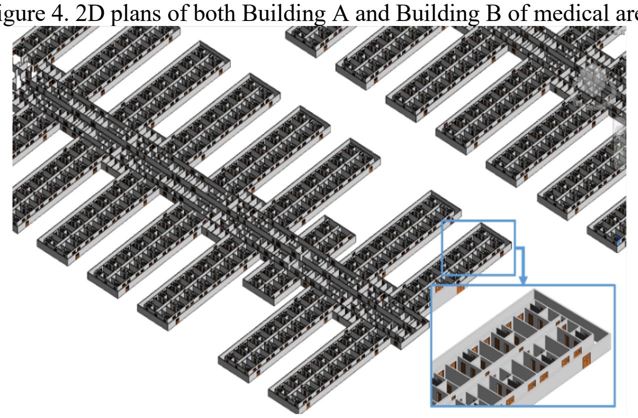

Figure 5. BIM model of Medical area

Development of Construction Planning of the Analogic Project

The focus group workshops defined the construction stages and their durations, and then built the related planning as shown in Figure 6. The produced planning for the analogic project took into account the following hypothesis that are realistic if the project has a complete buy-in of the policy makers:

- The owner is willing to afford the needed investment for that kind of fast-track project using digital aspects, and deliver the necessary payment warranties,
- The project will be funded through banks' funding (based on owners' warrantees) in order to overcome the payment delays and the initial expenses,
- The owner has a restricted team dedicated to fastening validations' process, and ensure the monitoring,
- To reduce the error gap, it is necessary to first validate the materials and equipment to be used and then build a model of the prefabricated unit and have it validated by the owner, architect, engineering firm, and control office,
- The importation process will be launched directly after validating materials and equipment samples. A period of 3 months and 3 weeks is the evaluated time to validate and get the first arrival of materials and equipment taking into consideration the supply chain issues imposed by travel restrictions and worldwide lockdown measures. This period will be used to:
    - Enhance BIM construction efficiency by providing the supervisors with the necessary BIM materials and 2-months training in BIM and COVID-19 measures to be implemented during the construction on-site starting on 26 Mar. 2020,
    - Have enough time to find and recruit the relevant workforce, especially that, according to

survey, in that period the worksites experienced a massive abandonment of the labors because of the fear to be affected because of workers density,

- Proceed with the preparative work (leveling, pipes, backfilling … and foundation) to build the superstructure with minimum of workforce and materials leading then to both handle the workforce aforementioned point, optimize costs and well prepare the logistics.

- Limitation of the three formal leaves of labor to 2 weeks per each (Figure. 6: time intervals in green),
- The project will be divided into six zones (Figure. 7), each one has its own teams and independent working materials with 3-shift work for tasks part of the critical path (Figure. 6: tasks in blue).

The total duration of the BIM construction process of the analogic project in the African context is 206 days in the best scenario.

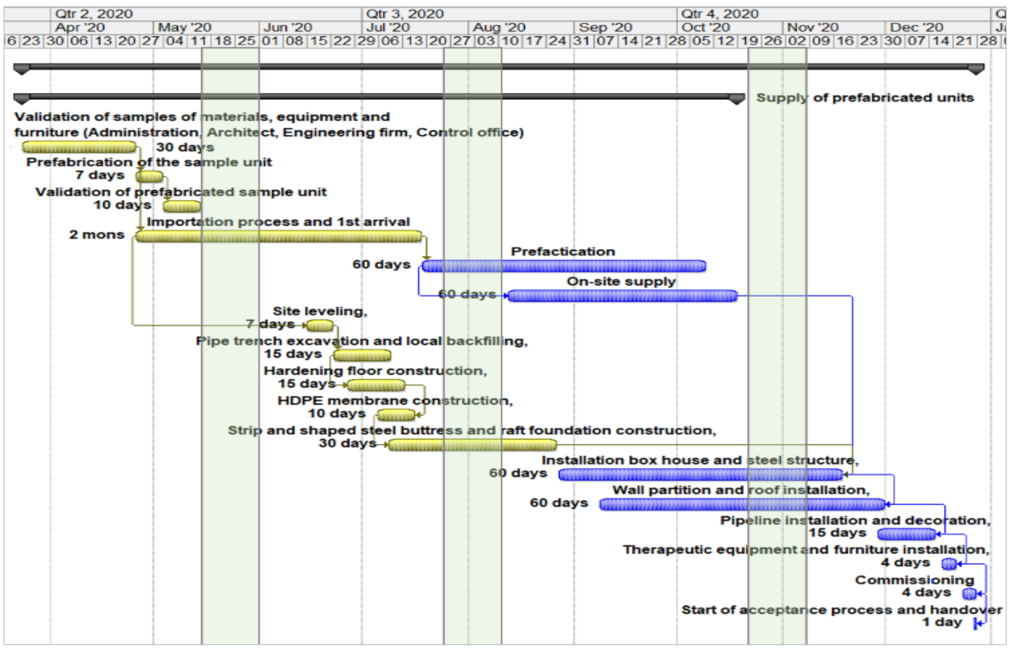

Figure 6. Immediate impacts of COVID-19 (March 2020) on construction site

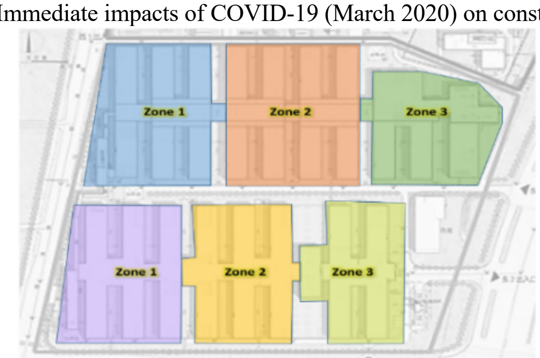

Figure 7. Worksite arrangement

Discussion

Despite the valuable benefits of BIM to both enable construction in crisis circumstances and considerably optimize time, costs and efforts in the AEC industry, Africa is still facing significant challenges hindering the efficient implementation of BIM and more importantly for fast-track construction. The comparative case study revealed that for the same project and under the same circumstances (lockdown, climatic conditions, and location features), in China, BIM-based fast-track construction process enabled the project to be completed in 12 days, whereas in the African context it would take at least 206 days in the best scenario. Indeed, the African firms and experts involved in this study pointed out several needed elements to be satisfied and challenges to be overcome in order to reach the full performances provided by BIM technology in the African context. Namely:

- Lack of skilled workforce in BIM technology for both development and realization stages:
  In the development stage, most architectural and engineering firms are still using non-collaborative tools and have not yet migrated towards BIM tools. While in the construction phase, other than large structures, the contractors are mainly using unskilled or even illiterate workforce, a fact that has been confirmed by several studies (Elliott, 2020; Ghanem, 2020).
- Lack of adequate bidding and payment conditions:
  The contractors are mainly hired based on the less expensive offer, the payment deadlines are significantly high (for instance, 90 to 120 days in Morocco) and for public projects, the invoices' validation process takes a long time. Therefore, the contractors are not willing to fasten work that would increase their expenses and wait for delayed payment.
- Lack of adequate infrastructure:
  To efficiently use BIM technology, the worksite should be well-connected to the cloud, which is not possible out of big cities in Africa because of lack or absence of power and/or internet.
- Lack of locally manufactured construction materials and technologies:
  African construction strongly depends on imported building materials and technologies due to poor local industrialization.

However, this study showed that the private African AEC operators are able to upgrade successfully their current practices toward BIM-based practices and fast-tack approaches if the policy makers pave the path for it. Namely, enhance infrastructure quality, dictate adequate regulations especially in terms of bidding and payment conditions, and promote local industrialization and innovative processes.

Conclusions

Through the analysis of two case studies, this study investigated the applicability of BIM-based building operation for fast-track construction in the African context and inferred the challenges as well as the needed elements to reach the full performances of BIM, with a specific focus on the planning during the construction stage. Based on a thoughtful comparison between the case studies, the research reveals that the needed time for the building operation of fast-track construction in the African context is 17 times more than in a BIM-expert environment. To decrease this substantial incompetency, the African AEC actors, either policy makers or companies, need to overcome the challenges and developed formal strategies to train the workforce in BIM technology, change the bidding and payments conditions, construct an adequate infrastructure mainly power supply and internet, and promote local industrialization of both technologies and martials related to construction field. This paper could be the basis for future research related to frameworks, technological tools, and/or strategies for implementing BIM-based fast-track construction in African countries. However, this study was limited to large-scale companies operating in several African countries, which does not represent all categories of companies composing the African AEC industry landscape and discussed only planning of the construction phase.

Therefore, further studies could be conducted to investigate these specific aspects.

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References

Alderton, M. (2021, October 20). Modular Hospitals: 3 Examples of Prefab COVID-19 Hospitals. *Redshift by Autodesk EN*. https://redshift.autodesk.com/modular-hospitals/

Arezki, R., Djankov, S., & Panizza, U. (2021). *Shaping Africa's Post-Covid Recovery*. Centre for Economic Policy Research (CEPR) and Financial Market Group (FMG).

CGTN. (2020a, February 6). *Time-lapse video shows how Leishenshan Hospital completed in 12 days*. https://www.youtube.com/watch?v=bEVkVdlNaxk

CGTN. (2020b, February 7). *Live: Updates on Wuhan's Leishenshan Hospital amid coronavirus outbreak*. https://news.cgtn.com/news/2020-02-06/Live-The-construction-of-Wuhan-s-Leishenshan-Hospital-NRHuyCspHO/index.html

Chen, L.-K., Yuan, R.-P., Ji, X.-J., Lu, X.-Y., Xiao, J., Tao, J.-B., Kang, X., Li, X., He, Z.-H., Quan, S., & Jiang, L.-Z. (2021). Modular composite building in urgent emergency engineering projects: A case study of accelerated design and construction of Wuhan Thunder God Mountain/Leishenshan hospital to COVID-19 pandemic. *Automation in Construction*, *124*, 103555. https://doi.org/10.1016/j.autcon.2021.103555

CSCEC Pakistan. (2020, February 12). *#Coronavirus Construction of #Leishenshan Hospital*. https://www.youtube.com/watch?app=desktop&v=WVJx0hlESXg+%2F

Elliott, R. (2020). *Study on the Economic Impact of COVID-19 in sub-Saharan Africa Demonstrates High Loss of Income and Usage of Digital Loans* (GeoPoll). Business Fights Poverty. https://businessfightspoverty.org/study-on-the-economic-impact-of-covid-19-in-sub-saharan-africa-demonstrates-high-loss-of-income-and-usage-of-digital-loans/

Fortune Business Insights. (2021). *Building Information Modeling (BIM) Market Size | Global Report, 2027* (Global Business No. FBI102986; p. 150). https://www.fortunebusinessinsights.com/building-information-modelling-software-market-102986

Ghanem, H. (2020). *Africa's Pulse: Assessing the economic impact of covid-19 and policy responses in Sub-Saharan Africa* (2021/052/AFR; Africa's Pulse, Volume 21, p. 136). The Office of the Chief Economist for the Africa Region (OCEAR), World Bank Group. https://reliefweb.int/report/angola/africas-pulse-april-2020-volume-21-assessing-economic-impact-covid-19-and-policy

Jeon, J., Padhye, S., Bhattacharyya, A., Cai, H., & Hastak, M. (2022). Impact of COVID-19 on the US Construction Industry as Revealed in the Purdue Index for Construction. *Journal of Management in Engineering*, *38*(1), 04021082. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000995

Jones, S. A., Laquisara-Carr, D., & Barnett, S. (2020). *Prefabrication and Modular Construction 2020* (SmartMarket Report, p. 68). DODGE Data & Analysis. https://www.construction.com/toolkit/reports/prefabrication-modular-construction-2020

Lalu, M., Tiong, I., & Shidqul, A. M. (2019). Application of Fast Track Method to Accelerate Project Implementation Time in the Hospital Construction. *International Journal of Scientific Engineering and Science*, *3*(11), 49–53.

Lin, C.-L., Chen, J. K. C., & Ho, H.-H. (2021). BIM for Smart Hospital Management during COVID-19 Using MCDM. *Sustainability*, *13*(11), 6181. https://doi.org/10.3390/su13116181

Lin, F., & Howell-Jones, M. (2020, August 7). Here's how smart construction could transform home-building after COVID-19. *World Economic Forum*. https://www.weforum.org/agenda/2020/08/here-s-how-smart-construction-could-transform-home-building-after-covid-19/

Luo, H., Liu, J., Li, C., Chen, K., & Zhang, M. (2020). Ultra-rapid delivery of specialty field hospitals to combat COVID-19: Lessons learned from the Leishenshan Hospital project in Wuhan. *Automation in Construction*, *119*, 103345. https://doi.org/10.1016/j.autcon.2020.103345

Meisels, M. (2020). *Explore digital transformation and business model trends, 2021 engineering and construction industry outlook* (p. 10). Deloitte Group.

Şahan, N. H. (2021, April 9). BIM and AI Integration In Combating Covid-19. *Surveying Group*. https://surveyinggroup.com/bim-and-ai-integration-in-combating-covid-19/

Schimanski, C. P., Pradhan, N. L., Chaltsev, D., Pasetti Monizza, G., & Matt, D. T. (2021). Integrating BIM with Lean Construction approach: Functional requirements and production management software. *Automation in Construction*, *132*, 103969. https://doi.org/10.1016/j.autcon.2021.103969

Wang, W., Gao, S., Mi, L., Xing, J., Shang, K., Qiao, Y., Fu, Y., Ni, G., & Xu, N. (2021). Exploring the adoption of BIM amidst the COVID-19 crisis in China. *Building Research & Information*, *49*(930–947), 1–18. https://doi.org/10.1080/09613218.2021.1921565

Yang, S., Fengyu, D., & Liangbo, M. H. (2020). Wuhan | Leishenshan Hospital, Digital Solutions for Pandemic Response. *Centre for Liveable Cities*, *18*, 6.

Zhou, M., Chen, Y., Su, X., & An, L. (2021). Rapid construction and advanced technology for a Covid-19 field hospital in Wuhan, China. *Proceedings of the Institution of Civil Engineers - Civil Engineering*, *174*(1), 29–34. https://doi.org/10.1680/jcien.20.00024

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Review of Building Renovation Materials for Structural and Non-Structural Components

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Building renovation materials and strategies have a significant impact on the safety, performance, comfortability, energy efficiency, sustainability, and cost of the building. In this paper, we investigated potential materials for retrofitting both structural and non-structural building components through a comprehensive literature review. The objective of this research is to support decisions for retrofitting building materials. Keywords for the literature review search from the databases include building retrofit, structural retrofit materials, cladding retrofit materials, building renovation. For structural building components, three main categories of renovation materials (the fiber-based, cementitious-based, and metal-based materials) and strategies are reviewed in terms of the mechanical properties and application under extreme loading conditions. Structural retrofitting materials have proven to alter the failure mode of structural members (e.g., from shear failure to flexural failure), increase ductility and energy dissipation capacity, and to improve earthquake and wind performance of the overall structural system. In the case of non-structural building components, we focus our review on renovation materials and strategies applied to building envelope systems. Since structural and non-structural components interact with one another, hybrid solutions including structural and energetic performance using lightweight materials should be considered for the renovation of building envelopes and structural systems.

Key Words: Building retrofit, Materials, Structural components, Non-structural components, Building envelopes

Introduction

Buildings are responsible for more than 40% of the energy use and for one-third of global greenhouse gas emissions (GHG) (Nielsen et al., 2016). Reinforcing and renovating buildings against earthquake damage, wind hazards, and explosive effect of blast is a techno-economic challenge (Raman et al., 2012). Researchers have investigated a broad range of construction materials to retrofit and strengthen building components with the goal of enhancing life-cycle performance and efficiency. Composite materials such as carbon/glass/aramid fibers integrated with polymer matrices are widely used in retrofitting and reinforcing structural components such as columns, beams and masonry walls (Täljsten, 1997). Other common structural retrofitting strategies include reinforced concrete jacketing, steel jacket, and steel plates bonding to retrofit reinforced concrete structures (Cheng et al., 2003;

Papanicolaou et al., 2011). At the same time, retrofitting practices of non-structural components that make up the building envelope are focused on enhancing performance measures related to the thermal comfort, energy efficiency and sustainability. In this respect, multidisciplinary approaches in material science, structural analysis, energy innovation, and wind and earthquake engineering should be applied in the building renovation field to seek a holistic performance of building operation. In this paper, we performed a comprehensive literature review to identify traditional and emerging building renovation materials applied to structural and non-structural building components. Advantages and drawbacks of different retrofitting materials and methods are summarized with the goal of supporting future building renovation decisions that consider both structural and non-structural building performance objectives for architectural/engineering/construction community.

Research Methodology

Literature review methods used in this paper included database searches using keywords such as building retrofit, structural retrofit materials, cladding retrofit materials, building renovation. More specific keywords were used to find studies focusing on specific materials or renovation strategies (e.g., fiber-reinforced polymers, shape memory alloys, steel jacketing, etc.). Independent literature searches were conducted to review building retrofit materials for structural and non-structural components. Databases used for the literature review included Google Scholars, Web of Science, and Engineering Village. Additional keywords used in our literature review were discovered by creating a visual network of the top 92 keywords found in studies related to building renovation materials. The network was developed by searching for articles in the Web of Science database that contained the words “building(s)”, “renovation, retrofitting, or rehabilitation”, and “material(s)” in their title, abstract, and author keywords. A total of 1,846 articles were found after limiting (filtering) the search to studies published between 1970-2022. The cluster colors in Figure 1 indicate the strong linkage of words within that cluster. Keywords in the green and blue clusters are associated with structural retrofitting strategies, particularly for reinforced concrete members (e.g., beams, columns, connections, etc.), while the red cluster include keywords related to building envelope performance measures (e.g., thermal insulation, energy efficiency, temperature). Further, the blue cluster suggests that the bulk of structural retrofitting studies have focused on mitigating damage in seismic events.

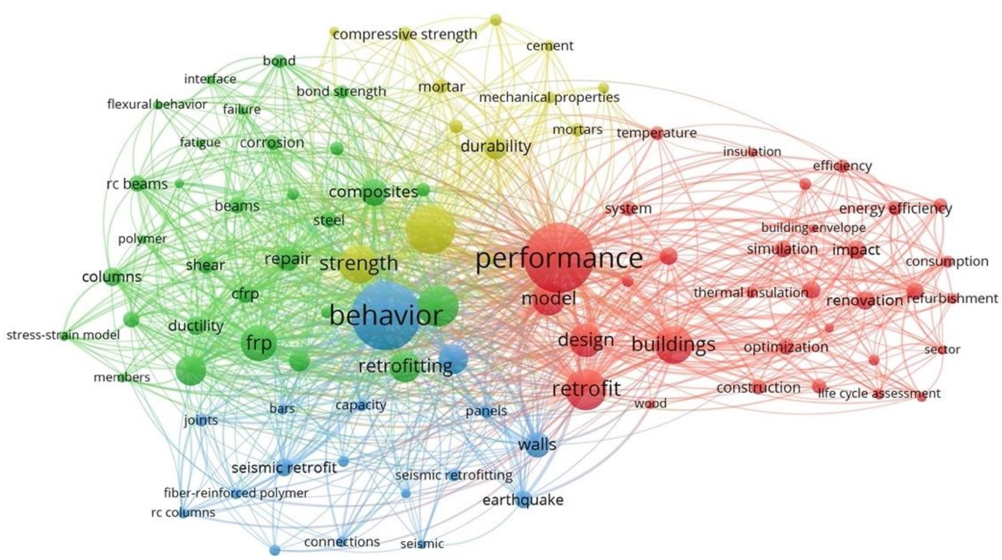

Figure 1. Network of keywords from Web of Science search on building renovation materials.

Building Retrofitting Materials

Structural Components

Modern approach for designing structural building components combines various materials to leverage their unique properties such as mechanical behavior, physical and chemical properties, durability, time-dependent and load-dependent behavior, all the way to the optimized performance of the holistic structure system (Rousakis, 2013). Modern retrofit design codes give recommendations of advanced retrofit materials used for different types of buildings such as the reinforced concrete structures, steel structures, composite structures, and masonry structures (Code, 2010). The following subsections offer a brief review of traditional and recently developed methods and materials used for retrofitting structural building components. Structural renovation materials include: high-performance cement-based materials, fiber-reinforced polymers, shape-memory alloys, and textile-reinforced mortars in the following sections.

Fiber-based Reinforcement Materials

Fiber-based reinforcement materials consist of organic and inorganic fibers. The nonmetallic reinforcing fibers embedded in a polymer matrix are called fiber-reinforced polymers (FRPs). FRP retrofit materials are light, durable and have high strength-to-weight ratios, resulting in economic and technical efficiency compared to traditional techniques. Fibers have high strength and high elastic modulus to transfer loads in the polymer. The matrix has low strength and low elastic modulus, which provide the protection for the fibers from the abrasion and aggressive conditions. Common fibers applied in structural retrofit and strengthening include carbon, glass, aramid, inorganic basalt, polyphenylene benzobisoxazole (PBO), polyethylene naphthalate (PEN), polyethylene terephthalate (PET), thermoplastic fibers including ultrahigh-molecular-weight (UHMW) polyethylene and polyvinyl alcohol (PVA) (Taerwe & Matthys, 2013). Carbon FRP (CFRP), glass FRP (GFRP), aramid FPR, and aramid/glass (A/G) hybrid are commonly used in strengthening structures against blast loads (Raman et al., 2012). Carbon fiber is widely used for the retrofit of the reinforced concrete structure. Its effectiveness lies in the light weight with high strength and good durability. Researchers developed new techniques using carbon fiber to solve for the insufficiency seismic capacity (Billah & Alam, 2014). The smallest unit of carbon fiber is monofilament with the radius 5-15 μm. The practical smallest unit is called strand consisting of 1,000-12,000 monofilaments (Tanaka et al., 1994). The elastic modulus of carbon fiber is similar to the steel while the strength is approximately 10 times that of steel. Glass fiber has high electrical resistance in the structural retrofit and strengthening. Among the common glass fibers, S-glass is stronger and stiffer than E-glass. Aramid fiber, shows good resistance to abrasion, organic solvents, and heat and high elastic modulus. According to the blast experiments on RC walls, A/G hybrid performed better in terms of reducing the residual displacements than CFRP (Muszynski & Purcell, 2003). FRP strengthening materials such as CFRP and E-glass enhanced the performance of RC panels in the ultimate resistance and structural behavior compared to ordinary RC panels (Tolba, 2002). Researchers also investigated that FRP sandwich scheme worked better than single-sided FRP in providing further protection and resisting effects from second explosion (Tanapornraweekit et al., 2010). Elastomeric polymer coating, such as spray-on polyurea-based lines (Knox et al., 2000) was suggested to retrofit the concrete block walls and temporary lightweight buildings by preventing fragmentation from lightweight structural components. Externally bonded grids are applied to retrofit the unreinforced masonry structures. The grids used for the open mesh structures include carbon, glass and basalt fibers and polypropylene or polyester. The bonding agents include mortars of different compositions of epoxy resin (Papanicolaou et al., 2011). Most the FRPs show linear elastic behavior before failure, while PET and PEN show bilinear behavior (Rousakis, 2013). FRP reinforcement completely changed the failure mode of the structures (Colomb et al., 2008). Experimental studies show that the FRPs could (i) change the failure mode from brittle shear failure to bending failure with remarkable ductility capacity (Priestley & Seible, 1995); (ii) increase the maximum load and final displacement; (iii) enhance the lap-splice performance and shear strength; (iv) improve the earthquake resistance capacity.

Cementitious-based Retrofit Materials

The widely used cementitious-based retrofit materials include cast-in-place ordinary concrete, shotcrete or gunite, self-consolidate concrete and fiber-enriched or polymetric mortars (Rousakis, 2013). The materials work as the matrix for reinforcements to retrofit and strengthen the structures or to repair the damaged concrete members. The cementitious-based materials are applied for performance-based solutions. Concrete is a composite heterogenous materials, which consists of cement, sand, gravel and water. The mechanical performance in macroscale level depends on the mechanical properties in microscale level. Microcracks happen at the interface between mortar and gravels even before the loading due to shrinkage, segregation, and thermal expansion in the mortar. The microcracks propagate during the loading from the different stiffness between aggregates and mortar. The crack propagation results in the low tensile strength and the nonlinear behavior of the concrete under loading. Various fiber-reinforced cementitious materials have been developed and applied in structural component retrofit to improve the tensile performance of concrete. These materials include: Ultrahigh-strength fiber-reinforced concrete (UHPFRC), fiber-reinforced cementitious composites (FRCCs). FRCCs have two types: strain-hardening cementitious composite (SHCC) and high-performance fiber-reinforced cement composite (HPFRCC). The high-ductility fiber reinforced cementitious-based materials increase the lateral load-carrying and deformation capacities by replacing the concrete core of the column under seismic loading. The retrofitted structural members such as the concrete columns have better performance in the zone of plastic hinge with better controlled concentrated local damage (Cho et al., 2012).

Metal-based Retrofit Materials

Steel Jacketing. Structural steel has been the primary metal-based material for strengthening existing structural building components, particularly column members and beam-column joints of reinforced concrete frames (Rodriguez & Park, 1991; Wu et al., 2003). The most common structural retrofitting technique is steel jacketing of reinforced concrete columns, where the original structural member is confined in a cage composed of steel angle and plate (or batten) elements (Di Trapani et al., 2021). In contrast to other structural retrofitting approaches (e.g., FRP and concrete jacketing), studies on steel jacketing have shown increased structural performance such as superior shear strength, greater deformation capacity, and enhanced overall ductility of the structural framing system (Villar-Salinas et al., 2021). In particular, steel jacketing is considered to be one of the most efficient methods for increasing ductility of damaged concrete columns (Xiao & Wu, 2003), which makes this approach an attractive alternative for seismic retrofitting. Despite the proven effectiveness of different steel jacketing approaches, some limitations have been documented regarding their reliability when compared to other jacketing materials (e.g., FRP and concrete jackets). For example, minimal enhancement in flexural strength and stiffness has been reported for RC columns with square or rectangular cross-sections, consequently limiting the effectiveness of the method for increasing the deformability of the structural element (Ma et al., 2017). An added disadvantage of steel jacketing is the possibility of premature failure due to debonding and/or peeling of the steel plates along the column-angle contact interface (Campione et al., 2017). Steel plates attached mechanically using anchor bolts may be one alternative to overcome failures associated with debonding, although local buckling of the steel plate under axial or eccentric compression may warrant consideration (Xu et al., 2017).

Shape Memory Alloys. In recent decades, several research studies have explored the suitability of shape memory alloys (SMAs) as a retrofitting material for building structures (Zareie et al., 2020; Zulkifli et al., 2020) given its unique thermomechanical properties. The crystalline structure of SMAs is characterized by two distinct phases (or states), namely martensite or austenite state. The transition from the martensite phase to the austenite phase (upon cooling) is solely dependent on temperature and stress. At lower temperatures (martensite state), SMAs can easily be deformed into any shape. Alternatively, when a SMA is heated, it returns to its pre-deformed (remembered) shape. Further, SMAs can exhibit pseodoelastic behavior (also termed "superelasticy") in which the material can sustain large recoverable strains with little to no permanent deformation. High fatigue strength during inelastic cyclic loading and relatively good resistance to corrosive agents are other attractive characteristics of SMAs for civil engineering applications, particularly for seismic retrofitting of structures (Hojatirad & Naderpour, 2021). The two most widely used SMAs are copper-aluminum-nickel and nickel-titanium (NiTi), but SMAs can also be generated by alloying zinc, copper, gold and iron. SMAs have proven effective when used as passive structural control devices in buildings to dissipate (dampen) vibration energy induced by extreme loading (Zareie et al., 2020). Specifically, steel braces equipped with martensite or austenite SMA elements have been tested and integrated into lateral load resisting systems of multi-story frames to enhance energy dissipation under seismic loads (Gao et al., 2016; Speicher et al., 2017; Qiu et al., 2020). SMAs have also been successfully applied to other structural components such as RC and masonry walls (Rezapour et al., 2021) and RC T-beams (Cladera et al., 2020) and beam-column joints (Hojatirad & Naderpour, 2021).

Non-Structural Components

Among diverse building retrofit such as roof, façade, HVAC, etc. (Li & Chen, 2020) building envelope is one of significant elements in renovation process in terms of it impacts the appearance (Tovarović et al., 2017), external surface temperature (Cronhjort, 2011), and building energy consumption (Chang et al., 2020). Multiple objectives such as cost, energy, comfort, and CO_2 emissions have been considered to provide adequate building envelope retrofit options (Chang et al., 2020). To increase energy efficiency of existing buildings, double skin façade (DSF) (Gelesz & Reith, 2015), double and triple glazed low-e glass (Eskin & Türkmen, 2008), biomass façade (Chang et al., 2017), laminated glass integrated with LED technology, installation of the brise soleil solar shading system (Tovarović et al., 2017), and integration of photovoltaic modules (Chang et al., 2021; Quan et al., 2015) have been studied. However, wind performance of building envelopes has often been overlooked so that inadequate design attention has limited wind resistance (Smith, 2017). As a result, windborne facade debris that can easily penetrate wall coverings has threatened indoor environment quality as well as outdoor pedestrian's safety. Damage to non-structural components causes economic losses as well as threats to life safety (Sousa & Monteiro, 2018).

Non-load bearing walls (non-structural envelope components) should be able to resist the positive and negative wind loads for screening rain / water by equalizing pressure and avoiding windborne envelope debris. Most of the cladding damage was caused by lack of hurricane-resistant construction, resulting in poor connections between cladding components and the main structural system (either by design or loss of strength due to corrosion) (Kareem, 1986). In high-wind areas, for exterior fenestration, laminated glazing that is bonding layers of float glass with plasticized polyvinyl butyral (PVB resin or polycarbonate (PC) resin can withstand high pressure (Spence & Kultermann, 2016). Laminated glass, composed by glass plies, can be used for structural purposes because it will attach to the interlayer even after the glass breaks and provide a residual load-bearing capacity (D'Ambrosio et al., 2019). Thus, the retrofit option of laminated glass will transform the use of glass being both non-structural and structural applications while providing transparent envelopes (Machado-e-Costa et al., 2016) have been studied. For retrofitting exterior opaque envelopes, a variety of materials have been studied for building renovation including Vacuum insulation panels (VIPs), Trombe walls, Phase Change Materials (PCM), etc. (Chang, 2020). For example, wood materials were considered as substitution of carbon-intensive materials based on life cycle carbon balance (Piccardo et al., 2020). Vacuum insulation panels (VIPs) with fiber felt/silica aerogel composite cores, one of energy efficient insulation materials, were studied to improve the thermal performance and the service life over 50 years (Liang et al., 2017). VIPs consist of inner core, multilayer envelopes, and getters and desiccants (Alam et al., 2011). The multilayer envelope can be either thick metal sheets or lighter multilayered metalized polymer file for protecting environmental and handling stresses (Alam et al., 2011). Trombe wall systems can reduce heating energy load by utilizing solar radiation but need additional insulation for summer to prevent undesirable overheating (Jaber & Ajib, 2011). In addition, phase change materials (PCM) can be applied to both the glass curtain wall system (Park et al., 2019) and the opaque envelope (Cascone et al., 2018) as a passive retrofit strategy for saving energy by utilizing optimal thermophysical properties in given weather conditions. Unreinforced brick masonry walls, one of non-structural retrofitting materials, have also been analyzed for achieving seismic performance and cost benefits (Sousa & Monteiro, 2018).

Meanwhile, extensive studies have found that exterior non-structural wall coverings not only directly interact with the structural system (Sousa & Monteiro, 2018) but also are vulnerable to damages under external loads such as wind and earthquake, etc. (Cardone et al., 2019). Therefore, to achieve sustainability including environment, economy, and society (in this research, the bearability under multiple wind hazards), a hybrid structural-plus-energy retrofitting solution based on innovative lightweight materials (Bournas, 2018) should be reviewed and applied for both wind load resistance and energy efficiency. In this respect, new composite materials such as cotton/polyester blend, SEBS (styrene–ethylene–butylene–styrene) -Biotex, PTFE (polytetrafluoroethylene)-fiber glass fabric, and SEBS-carbon fiber fabric have proposed to increase economic and environmental sustainability while enabling a lightweight load-bearing feature (Rodonò et al., 2019).

Conclusion

Building renovation materials play a significant role in the overall performance of building systems. A holistic assessment to identify the best building renovation practices requires a multidisciplinary approach that combines both structural and non-structural performance objectives related with structural safety, thermal comfort, energy efficiency and cost. In this study, we reviewed recent advances in building renovation materials and strategies for both structural and non-structural components, independently. In the renovation of structural components, different building materials (e.g., fiber-based polymers, cement-based, SMAs) and retrofitting techniques have proven effective in enhancing structural performance under to extreme loading conditions. However, the literature review indicates that the bulk of these approaches centered around seismic events and research on structural retrofitting strategies for other types of natural hazards (e.g., windstorms) is currently scarce (or absent) in literature. Conversely, renovation methods for non-structural components that make up the building envelope must provide adequate strength to resist extreme wind pressures that act on the exterior building façade. Additionally, the prevention of water intrusion from wind-driven rain is also a critical factor when assessing and improving building envelope performance. It is noted that both structural and non-structural components are integrated within building systems and their performance measures are distinctively different from one another. Therefore, multi-objective strategies should be implemented to clearly map competing objectives between both components when seeking the most adequate retrofitting material and approach.

References

Alam, M., Singh, H., & Limbachiya, M. C. (2011). Vacuum Insulation Panels (VIPs) for building construction industry–A review of the contemporary developments and future directions. *Applied Energy*, *88*(11), 3592–3602.

Billah, A. M., & Alam, M. S. (2014). Seismic performance evaluation of multi-column bridge bents retrofitted with different alternatives using incremental dynamic analysis. *Engineering Structures*, *62*, 105–117.

Bournas, D. (2018). Innovative materials for seismic and energy retrofitting of the existing EU buildings. *Publications Office of the European Union: Luxembourg*.

Campione, G., Cavaleri, L., Di Trapani, F., & Ferrotto, M. F. (2017). Frictional effects in structural behavior of no-end-connected steel-jacketed RC columns: Experimental results and new approaches to model numerical and analytical response. *Journal of Structural Engineering*, *143*(8), 04017070.

Cardone, D., Gesualdi, G., & Perrone, G. (2019). Cost-benefit analysis of alternative retrofit strategies for RC frame buildings. *Journal of Earthquake Engineering*, *23*(2), 208–241.

Cascone, Y., Capozzoli, A., & Perino, M. (2018). Optimisation analysis of PCM-enhanced opaque building envelope components for the energy retrofitting of office buildings in Mediterranean climates. *Applied Energy*, *211*, 929–953.

Chang, S. (2020). *DECISION SUPPORT FRAMEWORK FOR TRANSFORMING URBAN BUILDINGS AT MULTIPLE SCALES*. Georgia Institute of Technology.

Chang, S., Castro-Lacouture, D., Dutt, F., & Yang, P. P.-J. (2017). Framework for evaluating and optimizing algae façades using closed-loop simulation analysis integrated with BIM. *Energy Procedia*, *143*, 237–244.

Chang, S., Castro-Lacouture, D., & Yamagata, Y. (2020). Decision support for retrofitting building envelopes using multi-objective optimization under uncertainties. *Journal of Building Engineering*, *32*, 101413.

Chang, S., Yoshida, T., Castro-Lacouture, D., & Yamagata, Y. (2021). Block-Level Building Transformation Strategies for Energy Efficiency, Thermal Comfort, and Visibility Using Bayesian Multilevel Modeling. *Journal of Architectural Engineering*, *27*(3), 05021008.

Cheng, C.-T., Yang, J.-C., Yeh, Y.-K., & Chen, S.-E. (2003). Seismic performance of repaired hollow-bridge piers. *Construction and Building Materials*, *17*(5), 339–351.

Cho, C.-G., Kim, Y.-Y., Feo, L., & Hui, D. (2012). Cyclic responses of reinforced concrete composite columns strengthened in the plastic hinge region by HPFRC mortar. *Composite Structures*, *94*(7), 2246–2253.

Cladera, A., Montoya-Coronado, L. A., Ruiz-Pinilla, J. G., & Ribas, C. (2020). Shear strengthening of slender reinforced concrete T-shaped beams using iron-based shape memory alloy strips. *Engineering Structures*, *221*, 111018.

Code, P. (2010). Eurocode 8: Design of structures for earthquake resistance—Part 3: Assessment and retrofitting of buildings. *Incorporating Corrigendum March*.

Colomb, F., Tobbi, H., Ferrier, E., & Hamelin, P. (2008). Seismic retrofit of reinforced concrete short columns by CFRP materials. *Composite Structures*, *82*(4), 475–487.

Cronhjort, Y. (2011). Improving the energy efficiency of our built environment through retrofitting and urban infill: TES EnergyFacade in the Finnish context. *SB 2011 HELSINKI. World Sustainable Building Conference October 18-21, 2011*, 110–111.

D'Ambrosio, G., Galuppi, L., & Royer-Carfagni, G. (2019). A simple model for the post-breakage response of laminated glass under in-plane loading. *Composite Structures*, *230*, 111426.

Di Trapani, F., Sberna, A. P., & Marano, G. C. (2021). A new genetic algorithm-based framework for optimized design of steel-jacketing retrofitting in shear-critical and ductility-critical RC frame structures. *Engineering Structures*, *243*, 112684.

Eskin, N., & Türkmen, H. (2008). Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey. *Energy and Buildings*, *40*(5), 763–773.

Gao, N., Jeon, J.-S., Hodgson, D. E., & DesRoches, R. (2016). An innovative seismic bracing system based on a superelastic shape memory alloy ring. *Smart Materials and Structures*, *25*(5), 055030.

Gelesz, A., & Reith, A. (2015). Climate-based performance evaluation of double skin facades by building energy modelling in Central Europe. *Energy Procedia*, *78*, 555–560.

Hojatirad, A., & Naderpour, H. (2021). Seismic assessment of RC structures having shape memory alloys rebar and strengthened using CFRP sheets in terms of fragility curves. *Bulletin of Earthquake Engineering*, 1–26.

Jaber, S., & Ajib, S. (2011). Optimum design of Trombe wall system in mediterranean region. *Solar Energy*, *85*(9), 1891–1898.

Knox, K. J., Hammons, M. I., Lewis, T. T., & Porter, J. R. (2000). Polymer materials for structural retrofit. *Force Protection Branch, Air Expeditionary Forces Technology Division, Air Force Research Laboratory, Tyndall AFB, Florida*.

Li, Y., & Chen, L. (2020). A study on database of modular façade retrofitting building envelope. *Energy and Buildings*, *214*, 109826.

Liang, Y., Wu, H., Huang, G., Yang, J., & Wang, H. (2017). Thermal performance and service life of vacuum insulation panels with aerogel composite cores. *Energy and Buildings*, *154*, 606–617.

Ma, C.-K., Apandi, N. M., Sofrie, C. S. Y., Ng, J. H., Lo, W. H., Awang, A. Z., & Omar, W. (2017). Repair and rehabilitation of concrete structures using confinement: A review. *Construction and Building Materials*, *133*, 502–515.

Machado-e-Costa, M., Valarinho, L., Silvestre, N., & Correia, J. R. (2016). Modeling of the structural behavior of multilayer laminated glass beams: Flexural and torsional stiffness and lateral-torsional buckling. *Engineering Structures*, *128*, 265–282.

Muszynski, L. C., & Purcell, M. R. (2003). Use of composite reinforcement to strengthen concrete and air-entrained concrete masonry walls against air blast. *Journal of Composites for Construction*, *7*(2), 98–108.

Nielsen, A. N., Jensen, R. L., Larsen, T. S., & Nissen, S. B. (2016). Early stage decision support for sustainable building renovation–A review. *Building and Environment*, *103*, 165–181.

Papanicolaou, C., Triantafillou, T., & Lekka, M. (2011). Externally bonded grids as strengthening and seismic retrofitting materials of masonry panels. *Construction and Building Materials*, *25*(2), 504–514.

Park, J. H., Jeon, J., Lee, J., Wi, S., Yun, B. Y., & Kim, S. (2019). Comparative analysis of the PCM application according to the building type as retrofit system. *Building and Environment*, *151*, 291–302.

Piccardo, C., Dodoo, A., & Gustavsson, L. (2020). Retrofitting a building to passive house level: A life cycle carbon balance. *Energy and Buildings*, *223*, 110135.

Priestley, M. J. N., & Seible, F. (1995). Design of seismic retrofit measures for concrete and masonry structures. *Construction and Building Materials*, *9*(6), 365–377.

Qiu, C., Fang, C., Liang, D., Du, X., & Yam, M. C. (2020). Behavior and application of self-centering dampers equipped with buckling-restrained SMA bars. *Smart Materials and Structures*, *29*(3), 035009.

Quan, S. J., Li, Q., Augenbroe, G., Brown, J., & Yang, P. P.-J. (2015). A GIS-based energy balance modeling system for urban solar buildings. *Energy Procedia*, *75*, 2946–2952.

Raman, S. N., Ngo, T., Mendis, P., & Pham, T. (2012). Elastomeric polymers for retrofitting of reinforced concrete structures against the explosive effects of blast. *Advances in Materials Science and Engineering*, *2012*.

Rezapour, M., Ghassemieh, M., Motavalli, M., & Shahverdi, M. (2021). Numerical Modeling of Unreinforced Masonry Walls Strengthened with Fe-Based Shape Memory Alloy Strips. *Materials*, *14*(11), 2961.

Rodonò, G., Sapienza, V., Recca, G., & Carbone, D. C. (2019). A Novel Composite Material for Foldable Building Envelopes. *Sustainability*, *11*(17), 4684.

Rodriguez, M., & Park, R. (1991). Repair and strengthening of reinforced concrete buildings for seismic resistance. *Earthquake Spectra*, *7*(3), 439–459.

Rousakis, T. (2013). Retrofitting and strengthening of contemporary structures: Materials used. *Encyclopedia of Earthquake Engineering: Chapter; Beer, M., Patelli, E., Kougioumtzoglou, I., Au, I., Eds*.

Smith, T. (2010). Wind safety of the building envelope. *Whole Building Design Guide (WBDG)*.

Sousa, L., & Monteiro, R. (2018). Seismic retrofit options for non-structural building partition walls: Impact on loss estimation and cost-benefit analysis. *Engineering Structures*, *161*, 8–27.

Speicher, M. S., DesRoches, R., & Leon, R. T. (2017). Investigation of an articulated quadrilateral bracing system utilizing shape memory alloys. *Journal of Constructional Steel Research*, *130*, 65–78.

Spence, W. P., & Kultermann, E. (2016). *Construction materials, methods and techniques*. Cengage Learning.

Taerwe, L., & Matthys, S. (2013). *Fib model code for concrete structures 2010*. Ernst & Sohn, Wiley.

Täljsten, B. (1997). Strengthening of beams by plate bonding. *Journal of Materials in Civil Engineering*, *9*(4), 206–212.

Tanaka, T., Yagi, K., Kojima, N., Kimura, K., & Katsumata, H. (1994). Retrofit method with carbon fiber for reinforced concrete structures. *Advanced Composite Materials*, *4*(1), 73–85.

Tanapornraweekit, G., Haritos, N., Mendis, P., & Ngo, T. (2010). Finite element simulation of FRP strengthened reinforced concrete slabs under two independent air blasts. *International Journal of Protective Structures*, *1*(4), 469–488.

Tolba, A. F. F. (2002). *Response of FRP-retrofitted reinforced concrete panels to blast loading*. Carleton University.

Tovarović, J. Č., Ivanović-Šekularac, J., & Šekularac, N. (2017). Renovation of existing glass facade in order to implement energy efficiency and media facade. *Energy and Buildings*, *152*, 653–666.

Villar-Salinas, S., Guzmán, A., & Carrillo, J. (2021). Performance evaluation of structures with reinforced concrete columns retrofitted with steel jacketing. *Journal of Building Engineering*, *33*, 101510.

Wu, Y. F., Griffith, M. C., & Oehlers, D. J. (2003). Improving the strength and ductility of rectangular reinforced concrete columns through composite partial interaction: Tests. *Journal of Structural Engineering*, *129*(9), 1183–1190.

Xiao, Y., & Wu, H. (2003). Retrofit of reinforced concrete columns using partially stiffened steel jackets. *Journal of Structural Engineering*, *129*(6), 725–732.

Xu, X., Lu, Z., Li, L., & Jiang, C. (2017). Numerical study on the local buckling behaviour of bolted steel plates in steel jacketing. *Advances in Materials Science and Engineering*, *2017*.

Zareie, S., Issa, A. S., Seethaler, R. J., & Zabihollah, A. (2020). Recent advances in the applications of shape memory alloys in civil infrastructures: A review. *Structures*, *27*, 1535–1550.

Zulkifli, S. N. I., Hisbany, M. M., Ismail, R., Zakwan, F. A. A., Hazrina, A., Ismail, B. N., & Rashid, R. S. M. (2020). Application of shape memory alloys (SMA) as a retrofit and strengthening component on reinforced concrete columns. *Journal of Physics: Conference Series*, *1529*(4), 042104.

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Benefits of Multicultural Project Team Setting: Views of Professionals in the Ghanaian Construction Industry

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The management of culturally diversified team can most often create exasperating management quandaries. However, studies indicate that multicultural project team settings have the potential to achieve higher productivity than homogenous team. Hence, this study is conducted to explore the benefits of multicultural project team settings using the views of professionals in the Ghanaian Construction industry. The study adopted a data reduction technique to examine the benefits of multicultural project team setting. The data was subjected to principal component analysis after passing all of the requisite tests of survey instrument reliability, sample size adequacy, and population matrix, resulting in the identification of three thematic multicultural project team setting benefits. The findings of the study reveal that the three key benefits of multicultural project team setting are promotion of personal and professional growth, provides a strong competitive advantage and an avenue for effective decision-making. The findings of this study are intended to help organisations in managing multicultural team settings in bringing out the best in terms of increased organisational performance. The findings of this study will serve as an important document for the management of multicultural project teams.

Key words: Multicultural, Project Team, Identity

Introduction

Cultural diversity in recent years has the tendency of outperforming homogeneous groups on tasks which involves a variety of viewpoints especially in the construction industry (Tung, 2008). In recent years, there has been a realization that multicultural team setting is very significant in construction project management. Nam et al. (2009) described a multicultural team as a group inhabited by people from diverse cultures working together on activities or projects. Many benefits of cultural diversity in a team have gone unnoticed, such as the breadth of backgrounds, talents, and personal qualities that multicultural team members bring to an organisation (Alemu, 2016). In brainstorming exercises, ethnically diverse participants produce more high-quality ideas (Zander & Butler, 2010). The merits of such multicultural engagements are numerous, and the industry must possess the capabilities to acqui[1]re and maintain them to promote organisational benefits (Gibbs & Boyraz, 2015). Mockaitis et al. (2018) further backed this study by stipulating that the many strengths of multicultural teams integrate specialized competence in understanding the local [2]needs and demands and again serve as a grip among team members. Studies by Gilson et al. (2015) also stated that the use of multicultural groups will promote more flexible and innovation-oriented organisations. For any organisation in every field, culture and cultural differences are critical issues. Previous research from (Di Marco & Taylor, 2011) suggest that cultural boundary-spanned networks might initially outperform multicultural project networks due to improvements in effective collaboration. A multicultural team creates a mental view which in turn addresses the ways that people are unique to each other and the ways they share identity with others. Green & Mathieson (2016) indicate that due to the different cultures in organisational workforce, there is the need for researchers to direct their attention to examining multicultural team setting and its benefits. Previous studies focused mainly on effective leadership styles required to manage multicultural teams and how to overcome problems related to multicultural teams including misunderstandings and miscommunications (Lisak & Erez, 2015). Ochieng & Price (2010) stated that there is more significance on the engagement of multicultural teams and as such the benefits of multicultural team setting need to be explored to encourage the use of multicultural project team settings. Limited research works have been conducted on the benefits of multicultural project team setting in the construction industry, most especially in developing world, such as Ghana. However, much of the extant literature on cross-cultural collaborations suggests that researchers focus on the barriers and conflicts associated with cultural differences as opposed to the business opportunities (Mahalingam & Levitt, 2007). Therefore, this study explores the benefits of multicultural project team settings.

Overview of Multiculturalism

Since the issue of how people build a sense of belonging to a national, cultural, ethnic, or racial group becomes particularly important in situations of cultural clashing, mixing, and integration, the study of multiculturalism has exciting and transformative implications for social and personality psychology (Deaux et al., 2006). Furthermore, personality psychologists may research individual differences in identity and self-concept through the individual and contextual factors that affect how an individual makes sense of his or her multicultural experiences. Multicultural individuals provide researchers with a quasi-experimental design suitable for studying how culture influences behavior since they have two or more cultures that can be independently manipulated (Ochieng & Price, 2009). The degree to which a workgroup or organisation is heterogeneous in terms of personal and functional characteristics is a common concept of diversity. Extant literature on organisational diversity has produced inconsistent results on effects of diversity, with some researchers finding beneficial effects, such as increased creativity, productivity, and quality (Signorini *et al*., 2009). Previous research has focused on how people use social categorizations based on ethnic differences to make sense of their disparate worlds, putting social stability and integration at risk. It is true that creating a positive diverse work climate is difficult, but businesses should not have to be at the mercy of shifts in the workforce's demographic makeup or the tension that often follows these shifts. Organisations should take the lead by developing an atmosphere conducive to accepting and cultivating the advantages of such diversity, beginning with the introduction and eventual institutionalization of best practices that focus on the self-affirmation and inclusion of all individuals, in accordance with a strength-based approach. An all-inclusive work environment promotes individual thriving as a sense of progress in one's self development and personal growth (Spreitzer *et al*., 2005).

Benefits of Multicultural Team Setting

A number of studies have been published that highlight the benefits and drawbacks of multicultural teams. Studies on the construction industry's culture, the connection between culture and project performance, and the impact of culture and national cultural differences on construction are becoming increasingly popular (Kivrak et al., 2009). Previous research and experience in the construction industry have shown that cultural differences have a negative or positive impact on the daily operations of construction firms operating nationally or internationally (Misoc, 2017). Stahl et al. (2010) looked at how cultural differences affect project performance. According to the findings, cultural differences between partner organisations had a significant impact on project performance. Multiple viewpoints, diverse backgrounds, various problem-solving and decision-making styles, and smart ideas prevail in multicultural teams, according to Kirkman and Shapiro (2005). Rahman (2008) indicates that multicultural teams do better than homogeneous teams in finding out problems and solving them. Similarly, Nam et al. (2009) indicate that multicultural teams create the avenue for firms to make necessary gains in productivity. Misoc (2017) indicates an instance where, a multicultural financial firm reports higher levels of financial profitability than their culturally homogeneous counterparts. A multicultural team exhibits various benefits such as: skills and personal attributes and different perspectives. Multicultural teams are characterized with more ideas of higher quality in brainstorming work (Stephens et al., 2008). Trust among team members in a multicultural team setting generates understanding in the group and the result improves and facilitates team efficiency (Stahl et al., 2010). Matheson & Petersen (2020) indicate that differences in ethics of diverse cultural team members give lesser dangers in decisions.

The global market climate necessitates a high level of technical experience as well as cultural diversity awareness. Organisational scholars who understand the diversity of the workforce are continually examining multicultural work teams (Misoc, 2017). Stahl et al. (2010) stated that workforce diversity can improve team performance, and hence advance organisational efficiency and effectiveness. The breadth of experiences, talents, and personal qualities that multicultural team members bring to an organisation are only a few of the advantages of cultural diversity in a team. In brainstorming tasks, Ochieng & Price (2010) found that culturally diverse groups produce more high-quality ideas. According to Signorini et al. (2009) culturally diverse teams outperform homogeneous teams at identifying problems and generating solutions. The creation of an emergent team culture is aided by interaction among multicultural team members. As mutual member values foster collaboration and team success, a successful multicultural team has a strong emergent culture. According to Matheson & Petersen (2020) the positive effect and trust generated by the perceived shared understanding brings about performance improvement and boosts team efficacy.

Research Methodology

An extensive literature review was conducted to first identify the relevant benefits of multicultural project team setting. Afterwards, the variables were subjected to pre-assessment and pre-testing processes. The pre-assessment was used as a preliminary content validation where professionals who have involved in multicultural project teams assessed the various benefits of multicultural project team setting and determined whether the variables represent what the study set out to measure. Five Project Managers in the construction industry with considerable experience in multicultural project teams were involved in the pre-assessment of the questionnaire. The respondents were asked to comment on the variables, add more variables that seemed appropriate and rate their potential for inclusion in the study. The benefits of multicultural project team setting were considered for inclusion in the study if at least three of the experts agreed. After conferring with these experts, fifteen benefits of multicultural project team setting (see Table 1) were proposed. A structured questionnaire was then developed based on the proposed benefits of multicultural project team setting and distributed to the experts. Each variable was scored based on a five-point Likert scale from 1 for strongly disagree to 5 for strongly agree.

Due to the difficulty in accessing a sampling frame and also obtaining responses from various construction professionals who have involved in multicultural project teams, the study adopted a snowballing non-probability sampling technique. Initially, respondents were selected based on their involvement in multicultural project teams, subsequently, referrals to other interested (and similarly knowledgeable) professionals from these initial respondents was adopted to subsequently grow the sample frame. The sample size for the study was 200 construction professionals who have involved in multicultural project teams and data was gathered in person over the course of three months through a face-to-face survey. The 200 survey questionnaires distributed resulted in a 75% response rate, which was considered acceptable for the study.

There was a diverse group of people who took part in the survey, including 72 Project Managers representing 48%, 48 Quantity Surveyors representing 32%, 12 Structural Engineers representing 8%, and 18 Architects representing 12% of the respondents. Majority of the respondents worked in consulting firms (64%), whiles (36%) worked in construction firms.

The Cronbach's Alpha Coefficient test was conducted to check the reliability of the scale and internal consistency of the variables. Preliminary tests were performed to ascertain the suitability of the data for the factor analysis process. These included Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity.

Results and Discussions

The benefits of multicultural project team setting were analyzed using relative importance index to find the contribution a particular variable makes to the prediction of a criterion variable both by itself and in combination with other predictor variables and exploratory factor analysis to simplify complex and diverse relationships that exist among a set of observed variables by discovering the common factors that link that seemingly unrelated variables and providing an understanding of the underlying factors of the dataset.

Table 1
RII ranking of the benefits of multicultural project team setting

Code	Benefits	RII	Standard Deviation	Rank
B1	Different decision-making styles and smart ideas prevail in multicultural teams	0.967	.455	*1st*
B2	Different problem-solving approaches exist in multicultural teams	0.933	.702	*2nd*
B3	It gives learning opportunity and knowledge sharing	0.913	.763	*3rd*
B4	Work force diversity advances organisational efficiency and effectiveness	0.867	.872	*4th*
B5	Formation of an emergent team culture	0.847	.886	*5th*
B6	Culturally diverse project team give an organisation a strong competitive advantage	0.827	.887	*6th*
B7	Employing multicultural teams, companies make significant gains in productivity	0.819	.893	*7th*
B8	Financial profitability is higher in multicultural team settings	0.813	.895	*8th*
B9	Ethnically diverse participants produce more high-quality ideas	0.804	.908	*9th*
B10	Multicultural team members have better capabilities	0.793	.915	*10th*
B11	Potential for promoting social and psychological well-being	0.773	.887	*11th*
B12	Fosters organisational commitment and trust	0.768	.883	*12th*
B13	Greater opportunity for development	0.764	.852	*13th*
B14	Fosters positive intergroup relations that result in organisational performance	0.737	.868	*14th*
B15	Allows firm to attract and retain the best talent	0.707	.808	*15th*

Table 1 shows that the respondents agreed to the existence of different decision-making styles and smart ideas in multicultural teams as the most perceived benefit with an RII value of 0.967. It was ranked first and hence deemed the most important benefit of multicultural project team setting. This finding is consistent with the study of Kirkman & Shapiro (2005) who states that multiple perspectives, varied experiences, and decision-making styles prevail in multicultural teams. In addition, the respondents also agreed that the existence of different problem-solving approaches in multicultural teams as a benefit of multicultural project team setting with an RII value of 0.933 ranked as the second most important benefit of multicultural project team setting. This finding is consistent with the study of Rahman (2008), who indicates that multi-cultural teams do better than homogeneous teams in finding out problems and solving them. Nonetheless, the attraction and retainaship of the best talent with RII value of 0.707 was ranked as the fifteenth and the least important benefit of multicultural project team setting. These findings are consistent with previous studies that also emphasized that organisational diversity has produced inconsistent results on effects of diversity, with some researchers finding beneficial effects, such as increased creativity, productivity, and quality (Signorini *et al*., 2009). Spreitzer et al. (2005) indicate that an all-inclusive work environment promotes individual thriving as a sense of progress in one's self development and personal growth. Kirkman & Shapiro (2005) indicate that multiple perspectives, varied experiences, different problem-solving and decision-making styles exist in multicultural teams. Rahman (2008) indicates that multicultural teams do better than homogeneous teams in finding out problems and solving them. Similarly, Nam et al. (2009) indicate that multicultural teams create the avenue for firms to make necessary gains in productivity. A multicultural team exhibits various benefits such as: skills and personal attributes and different perspectives (Stahl et al., 2010). According to Stephens et al. (2008) multicultural teams are characterized with more ideas of higher quality in brainstorming work.

Factor analysis (FA)

Owusu-Manu et al. (2019) postulated that before analysing data from a survey, one must check the internal consistency of the variables and the reliability of the scale used. Cronbach's Alpha's Co-efficient test is widely used in checking the reliability of scales. Cronbach's Alpha Co-efficient of 0.700 or more is mostly considered to be reliable (Owusu-Manu et al., 2019). The Cronbach's Alpha Coefficient value was 0.979 which is above 0.700, which shows a high reliability of the scale. Hence, it can be concluded that there is good internal consistency among the variables used for the study.

Factor analysis according to various researchers categorizes small number of factor groupings that is used in representing sets of many inter-related variables (Kissi et al., 2020). Owing to the large number of variables (15 benefits: see table 1) involved in this research, there was the need to reduce the items to form a smaller coherent number, hence, the use of factor analysis which is a data reduction technique. In measuring the sampling adequacy for appropriateness of the data, the data was subjected to the Kaiser Meyer Olkin (KMO) measure and Bartlett's test of Sphericity with the KMO recording a value of 0.901 which is greater than 0.500 for factor analysis (Kissi et al., 2020).

Table 2

KMO *and Bartlett's test*

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.901
Bartlett's Test of Sphericity	Approx. Chi-Square	5.187E3
	df	105
	Sig.	.000

The Bartlett's Test indicates relationship among the variables. It also checks whether the correlation matrix is an identity matrix by testing the null hypothesis. The significant level of the test was adequate to reject the null hypothesis suggesting that the variables in the correlation matrix is not an identity matrix (Owusu-Manu et al., 2021). This indicates a strong relationship among the variables making it appropriate in the use of factor analysis.

After this the variables were taken through a varimax rotation converged in 6 iterations as presented in Table 3. Varimax simplifies the interpretation of the factors as compared to other rotation methods. Each of the variables is loaded on a factor with each variable exceeding 0.500.

Table 3

Rotated component matrix

Code	**Component**	**Component**		
		1	**2**	**3**
Component 1: Promotes Personal and Professional growth				
B10	Multicultural team members have better capabilities	**.680**		
B11	Potential for promoting social and psychological well-being	**.797**		
B12	Fosters organizational commitment and trust	**.813**		
B13	Greater opportunity for development	**.811**		
Component 2: Provides an organisation competitive advantage				
B4	Work force diversity can advance organisational efficiency and effectiveness		**.783**	
B7	Employing multicultural teams, companies make significant gains in productivity		**.760**	
B8	Financial profitability is higher in multicultural team settings		**.745**	
B14	Fosters positive intergroup relations that result in organisational performance		**.896**	
B15	Allows firm to attract and retain the best talent		**.943**	
B5	Formation of an emergent team culture		**.786**	

B6	Culturally diverse project team give an organisation a competitive advantage		**.770**	
Component 3: Avenue for effective decision-making				
B2	Different problem-solving approaches exist in multicultural teams			**.917**
B1	Different decision-making styles and smart ideas prevail in multicultural teams			**.938**
B9	Ethnically diverse participants produce more high-quality ideas			**.718**
B3	It gives learning opportunity and knowledge sharing			**.794**

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations

Component 1: Promotes Personal and Professional growth

This principal component is responsible for 38.111% of the total variances. The variables loaded on this component can be observed to have a direct relationship with the promotion of personal and professional growth among individuals in a multicultural project team setting. The findings under this factor agree with extant literature. The global market climate necessitates a high level of technical experience as well as cultural diversity awareness to aid in individual and organisational development. The breadth of experiences, talents, and personal qualities that multicultural team members bring to an organisation that encourages personal and professional development are just a few of the advantages of cultural diversity on a team (Arslan et al., 2021). A multicultural team, unlike a homogeneous or monocultural team, aids in the growth of individuals because team members cultivate and depend on a team culture based on simple guidelines, success goals, and participant experiences (Misoc, 2017).

Component 2: Provides an organisation competitive advantage

This principal component is responsible for 35.006% of the total variances. The creation of an emergent team culture is aided by interaction among multicultural team members. Workforce diversity can improve team performance, and hence advance organisational efficiency and effectiveness which gives an organisation a competitive advantage. The positive effect and trust generated by perceived shared understanding fuels performance improvement and boosts team efficacy which enables an organisation to perform better than others (Ochieng & Price, 2010). Mobilizing the passion and teamwork of people from different cultures working together will contribute to more innovative solutions, giving multicultural project teams a significant competitive advantage.

Component 3: Avenue for effective decision-making

This principal component is responsible for 21.828% of the total variances. Stephens et al. (2008) indicate that ethnically diverse groups generate more ideas of higher quality in brainstorming tasks. Similarly, Najdowski et al. (2021) indicates that culturally diverse teams outperform homogeneous teams at identifying problems and generating solutions. Multicultural project teams have diverse people from diverse backgrounds, hence, enabling them to make effective decisions.

Conclusions

This study identified the key benefits of multicultural project team setting. The study succeeded in identifying three major benefits of multicultural project team setting. This research provides a new perspective on the benefits of multicultural project steams. These results have ramifications for managers who lead multicultural teams and are dedicated to increasing team productivity and success. Managers in multicultural organizations must put in place policies that will yield the benefits found in this study in order to operate efficiently and achieve high levels of team success as the workforce's cultural diversity continues to grow. This research findings suggest that, cultural diversity is beneficial for a multicultural project teamwork. The findings reveal that a multicultural project team promotes personal and professional growth, provides an organisation a strong competitive advantage, and an avenue for effective decision-making. Multicultural project team setting has greater access to multicultural resources and consequently a better chance to exploit their potential for the organisation to work efficiently as part of a team and achieve high levels of team success.

The findings of this study will stimulate much needed debate on the adoption of cultural diversity in projects in order to take advantage of its related benefits. This study will also serve as a source of empirical data to motivate others to conduct further studies on the subject to confirm or otherwise, the findings of this study. Outcomes of the findings of the study provide stakeholders in infrastructure development an insight into the benefits of the adoption of cultural diversity in projects. Based on the findings, the following recommendations are made: 1) the use of multicultural project teams by firms/companies plays a critical role in the firm's success; thus, project managers ought to see the need to embrace cultural diversity in projects due to the benefits cultural diversity brings; and 2) public awareness of multicultural project teams is essential because it leads to the high demand and, consequently, the improved delivery of projects. Despite the advances in understanding gained through this research, the study had some limitations. Relatively, the sample size was small. Nonetheless, the level of education and years of experience of the respondents in multicultural projects still validate the study's authenticity for future reference. Further studies can be undertaken on a large set. Future studies can also explore these issues in other African countries to confirm, or otherwise, the study's findings.

References

Alemu, M.M. (2016). Multicultural team management in the context of a development work. *Journal of Sustainable Development*, *9*(1).

Arslan, A., Haapanen, L., Ahokangas, P. and Naughton, S. (2021). Multicultural R&D team operations in high-tech SMEs: Role of team task environment and individual team members' personal experiences. *Journal of Business Research*, *128*, pp.661-672.

Behfar, K., Kern, M. and Brett, J. (2006). Managing challenges in multicultural teams. In *National culture and groups*. Emerald Group Publishing Limited.

Deaux, K., Reid, A., Martin, D. and Bikmen, N. (2006). Ideologies of diversity and inequality: Predicting collective action in groups varying in ethnicity and immigrant status. *Political Psychology*, *27*(1), pp.123-146.

Di Marco, M.K. and Taylor, J.E. (2011). The impact of cultural boundary spanners on global project network performance. *The Engineering Project Organization Journal*, *1*(1), pp.27-39.

Gibbs, J.L. and Boyraz, M. (2015). International HRM's role in managing global teams. *The Routledge companion to international human resource management*, pp.532-551.

Gilson, L.L., Maynard, M.T., Jones Young, N.C., Vartiainen, M. and Hakonen, M. (2015). Virtual teams research: 10 years, 10 themes, and 10 opportunities. *Journal of management*, *41*(5), pp.1313-1337.

Kirkman, B.L. and Shapiro, D.L. (2005). The impact of cultural value diversity on multicultural team performance. In *Managing multinational teams: Global perspectives*. Emerald Group Publishing Limited.

Kissi, E., Adjei-Kumi, T., Twum-Ampofo, S. and Debrah, C. (2020). Identifying the latent shortcomings in achieving value for money within the Ghanaian construction industry. *Journal of Public Procurement*.

Kivrak, S., Ross, A., Arslan, G., Tuncan, M. and Dainty, A. (2009). Impacts of cultural differences on project success in construction. In *Proceedings of 25th Annual ARCOM Conference, Association of Researchers in Construction Management, Nottingham* (pp. 7-9).

Lisak, A. and Erez, M. (2015). Leadership emergence in multicultural teams: The power of global characteristics. *Journal of World Business*, *50*(1), pp.3-14.

Mahalingam, A. and Levitt, R.E. (2007). Institutional theory as a framework for analyzing conflicts on global projects. *Journal of construction engineering and management*, *133*(7), pp.517-528.

Matheson, B. and Petersen, E.J. (2020). Engaging US students in culturally aware content creation and interactive technology design through service learning. *IEEE Transactions on Professional Communication*, *63*(2), pp.188-200.

Misoc, I. (2017). The effects of cultural diversity on team performance: A comparison between the performance of monocultural teams and the performance of multicultural teams in tourism organizations. International Journal of Academic Research in Business and Social Sciences, 7(7), pp.207-218.

Mockaitis, A.I., Zander, L. and De Cieri, H. (2018). The benefits of global teams for international organizations: HR implications.

Najdowski, A.C., Gharapetian, L. and Jewett, V. (2021). Toward the development of antiracist and multicultural graduate training programs in behavior analysis. *Behavior Analysis in Practice*, pp.1-16.

Nam, C.S., Lyons, J.B., Hwang, H.S. and Kim, S. (2009). The process of team communication in multi-cultural contexts: An empirical study using Bales' interaction process analysis (IPA). *International Journal of Industrial Ergonomics*, *39*(5), pp.771-782.

Ochieng, E.G. and Price, A.D. (2010). Managing cross-cultural communication in multicultural construction project teams: The case of Kenya and UK. *International Journal of Project Management*, *28*(5), pp.449-460.

Ochieng, E.G. and Price, A.D. (2009). Framework for managing multicultural project teams. *Engineering, Construction and Architectural Management*.

Oertig, M. and Buergi, T. (2006). The challenges of managing cross-cultural virtual project teams. *Team Performance Management: An International Journal*.

Owusu-Manu, D.G., Babon-Ayeng, P., Ghansah, F.A., Debrah, C., Boateng, F. and Edwards, D.J. (2019). Analysing the relationship between construction employees' mindset behaviour and project performance. *43rd Aubea*, pp.133-143.

Owusu-Manu, D.G., Mankata, L.M., Debrah, C., Edwards, D.J. and Martek, I. (2021). Mechanisms and challenges in financing renewable energy projects in sub-Saharan Africa: a Ghanaian perspective. *Journal of Financial Management of Property and Construction*.

Rahman, A. (2008). Leadership for Multicultural Teams: The Challenges in Managing Cross-cultural Conflicts.

Ramthun, A.J. and Matkin, G.S. (2012). Multicultural shared leadership: A conceptual model of shared leadership in culturally diverse teams. *Journal of Leadership & Organizational Studies*, *19*(3), pp.303-314.

Signorini, P., Wiesemes, R. and Murphy, R. (2009). Developing alternative frameworks for exploring intercultural learning: a critique of Hofstede's cultural difference model. *Teaching in Higher Education*, *14*(3), pp.253-264.

Spreitzer, G., Sutcliffe, K., Dutton, J., Sonenshein, S. and Grant, A.M. (2005). A socially embedded model of thriving at work. *Organization science*, *16*(5), pp.537-549.

Stahl, G.K., Mäkelä, K., Zander, L. and Maznevski, M.L. (2010). A look at the bright side of multicultural team diversity. *Scandinavian Journal of Management*, *26*(4), pp.439-447.

Stevens, F.G., Plaut, V.C. and Sanchez-Burks, J. (2008). Unlocking the benefits of diversity: All-inclusive multiculturalism and positive organizational change. *The journal of applied behavioral science*, *44*(1), pp.116-133.

Tung, R.L. (2008). The cross-cultural research imperative: The need to balance cross-national and intra-national diversity. *Journal of International Business Studies*, *39*(1), pp.41-46.

Najdowski, A.C., Gharapetian, L. and Jewett, V. (2021). Toward the development of antiracist and multicultural graduate training programs in behavior analysis. *Behavior Analysis in Practice*, pp.1-16.

Zander, L. and Butler, C.L. (2010). Leadership modes: Success strategies for multicultural teams. *Scandinavian Journal of Management*, *26*(3), pp.258-267.

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Evaluating Various Job Functions to Map a Typical Career Path in the Roofing Industry

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The general contractors contract the majority of the work on construction projects to sub-contractors. Hence, attracting the next generation of workforce, Generation Z (Gen Z), at the sub-contractor level is critical when addressing workforce issues. Roofing is one of the critical scopes within a construction project provided by a sub-contractor. Gen Z has various characteristics and preferences to consider when attracting them to the roofing industry. One of the significant attraction factors for Gen Z is a visual career path within a specific industry. This paper aims to document a general career path to attract a new generation of professionals and retain current professionals in the roofing industry. A focus group with nine (9) roofing contractor companies from different regions of the U.S. helped map a typical career path and collect information on job responsibilities, compensation for each position, experience requirements, and standard benefits within roofing contracting organizations. Educators, trade schools, and roofing contractors can use the information and the proposed flowchart in response to the need for a visual career path to attract Gen Z workers.

Key Words: Generation Z, Career Path, Workforce, Roofing

Introduction and Literature Review

The construction industry plays an integral role in the U.S. economy. Construction is a complex industry that creates supply and demand for other industries, such as manufacturing and infrastructure. In the United States, the construction industry employs about 6%-10% of the workforce (Assaad, 2020). A typical construction project consists of the principal general contractor and a subcontractor. The nature of the relationship between the two is a contractual partnership that is transactional, cost-driven, and sometimes adversarial (Martin and Benson, 2021). One common denominator between both general contractors and subcontractors is the significance of a strong and skilled workforce.

General contractors emerged in the 1880s due to the construction industry becoming more complex and specialized (Wermiel, 2006). General contractors are significant to the construction industry because they are key to aligning the execution of all scopes to better the project at hand. They are responsible for the coordination and execution of the entire construction project and usually employ a higher-level approach to the project than the subcontractors. Therefore, the general contractor workforce must embody a strong sense of emotional intelligence and organizational and interpersonal skills. The contractor workforce can be divided into field and office career paths. Research has found that the office workforce display high levels of interpersonal skills, empathy, and social responsibility compared to the workforce in the field (Songer and Walker, 2004).

Operating within the same industry, but differently than general contractors, are the subcontractors. Subcontractors typically sign a contract with the general contractor agreeing to perform a specialized scope of work. The goal of a subcontractor is to further develop a horizontal and integrated structure, supporting a broader project with the completion of their individual scope (Errasti, 2007). With a precise skillset in one specific scope of work, the subcontractor workforce tends to include skilled labor who demonstrate a depth of knowledge. Within the construction industry, people are the greatest asset. Moreover, subcontractors perform most of the work on a construction project (Dykstra, 2018), around 80-90% (Hinze and Tracey, 1994). Hence, it is critical to focus on workforce issues within the subcontractor workforce.

The construction industry is projected to have a 2.9% annual employment growth rate, making it the most rapidly growing industry in the goods-producing sector (Henderson, 2012). Just like the construction industry, the roofing sector expects to see a significant increase in the need for workers. The roofing contractor industry expects to increase its workforce by 3.8% in 2021 (IBISWorld, 2021). The roofing industry is composed of subcontractor organizations that complete their scope of work in part of the broader project. According to the U.S. Bureau of Labor Statistics, the roofing industry currently has 128,680 employees working at a mean hourly wage of $22.60. The roofing industry is experiencing significant changes in advanced technologies, increased safety, and better communication with clients and trade partners (Delvinne et al., 2020). These changes are causing the roofing industry to be a highly desirable work environment but need additional employees to meet the industry demands.

The construction industry must direct its attention to the next generation of workers entering the workforce, Generation Z (Gen Z), to address worker shortage issues. Since Gen Z are more likely to pick an industry that aligns with their preferences, the industry must understand Gen Z's career preferences to overcome workforce issues. This generation desires a strong organizational culture that fosters relationships within the workplace. As a product of these relationships, they desire to have their ideas listened to by managers (Özkan, Mustafa & Yılmaz, Betul, 2015). Gen Z workers desire to be on a team. The generation displays a fear of missing out, and team inclusion is one way to combat this fear (Liu, Liu, Yoganathan, Osburg, 2021). Furthermore, this generation is self-confident and high achieving, which leads them to work hard to meet their aspirations. Additionally, different from other generations, Gen Z workers are conscious about their brand and online presence. A shift in personal enjoyment to professional branding through social platforms plays an integral part in their self-expression (Vitelar, 2013). Developing leadership qualities is another aspect of Gen Z (Panvar et al., 2019). Knowledge about different career opportunities linked with career growth is also an important attraction factor (Bigelow et al., 2019). Hence, a visual career path to attract Gen Z into any industry is essential.

After conducting an in-depth literature review, there is a lack of studies documenting a visual career path in the roofing industry. This paper aims to develop and document a general career path to attract a new generation of professionals to the roofing industry. Furthermore, the paper analyzes and compares responsibilities, compensation, experience, and benefits for each position within roofing contracting organizations.

Methodology

Figure 1 shows the four (4) phase research methodology of the study.

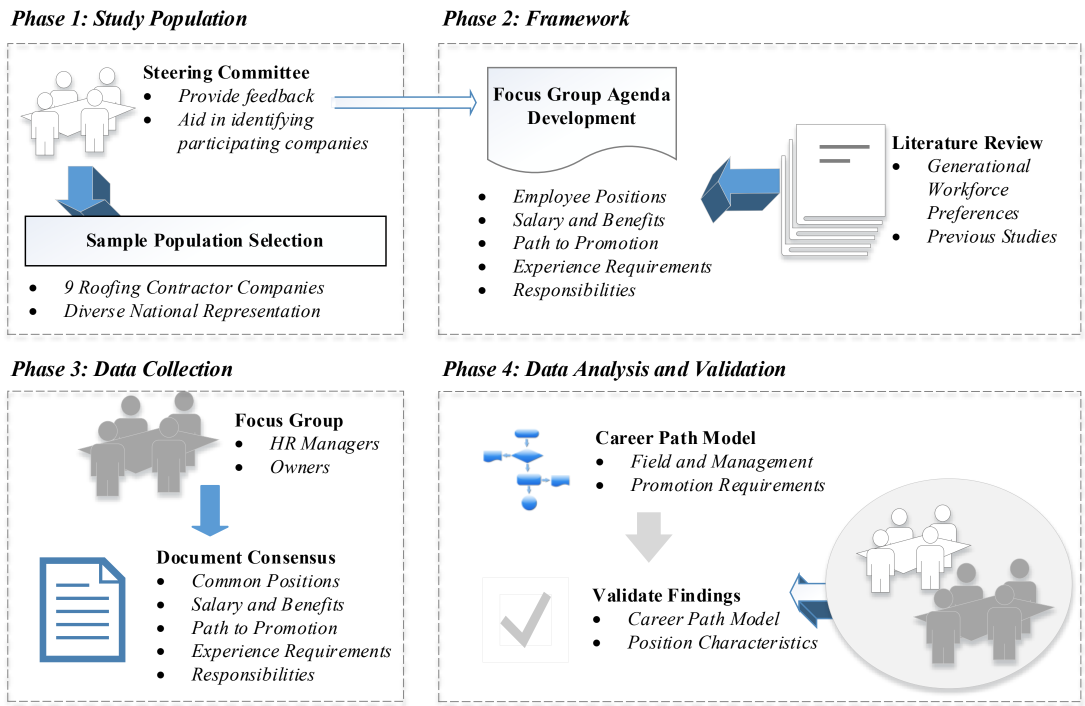

Figure 1. Phases of Methodology

Phase one consisted of forming a steering committee that assisted in developing the study framework and selections of participating companies. The focus group participants were selected members from the National Roofing Contractors Association. A total of nine (9) roofing contractor companies participated in the focus group over Zoom. The participants represented seven different states, covering all regions of the United States. Participants were also representative of small and large companies, with company revenue ranging from 8.5 million to 670.5 million (95.32 million average). The significance of the focus group was being able to prioritize quality over quantity by selecting diverse participants and asking in-depth questions.

The research framework was established in phase two and included an in-depth literature review on generational workforce preferences that influenced the focus group agenda. The agenda included discussion around various positions in the roofing industry, salary and benefits for each position, path to promotion, experience requirements for promotion, and individual job responsibilities.

In phase three, the data was collected through focus group discussions among (9) nine roofing contractor companies. The primary participants of the focus group were the H.R. Managers and/or the company owners that had an in-depth knowledge about their company's positions and individual job characteristics. One participant from each company was represented in the focus group. The focus group was executed by the researchers over zoom and lasted about one-hundred-twenty (120) minutes. The key information such as the common positions within each company, starting position for a new worker entering into the roofing industry, and their typical career path and promotion path were collected in this phase. Salary, benefits, experience, education requirements and the responsbilities for each position were also collected. The data was documented through consensuses among the participants in the focus group after each discussion point. Each individual company was given dedicated time during the focus group to discuss their company's positions and individual job characteristics. The data for the various jobs was documented and mapped in real-time during focus group. After each discussion point, the participants were asked to provide any changes or updates to reach consensus.

In phase four, the focus group discussions were analyzed to develop a general career path within roofing contractor organizations and specifically analyze the positions, experience requirements, responsibilities, average compensation ranges, and the benefits offered for each position. The mapped career path and the relevant information for each position was again validated with the nine (9) roofing contractor companies participants to reach consensus.

Results

Responsibilities

The common positions and their responsibilities for roofing contractors were collected. The positions were determined based on the common positions utilized by the individual participating companies from the focus group. The data shows that as employees progress into higher positions within a company, responsibilities broaden in scope. The entry-level positions tend to be more technical in practice than higher positions requiring more leadership and management skills. The entry-level positions are narrow in scope, focusing on a few responsibilities, compared to higher-level positions that incorporate a broader range of duties. The responsibilities of positions in both the field and office demonstrate the same trend of broadening in scope as position ranks become higher. Furthermore, the leadership demands as one progresses in both the field and the office grow. The sales associate focuses more on the technical side of making sales, while the manager leads the team and expands business operations. The findings for the individual positions are outlined below.

- Field Technician: Installation, material handling, and cleanliness on the jobsite.
- Field Coordinator: Overseeing projects and coordinating activities that involve sub-contractors.
- Field Superintendent: Overseeing progress on-site, meeting labor/productivity goals, crew scheduling, and safety.
- Junior Project Manager: Assisting the project manager as needed, arranging and managing jobsite meetings, estimating for more straightforward scope and low-cost jobs, estimating maintenance and service jobs. Depending on company, may be identified as a Junior Estimator
- Project Manager: Estimating and managing projects, overseeing daily operations, managing reports and documentation, bidding process, and H.R. functions: safety, production and on job mentorship. Depending on company, may be identified as an Estimator
- Senior Project Manager: Managing a team of project managers or a team of estimators, mentor to junior project managers / junior estimators / project managers / estimators.
- QA / QC Director: quality check surveying, I.R. scan, preventative maintenance plans, technical services.

- Sales Associate: Establishing and maintaining customer relationships, seeking new business opportunities.
- Sales Manager: Managing the sales team and expanding business operations

Compensation

The average compensation for each position is shown in *Table 1*. There is an overlap in compensation between field and office, both showing steady compensation increases as the employee progresses in their career. On the field side, there is a 39% increase from entry Field Technician to Field Superintendent. On the management side, there is a 56% increase from entry-level junior project manager/junior estimator to senior project manager/senior estimator. The highest paid position is the QA/QC Director since this is the most experienced and high-ranked position. The sales position compensations are significantly lower than other positions, but the sales team also makes a healthy commission on sales.

Table 1

Average and Range of Compensation

Position	Average	Range
Field Technician	$57,500	$50,000 - $65,000
Field Co-Ordinator	$60,000	$50,000 - $70,000
Field Superintendent	$80,000	$70,000 - $90,000
Junior Project Manager	$57,500	$50,000 - $65,000
Project Manager	$70,000	$65,000 - $75,000
Senior Project Manager	$90,000	$90,000 and above
QA/QC Director	$107,500	$100,000 - $ 115,000 and above
Sales Associate	$57,500	$50,000 - $65,000
Sales Manager	$70,000	$65,000 - $75,000

Experience

When analyzing a career path, the experience requirement increase as the employee progresses. Entry-level positions need little experience, and more emphasis is placed on training programs or college and university degrees. However, as an employee progresses in their career, experience gained in preceding positions is essential to promotion. On average, typical years experience before promotion from entry-level positions (Field Technician and Jr PM/Estimator) is four (4) to seven (7) years. However, this can be accelerated based on company needs and employee capability. The field and office career paths reflect similar experience requirements. It is important to note there can be overlap in the career paths. For example, a junior estimator or junior project manager could be qualified based on field experience. The experience required and the sequential job promotion do not always have to be linear, strictly sticking to the field or the office. The experience requirements for the individual positions are outlined below.

- Field Technician: Entry level position, trade school-based experience, years before promotion: four (4) to seven (7)
- Field Coordinator: About four (4) to seven years (7) years of experience as a field technician, can move up faster if given adequate training and proper orientation
- Field Superintendent: Prior experience as a field technician and/or field coordinator, leadership and technical skills needed, years before promotion to O&M: one (1)
- Junior Project Manager: May be hired internally from the field with prior field experience or a college graduate, years before promotion: four (4) to seven (7)
- Project Manager: About five (5) to seven (7) years of experience as a junior project manager or junior estimator
- Senior Project Manager: Project managers and estimators with leadership skills
- QA / QC Director: Need extensive amount of experience in the industry, detailed knowledge of the processes, assemblies, and procedures
- Sales Associate: may be hired internally from the field with prior field experience or a college graduate

Benefits

A detailed matrix of benefits for each position is outlined in Table 2.

Table 2

Position Benefits

Position	**Insurance**	**401K match**	**Bonuses Programs**	**Vehicle or vehicle allowance**	**Profit-sharing bonus**	**PTO**	**Base salary plus commission**
Field Technician	X	X	X	X	X	X	
Field Co-ordinator	X	X	X	X	X	X	
Field Superintendent	X	X	X	X	X	X	
Junior Project Manager	X	X	X	X	X	X	
Project Manager	X	X	X	X	X	X	
Senior Project Manager	X	X	X	X	X	X	
QA / QC Director	X	X	X	X	X	X	
Sales Associate	X	X			X	X	X
Sales Manager	X	X			X	X	X

There is little to no variation in benefits across the career path for both the field and office sectors. All positions for both field and office receive the same benefits that include insurance (health, vision, dental), 401K match, bonuses (depending on the company), vehicle or vehicle allowance, profit sharing bonus, and paid time off. However, the sales team (associate and manager) receives different benefits. Their benefits include insurance (health, vision, dental), 401K match, profit sharing bonus, paid time off, and base salary plus commission. Consistent benefits are critical since it ensures the same care and coverage from the company, irrespective of position.

Career Path

As displayed in *Figure 2*, a potential workforce in the roofing contractor organization can choose either the field or the management path.

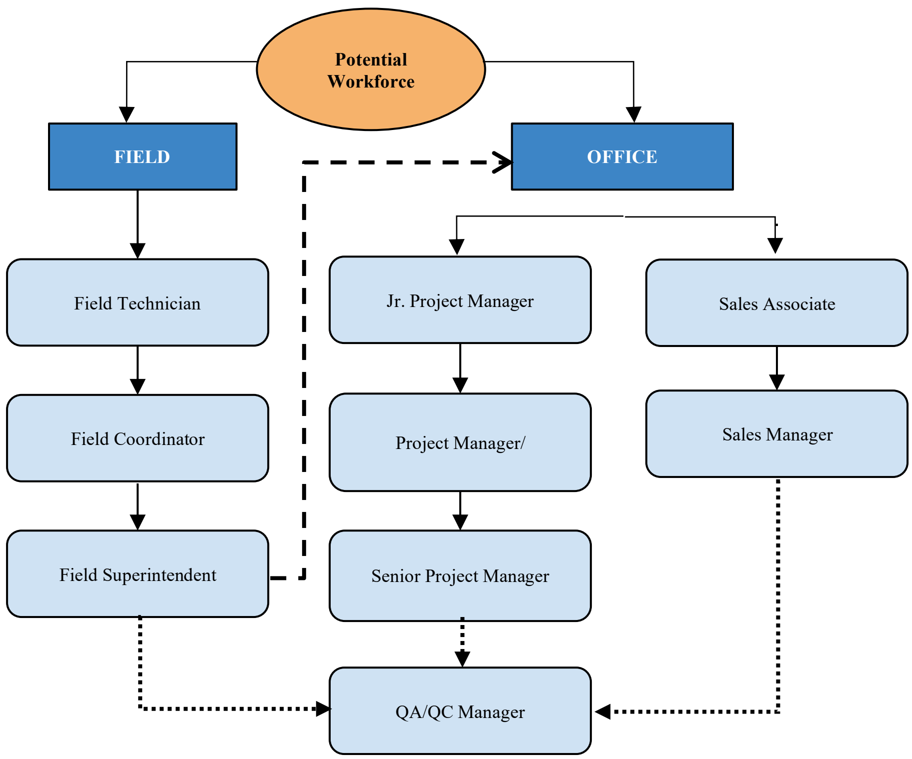

Figure 2. Visual Career Path Model

A recent college graduate looking for an entry-level position within roofing contracting companies would either be employed as a field technician or field coordinator classified as "field position" or a junior project manager/estimator or sales associate classified as "office position." Over time this employee will progress in rank throughout their career. QA / QC Manager positions generally require extensive experience within the roofing industry and are not typically considered entry-level positions.

Conclusion

The main objective of this study was to develop and document a general career path to attract a new generation of professionals and retain current professionals within the roofing industry. As an employee progresses in their career path, they take on a broader scope of responsibilities, including leadership and management. There is a 39% increase in compensation from the entry field positions to the highest field positions and a 56% increase in entry office positions to the highest office position within the career path model. The highest-paying position within the career path model was the QA/QC Director, earning an average of $107,500 compensation annually. Experience required increases as employees progress along their career path. Typically, an average of four to seven years is expected in each phase of the career path before promotion. This is applicable for both the management and the field. The benefits associated with each position for field and management, with the exception of the sales team, are similar across the career path.

The contractor's section of the roofing industry allows employees to take on greater responsibility with time, become leaders within the industry, earn a rewarding compensation, work hard to gain the experience needed for a promotion, and receive decent benefits. All of these components of the visual career path align with Generation Z's career expectations. Knowledge gained from the literature review points to a generation that desires career advancement, leadership opportunities, and a great reward for hard work. While these align with the components discussed in the study, the most significant conclusion to be made is Generation Z's desire for a clear and visual career path. Roofing contractors can use the information and the flowchart proposed to attract Generation Z. The flowchart clearly defines the career path they would embark on once entering the roofing contracting organization.

The limitation of this study is the representative sample of the focus group. Even though the participants represented each region in the U.S., further research is needed that analyzes more companies from every state to validate the findings. Further research is also needed to guage the perception and interest of Gen Z about the proposed career path in the roofing industry. The results of this study pave a path to future research in motivators for success and promotion among the Gen Z workforce. This study outlines the visual career path associated with the preferences of Generation Z, but future research is also needed as to what motivates Generation Z to progress in their career path.

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References

Ander Errasti, Roger Beach, Aitor Oyarbide, Javier Santos (2007) A process for developing partnerships with subcontractors in the construction industry: An empirical study, International Journal of Project Management, Volume 25, Issue 3

Assaad, Rayan, and Islam H. El-adaway. (2020) "Impact of Dynamic Workforce and Workplace Variables on the Productivity of the Construction Industry: New Gross Construction Productivity Indicator: Journal of Management in Engineering: Vol 37, No 1." *Journal of Management in Engineering*, American Society of Civil Engineers

Bigelow, B. F., Perrenoud, A. J., Rahman, M., & Saseendran, A. (2019). An exploration of age on attraction and retention of managerial workforce in the electrical construction industry in the United States. International Journal of Construction Education and Research, 17(1), 3-17. https://doi.org/10.1080/15578771.2019.1611678

Delvinne, Hasini Hiranya, et al. (2020) "Construction Workforce Challenges and Solutions: A National Study of the Roofing Sector in the United States: Construction Research Congress 2020." *Proceedings*, American Society of Civil Engineers

Dykstra, Alison. (2018) *Construction Project Management: A Complete Introduction*. Kirshner Publishing Company.

Henderson, Richard. (2012) "Employment Outlook: 2010–2020 - BLS." *Bls.gov*

Hinze, Jimmie, and Andrew Tracey (1994) "The Contractor-Subcontractor Relationship: The Subcontractor's View: Journal of Construction Engineering and Management: Vol 120, No 2." *Journal of Construction Engineering and Management*, American Society of Civil Engineers.

Hongfei Liu, Wentong Liu, Vignesh Yoganathan, Victoria-Sophie Osburg (2021) COVID-19 information overload and generation Z's social media discontinuance intention during the pandemic lockdown, Technological Forecasting and Social Change, Volume 166

"Industry Market Research, Reports, and Statistics." (2021) *IBISWorld*

Loosemore Martin, Lim Benson. (2021) Relationship quality in construction projects: A subcontractor perspective of principal contractor relationships, International Journal of Project Management, Volume 39, Issue 6

Ozkan, M. and Solmaz, B. (2015a) The Changing Face of the Employees – Generation Z and Their Perceptions of Work (A Study Applied to University Students), 4th World Conference on Business, Economics and Management (WCBEM), Procedia Economics and Finance, 26 (2015): 476-483.

Panwar, S. and Mehta, A. (2019) Fostering Leadership in Generation Z: Onus on Whom? The IUP Journal of Soft Skills, 8(3).

"Roofers : Occupational Outlook Handbook." (2021) *U.S. Bureau of Labor Statistics*, U.S. Bureau of Labor Statistics

Songer, Anthony D, and Brian Walker. (2004). GENERAL CONTRACTOR EMOTIONAL INTELLIGENCE IN THE CONSTRUCTION INDUSTRY. *Arct.cam.ac.uk*. h

Vitelar, A. (2019) Like Me: Generation Z and the Use of Social Media for Personal Branding. Management Dynamics in the Knowledge Economy, 7(2), 257-268.

Wermiel , Sara E. (2006) Norcross, Fuller, and the Rise of the general contractor in the United States in nineteenth century. *Arct.cam.ac.uk*.

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Distinguishing Human Factors of Top-Performing Project Managers in the Sheet Metal and Air Conditioning Trades

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The construction trades seek strategies to overcome the labor shortages currently affecting the marketplace. One innovative tool that has gained increased attention is the application of human dimension assessments from the social sciences to the construction trades. For example, this study utilized three human dimension measures – assessments of personality, emotional intelligence, and behavioral tendencies – in the context of project managers (PMs) in the sheet metal and air conditioning trades. This preliminary study assessed 42 PMs from across the United States. The direct supervisors of each PM completed a detailed performance review which was then used to identify the absolute top performers "cream of the crop" from this nationwide pilot study. Analysis revealed several statistically significant differences between the Top-Performing PMs and the remaining participants. Such information is beneficial to the specialty trades in several ways: First, moving toward a nationwide benchmark of human dimensions for PMs from across the country (albeit on a pilot-scale), which can be used for recruitment and talent development purposes. Second, the results contributed to the distinguishing characteristics of Top-Performing PMs, which may be beneficial for internal talent development purposes.

Key Words: Specialty Trades, Project Managers, Personality, Emotional Intelligence

Introduction

The construction trades are experiencing labor shortages throughout the United States and beyond, as highlighted by the Engineering News-Record (ENR) (Rubin et al. 2021). In response, contractors are increasingly seeking tools to overcome this challenge. One strategy that contractors use is to expand their internal recruitment and talent development programs. Enhanced recruiting practices enable contractors to attract and assess candidates that may be a "best fit" for specific job roles. Expanded talent development programs typically seek to utilize additional tools to assist existing employees in improving their technical abilities and their so-called “soft skills”, which can improve collaboration, leadership, and communication in a project team setting.

As one example of this, a nation-wide study of the top 400 commercial general contractors (GCs) found that one-third of GCs have started using personality profile assessments (Childs et al. 2017). Among these GCs, the primary purposes of utilizing such tools were stated to be for (1) hiring, (2) leadership development, (3) promotions, and (4) team placement. The study also noted that several GCs felt these tools could be used in their retention programs to reduce employee turnover.

The objective of this study was to build upon the above-noted industry needs and increased usage of tools from the social sciences, such as personality profiles noted by Childs et a. (2017). A pilot study was commissioned by the New Horizons Foundation (NHF) on behalf of the Sheet Metal and Air Conditioning Contractors’ National Association (SMACNA). A total of 42 PMs from SMACNA contractors participated in the pilot study. Each PM completed three assessments: personality inventory, emotional intelligence diagnostic, and behavioral assessment. In addition, direct supervisors of each PM also completed a detailed performance review which was standardized across all participants. Results illustrated the beginnings of e nationwide benchmark of SMACNA PM human dimensions and revealed the distinguishing characteristics of the Top-Performing PMs from the data sample.

Literature Review

Literature on organizational behavior and management has long been a well-established academic discipline, where many approaches and techniques have been created to assist employee talent development. Numerous studies have explained the importance of human resource management to organizational performance (Delaney and Huselid 1996; Ericksen and Dyer 2005; Youndt et al. 1996). However, little have addressed the specific context and challenges in project-based industries. Furthermore, very little has sought to capture effective approaches within the construction sector or examine how these activities could be adapted and implemented to improve the performance and job satisfaction of the industry’s workforce (Loosemore et al. 2003; Maali et al. 2020).

Construction is one of the most labor-intensive industries, yet human resource management issues are given insufficient attention in the literature, as noted by previous researchers (Raidén et al. 2001; Tabassi and Bakar 2009). Throughout the years, the need for young talent in the construction industry is becoming more apparent, and the pool of new talent is shrinking due to shifting demographics and other market constraints. Most project leaders within the industry will leave for retirement in the next handful of years, and companies are faced with challenges to fill up those job vacancies with new, qualified professionals (Wiezel et al. 2016).

Druker and White (1995) stated that Human Resource Management (HRM) practices in the industry remain under-researched and underdeveloped, despite representing one of the United Kingdom’s largest industries. Therefore, the identification of a competency profile for top-performing project managers should be highlighted. It is crucial to help people find places within a company where their personalities mesh well to help them be the most productive and enjoy high job satisfaction. Their understanding of personality and behavior can directly relate to turnover (Deviney et al. 2009). With increased job satisfaction and productivity, companies can maintain low employee turnover, which will help them achieve greater levels of economies and experience and reduce the cost of training and human resource issues that arise in a conflicted setting (Oedekoven and Hay 2010; Maali et al. 2021). Given the importance of managing people at the operational level, this will be an important procedure in developing new and improved approaches in human resource management within the construction industry (Cheng et al. 2005).

Methodology

Data Collection

Invitations to participate in the study were provided to SMACNA members. A total of 42 PMs participated in full. Each participant completed a detailed Human Dimension Assessment and had their direct supervisor submit a Performance Assessment to assess the participant's skill set and job performance. For this study, the PM job role was defined as individuals responsible for the contract administration and performance of awarded projects and marketing the company's services. This definition was crafted with input from a steering committee of SMACNA company owners and was included since different companies tend to vary their job titles.

Supervisor Ratings of PM Performance

Performance Assessments were collected from the direct supervisor of every participating PM. The performance assessment comprised the seven major performance categories, each of which is described below.

The first four performance categories were designed to measure PM performance in the areas of Technical Skills, Leadership & Communication Skills, Ability to Change & Adapt, and overall Job Performance. Each of these categories consisted of multiple questions, measured on a scale of 1-10. For example, technical skills included PM abilities in job site layout, safety, scheduling, means & methods, and more. The 1-10 scale was defined as:

- Scores of 9 to 10 referred to top performers based on the supervisor's experience.
- Scores of 5 referred to performers who were roughly average in their role.
- Scores of 1 to 2 referred to the lowest performances in the supervisor's experience.

Fifth, a percentile assessment scale was used for each participant's overall performance relative to their peers. The scale was Top 1%, Top 2%, Top 5%, Top 10%, Top 15%, Top 25%,Top 50% (Above average), and Bottom 50% (Below Average). Sixth, a scale of 1-10 was used to rate how comfortable the company would be assigning the participant to a high-profile project. The scale ranged from 10 = Definitely Yes, 8= Probably Yes; 5 = Maybe; 3 = Probably Not to 1 = Definitely Not. Finally, the supervisors were asked a Yes-vs.-No question of whether the PM was absolutely considered the "cream of the crop" among all PMs in their company.

Human Dimension Assessments used in this Study

Participants completed a human dimensions (HD) assessment with three components: the HEXACO Personality Inventory, Emotional Intelligence Diagnostic, and the QDiSC-101 Behavioral Assessment.

HEXACO Personality Inventory

A widely used assessment that contains 60 questions to measure the "Big 6" personality domains. The assessment was developed by Ashton & Lee (2007) and is an open-source tool provided for researchers to use in a wide array of contexts. Each domain contains four sub-domains that provide more specific personality descriptors. The domains, sub-domains, and personality descriptors are summarized below:

- **Honesty-Humility (H):** contains the sub-domains of Sincerity, Fairness, Greed Avoidance, and Modesty. Typical personality descriptors include sincere, honest, faithful, loyal, modest/unassuming *versus* sly, deceitful, greedy, pretentious, hypocritical, boastful, pompous.
- **Emotionality (E):** contains the sub-domains of Fearfulness, Anxiety, Dependence, and Sentimentality. Personality descriptors include emotional, oversensitive, sentimental, fearful, anxious, vulnerable *versus* brave, tough, independent, self-assured, stable.
- **Extraversion (X):** contains the sub-domains of Social Self-Esteem, Social Boldness, Sociability, and Liveliness. Personality-descriptors include outgoing, lively, extraverted, sociable, talkative, cheerful, active *versus* shy, passive, withdrawn, introverted, quiet, reserved.
- **Agreeableness (A):** contains the sub-domains of Forgivingness, Gentleness, Flexibility, and Patience. Personality-descriptors include patient, tolerant, peaceful, mild, agreeable, lenient, gentle *versus* ill-tempered, quarrelsome, stubborn, choleric.
- **Conscientiousness (C):** contains the sub-domains of Organization, Diligence, Perfectionism, and Prudence. Personality descriptors include organized, disciplined, diligent, careful, thorough, precise *versus* sloppy, negligent, reckless, lazy, irresponsible, absent-minded.
- **Openness (O):** contains the sub-domains of Aesthetic Appreciation, Inquisitiveness, Creativity, and Unconventionality. Personality-descriptors include intellectual, creative, unconventional, innovative, ironic *versus* shallow, unimaginative, conventional.

For HEXACO scores, it is important to note that higher scores are not necessarily considered to be "better" nor "worse." Each domain is simply a spectrum or range of personality traits, and each domain's high vs. low side is completely arbitrary. Therefore, readers should not assume that higher scores are "better" nor that lower scores are "worse."

Emotional Intelligence Diagnostic

An assessment of the participant's capability to recognize and manage their own emotions and the emotions of others. The 28-question diagnostic (TalentSmart 2011) provides an Emotional Intelligence Quotient (EQ) measured on a scale of 1 to 100, where EQ is a compilation of four skills:

- **Self-Awareness:** the ability to understand your emotions as they happen.
- **Self-Management:** the ability to control your emotional reactions.
- **Social Awareness:** the ability to understand the emotions of other people (even if you do not share the same feelings)
- **Social Management**: the ability to use emotional awareness to create more successful interactions.

QDisc-101 Behavioral Assessment

QDISC-101 (pronounced "QueDISC one O one") is a simplified version of the four-quadrant behavior diagnostic tool (or instrument) known commonly as DISC. Dr. Avi Wiezel derived this instrument from Jones & Hartley (2013) and was granted a Creative Commons License by the authors of the paper. This assessment contains 24-questions in each of the following four groups:

- **Dominance (D):** associated with control, power, and assertiveness. Actions are focused on accomplishing results. Individuals with high D scores are perceived as demanding, determined, and pioneering.
- **Influence (I):** associated with social interaction skills and communication. Actions are focused on building relationships and persuading others. Individuals with high I scores are perceived as convincing, magnetic, and optimistic.
- **Steadiness (S):** associated with patience, resilience, and thoughtfulness. Actions are focused on compliance and cooperation. Individuals with high S scores are perceived as calm, stable, and unemotional.
- **Compliance/Conscientious (C):** associated with structure and organization. Individuals with high C scores are perceived as cautious, precise, and tactful.

The four behavior types in DISC are determined by two sub-scales of:

- **Work Orientation:** rated on a scale ranging from -4 to 4 (-4= task-oriented; 4 = people-oriented).
- **Communication Style:** rated on a scale ranging from -4 to 4 (-4= reserved communication; 4 = open-style communication).

Method of Analysis

Data analysis was performed in four steps. First, the overall collected performance ratings from participant's supervisors were analyzed to understand participants' average performance and skillset. Second, human dimensions assessment scores of non-construction population obtained from the original research of the three human dimension assessments (HEXACO, EQ, and QDisc-101) were compared with the collected human dimensions assessment scores for SMACNA PMs to highlight differences between construction PMs and other non-construction population. Third, the collected performance ratings were used to identify the absolute top performing SMACNA PMs "cream of the crop" among the 42 PMs who participated in the study. Finally, human dimensions assessment scores of the identified top-performing PMs were compared with scores of the other participating PMs to distinguish characteristics of top-Performing PMs "cream of the crop".

Results & Discussion

This section is organized into three sections: first, the overall results of the supervisors' performance ratings; second, the general human dimensions across all 42 participating PMs compared with typical results for the general non-construction populations; and third, the distinguishing characteristics of the Top-Performing PMs.

Supervisor Ratings of PM Performance

Table 1 on the next page shows that the participants had very strong performance assessments as rated by their direct supervisors. In the 1-10 scales, the average performance assessments ranged from 7.7 to 8.1 out of 10. These results indicate that the participants had skillsets that were substantially above average. In addition, when compared to all other peers in their job role, the average participant rating was rated as being in the top 10% of all peer performers. Finally, 86% of the PMs were rated as between "Yes" and "Definitely Yes" regarding whether their supervisors would assign them to a high-profile project, and 76% were classified as representing the "cream of the crop" of all the company's PMs.

Comparison with the General (Non-Construction) Population

The human dimensions assessment results from the participating PMs were compared with typical measurements of the general non-construction population. The non-construction scores were obtained from the original research for each of the three human dimension scales used in the study.
For the HEXACO Personality Inventory, the SMACNA PM results were compared with the average results reported by the creators Ashton & Lee (2007, 2009, 2017). The participating PMs scored in the top 20% of the general population in Honesty-Humility (H) and Conscientiousness (C). In addition, scored in the low range of Emotionality (E) and slightly so for Openness (O). Also, PMs scores were roughly in line with the non-construction population for the remaining scales of Extraversion (X) and Agreeableness (A).

For Emotional Intelligence, PMs scores in the range of 70-79, interpreted by TalentSmart (2011) as "could become a strength with some improvement." Since all scores were in the 70-79 range, SMACNA PMs can be considered to having a balanced emotional intelligence.

For the QDiSC-101 behavioral assessment, PMs had a balanced preference for task-oriented vs. people-oriented work and reserved vs. open styles of communication, with scores around zero for both subscales.

Table 1

Average Performance Ratings Provided by Supervisors

Performance Category	**Scale of the Performance Assessment**	**Average Performance Assessment for PMs**
Number of Individuals in the Sample	#	42
Technical Skills	1-10	8.0
Leadership & Communication Skills	1-10	7.7
Ability to Change & Adapt	1-10	8.1
Overall Job Performance	1-10	8.1
Percentile vs. all peers	Percentile	Top 10%
Would your company put this PM on a high-profile project?	1-10	8.6
This PM is absolute "cream of the crop" compared with all PMs at your company?	% of Yes	76%

Distinguishing Characteristics of Top-Performing PMs

The absolute top-performing PMs among the 42 PMs who participated in this study were identified using the collected supervisor ratings of each PM performance; top-performing PMs represent the top 10% of all participants, essentially representing the top PM from the four separate SMACNA contractors located across the country.
The human dimensions assessment results were compared between top-performing PMs and other participating PMs, and the following characteristics were distinguished.

Compared with other PMs, the Top-Performing PMs have **lower scores** in:

- **Extraversion (─20% vs. other PMs) including the three sub-dimensions of Sociability (─25%), Liveliness (─31%); and Social Boldness (─22%):** Lower scores in these areas correspond with individuals who are less driven by a need for social interaction and tend to be more quiet, serious, and introspective. They tend to prioritize tangible things over relationships and are analytical and matter-of-fact in their interactions. When they do interact and communicate, they are thoughtful and sincere. However, this is not to say that less-extraverted individuals necessarily avoid social interaction. Top-Performing PMs can become comfortable with a small group of close co-workers, particularly when mutual trust is earned over time

- **Fearfulness (─21% vs. other PMs):** Top-Performing PMs may be bolder and less sensitive to failure (more resilient)

- **Flexibility (─15% vs. other PMs):** More willing to stand up against another person's unreasonable suggestions. Less tendency to compromise and accommodate to avoid arguments (prefer to address disagreements head-on when in the project's best interest).

- **Creativity (─18% vs. other PMs):** Tendency to stick to what works because the "tried-and-true" is their preferred way forward; avoids the pursuit of new solutions to problems unless necessary (less experimental).

Compared with other PMs, the Top-Performing PMs have <u>**higher scores**</u> in:

- **A more Reserved Communication Style (3-times more reserved than other PMs):** This means that Top-Performing PMs are more reserved (as opposed to assertive) in their communication style. Top-Performing PMs prefer to consider things carefully and thoroughly before speaking or deciding.

- **Gentleness (+19% vs. other PMs):** Top-Performing PMs tend not to dwell on past mistakes of others (do not hold past mistakes against employees). Instead, they focus on moving forward to get the project done and are more willing to allow people to grow and improve.

Conclusion

In today's hyper-competitive environment, contractors must attract, develop, and maintain talent in their construction management workforce. Results from this study suggest several applications for Hiring & Recruitment and broader Talent Development efforts.

There were several distinctive characteristics of Top-Performing PMs. Compared with others, the Top-Performing PMs tended to be less extroverted and more reserved in their communication style. Top-Performing PMs also had lower fearfulness (greater resiliency and boldness), lower flexibility (prefer to address disagreements head-on when in the best interest of the project), and lower creativity (PMs are problem-solvers who will stick to "tried-and-true solutions when available). Finally, Top-Performing PMs are more gentle (willing to allow people to grow and improve).

These results are intended as a pilot study but eventually aimed at helping specialty contractors hire, develop, and maintain talent in their construction management workforce, which are increasingly challenging issues in the current environment with a workforce in transition.

- ***Hiring New Personnel***: increased probability of finding employees who are the right "fit" for the project management job role and can develop into top-performers. Contractors can use interview questions designed to investigate the human dimension traits that are most important for the job role. This is helpful because these traits can be hard to evaluate "on paper", such as a traditional resume.

- ***Internal Talent Development***: help employees grow and achieve their maximum potential by developing the skills most associated with top performance in their job roles. Help employees who may not naturally have those strengths by providing coaching and awareness. Mentorship and performance evaluations can focus on developing the most needed skills in the employee's job role. Several suggestions are provided in the report.

Limitations and Recommendations for Future Research

One limitation was that the study did not attempt to measure the unique company culture present at different specialty contractor organizations. Further, no distinctions were made for the slightly different responsibilities each contractor might include for the PM job role; for example, some contractors might engage their PMs more heavily in sales and business development, whereas other contractors might promote a much higher level of PM engagement in the management of field labor productivity. In each of those cases, the model of successful traits may differ depending on the responsibilities prioritized in the job role. Future research is recommended to account for these potential differences. Furthermore, these results are specific to the sheet metal and air conditioning trades and may not represent other specialty trades in the construction industry (such as electrical trades or others). Finally, these results are only intended as a pilot study. They should not be taken to represent a finalized nor fully confirmed national benchmark of the human dimensions of PMs in the specialty trades. Additional data collection is recommended to add greater statistical power to the results.

References

Ashton, M. C., & Lee, K. (2007). Empirical, Theoretical, and Practical Advantages of the HEXACO Model of Personality Structure. Personality and Social Psychology Review, 11(2), 150–166.

Ashton, M. C., & Lee, K. (2009). The HEXACO-60: A short measure of the major dimensions of personality. Journal of Personality Assessment, 91, 340-345.

Ashton, M. C., & Lee, K. (2017). HEXACO Personality Inventory-Revised (HEXACO-PI-R). In V. Zeigler-Hill & T. K. Shackelford (Eds.), Encyclopedia of Personality and Individual Differences (pp. 1-3). Cham: Springer International Publishing.

Cheng, M. I., Dainty, A. R., and Moore, D. R. (2005). "What Makes A Good Project Manager?" *Human Resource Management Journal*, 15(1), 25-37.

Childs, B., Weidman, J., Farnsworth, C., & Christofferson, J. (2017). "Use of Personality Profile Assessments in the U.S. Commercial Construction Industry." *ASC International Journal of Construction Education and Research*, 13(4), 267-283.

Delaney, J. T., and Huselid, M. A. (1996). "The Impact of Human Resource Management Practices on Perceptions of Organizational Performance." *Academy of Management Journal*, 39(4), 949-969.

Deviney, D., Mills, L. H., and Gerlich, R. N. (2010). "Environmental Impacts on GPA For Accelerated Schools: A Values and Behavioral Approach." *Journal of Instructional Pedagogies*, 3.

Druker, J., White, G., Hegewisch, A., and Mayne, L. (1996). "Between Hard and Soft HRM: Human Resource Management in the Construction Industry." *Construction Management & Economics*, 14(5), 405-416.

Ericksen, J., and Dyer, L. (2005). "Toward a Strategic Human Resource Management Model of High Reliability Organization Performance." *The International Journal of Human Resource Management*, 16(6), 907-928.

Jones, C.S. and Hartley, N.T. (2013) "Comparing Correlations Between Four-Quadrant And Five-Factor Personality Assessments" *American Journal of Business Education*, July/August 2013, Vol 6, No. 4, pp. 459 – 470.

Loosemore, M., Dainty, A., and Lingard, H. (2003). *Human Resource Management in Construction Projects: Strategic and Operational Approaches*. Taylor & Francis Group.

Maali, O., Lines, B., Smithwick, J., Hurtado, K., & Sullivan, K. (2020). "Change management practices for adopting new technologies in the design and construction industry". *Journal of Information Technology in Construction*, 25, 325-341.

Maali, O., Shalwani, A., Lines, B., Sullivan, K., & Perrenoud, A. (2021). A Spectrum of Employee Reactions to the Adoption of Organizational Changes in the AEC Industry. *EPiC Series in Built Environment*, 2, 91-99.

Oedekoven, D., and Hay, J. (2010). "Relationship Awareness: How Managers Can Improve Employee Performance." *Rangelands*, 32(4), 13-16.

Raidén, A. B., and Dainty, A. R. (2006). "Human Resource Development in Construction Organisations." *The Learning Organization*.

Rohm, R. A. (2013). What is disc? It is a powerful way to understand people and their personality types! Retrieved March 16, 2021, from https://www.discoveryreport.com/introduction-to-disc-personality-types.html

Rubin, D. K., Voorhis, S. V., & Leggate, J. (2021, October 27, 2021). Industry Labors to Fill Growing Workplace Gaps. Engineering News Record (ENR). Retrieved from https://www.enr.com/articles/52797-industry-labors-to-fill-growing-workplace-gaps

Tabassi, A. A., and Bakar, A. A. (2009). Training, motivation, and performance: The case of human resource management in construction projects in Mashhad, Iran. *International Journal of Project Management*, 27(5), 471-480.

TalentSmart (2011). *Emotional Intelligence Appraisal Teaching Manual. San Diego, CA:TalentSmart.*

Wiezel, A., Sullivan, K., Gunnoe, J., and Perrenoud, A. (2016). "Best Practices for Project Manager Succession." CII Research Report 325-1. *Construction Industry Institute*.

Youndt, M. A., Snell, S. A., Dean Jr, J. W., and Lepak, D. P. (1996). "Human Resource Management, Manufacturing Strategy, and Firm Performance." *Academy of Management Journal*, 39(4), 836-866.

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Differences between Job Roles in the Specialty Trades: A Human Factors Approach

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The construction industry is an industry that relies heavily on labor and skilled personnel. While workforce shortage is currently increasing due to current market conditions and shifting demographics. Innovative human resource management practices, such as the use of human factor measurements should be developed to overcome the current and future challenges. The study developed a Human Factor (HF) instrument with three components: personality inventory, emotional intelligence, and behavioral measurement. 182 participants within four job roles Project Managers (PMs), Field Leaders (FLs), Estimators (ESTs), and Detailers (VDCs) from the sheet and metal contractors have taken the HF instrument. Comparison results showed that the four job roles have several differences in HF, including FLs had higher Modesty than PMs; FLs had lower Openness to Experience than VDCs; FLs had higher Greed-Avoidance, lower Fairness, and lower Inquisitiveness than ESTs; PMs had higher Dependence, higher Sentimentality, and lower Creativity than VDCs; PMs had lower Prudence than ESTs, and there were no statistically significant differences between VDCs and ESTs. These results can help contractors hire, develop, and maintain talent in their organizations. Given the limited number of participants, future research is recommended to expand the data pool to other specialty trades across the construction industry.

Key Words: Human Factors, specialty trades, emotional intelligence, personality characteristics, Human Resource Management (HRM).

Introduction

Human resource management is an essential factor in the overall performance of any organization (Delaney and Huselid 1996; Ericksen and Dyer 2005). Within the construction industry, there are a lot of Human Resource management issues that the literature has given insufficient attention to (Raidén et al. 2001; Tabassi and Bakar 2009). The construction industry is a labor-intensive industry. It is currently suffering from fewer available human resources to fill up job vacancies due to current market conditions and shifting demographics (Wiezel et al. 2016). due to this, new tools and practices should be studied to support the human resource management practices in the construction industry.

The objective of this study was to identify the human factors (personality, emotional intelligence, and behavioral traits) of individuals who perform different job roles within the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) contractors, including Project Managers (PMs), Field Leaders (FLs), Estimators (ESTs), and Detailers (VDCs).

To identify the human factors, the study created human factors (HF) instrument, which is a composite of three well developed and reliable assessments including, HEXACO personality inventory (a measurement of personality), QDiSC behavioral instrument (a measure of behavioral response), and Emotional Intelligence Quotient (a measurement of emotionality). Understanding the differences between roles is helpful in scenarios when an employee is transitioning between roles or being promoted to another role. It is also beneficial when interviewing new candidates who may be qualified "on paper" because the company might be more likely to find the best "fit" candidate based on the needs of the job role. In addition, evaluating differences in personality traits for different job roles provides valuable information when employees transition from one role to another. For example, consider a field leader moving into a detailer position (e.g., perhaps in a situation where the company is advancing an individual with valuable tradecraft knowledge and first-hand field experience into their BIM/VDC/Detailer group). If significant HF differences exist between the FL and VDC roles, then taking an HF assessment can help identify traits that should be considered when employees transition between these roles. For example, some FLs may have HF traits that are "good fits" for the VDC role; in these cases, there might be a greater probability of a successful transition. In other instances, FLs may not be as good of a "fit" for a VDC position, so guidance on specific areas they can work on would be helpful.

Literature Review

Many techniques and methods have been formed to assist talent development of employees. The importance of human resource management (HRM) to organizational performance was explained by previous studies (Delaney and Huselid 1996; Ericksen and Dyer 2005). However, little has addressed the project-based industries' specific settings and challenges. Furthermore, very little has sought to capture practical approaches within the construction sector or examine how these activities could be adapted and implemented to improve the performance and job satisfaction of the industry's workforce (Loosemore et al. 2003; Maali et al. 2020).

Previous researchers have noted that the construction industry literature is significantly limited regarding human resource management issues, despite that the construction industry is one of the most labor-intensive industries (Raidén et al. 2001; Tabassi and Bakar 2009). The need for young talent in the construction industry is noticeably rising throughout the years, and the pool of new talent is shrinking due to shifting demographics and other constraints. In addition, most project leaders within the industry will leave for retirement in the next handful of years, and companies are faced with challenges to fill up those job vacancies with new, qualified professionals (Wiezel et al. 2016).

This generates a need to develop and research new human resource management practices within the construction industry (Druker and White 1996). The use of new HRM practices in the construction industry, such as using personality profile assessments, was analyzed by Childs et al. (2017), who found some basic purposes of using such personality profile assessments for hiring, leadership development, promotions, and team placement.

Other industries have begun using human factors for other purposes such as reducing employee turnover, hiring, promoting, team building, and or leadership development in the health care industry (Johnson et al. 2011), tourism industry (Sohn and Lee 2012), or in general (Žiaran 2015). Several studies have analyzed the link between personality assessments and different construction activities in the construction industry. For example, different personality traits of project managers can have a different impact on project managers' perception of risk tendency (Wang et al. 2016), career development Madter et al. (2012), and project success Carr et al. (2002), or impacts of employee behavioral response to change initiatives on change outcomes (Maali et al. 2021) reaction These studies showed that personality measures are widely used in many industries.

The literature review of human factor assessments (HF) revealed multiple related assessments. However, based on the literature review, the study selected three well-developed and reliable assessments; HEXACO personality inventory (to measure personality), QDiSC-101 behavioral instrument (to measure behavioral response), and Emotional Intelligence Quotient (to measure emotionality). The HEXACO personality inventory was developed by Ashton and Lee (2009) is one of the most reliable assessments of personality inventories Gao et al. (2020). the HEXACO Personality Inventory assesses 6 different personality dimensions: Honesty-Humility (H), Emotionality (E), Extraversion (X), Agreeableness (A), Conscientiousness (C), and Openness (O).

The QDisc-101 Behavioral Assessment used in this study was developed by Dr. Avi Wiezel, who derived it from the four-quadrant behavior diagnostic tool from Jones & Hartley (2013). Studies have shown that using this tool improves office relationships (Scarbecz 2007) as a predictor of employee retention and job success (Deviney et. al. 2010). The tool provides information about behavior priorities and preferences at the workplace by assigning participants to one of the four quadrants (Dominant - D, Inspiring - I, Supportive - S, and Cautious – C by providing scores of work orientation (task vs. people) and communication style (reserved vs. assertive).

The Emotional Intelligence Quotient (EQ) by TalentSmart (2011) provides scores measured on a scale of 1 to 100 for overall emotional intelligence and other four emotional skills, including self-awareness, self-management, social awareness, and social management. This assessment was validated across many industries and job functions (Sunindijo and Hadikusumo 2014).

Methodology

Research Objective

The research objective was to identify differences in HF scores between each of the four job roles of SMACNA participants. Understanding the differences between roles is helpful in scenarios when an employee is transitioning between roles or being promoted to another role. It is also beneficial when interviewing new candidates who may be qualified “on paper” because the company might be more likely to find the best “fit” candidate based on the needs of the job role.
The first research objective was accomplished by reviewing the results of the human factors assessment for all participants in each job role. The results for each job role were analyzed to find statistically significant differences. The Human Factors Assessment section of this paper describes the human factors assessment in greater detail. This paper's Results and Discussion section describes the

differences in each combination of job roles (FL vs. PM, FL vs. VDC, FL vs. EST, PM vs. VDC, PM vs. EST, and EST vs. VDC). Several takeaways are recommended based on the specific differences found between the roles. A pilot study was commissioned by the New Horizons Foundation (NHF) on behalf of the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) to achieve research objectives.

Data Collection

A total of 182 participants from 10 companies across the country volunteered to complete the HF Assessment. The participants were from four job roles Project Managers (PMs), Field Leaders (FLs), Estimators (ESTs), and Detailers (VDCs). Table 1 shows the count of participants by their job role.

Table 1

Number of participants by Job Role

Job Role Participants	Number of practicians
Project Managers (PMs)	42
Field Leaders (FLs)	88
Estimators (ESTs)	25
Detailers (VDCs)	27
TOTAL	182

The following job role descriptions were used in this study; *Project Managers (PMs)*: Responsible for the contract administration and performance of awarded projects and marketing the company's services. *Field Leaders (FLs)*: Drives field outcomes in labor production, quality control, and resource management to consistently deliver strong results in areas where they have control. Works closely with the PM to ensure timely delivery of tools, information, and material to support production. Note: the FL role included volunteers that typically had one of the following job titles: foreman, general foreman, superintendent, field executive, or a similar job title. *Estimators (ESTs)*: Responsible for coordinating the mechanical and HVAC bid process by leading the preparation and assembly of major estimate items. *Detailers (VDCs)*: Responsible for the layout of HVAC and mechanical items (ductwork, piping, plumbing, equipment, controls, etc.) by creating a constructible model. It is noted that all data collection took place during Fall 2020, amid the COVID-19 pandemic, which may have impacted the number of responses.

Human Factors Assessment

Participants completed the human factors (HF) instrument, which includes a composite of three assessments, including HEXACO personality inventory (a measure of personality), QDiSC-101 behavioral instrument (a measure of behavioral response), and Emotional Intelligence Quotient (a measurement of emotionality).

HEXACO Personality Inventory

There are domains and sub-domains of the HEXACO personality inventory. *Honesty-Humility (H):* contains the sub-domains of Sincerity, Fairness, Greed Avoidance, and Modesty. Typical personality descriptors include sincere, honest, faithful, loyal, modest/unassuming *versus* sly, deceitful, greedy, pretentious, hypocritical, boastful, pompous. *Emotionality (E):* contains the sub-domains of Fearfulness, Anxiety, Dependence, and Sentimentality. Personality descriptors include emotional, oversensitive, sentimental, fearful, anxious, vulnerable *versus* brave, tough, independent, self-assured, stable. *Extraversion (X):* contains the sub-domains of Social Self-Esteem, Social Boldness, Sociability, and Liveliness. Personality-descriptors include outgoing, lively, extraverted, sociable, talkative, cheerful, active *versus* shy, passive, withdrawn, introverted, quiet, reserved. *Agreeableness (A):* contains the sub-domains of Forgivingness, Gentleness, Flexibility, and Patience. Personality-descriptors include patient, tolerant, peaceful, mild, agreeable, lenient, gentle *versus* ill-tempered, quarrelsome, stubborn, choleric. *Conscientiousness (C):* contains the sub-domains of Organization, Diligence, Perfectionism, and Prudence. Personality descriptors include organized, disciplined, diligent, careful, thorough, precise *versus* sloppy, negligent, reckless, lazy, irresponsible, absent-minded. *Openness (O):* contains the sub-domains of Aesthetic Appreciation, Inquisitiveness, Creativity, and Unconventionality. Personality-descriptors include intellectual, creative, unconventional, innovative, ironic *versus* shallow, unimaginative, conventional. Each domain and subdomain are measured on a scale of 1 to 4. However, higher scores are not necessarily better or worse when compared to lower scores. It instead represents a score on a spectrum (ranging from the low to the high side) of any personality domain or subdomain.

Emotional Intelligence Diagnostic

This instrument measures four emotional skills. *Self-Awareness:* the ability to understand your emotions as they happen. *Self-Management***:** the ability to control your emotional reactions. *Social Awareness*: the ability to understand other people's emotions (even if you do not share the same feelings). *Social Management:* the ability to use emotional awareness to create more successful interactions. In addition to the overall Emotional Intelligence score, all emotional skills are measured on a scale of 1 to 100.

QDisc-101 Behavioral Assessment

This instrument measures four behavior types. *Dominance (D)*: associated with control, power, and assertiveness. Actions are focused on accomplishing results. Individuals with high D scores are perceived as demanding, determined, and pioneering. *Influence (I)*: associated with social interaction skills and communication. Actions are focused on building relationships and persuading others. Individuals with a high I score are perceived as convincing, magnetic, and optimistic. *Steadiness (S)*: associated with patience, resilience, and thoughtfulness. Actions are focused on compliance and cooperation. Individuals with high S scores are perceived as calm, stable, and unemotional. *Compliance/Conscientious (C)*: associated with structure and organization. Individuals with high C scores are perceived as cautious, precise, and tactful. The above-listed behavior types in DISC are determined by two sub-scales; *Work Orientation*: rated on a scale ranging from -4 to 4 (-4= task-oriented; 4 = people-oriented), and *Communication Style*: rated on a scale ranging from -4 to 4 (-4= reserved communication; 4 = open-style communication).

Method of Analysis

Data analysis was performed in three steps. First, the Kruskal-Wallis H test was used to determine whether there were any differences in the HF scores between the four job roles. Second, post hoc tests using Dunn’s (1964) procedure with a Bonferroni correction were performed for multiple comparisons between the four job roles. Finally, Descriptive analysis of and percentage difference of significant results were performed to present and better interpret the results.

Results & Discussion

The Kruskal-Wallis H test was conducted to determine differences in the HF assessment scores between the four job roles. Visual inspections of boxplots between the four job roles across all HF instrument scores were similar. Table 2 list 11 HF scores that had significant ($p < .05$) Kruskal-Wallis H test results (median HF score was statistically significantly different between groups of job role) and the corresponding results of post hoc test results.

Table 2

Post Hoc test results of significant different HF scores

HF Assessment	Post-Hoc Test Result (pairwise comparison)
Fairness	Significant between FLs and PMs, and between FLs and ESTs
Greed-Avoidance	Significant between FLs and ESTs
Modesty	Significant between FLs and PMs
Dependence	Significant between PMs and VDCs
Sentimentality	Significant between PMs and VDCs
Prudence	Significant between PMs and ESTs
Openness	Significant between FLs and VDCs
Aesthetic Appreciation	Significant between FLs and VDCs
Inquisitiveness	Significant between FLs and ESTs
Creativity	Significant between PMs and VDCs
Unconventionality	Significant between FLs and VDCs

Overall Differences across the Human Factors Assessment

There were no significant differences between the roles at the overall emotional quotient level or within any of the sub-skills for the Emotional Intelligence Diagnostic. For the Q-DISC 101 Behavioral Assessment, there were no significant differences between the roles for communication style and work orientation. However, for the HEXACO Personality Inventory, there were several significant differences ($P < .05$) between the four job roles at the domain level (e.g., H, E, X, A, C, O scores) and at the sub-domain. These differences are described below.

Specific Differences between the Four Job Roles

Each combination of job role pairings is described below to highlight the statistically significant differences. Discussion of specific meaning for each pairing is also included to provide practical guidance on how the industry may apply the results.

Field Leaders (FLs) vs. Project Managers (PMs)

There was only one difference between FLs and PMs in a single area of the Honesty-Humility domain. On average, FLs had Higher Modesty (+11%) than PMs, which means FLs tend not to consider themselves superior to others or entitled to privileges that others do not have. Instead, they see themselves as ordinary team members to a greater extent than PMs. Conversely, PMs tend to recognize their role in overseeing the project's well-being. Although there were minimal HF differences, companies should monitor instances where a FL transitions to the PM role and ensure the individual is willing to take on the different perspectives and responsibilities of the position.

Field Leaders (FLs) vs. Detailers (VDCs)

There were three differences between FLs and VDCs, all in the same domain. On average, FLs tended to have Lower Openness to Experience (−9%) than VDCs, including Lower Unconventionality (which corresponds with FLs tending to stick with "tried-and-true" ideas and avoid unconventional, radical, or unusual ideas to a greater extent than VDCs) and Lower Aesthetic Appreciation (which means FLs tend to see beauty in simplicity and typically prefer simple solutions over complex ones). This means that if a FL is transitioning to a VDC role, they should be encouraged to use their field expertise to think "outside-the-box" in their new role more than they might be accustomed to. For example, FLs who are great problem-solvers are likely candidates to successfully build on this strength when transitioning to a VDC role. It should be noted that at least one company that participated in this study also has tested for visual-spatial skills when moving individuals from the field into a BIM/VDC/Detailer role. The purpose of this test is to understand the individual's ability to "see" in 3-dimensions and work in model space.

Field Leaders (FLs) vs. Estimators (ESTs)

There were three differences between these roles in different sub-domains; (1) On average, FLs had Higher Greed-Avoidance (+10%) than ESTs, which means FLs tend to be relatively less motivated by social-status considerations, (2) FLs had Lower Fairness (−7%) than ESTs, which means that ESTs are scrupulous about not bending the rules, and (3) FLs had Lower Inquisitiveness (−12%) than ESTs, which means FLs are focused on getting work done quickly and have less curiosity about stopping to uncover why things are the way they are. The opposing differences in Greed-Avoidance and Fairness seem to balance out, especially since both are part of the Honesty-Humility (H) domain. Moreover, the lower Inquisitiveness of FLs seems reasonable given their role of leading the production in the field.

Project Managers (PMs) vs. Detailers (VDCs)

There were three differences between PMs and VDCs. Two of these differences were in the Emotionality (E) domain and the third was in the Openness to Experience (O) domain; (1) On average, PMs had Higher Dependence (+29%) than VDCs, which corresponds with a solid ability to identify difficulties or challenges and share that information with others who can provide helpful feedback and collaboration. (2) PMs had Higher Sentimentality (+15%) than VDCs, which means that VDCs tend to rely less on emotional intuition and personal relationships when making business decisions. And (3) PMs had Lower Creativity (−14%) than VDCs, which corresponds with a greater tendency to stick to what works as the "tried-and-true" is their preferred way forward. PMs of course still have problem-solving skills but typically will not rock the boat by trying to solve problems in a new, different, or experimental way. This means that PMs who have shown creativity, innovativeness, and ability to "think-outside-the-box" may be more successful candidates transitioning to a VDC role. Conversely, VDCs who show strong relationship-building skills may have a greater likelihood of success in moving to a PM role.

Project Managers (PMs) vs. Estimators (ESTs)

There was only one difference in a sub-area of the Conscientiousness (C) domain. On average, PMs had Lower Prudence (−7%) than ESTs. This means that ESTs are less likely to act on impulse and tend to be cautious and carefully consider their options. PMs, conversely, are better equipped to act on a “gut-feeling” without needing to pause to analyze the possible consequences. This means that PMs who transition into a full-time EST role may be more successful if they have a history of being cautious, non-impulsive, and highly measured in their actions compared with their peers. ESTs who move to a PM role may be encouraged to act decisively and prudently in the project's best interest, given the number of stakeholders who may be awaiting their input. Yet overall, it is not surprising to see minimal differences between PMs and ESTs, given that PMs often have substantial estimating responsibility (such as providing input on bids or when handling change orders)

Detailers (VDCs) vs. Estimators (ESTs)

There were no differences among the 37 human factors characteristics used in this study. This could be due to the relatively smaller sample sizes collected for VDCs and ESTs. Gaining additional participation in the future may reveal differences between these roles.

Conclusion

There were differences in HF characteristics between all job roles (except EST vs. VDC, which may be due to the smaller sample sizes in these two roles). The information obtained from the human factors HF instrument is helpful for contractors who are evaluating: (1) New-hire candidates, where the candidate can be asked interview questions that explore their “fit” for the distinctive traits of the job role they are interviewing for. (2) Current employees who are transitioning between roles (moving from FL to PM, for example): the employee can better understand their “match” or “fit” for the new job role and can be coached to develop the strengths that will be most helpful in performing the new role. Given that this study was conducted at a pilot scale with a limited number of participants, future research is recommended to expand the data pool and investigate distinguishing characteristics between the four job roles and other additional roles.

References

Ashton, M. C., & Lee, K. (2009). The HEXACO-60: A short measure of the major dimensions of personality. Journal of Personality Assessment, 91, 340-345.

Carr, P. G., De La Garza, J. M., and Vorster, M. C. (2002). “Relationship between Personality Traits and Performance for Engineering and Architectural Professionals Providing Design Services.” Journal of Management in Engineering, 18(4), 158-166.

Childs, B., Weidman, J., Farnsworth, C., & Christofferson, J. (2017). "Use of Personality Profile Assessments in the U.S. Commercial Construction Industry." *ASC International Journal of Construction Education and Research*, 13(4), 267-283.

Delaney, J. T., and Huselid, M. A. (1996). “The Impact of Human Resource Management Practices on Perceptions of Organizational Performance.” *Academy of Management Journal*, 39(4), 949-969.

Deviney, D., Mills, L. H., and Gerlich, R. N. (2010). “Environmental Impacts on GPA For Accelerated Schools: A Values and Behavioral Approach.” *Journal of Instructional Pedagogies*, 3.

Druker, J., White, G., Hegewisch, A., and Mayne, L. (1996). “Between Hard and Soft HRM: Human Resource Management in the Construction Industry.” Construction Management & Economics, 14(5), 405-416.

Dunn, O. J. (1964). "Multiple comparisons using rank sums." Technometrics, 6(3): 241-252.

Ericksen, J., and Dyer, L. (2005). “Toward a Strategic Human Resource Management Model of High Reliability Organization Performance.” *The International Journal of Human Resource Management*, 16(6), 907-928.

Gao, Y., González, V. A., and Yiu, T. W. (2020). “Exploring the Relationship between Construction Workers’ Personality Traits and Safety Behavior.” Journal of Construction Engineering and Management, 146(3).

Johnson, M. K., Rowatt, W. C., and Petrini, L. (2011). “A New Trait on the Market: Honesty–Humility as a Unique Predictor of Job Performance Ratings.” Personality and Individual Differences, 50(6), 857-862.

Jones, C.S. and Hartley, N.T. (2013) “Comparing Correlations Between Four-Quadrant And Five-Factor Personality Assessments” *American Journal of Business Education*, July/August 2013, Vol 6, No. 4, pp. 459 – 470.

Loosemore, M., Dainty, A., and Lingard, H. (2003). Human Resource Management in Construction Projects: Strategic and Operational Approaches. Taylor & Francis Group.

Maali, O., Lines, B., Smithwick, J., Hurtado, K., & Sullivan, K. (2020). “Change management practices for adopting new technologies in the design and construction industry*”. Journal of Information Technology in Construction*, 25, 325-341.

Maali, O., Shalwani, A., Lines, B., Sullivan, K., & Perrenoud, A. (2021). A Spectrum of Employee Reactions to the Adoption of Organizational Changes in the AEC Industry. *EPiC Series in Built Environment*, 2, 91-99.

Madter, N., Bower, D. A., and Aritua, B. (2012). “Projects and Personalities: A Framework for Individualising Project Management Career Development in the Construction Industry.” International Journal of Project Management, 30(3), 273-281.

Raidén, A. B., and Dainty, A. R. (2006). “Human Resource Development in Construction Organisations.” *The Learning Organization*.

Scarbecz, M. (2007). “Using the DISC System to Motivate Dental Patients.” The Journal of the American Dental Association, 138(3), 381-385.

Sohn, H. K., and Lee, T. J. (2012). “Relationship Between HEXACO Personality Factors and Emotional Labour of Service Providers in the Tourism Industry.” Tourism Management, 33(1), 116-125.

Sunindijo, R. Y., and Hadikusumo, B. H. (2014). “Emotional Intelligence for Managing Conflicts in the Sociocultural Norms of the Thai Construction Industry.” Journal of Management in Engineering, 30(6).

Tabassi, A. A., and Bakar, A. A. (2009). Training, motivation, and performance: The case of human resource management in construction projects in Mashhad, Iran. *International Journal of Project Management,* 27(5), 471-480.

TalentSmart (2011). Emotional Intelligence Appraisal Teaching Manual. San Diego, CA:TalentSmart.

Wang, C. M., Xu, B. B., Zhang, S. J., and Chen, Y. Q. (2016). “Influence of Personality and Risk Propensity on Risk Perception of Chinese Construction Project Managers.” International Journal of Project Management, 34(7), 1294-1304.

Wiezel, A., Sullivan, K., Gunnoe, J., and Perrenoud, A. (2016). “Best Practices for Project Manager Succession.” CII Research Report 325-1. *Construction Industry Institute*.

Žiaran, P. (2015). “Humility and Self-Esteem as Key Predictors of Ethical Attitude in Leadership.” Procedia Economics and Finance, 34, 689-696.

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Development; An exploratory investigation into the underlying perceptions influencing soft skills training and development participation and decision-making

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Abstract

The purpose of this study was to explore the factors that influence training and development participation from an employer and employee perspective. A mixed-methods research approach was used to uncover underlying perceptions among employers and employees in relation to soft skills training and development participation decision-making. The employer's perspective was based on semi-structured interview data from market leading international construction companies. This was triangulated with survey data from the employee's perspective to generate richer insights. Results suggested a lack of priority among leadership is the main barrier to soft skills training and development for employees, primarily because of the perception of its worth and a lack of time to release employees for training. The research indicates a critical role for leadership to take a lead in enabling soft skill training and development beyond the management layer and allow wider access across the organization. Ongoing training and development in soft skill competencies should be consistently incorporated into the training and development strategies across all levels and disciplines to enhance individual employee productivity as well as overall organizational performance. Furthermore, the findings bring to light the need to measure and link soft skills training and development to individual and organizational performance indicators.

Keywords: soft skills, training and development, leadership, participation, decision-making

Introduction

Human resources are universally accepted as the most valuable asset in today's corporate world. Companies worldwide invest in training and development initiatives to increase employee productivity, organizational effectiveness and competitive advantage (Aguinis & Kraiger, 2009). Several studies have found that organizations spend 85% of their training and development budgets on job-specific, technical or hard skills training, with the remaining 15% on soft skills (Wesley et. al., 2017). However, a report published by Development Economics Ltd. (2015) highlighted that the lack of investment in softs skills training and development will have a long-term negative impact on organizational performance, if not addressed adequately (Clarke, 2016). Based on their initial calculations for the UK, a soft skills deficit will cost the economy GBP 8.4 billion per annum.

In recent years, it has been established that hard skills alone are not enough for organizations to deliver sustained competitive advantage (James & James, 2004). While organizations continue to invest most of their budgets in hard skills training and development, there is a growing recognition that soft skills are an increasingly vital complement to hard skills in organizations. Identifying the factors that influence the decision-making related to soft skills training and development participation becomes critically important for organizations to develop the necessary organization wide soft skill capabilities that will ensure endurable individual and organizational performance as well as sustainable competitive advantage.

The purpose of this paper is to explore the factors that influence training and development participation decision-making from an employer and employee perspective.

Soft Skills

The concept of soft skills has been widely used in both academic and professional contexts for many years (Robles, 2012). Soft skills are generally described in terms of interpersonal abilities and personal qualities and are frequently referred to as people skills. Maniscalco (2010) referred to soft skills as a cluster of qualities, personal traits, attitudes and habits that everyone possesses, although in varying degrees. In the literature, there is much debate about the exact definition of soft skills. However, no universally agreed definition is available and several interpretations of the soft skills concept are applied (Wesley et. al., 2017). The most important soft skills identified in the literature include communication, interpersonal or social skills, people management, leadership, negotiation, time management and problem-solving (Crawford et al., 2011; James & James, 2004).

Hard Skills versus Soft Skills

Organizations nowadays require employee skills that are generally categorized as hard skills and soft skills. Whereas hard skills refer to technical knowledge or procedural skills, the term soft skills refers to the interpersonal and social skills and attitude that can make someone a compatible employee or team worker (Maniscalco, 2010). Traditionally, the view was held that hard skills should take precedence over soft skills (Evenson, 1999). Some senior executives nowadays still assert that soft skills are of very little use or very little value to the organization (Onisk, 2011). The main rationale for this is based on the assumption that hard skills are often considered to be specific, teachable and transferrable abilities that can be precisely defined, described and measured (Yen et. al., 2001). Contrary, soft skills are frequently regarded as less tangible, harder to define and more difficult to quantify (Bronson, 2007). For example, soft skills such as communicating, listening, interacting with people and managing people play a large role in organizations and are considered valuable skills but can be difficult to define and measure. However, for organizations to remain competitive employees must develop advanced soft skills in addition to hard skills. As such, soft skills can be considered as core employee skills or key competencies, according to Gibbons and Lange (2000).

Importance of Soft Skills in Organizations

Academics and practitioners agree that both hard skills and soft skills are important to improve employee productivity and organizational performance. Lopes, Cote and Salovey (2006) examined the relationship between soft skills and performance at work. They found that the abilities associated with employee's emotional intelligence can contribute directly to improvement in individual performance in the workplace. Particularly, soft skills such as interpersonal skills, communication, effective influencing, conflict management, negotiation skills and stress management skills show a strong correlation (Lopes, Cote & Salovey, 2006). Several authors maintained that a focus on only developing the hard skills results in employees being overly task-oriented and rule-adherent, which in turn can have a major impact on interpersonal skills development and diminish relationship and initiative-driven skills. Bailly and Léné (2013) asserted that organizations must focus on the development of employee soft skills to personify organizational processes that involve people and to optimize interactions with external parties such as customers, suppliers and other stakeholders. Additionally, Muzio et al. (2007) insisted that an excessive dependence on hard skills, at the expense of soft skills may ultimately threaten an organization's future.

Factors Influencing Training and Development Decisions

While the potential benefits of training and development are widely acknowledged in the literature, few insights exist regarding the factors that influence the decision-making associated with soft skills training and development participation. Traditionally, the main factors influencing training and development decisions were essentially time and money (Marlow, 1998). Aguinis and Kraiger (2009) argued that the key factors influencing training and development decisions include competency development, productivity increase and performance improvement. Other important factor include organizational Human Resources and Training policies, the introduction of new technologies, procedures and processes (Salas & Stagl, 2009) and employee-related factors such as employee's age, self-belief and attitude or motivation towards training and development (Maurer, Weiss & Barbeite, 2003). Susomrith and Coetzer (2013) further identified that employees themselves influence training and development decision-making by seeking information, selecting and suggesting training opportunities to their managers.

Challenges to Soft Skills Training and Development Participation

Several challenges and barriers to training and development have been identified from an employer's perspective, including the cost of training and development, the associated opportunity cost, the lack of suitable training and development opportunities, risk of post-training employee resignation as result of upskill and the (negative) attitudes of management towards professional training and development initiatives (Coles et. al, 2002; Storey & Greene, 2010).

The specific challenges and barriers identified in the literature related to soft skills training and development in organizations are limited and are mainly associated with the problematic transfer of the newly acquired soft skills (Burke & Hutchins, 2007; Laker & Powell, 2011). For example, the authors highlight that where soft skills refer to intrapersonal or interpersonal skills regarding interactions with others, the transfer of such skills is difficult to design, deliver and measure. However, White (2005) observed that organizations often do not consider soft skills training and development activities a priority. Ibrahim et. al (2017) also suggested that organizations generally do not recognize the importance of soft skill training and development on the organizational and employee performance.

Study Design

The primary objective of this study was to explore the factors that influence training and development decision-making in relation to professional soft skills training participation, from an employer perspective as well as an employee perspective. To achieve this, a mixed-methods research design was adopted. Creswell (2013) recommended the application of this research design to confirm, cross-validate or corroborate findings and is particularly useful when expanding qualitative data with quantitative data. The ability to compare, contrast and weave data from the employer and employee perspective allowed for richer empirical data analysis.

Employer Perspective

A qualitative approach was applied to collect data from the employer's perspective. Participants were drawn from a sample of successful, market leading international construction companies with their head offices in Ireland. Three participants were selected with senior Human Resources Management experience and with substantial involvement in the decision-making relating to training and development participation of employees in their respective organizations. Data collection was based on one-to-one semi-structured interviews to explore the factors that influence soft skills training and development participation decision-making in organizations in more depth. The initial data analysis of the semi-structured interviews included an assessment of the interview responses to identify any specific patterns within the collected data. The participants' interview transcripts were analysed systematically to assess the gathered data and to observe similarities and differences between individual responses.

Table 1

Qualitative data collection themes for semi-structured interview guide
1. Introduction
2. Training and development
3. Factors influencing Training and development
4. Importance of Soft Skills Development
5. Impact on performance
6. Barriers to Soft Skill Training and development participation
7. Close Interview

Employee Perspective

A quantitative research approach was adopted to collect data from the employee perspective. The data collection method was based on survey among participants that attended soft skills training courses with a training company in Dublin. The participants were requested to complete a questionnaire about several factors relating to their training participation. The final sample in this research was based on 104 completed and valid questionnaires. The survey data was tabulated into numerical form using Microsoft Excel and transferred to the Statistical Packages for Social Sciences (SPSS, version 24.0) software for statistical analysis.

Table 2

Qualitative data questionnaire question categories
1. Main reason to attend training course
2. Who made decision to attend training course
3. Assessment of training need
4. Reason to select training course
5. Outcome of training course
6. Benefits from attending training course
7. Impact of training measured
8. Main barriers to training participation
9. Anything else

Findings and Analysis

The research findings reveal that training and development in general is considered very important due to the nature of the industry and the projects. However, soft skills training and development among the participating companies does not receive sufficient time and budget allocation.

Training and Development Strategy

While all participating companies indicated to maintain a training and development strategy, in Walls training and development is considered a critical aspect for the ongoing development of existing employees as well as attracting new employees. In SISK organizational productivity and performance is based on five pillars, which include Value, Zero, People, Performance and Partners. The ‘People Pillar’ incorporates the company’s Training Strategy and is designed to support its people to deliver on its corporate and functional strategies. Hegarty does not have a formal training and development strategy but maintains a company-wide training plan. Yet, the company has a big focus on employee development that can directly contribute to improving the organizational performance. The research findings showed that all participating companies coordinate their training and development plans and policies centrally. This is broadly in line with the extant literature, which suggests that if a training and development Strategy is incorporated into the organization’s overall strategy it is expected to deliver direct benefits to the organization (McAdam & McClelland, 2002). Pearce and Robinson (2005) also affirm that a company-wide integrated training and development approach can increase productivity, quality of work and employee motivation.

Role of Leadership

All participating companies highlighted that the role of the leadership is significant in relation to training and development initiatives in their organizations. Walls explains that the senior management team is heavily engaged in the training and development initiatives. The company has a training and development committee that leads the training and development initiatives across the company and consists of 12 members from across all divisions who meet once a month, chaired by the Construction Director. The SISK board plays a very active role in training and development activities which then cascades down to divisional, departmental and director level. Generally, the direct line manager is the primary decision maker in relation to training and development courses. Hegarty outlined that the role of the leadership in relation to training and development depends on the specific training intervention. For example, higher level training requirements are discussed at director level and require their approval, while Human Resources signs off on smaller, shorter courses, such as manual handling or first aid training.

The literature does not provide much insight about the role of the leadership in relation to the training and development initiatives in organizations. Úbeda-García et al. (2013) found that organizational training policies are one of the primary ways for organizational leadership to influence training and development activities. While this study showed that leadership in the participating organizations played an active role in the training and development decision making, the employee respondents indicated that they themselves made the decisions to attend the training course. This difference may be explained by the type of course and the level of seniority of the respondents attending the soft skills training.

Importance of Soft Skills Training and Development

The research findings from the participating companies suggested that soft skills training and development is considered important but currently does not receive sufficient attention. Walls outlined that soft skills are very important for the company, yet its profile needs to be raised. Walls also noted that with promotions of people into management roles deficiencies arise in relation to the softer people skills. Therefore, Walls Group is looking to increase the importance and focus of soft skill competency development across the company. SISK confirmed that people management and communications skills are vital, as it allows people to work better with other people within the company, clients and contractors. Hegarty asserted that while soft skill training and development is important, the company could do more of. Hegarty's primary focus is on the technical, hard skills, because they provide the necessary certification for the employees to do their jobs. Yet, soft skills are becoming increasingly important and the company is expected to increase soft skills training.

Organizational Culture Change

Walls stated that soft skills training and development are paramount in the context of Walls' culture change efforts. Walls increased its turnover from €85 million to €250 million in the past four years and hired many new recruits in the past 18 months. This rapid growth did not go 'without growing pains' and the company needed to support the line managers and new recruits at all levels to make this cultural shift; soft skills are considered a key part of this. SISK highlighted that enhancing people skills is critical in the construction industry overall, because working better with people will increase not only individual productivity but also team productivity. A range of soft skills can benefit staff such as communication skills, time management and better manage the workload. Hegarty pointed out that if they can develop managers' soft skills this without doubt will lead to a change in the 'old-school mind-set', through a more fluid workplace and increased openness, which can contribute to the overall culture change in the company.

Gibbons and Lange (2000) have suggested that soft skills should be considered a key competency and critical to an employee's core skills set. Lopes, Cote and Salovey (2006) also highlighted a strong relationship between soft skills and improved staff performance. While the research findings suggested that soft skills training and development is considered important, all participating companies acknowledge that they could do more. The companies also recognized the potential benefits in support of productivity improvement, employee motivation and cultural change. Yet, soft skills training and development is not being prioritised by the participating companies, even though there is recognised that soft skills can help to more effectively utilize employee's hard skills. This is consistent with the findings of Bronson (2007) suggesting that soft skills are often regarded as less tangible, harder to define and more difficult to measure. White (2005) also indicated that organizations often do not consider soft skills training and development a priority. However, the participating companies indicated that they are considering increasing the focus on soft skills training and development initiatives in the future.

Barriers to Soft Skills Training and Development Participation

The research found that the most important barrier to soft skills training and development among the participating companies was the lack of time. Walls explicitly mentioned that making time available is the biggest challenge. Furthermore, Walls highlighted cost as a major challenge, because builders are typically very cost conscious and generally don't want to spend any money. SISK outlined that the support of the line managers is one of the main barriers. For example, the challenge with training and development participation is the release of employees by their line managers. Often an urgent concrete pour, last minute delivery or lack of advance planning cause curve balls and can prevent the release of employees for training. Hegarty highlighted that one of the main barriers is generational, summarized by 'sure it hasn't caused any issues yet' or 'it has never been a problem before.' In addition, the younger generation is led by (older) managers with more traditional views and 'old-school vibes.' which can cause a barrier to soft skill training and development participation.

The research from both the participating companies and the respondents survey indicated that the most important challenge to soft skills training and development participation was the lack of time. These results are in line with the literature, as Susomrith and Coetzer (2013) indicated that commonly experienced challenges to soft skills training and development participation include the lack of time and the cost of the training. Furthermore, Ibrahim et al. (2017) asserted that the line-manager can be the barrier to soft skill training and development, especially if the manager does not recognize its importance. Susomrith and Coetzer (2013) found that the negative attitudes of management towards training and development participation can be a barrier. Storey and Greene (2010) also reported that the negative attitudes of management towards professional training and development initiatives can be a barrier to training participation. While it is not clear whether this attitude is specific to the individual manager or the organization overall, Hegarty did outline that the main barrier in their organization is culture.

Due to the restricted word count of the ASC formatting guidelines all the qualitative findings and SPSS statistical analysis results are not included and therefore the richness of the data could not be fully leveraged.

Reflection and Recommendations

The results of this study have several important implications for organizational leadership and senior management. First, the research indicates that a key factor influencing the soft skills training and development participation decisions is the lack of priority related to soft skills development among leadership. Although companies incorporate a formal training and development strategy, the current focus of the training plans is centred around hard skill competencies. As such, the overriding conclusion is that the leadership should take a lead in enabling soft skills training and development participation beyond the management layer and make it accessible to all employees across the organization. Ongoing training and development in soft skill competencies should be consistently incorporated into the formal training and development strategy and individual training plans across all levels and disciplines in the organization.

Second, the results emphasize that a key factor influencing the soft skills training and development decision is the requirement to promote a company-wide soft skills training and development culture. This is particularly paramount with regards to the current perception of the worth of soft skill training and development in the ‘hard’ construction industry. The leadership should impress the importance of soft skills training and development upon its senior managers and actively support the development of soft skills, such as negotiation skills, time management and communication skills. Particularly since it is recognized that these advanced competencies can significantly improve individual performance, contribute to client projects and drive overall performance.

Third, one of the most fundamental factors influencing the soft skills training and development participation decisions that arises from this research is the ability to successfully retain and engage employees. While this study highlights that hard skills training and development decision are generally influenced by market needs, client-project and competitive needs, soft skills training and development initiatives are typically initiated by employees themselves. Therefore, the leadership has a very desirable opportunity to leverage employee soft skills training and development participation to simultaneously increase competency development, performance improvement and employee retention.

Finally, the findings brought to light that training and development participation is not directly measured or linked to individual or organizational performance indicators. Therefore, it is critical for the leadership to link soft skills training and development initiatives directly to individual and organizational performance. The leadership should incorporate this in their organization’s formal appraisal and performance management or personal development program.

References

Aguinis, H., & Kraiger, K. (2009). Benefits of training and development for individuals and teams, organizations, and society. *Annual review of psychology*, *60*.

Bailly, F., & Léné, A. (2015). What makes a good worker? Richard Edwards is still relevant. *Review of Radical Political Economics*, *47*(2).

Bronson, E. (2007). Career and technical education is ideally suited to teaching students the soft skills needed to succeed in the 21st century workplace. *Techniques: Connecting Education & Careers*, *82*(7).

Burke, L. A., & Hutchins, H. M. (2007). Training transfer: An integrative literature review. *Human resource development review*, *6*(3).

Coles, B., Hutton, S., Bradshaw, J., Craig, G., Godfrey, C., & Johnson, J. (2002). Literature review of the costs of being" not in education, employment or training”.

Clarke, M. (2016). Addressing the soft skills crisis. *Strategic HR Review*, *15*(3), 137-139.

Crawford, P., Lang, S., Fink, W., Dalton, R., & Fielitz, L. (2011). Comparative analysis of soft skills: What is important for new graduates. *Washington, DC: Association of Public and Land-grant Universities*.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications, Incorporated.

Evenson, R. (1999). Soft skills, hard sell [Electronic version]. Techniques: Making Education & Career Connections.

Gibbons-Wood, D., & Lange, T. (2000). Developing core skills–lessons from Germany and Sweden. *Education+ Training*, *42*(1).

Ibrahim, R., Boerhannoeddin, A., & Bakare, K. K. (2017). The effect of soft skills and training methodology on employee performance. *European Journal of Training and development*, *41*(4).

James, R. F., James, M. L. (2004). *Teaching career and technical skills in a “mini” business world.* Business Education Forum.

Laker, D. R., & Powell, J. L. (2011). The differences between hard and soft skills and their relative impact on training transfer. *Human Resource Development Quarterly*, *22*(1).

Lopes, P. N., Cote, S., & Salovey, P. (2006). An ability model of emotional intelligence: Implications for assessment and training. *Linking emotional intelligence and performance at work: Current research evidence with individuals and groups*.

Maniscalco, R. S. (2010). The Impact of the European Policies on the New Skills for the New Jobs. *Review of European Studies*.

Marlow, S. (1998). So much opportunity–so little take up: the use of training in smaller firms. *Journal of Small Business and Enterprise Development*, *5*(1).

Maurer, T. J., Weiss, E. M., & Barbeite, F. G. (2003). A model of involvement in work-related learning and development activity: The effects of individual, situational, motivational, and age variables. *Journal of applied psychology*.

McAdam, R., & McClelland, J. (2002). Individual and team-based idea generation within innovation management: organizational and research agendas. *European Journal of Innovation Management*, *5*(2).

Muzio, E., Fisher, D. J., Thomas, E. R., & Peters, V. (2007). Soft Skills Quantification (SSQ) Foi Project Manager Competencies. *Project Management Journal*, *38*(2).

Onisk, M. (2011). Is measuring soft-skills training really possible. *Appcon: Sidney, Australia*.

Pearce, J. A., & Robinson, R. (2005). Strategic management: strategic formulation and implementation. *Irwin, Homewood*, *3*, 7.

Robles, M. M. (2012). Executive perceptions of the top 10 soft skills needed in today’s workplace. *Business Communication Quarterly*.

Salas, E., & Stagl, K. C. (2009). Design training systematically and follow the science of training. *Handbook of Principles of Organizational Behavior: Indispensable Knowledge for Evidence-Based Management, 2nd edn (Chichester: John Wiley & Sons)*.

Storey, D. J., & Greene, F. J. (2010). *Small business and entrepreneurship*. Financial Times/Prentice Hall.

Susomrith, P., & Coetzer, A. J. (2013). An exploratory study of factors influencing the participation in training and development of engineers in small businesses.

Úbeda-García, M., Marco-Lajara, B., Sabater-Sempere, V., & Garcia-Lillo, F. (2013). Training policy and organizational performance in the Spanish hotel industry. *The International Journal of Human Resource Management*, *24*(15).

Wesley, S. C., Jackson, V. P., & Lee, M. (2017). The perceived importance of core soft skills between retailing and tourism management students, faculty and businesses. *Employee Relations*.

White, P. R. (2005). http://www.appraisalinstitute.org/ Accessed 20 March 2019.

Yen, D. C., Lee, S., & Koh, S. (2001). Critical knowledge/skill sets required by industries: an empirical analysis. *Industrial Management & Data Systems*, *101*(8).

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Post-COVID Analysis on Workplace Design and Trend

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Abstract

Prior to the COVID pandemic, workspace design lowers workstation panels, densifies work seating, and increases spontaneous interaction to provide amenity spaces and engage community collaboration. As a recent response to COVID-19, workplaces were forced to shut down and allow employees to work in the comfort of their homes, allowing the opportunity to re-prioritize their use of time. There are mixed reviews on how employees respond to the work-from-home conversation. However, none of these responses address any of the design trends. This year-long social experiment of working from home informed the future. It provided a new outlook on what employees truly want in workplace design. This study aims to determine which environment allows workers the most productivity and which lifestyle they prefer. Survey and focus group methods were used in this research. The survey questionnaire was sent to the AED community to determine overall productivity, the value of office space amenities and resources, comfort for the personal and professional blend of life. Respondents were narrowed down to the AED (architectural, engineering, design) community to those knowledgeable and experienced in the design trends. Based on the research findings, the workplace would thrive from a normalized hybrid work culture where remotely perform routine tasks. The total elimination of a workplace site may be unrealistic. However, days would be best set at home for routine tasks accounting for most designers. Productivity is studied to be higher while accommodating for a better work-life balance.

1 Introduction

Before the 2020 cultural collapse, workplace design abused buzzwords such as spontaneous interaction, culture, employee health and well-being, and sustainability. Design strategies included lowering workstation panels and densified work seating to provide amenity spaces and engaging community areas. Collaboration and coworker friendship became an integrated component of the office culture routine. These recurring design techniques targeted comfort and unique environments to increase young professional employee interest and retention while reducing the footprint to facilitate. In the past year, work culture has been manipulated by COVID-19. As an initial response, essential workers are defined and encouraged to continue working in the danger zone, while other non-essential workers begin the new adventure of the work-from-home lifestyle. There are mixed reviews on how employees respond to the work-from-home conversation. However, none of these responses address any of the design trends investing research into the prior years. So why build these fashionable workplaces to accommodate our everyday work? Research into the future of workplace design alludes to minimal modification from current planning strategies. Articles written by designers and real estate brokers are dedicated to defending the importance of the historic investment in the densified sea of workstations showcasing a monumental stair and coffee bar rather than integrating the recent discovery in satisfaction of employees work from home lifestyle. The community is questioning the physical changes of de-densifying as short-term fixes (Vaughn, 2020), and is claiming open floor plans are the trend (Vicus Partners, 2021). The quick fix and future seem to fall into the same category, including further integration of technology and cleanable surfaces. As employees have gained experience working remotely during the pandemic, their confidence in their productivity has grown. The number of people who said they worked more productively increased by 45 percent from April to May (Lund, Madgavkar, Manyika, & Smit, 2021). It is acknowledged that water-cooler conversations, meetings, and social engagements are a distraction, whether enjoyed or wasteful, to employees (Delecourt, 2021). Relevant questions, for example, “Has working from home succeeded only because it is viewed as temporary, not permanent?” arise regarding the future of talent and that of a real estate crisis associated with a transition to work from home future. (Delecourt, 2021).

However, has anyone asked the question, why go back? Or, at least, instead of forcing this new way of life into our existing definition of the workplace, should we consider adapting our definition of workplace given this new work-from-home model? This year-long social experiment of working from home should inform the future and provide a new outlook on what employees truly want in workplace design. This study narrowed it down to the AED (architectural, engineering, design) community, to those knowledgeable and experienced in the design trends and benefits they are intended to provide. The survey questionnaire was sent to the AED community to determine overall productivity, the value of office space amenities and resources, comfort for the personal and professional blend of life. The objective is to determine which environment allows them the most productivity and which lifestyle they prefer.

2 Methods and Procedures

Survey and focus group methods were used in this research. The same criteria applied to all people eligible to participate in the research with the following assumptions. 1) This research cannot apply to careers such as general labor, healthcare, or education as they require physical interaction, not a desk-based job with this work-from-home opportunity. Participants were all within the AED community – architect, engineer, or designer to streamline this research to a specific sector. This defines an equal set of work activities, including drafting, creative collaboration with peers, material planning, and client presentations. This also sets a standard for people who understand and have experienced trendy workplace design. 2) Employees must have remained at their company throughout the work from the home era. This is important to eliminate any variability in transition except for the workplace shift and allow these employees to understand the typical office culture of this company compared to the new work-from-home style. 3) Employees must have worked from home for some time.

A questionnaire was developed to investigate productivity, overall satisfaction, and future work expectations by reducing the physical workplace. The questionnaire was administered through a service called SurveyMonkey (http://www.surveymonkey.com). The recipients of the questionnaire survey were obtained through social media, past coworkers, college classmates, and others within the geographically diverse AED community. Seven questions were asked in the survey, each item directly related to productivity, satisfaction, and future work expectations, as shown in Table 1.

#	Questions
1	While working from home, do you find your productivity is greater/lesser/or equal than in the office?
2	Do you find you work greater/lesser/or equal hours a week than in the office?
3	Do you find fewer/greater/or equal distractions at home than within the office?
4	Do you find your mental and physical health (directly correlated to your new working schedule and resources) has changed while working from home?
5	Do you find you are provided sufficient resources to communicate with your superior and project teams as needed while working from home?
6	Given the experience in both WFH and office, how would you prefer a typical work week for the future?
7	Have you or do you have a timeline for returning to the office?

Table 1: Questionnaire

The researchers reached out to seven people creating two zoom-based focus groups. Participants ranged at varying levels of experience, within different companies from Nashville to Philadelphia and from residential designers with four employees to commercial architects with over 4,000 global employees. For each focus group, the researcher introduced the discussion by asking about their satisfaction of work from home specifically targeting work/home balance, productivity, and overall well-being.

3 Results and Findings

Question 1: While working from home, do you find your productivity greater/lesser/or equal than in the office?

80% of respondents who took the survey felt that their productivity was equal or greater at home than within the office, as shown in figure1. Within the focus group, it was discussed that productivity has a new definition while working from home. It is expected in any work environment, employees take breaks. Instead of these breaks spent by casual coffee station conversation, integration of household chores and family interaction makes employees feel more productive even when they are not specifically focusing on their workplace tasks.

Question 2: Do you find your work greater/lesser/ equal hours a week than in the office?

Of this added productivity, 40% said they work greater hours, 35% equal, and 25% lesser, as shown in figure 2. From focus groups, the shortened workweek hours could be a direct product of the pandemic and reduction in staffing hours, or it could be that with the heightened productivity taking fewer hours to accomplish work. Those working more hours could be associated with the new flexible pace offered while working at home, or given the reduction in staffing, employees have to work the additional time to make up for the loss of coworkers. Within both focus groups, there was an extensive discussion on pace. As mowing the lawn and having lunch with their children became a part of the workday, it no longer is an 8-hour block of time dedicated to just working. There is a blur between working hours and personal hours, preventing employees from turning their computers off until later. The pace of completing work within the traditional working window is no longer relevant.

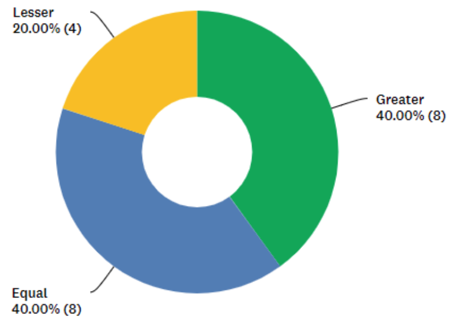

Figure 1: While working from home, do you find your productivity greater/lesser/or equal than in the office?

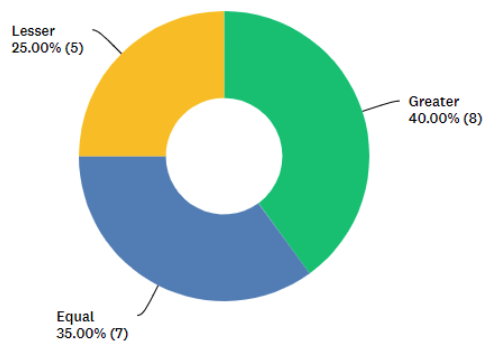

Figure 2: Do you find your work greater/lesser/ equal hours a week than in the office?

Question 3: Do you find fewer/greater/ equal distractions at home than within the office?

Half of the participants indicated that there were fewer distractions at home than within the workplace, as shown in figure 3. From discussions and questions further addressing clarifications and descriptions, people's primary distraction while working from home is children. However, it is noted that families experiencing this unusual teaching method for the year 2020 would not typically experience this or these associated distractions in the future. Another note was that of these distractions, they were primarily declared productive rather than fruitless.

Question 4: Do you find your mental and physical health (directly correlated to your new working schedule and resources) has changed while working from home?

The survey results in figure 4 show over half found better mental and physical health while working from home. In our era of digital resources, employees were able to hop on the Peloton or take an exercise class on Youtube rather than squeezing in a trip to the gym after a long commute, which has been primarily closed throughout this year. The additional and flexible time also allows people to prepare proper meals or take a break to walk their dog. A focus group participant described this newfound balance of personal health and work as a direct product of this work-from-home lifestyle. Mental health has changed with a reduction in stress for this additional productive time. Unanimously, those who live alone noted that the isolation was unhealthy for their well-being. Those living in larger cities also noticed a decrease in physical activity when eliminating their commute to work.

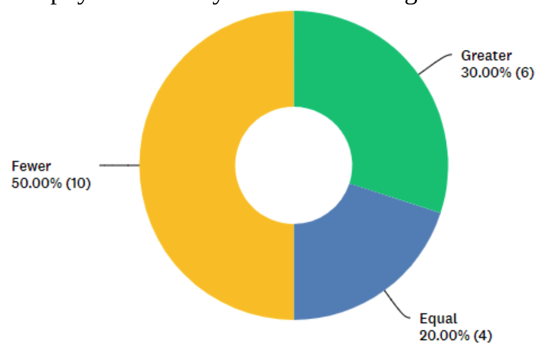

Figure 3: Do you find fewer/greater/or equal distractions at home than within the office?

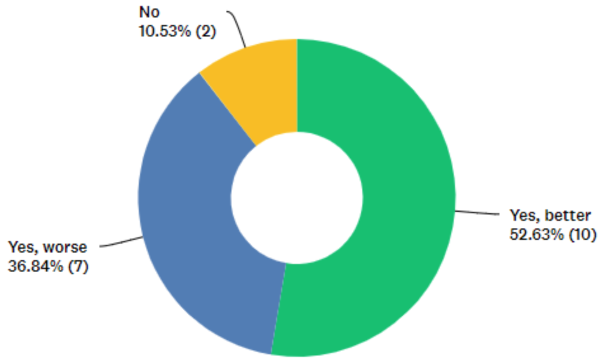

Figure 4: Do you find your mental and physical health (directly correlated to your new working schedule and resources) has changed while working from home?

Question 5: Do you find you are provided sufficient resources to communicate with your superior and project teams as needed while working from home?

The majority of participants believed they were equipped to perform their work from home, as shown in figure 5. Those who felt unequipped noted they worked for more traditional employers whose companies had minimal integrated technology into their work cultures prior to working from home. One had to bring a full desktop setup home while working from home. Another issue with proper equipment not supplied by the employer is space and personal resources. A year ago, fast internet connection, comfortable seating, and dedicated work surface were not found in every home. Working at a kitchen table is not sustainable.

Question 6: Given the experience in both work-from-home and office, how would you prefer a typical work week for the future?

When asked preference for future working accommodations, only one person preferred to return to the traditional office culture every day. 85% preferred to work in a hybrid culture, as shown in figure 6. In discussion, most people preferred an irregular schedule of work/home to provide the flexibility of personal obligations and based on working type requirements each week. Those with children unanimously preferred a hybrid with more work-from-home days. Working from home over the last year has presented opportunities and challenges to employees. The new repetitive buzz words are irrelevant to those of sustainability, social interactions, and company cultures instead of booming with topics of productivity and work-life balance. Employees have control of their time. A day is no longer divided into work and home hours but instead blurred to create one holistic life.

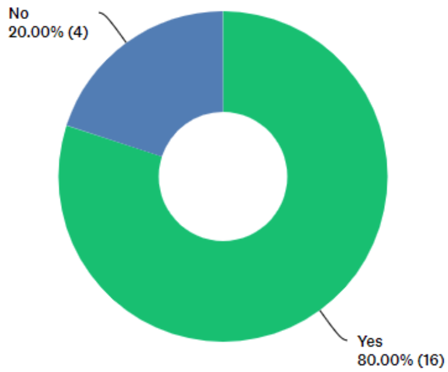

Figure 5: Do you find you are provided sufficient resources to communicate with your superior and project teams as needed while working from home?

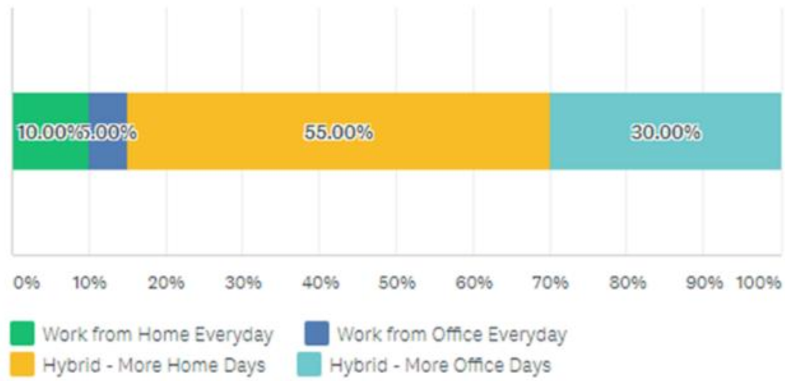

Figure 6: Given the experience in both work-from-home and office, how would you prefer a typical work week for the future?

Question 7: Have you or do you have a timeline for returning to the office?

In reflection on the past year of work from home, employees note the decrease in collaboration and ability to engage in creative processing as a team, as shown in figure 7. Lack of design library access has become a nuisance. Furthermore, there is pressure and guilt associated with the inability of superiors to monitor attendance and productivity. Employees are now responsible for creating the working environment that is best suited for them and their own accountability for keeping themselves on task with the inability of supervisors to micromanage. Work-life balance, productivity, and overall satisfaction have excelled. The AED community, those who have preached the value of working within a trendy workplace, acknowledge the flaws in an exclusive work from home model, but otherwise prefer to work from home to working in the office.

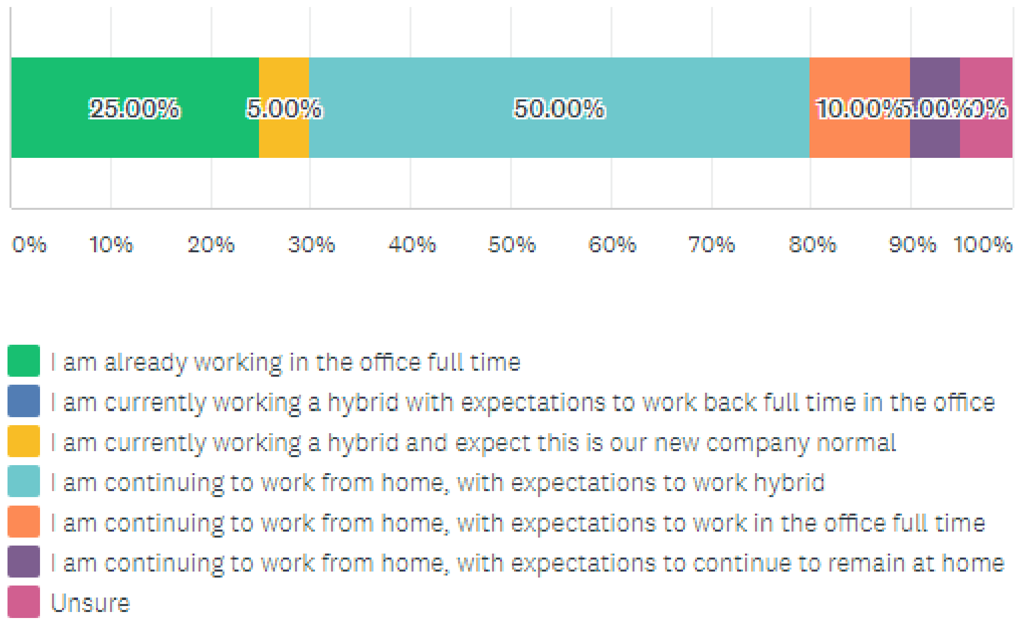

Figure 7: Have you or do you have a timeline for returning to the office?

4 Discussions

4.1 Opportunities

Companies that currently have an entire work-from-home model (prior to the 2020 pandemic) saw a 25% lower turnover rate (Ludichart, 2020). By modifying our definition of the workplace to a hybrid environment balancing routine tasks at home, many opportunities become available for employees and employers. In addition to this research proving productivity and employee satisfaction increases, there is a potential opportunity to access new talent pools with fewer locational constraints, adopt innovative processes to boost productivity, create an even stronger culture, and significantly reduce real-estate costs (Delecourt, 2021). This would, in turn, increase employee retention rates.

Employers would lower costs financially by reducing amenities, rental footprint with associated overhead, and basic office necessities such as toilet paper and coffee. Ludichart (2020) estimated that a typical business would save $11,000 per person per year by switching to an entirely remote working environment. (Ludichart, 2020). Reduction in real estate demand would also help prevent urban sprawl and allow to de-densify cities. By minimizing commuters to work every day, traffic and CO2 emissions caused by cars can decrease. The EPA announced that 600 million tons of construction and demolition debris were generated in the United States in 2018 (EPA, 2020), with predictions to increase exponentially over the next 4 years. By reducing the need for real estate, It can reduce the construction and demolition waste.

4.2 The agile workplace

In recent years, people have begun to see the evolution of WeWork-style working spaces to thrive and combat the typical permanent workplace. This style of co-working facilitates temporary dedicated working environments and collaborative spaces to rent as needed. Memberships allow for employers to cover expenses without the associated owner/rental overhead. Companies where employers are dispersed geographically, can all benefit from their local sites. This model has served larger and technologically advanced clients over the last few years, panicking real estate agents at the thought of eliminating permanent workplaces. This has not been a usual work model thus far but shows promise when considering reducing work hours and weighing the value of permanent real estate.

4.3 Conflicts

As with any progression, there are certainly some potential conflicts to navigate through. The elephant in the room with a discussion of reduction in real estate demand is that a mass exodus from the real estate market would result in a severe recession or worse (Brownell, 2020). Further, how would this affect the construction industry and design industry? The reduction in real estate reduces design needs and, therefore, construction. Commercial Real Estate Services (CBRE) published that in the 2019/20 fiscal year over $16 billion was approved in CBRE managed workplace construction costs with just one real estate broker.

Less severe challenges would arise in workplace culture. Companies would have to re-evaluate their culture model, integrating opportunities for community building. If the work from home future results in a sprawled geography of their employees, these activities may only exist virtually. Spontaneous intimate collaboration would be the wayside requiring millennials to pick up the phone and call a coworker for help. Inexperienced designers would miss opportunities to overhear others solve problems and observe the evolution of a successful finish palette. The next generation would need to adapt to a life of isolated work balanced by virtual critiques.

Another topic of discussion is relationships between management and their employees. How can employers monitor their employee productivity? Employers may have to learn to trust their employees or continue to embrace technology and adopt tracking software. How can employers track their employee's growth and successes? How could companies determine who is suited for promotions or raises without inadvertent check-ins and observation? The "water cooler" effect is described as the informal visualization and quick interaction a superior has with the employees. These brief moments consistently remind a superior who may not directly work with these employees that they are active and interject enough personal connection for an employer to consider them in future promotions. By working from home, this connection would be lost, or worse, irregularly reduced to only those in the office frequently for meetings or other required visits. This could potentially create an ununiform and biased position for employees. Companies may require a new set of criteria for qualifying success.

5 Limitations

It is acknowledged that this recent cultural revolution has not only changed our current working state but that of our entire lives. There is an overarching social void in the world that would otherwise not impose a disproportional role in our working conditions. Additionally, this instance of pandemic culture is rare. It cannot be considered for normal work from home life going forward. The subject group was comprised of diverse ages with different family situations, usual methods and time of commutes, personalities, and experience levels. Companies also provided varying levels of technology for employees, causing some unnecessary burdens in their work from home experience.

6 Conclusions and Recommendations

In recent years, design research has focused on creating a workplace to foster employee interaction, ultimately leading to employer creativity and employee retention. As a recent response to COVID-19, workplaces were forced to shut down and allow employees to work in the comfort of their homes, allowing the opportunity to re-prioritize their use of time. After six months of this global experiment, functional work has become a laptop and a fast connection, wherever you are (Schwarz, 2020). This research was designed to evaluate the future of workplace culture based on a measure of productivity and employee satisfaction. The study targeted the design community, allowing those to compare to a trendy and previously successful office. This research proves that the majority of people prefer a work-from-home culture with the integration of office days as required. Productivity is studied to be higher while accommodating for a better work-life balance. The workplace would thrive from a normalized hybrid work culture where remotely perform routine tasks. However, the total elimination of a workplace site may be unrealistic.

References

Bacevice, P., Mack, J., & Triebner, M. (2020). Reimagining the urban office. Retrieved from https://hbr.org/2020/08/reimagining-the-urban-office

Boland, B., Smet, A., Palter, R., & Sanghvi, A. (2021). Reimagining the office and work life after covid-19. Retrieved from https://www.mckinsey.com/business-functions/organization/our-insights/reimagining-the-office-and-work-life-after-covid-19

Brownell, B. (2020). Rethinking office design trends in a post-covid world. Retrieved from https://www.architectmagazine.com/practice/rethinking-office-design-trends-in-a-post-covid-world_o

Delecourt, J. (2021). Reimagining office culture and working life after covid-19. Retrieved from https://www.ardian.com/news-insights/reimagining-office-culture-and-working-life-after-covid-19

Dominika. (2020). Reimagining the office and work life AFTER covid-19. Retrieved from https://blog.spacebase.com/2020/10/13/reimagining-the-office-and-work-life-after-covid-19/

EPA. (2021). Facts and figures about materials, waste and recycling. Retrieved from https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling

LucidChart. (2020). Benefits and challenges of working remotely. Retrieved from https://www.lucidchart.com/blog/benefits-and-challenges-of-remote-workers

Lund, S., Madgavkar, A., Manyika, J., & Smit, S. (2021). What's next for remote work: An analysis of 2,000 TASKS, 800 jobs, and nine countries. Retrieved from https://www.mckinsey.com/featured-insights/future-of-work/whats-next-for-remote-work-an-analysis-of-2000-tasks-800-jobs-and-nine-countries

Prakash, O. (2020). Work from home: How a business can overcome productivity & utilization challenges. Retrieved from https://www.saviom.com/blog/work-home-business-can-overcome-productivity-utilization-challenges/

Schwarz, D. (2020). Post-COVID workplace Design: A more revolutionary vision. Retrieved from https://www.workdesign.com/2020/10/a-more-revolutionary-vision-for-post-covid-workplace-design/

Smith, C. (2019). North America Fit-out Cost GUIDE 2019/2020 Edition. Retrieved from https://issuu.com/cbreseamarcomms/docs/nam_fit-out_cost_guide_2019-20_final_ss

Vaughn, E. (2020). Redesigning the office for the Next 100-Year FLU (yes, it’s coming). Retrieved from https://www.npr.org/sections/health-shots/2020/09/14/909805060/redesigning-the-office-to-maximize-health

Vicus Partners. (2021). Office design trends for the Post Covid-19 World. Retrieved from https://vicuspartners.com/articles/6-office-design-trends-post-covid-19/

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Evolution of Patterns in Inclusion, Diversity, Equity, and Accountability (IDEA) and Race, Ethnicity, and Language (REAL) in Construction Job Market using Web Scraping and Text Mining Techniques

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The primary objective of this research is to characterize job market trends and identify patterns in Inclusion, Diversity, Equity, and Accountability (IDEA) and Race, Ethnicity, and Language (REAL) in the construction industry. Workforce IDEA and REAL are major concerns in the construction industry. The construction industry has challenges of embracing the workforce IDEA and REAL such as age, language, sexual orientation, and disability. IDEA and REAL have impacts on hiring as well. However, there is a lack of data and research related to IDEA and REAL for the construction industry. In this respect, this research collects construction job market data using web scraping. Text mining techniques are then applied to detect words related to IDEA, REAL, job types, and wage changes during the web scraping period. We devise a new data-driven text mining model including the web scraping technique to provide market trends and identify patterns related to IDEA and REAL in the construction industry. This research will contribute to the body of knowledge of capturing the data regarding IDEA and REAL by harvesting large-scale data across disciplines in a searchable and organized structure.

Key Words: Construction workforce, Job market, Diversity, Inclusion, Web scraping, Text Mining

Introduction

Inclusion, Diversity, Equity, and Accountability (IDEA) play a significant role in any workforce and are important indicators for the sustainable development of an industry (Karakhan, Gambatese, Simmons, & Al-Bayati, 2021). IDEA-related policies or systems for a specific group can cause changes in the productivity of the overall workforce (Toohey, 2009). The construction industry is a labor-intensive industry; for example, contractors such as mechanical or electrical trades account for labor costs up to 50% of the total cost of projects (Hanna et al. 2005). Although the importance of the labor force in the construction industry cannot be overemphasized, the construction industry is still far from achieving IDEA (Powell & Sang, 2013) which can lead to changes in labor productivity.

Previous projects and researches have been focused on organizational sustainability or worker safety and health rather than IDEA issues (Gambatese, Karakhan, & Simmons, 2019). Race, Ethnicity, and Language (REAL) also has a significant impact on the workforce in hiring, such as determinants of employers' hiring decisions and hiring discrimination (Baert, 2018).

The structure of the workforce in the construction industry is quite unique compared to other industry. The proportion of women in the construction industry is 10.9%, which is significantly lower than the average (46.8%), and the proportion of Hispanic or Latino is 30.0%, which is higher than the average (17.6%) in the overall industry (U.S. Bureau of Labor Statistics, 2020). Some studies conducted interviews and surveys for male-dominated structure in construction. For example, Galea et al. (2015) had interviews with senior managers and analyzed formal policies. The study concluded that previous initiatives and policies are more likely to promote increasing the numbers of women in construction rather than gender practices and outcomes (Galea, Powell, Loosemore, & Chappell, 2015). On the other hand, some studies are focused on low-literacy and low-English-proficiency workers, including Hispanic workers. A case study suggests scenario-based 3D training materials to reduce construction fall fatalities for the workers who are not proficient in English (Lin, Lee, Azari, & Migliaccio, 2018). However, previous studies have limited to particular problems rather than overall impacts of IDEA or REAL in the job market and small size of data collected by interviews, surveys, or case studies. There is also a lack of research directly on IDEA or REAL related to hiring.

In this respect, this research aims to investigate impacts of IDEA and REAL on the construction job market by analyzing job description data. Today, online job postings contain various contents such as job requirements, company descriptions, or what kind of company values they pursue. This research assumed that online job postings contain related words to achieve IDEA and REAL in the construction industry. Publicly available construction job information posted on Indeed.com is utilized to collect throughout the United States. Texts in job descriptions are analyzed by using text mining techniques. Therefore, this study identifies the trends towards how much IDEA and REAL are considered in the construction job market. The findings will contribute to understanding and developing IDEA and REAL in the construction industry.

Methodology

This research has the following steps in Figure 1. Data collection is mainly done by web scraping using bots. The code for bots is formulated based on R programming language. The data contains job postings from 04/25/2020 to 05/07/2021. Some missing periods due to changes on the website, problems with scraping, or tests at the beginning level are not included in the research. The number of raw data points is about 13.5 million. This study also includes unemployment rates, job types in the construction industry from BLS (U.S. Bureau of Labor Statistics, 2021), region and division data from the U.S. Census (U.S. Census Bureau, 2010).

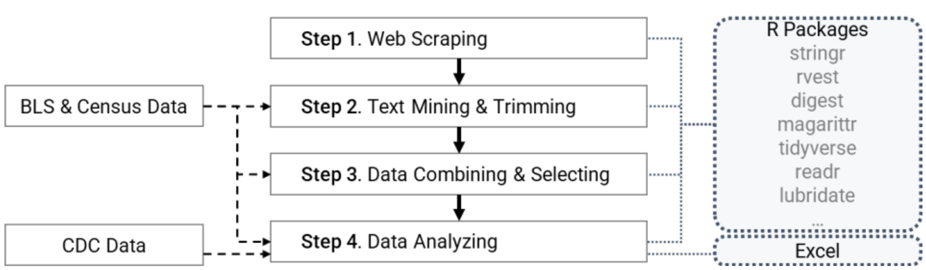

Figure 1. Research Framework

Data processing is also formulated using R programming language. Raw data is summarized in Table 1. To process the raw data from web scraping, this research first defines four forms of wages in three terms, Min, Max, and Fixed wages in Table 2. Based on the criteria from BLS data, this study calculates and unifies units of wages as 40 hours in a week and 52 weeks in a year. Job postings are classified based on keywords of IDEA and REAL. Job title, job summary, and job description are also used for classifying job postings when matching job types. Each data point is also categorized by four regions and nine divisions (U.S. Census Bureau, 2010). Google API is used to match location information from job postings and the regions and divisions. In addition, to refine the data, this research combines overlapped data points from different dates, deletes data not including critical information such as wages, and excludes data not classified by job types and outliers. 13,450,369 data points are converted into 371,789 data points on these processes. Lastly, the data is converted to .csv file format for data analysis.

Table 1

Raw data summary

Data	Source	Description
1. Web Scraping	Indeed	Date, state, location(mostly city level), salary, number of days from upload, job title, summary, description
2. Job Types	BLS	Based on NAICS
3. Wage by Job Types	BLS	Most of job types in the construction industry
4. Region and Divisions	Census	Four regions and nine divisions in the United States
5. Unemployment Rate	BLS	Monthly rate

Table 2

Converting wages into Min/Max/Fixed wage

Examples	Min Wage	Fixed Wage	Max Wage
$10 ~ $20 / hour	$10		$20
From $10 / hour	$10		
Up to $20 / hour			$20
$15 / hour		$15	

Classification keywords for IDEA and REAL are as follows:

- IDEA: diversity, equity, inclusion, creed, religion, gender; and
- REAL: spanish, chinese, mandarin, tagalog, filipino, vietnamese, french, cajun, italian, german, polish, greek, portuguese, japanese, yiddish, korean, russian, caucasian, hispanic.

Classification keywords for Job Types are as follows:

- labor, helper | assistant, painter, operator, drywall | ceiling | taper | hanger, glazier, insulat, inspector | examiner, electric, hazardous material | asbestos | lead, mason | stone, carpent, floor | tile | marble | carpet, iron | steel | rebar, sheet metal | sheetmetal, plumb | steamfit | fitter, solar | pv, roof, elevator | escalator, boiler

After processing the data in Table 1, the final data set has 50 columns (Table 3). R programming language and Excel are used to analyze the final data set.

Table 3

Final data summary

Column Name	Format and Unit	Data Source (Table 1)
UniqueID	Char.	Data.1: uniqueid (overlapped combined)
Startdate	Date	Data.1: scraped date, number of days from upload
State	Char., 2digits	Data.1: state
Year-month	Char., 6digits	Data.1: combine year and month
Year-week	Char., 6digits	Data.1: combine year and week
IDEA words	0, 1, or NA	Data.1: job description
REAL words	0, 1, or NA	Data.1: job description
Job types (27 Columns)	0, 1, or NA	Data.1: detect from job title, summary, description Data.2: job types
Hourly mean Hourly max Hourly fixed	$/hour	Data.1: extract from salary, trimming Data.3: 40 hours in a week, 52 weeks in a year
Region and Divisions (13 Columns)	0, 1, or NA	Data.1: state Data.4: regions and divisions

Results

This study finally analyzes job postings related to IDEA and REAL. It first analyzes and visualizes the trends of texts in job postings. It also classifies them into IDEA and REAL and analyzes the trend of wage included in the job postings accordingly. Also, the job postings are classified by job types and regional information. These results will confirm the impact of IDEA and REAL on the overall construction job market by comparing average wages from job postings.

To find which words are mainly included in IDEA and REAL (Figure 2), R packages such as tm, SnowballC, wordcloud, RColorBrewer are used for the analysis and visualization. Collateral texts including numbers, punctuations, extra spaces are carried out in this process. Words among top 50 for IDEA and REAL are as follows:

- IDEA: disability, electrical, requirements, status, employee, federal, color, race, religion, perform, opportunity, veteran, information, equal, origin, national; and
- REAL: commercial, customer, English, experienced, fulltime, good, high, school, hour, looking, management, office, quality, remotely, responsible, Spanish; and
- In Both IDEA and REAL: ability, applicants, company, construction, equipment, experience, job, must, required, safety, team, time, will, work, years, etc.

Figure 2. Visualization for job postings with IDEA (Left) and REAL (Right)

Data extracted from job postings also provides average wages with IDEA and REAL. The monthly averages of max and min wages show similar trends. Both wages have decreased from April 2020 to June 2020, and they recovered during the next five months. In case of comparing all average wages with IDEA and REAL data, the average wage with IDEA shows higher than the others (Figure 3).

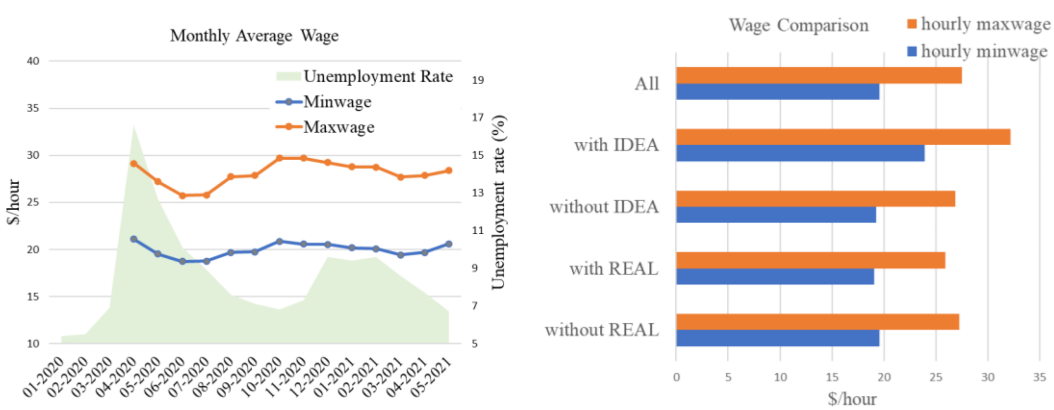

Figure 3. Monthly average wages and wage comparisons with/without IDEA and REAL

The average wage with IDEA shows higher numbers than without IDEA in every month for both max and min wage. On the other hand, monthly average wage with REAL decreases faster than monthly average wages without REAL from April 2020 to June 2020 and recovers faster during the next months (Figure 4).

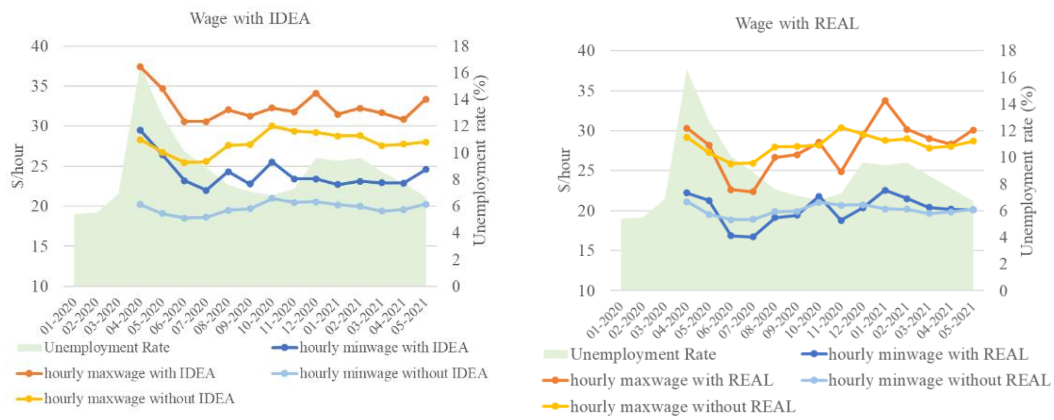

Figure 4. Monthly wage changes by IDEA (Left) and REAL (Right)

The averages of min and max wages from job postings by job types are compared in Figure 5. The average wages with IDEA show higher wages in most of job types except for operator, glazier, and flooring compared to average wages. However, the average wages with REAL show lower wages in many job types, such as helper, operator, insulator, electrician, and hazardous. Only painter, ceiling, mason, ironsteel, PV (photovoltaic), and boiler show higher wages with both REAL and IDEA.

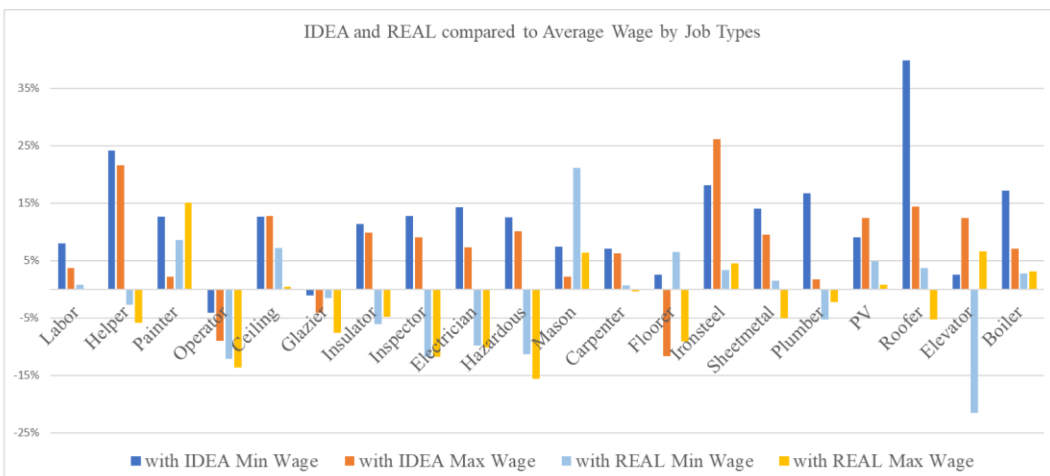

Figure 5. with IDEA and REAL wages compared to average wage by job types

By four regions and nine divisions, job postings with IDEA offer higher wages than average wages in all the regions and divisions. In case of job postings with REAL, wages are only higher in the Midwest region and the West North Central and East South Central divisions (Figure 6).

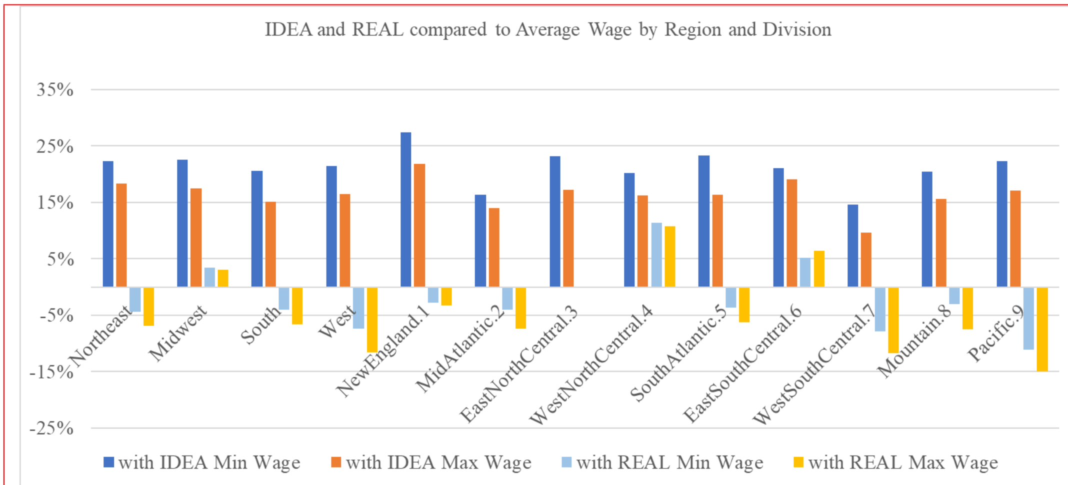

Figure 6. with IDEA and REAL wages compared to average wage by region and division

Conclusions

Web scraping and text mining techniques have been conducted to identify patterns in Inclusion, Diversity, Equity, Accountability (IDEA), Race, Ethnicity, and Language (REAL) for the construction job market in this research. This study also finds words that frequently appear in job postings which include words related to IDEA and REAL. In addition, the study analyzes trends including wage, monthly data, job types, and regions and divisions. Overall, job postings with IDEA words offer higher wages compared to average wages, but job postings with REAL do not (Figure 3). When the unemployment rate increases, average wages with REAL decrease more rapidly than wages with IDEA (Figure 4). Also, the impact of IDEA and REAL is different by job types and region and divisions (Figure 5 and 6). Especially in some job types and region and divisions, job postings with REAL offer lower wages compared to average wages. Job postings with REAL offer relatively unfavorable wages in many cases in this study. It is encouraging that job postings with IDEA offer higher wages, but we should pay more attention to REAL.

Findings in this paper will support the job market, benefitting both employers and employees and contribute to the body of knowledge for the sustainable workforce developments in the construction industry. The study detects where the construction industry should take into account IDEA and REAL to achieve balanced development including job types and regions and divisions. In addition, the data-driven approach using web scraping and text mining assists in the continuous monitoring of trends in workforce IDEA and REAL in the construction industry. Although this study has limitations in terms of whether data from web scraping can represent the entire construction job market, it has advantages in using far more data about workforce IDEA and REAL than other studies. This research also has limitations in that it did not consider the impacts of the pandemic on the construction job market. We plan to consider the impacts of COVID-19 with the data provided by the Centers for Disease Control and Prevention (CDC, 2021) for future work. This data-driven approach in this study will also enable us to integrate construction labor market data with other big data and contribute to sustainable workforce development in the construction industry.

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References

Baert, S. (2018). Hiring Discrimination: An Overview of (Almost) All Correspondence Experiments Since 2005. In *Audit Studies: Behind the Scenes with Theory, Method, and Nuance* (pp. 63–77). Springer, Cham. https://doi.org/10.1007/978-3-319-71153-9_3

CDC. (2021). CDC COVID Data Tracker. Retrieved June 4, 2021, from Centers for Disease Control and Prevention website: https://covid.cdc.gov/covid-data-tracker/#datatracker-home

Construction and Extraction Occupations : Occupational Outlook Handbook: : U.S. Bureau of Labor Statistics. (2021). Retrieved June 4, 2021, from U.S. Bureau of Labor Statistics website: https://www.bls.gov/ooh/construction-and-extraction/home.htm

Galea, N., Powell, A., Loosemore, M., & Chappell, L. (2015). *Construction Management and Economics Designing robust and revisable policies for gender equality: lessons from the Australian construction industry*. https://doi.org/10.1080/01446193.2015.1042887

Gambatese, J. A., Karakhan, A. A., & Simmons, D. R. (2019). *Development of a Workforce Sustainability Model for Construction*.

Karakhan, A. A., Gambatese, J. A., Simmons, D. R., & Al-Bayati, A. J. (2021). Identifying Pertinent Indicators for Assessing and Fostering Diversity, Equity, and Inclusion of the Construction Workforce. *J. Manage. Eng. J. Manage. Eng*, 37. https://doi.org/10.1061/(ASCE)

Lin, K.-Y., Lee, W., Azari, R., & Migliaccio, G. C. (2018). Training of Low-Literacy and Low-English-Proficiency Hispanic Workers on Construction Fall Fatality. *Journal of Management in Engineering*, *34*(2), 05017009. https://doi.org/10.1061/(asce)me.1943-5479.0000573

Powell, A., & Sang, K. J. C. (2013). *Construction Management and Economics Equality, diversity and inclusion in the construction industry*. https://doi.org/10.1080/01446193.2013.837263

Toohey, T. (2009). *Australia's hidden resource: the economic case for increasing female participation*. Goldman Sachs JBWere.

U.S. Bureau of Labor Statistics. (n.d.). Unemployment Rate - Construction Industry, Private Wage and Salary Workers. Retrieved June 1, 2021, from U.S. Bureau of Labor Statistics website: https://data.bls.gov/timeseries/LNU04032231?amp%253bdata_tool=XGtable&output_view=data&include_graphs=true

U.S. Bureau of Labor Statistics. (2020). Labor Force Statistics from the Current Population Survey. *Labor Force Statistics from the Current Population Survey*. Retrieved from https://www.bls.gov/cps/cpsaat18.htm

U.S. Census Bureau. (2010). Census regions and divisions of the United States. Retrieved June 1, 2021, from U.S. Census Bureau website: https://www2.census.gov/geo/pdfs/maps-data/maps/reference/us_regdiv.pdf

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Women in the Construction Industry Preferences to Working in the Field vs. in the Office

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This study aims to gain insight into the preference of field versus office jobs for women in the construction industry. As more women enter this workforce, identifying the reasons for their choices may provide valuable information to remove barriers to their success. Many factors exist that create barriers for women entering the construction field, thus keeping the percentage of females in construction lower than other industries. Likewise, many women in the industry have successful careers and can identify the factors that influenced their preference for field or office. The survey respondents were limited to females that worked or currently work in the construction industry in the U.S. This study found that women in construction preferred work locations depending on their work experience, but they tended to prefer the field when they had experience in both field and office. The intended audiences for this study are construction companies and human resources professionals who would like insight into the factors that influence women's decisions related to jobs in the industry. Globally, this sector faces a shortage of skilled workers, and creating a more welcoming environment for women workers may alleviate this issue.

Key Words: Construction industry, Female preference, Field job, Office job

Introduction

Women have made significant strides in the workplace over the past decade, and today approximately half of the world's workforce is women. In 2018, about 51 percent of the U.S. population was female, and they made up approximately 57 percent of total employment across all industries, which was close to 76 million (U.S. Bureau of Labor Statistics, 2019). The construction industry is one of the growth engines for a country's infrastructure, and industrial development is among the world's largest industrial employers. However, it is typically a male-dominated industry and presents a major challenge for equal opportunities for women.

Construction has an unenviable status of being the industry with the lowest representation of women. According to the BLS report (U.S. Bureau of Labor Statistics, 2019), only 1,102,000 (9.89 percent) out of 11,181,000 people working in the construction industry were women in 2018. The U.S. Bureau of Labor Statistics (2019) reported the following data regarding women's participation in the construction industry, as well as overall employment for the year 2018 in Figure 1 below. The percentage of women workforce in the construction industry was far lower than in other industries. Over the years, there has been a steady but small rise in the number of women entering the workforce in professional engineering/ management positions. Despite this small increase, the construction industry is still an extreme case with of the lack of women engineering/ management professionals.

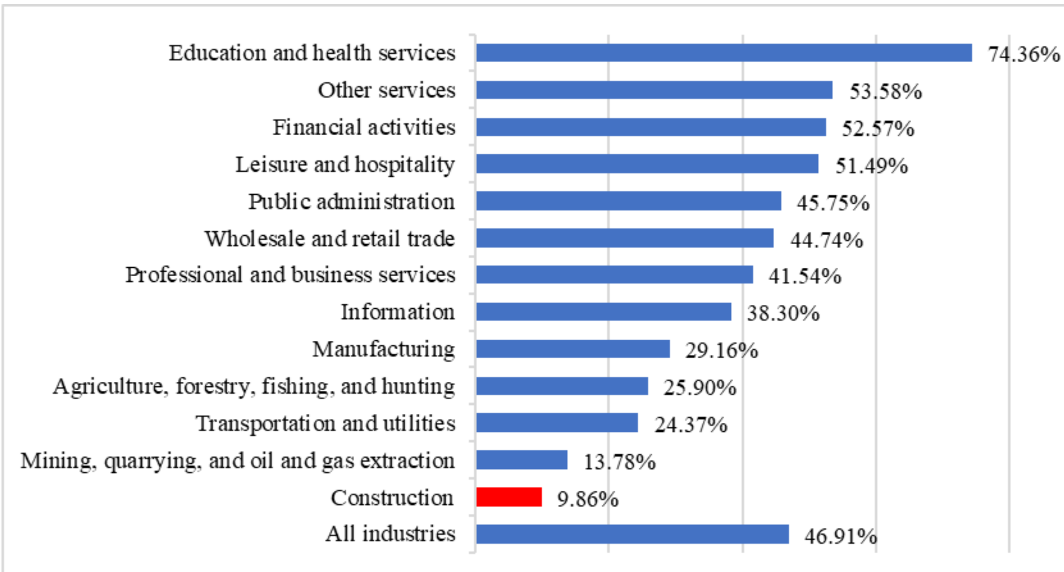

Figure 1. Percentage of women working in construction in 2018 (Data source: U.S. Bureau of Labor Statistics, 2019)

As in any other profession, the options are diverse in the construction sector ranging from various administrative, managerial positions to consultants, site engineers/inspectors, superintendents, and laborers. However, the construction field finds most of its female employees concentrated either in the clerical/secretarial positions, sales agents, or in positions in the design offices. It is rare to find women contractors and site engineers in the construction sector or women in any other positions directly involved with the building process (Menches & Abraham, 2007). Therefore, this research aims to identify the influences and barriers for work environment preference of women in the construction industry between the office and field jobs.

Literature Review

Work Features in Construction Field

The construction industry is commonly described as a traditional, male-dominated, heavy industrial environment, showing gender-specific features (Malone & Issa, 2013). Therefore, there is a perception that women may experience problems being accepted into the male-dominated work environment

(Dainty & Lingard, 2006). In addition to the nature of the work environment, the work culture can be affected by several factors, such as work location and family situation. There are big differences in tasks between field and office work. The features of tasks in construction sites show masculine works, inflexibility, and rigid work schedule (Alvanchi et al., 2012). Furthermore, according to a study in the U.K., work hours differ depending on work locations (on- and off-site) and family situations. Women working on the site tended to work longer hours (55.6 hours/week) than those working off-site (43.9 hours/week), and working-hours were also affected by the family situation, showing that women having children work shorter hours (42.1 hours/week) compared to the ones without children (47.1 hours/week) (Dainty & Lingard, 2006). In addition to this, some workers have suffered from physical and mental fatigue as well as a decrease in performance caused by prolonged working hours (Alvanchi et al., 2012).

Flexibility in work schedule and location enhances work-life balance (Dizaho et al., 2017). However, due to the high investment costs, construction sites try to keep the overall construction schedule as short as possible, which leads to dynamic working hours, including night shifts and overtime. Many people employed in the construction sector and their families find this trait somewhat difficult to cope with. Furthermore, a lack of work-life balance sometimes causes mental health issues (Kotera et al., 2020). Therefore, occupational health and organizational effectiveness related to work-life balance in the construction industry should be of the utmost importance regardless of gender (Lingard et al., 2007). A study by Hill et al. (2008) found that it is more difficult for women to balance family and work than men, and the difficulty was also observed in the construction field (Watts, 2009). The study revealed that one of the main reasons that women left the construction industry was the imbalance between family and work (Malone & Issa, 2013).

Besides, working in the construction industry requires travel, especially in the field. Some women find it difficult to deal with the responsibilities of a family and stay within the construction industry. For example, the nature of a project-based industry necessitates the employment of a transient workforce, which can move from one project location to the next. These characteristics are particularly problematic for women with dependents since separation from the family remains central to the demands of the construction industry. Construction work and particularly site-based roles are demanding and can impinge on social activities and family responsibilities. Some women thus perceive that they must make a tough choice between a career and a family-oriented lifestyle, resulting in women preferring family to career, especially if they are married or have children (Dabke et al., 2008).

The construction industry is known to have extreme working conditions that put workers at risk daily, even when complying with safety regulations. Workers are subject to heights, chemicals, noise pollution, heat exhaustion, and other high-risk factors. According to the U.S. Bureau of Labor Statistics (2020), 5,333 workers died in 2019, which increased by 2 percent from 2018. With the high fatality rate, it is effortlessly concluded that construction has numerous unfavorable conditions that could cause a worker's life. Beyond the fatality rate, women are more likely to suffer from musculoskeletal disorders in the neck, upper back, shoulder, elbow, wrist, and hip (Merlino et al., 2003). Overall, men and women both suffer from short-term and long-term health issues, but women are prone to more issues at a higher rate.

Attraction Factors to Construction Industry

A labor shortage is one of the challenges that the construction industry faces. The need for employment in construction is projected to grow steadily into the year 2022 by a 21.4% increase from 2012, making it an easy career choice (U.S. Bureau of Labor Statistics, 2013). The gross underrepresentation could help solve some of the labor shortages. More recently, universities nationally have been offering coursework, degrees, and graduate studies in construction administration, construction engineering, and construction management. From a survey targeting students majoring in construction management in higher education, over 90% of both male and female students planned to work in the construction industry after graduation (Bigelow et al., 2018). As a result, more women are getting exposed to the construction industry, showing an average of 13.02% of female students completing bachelor's level educations in 2019 (Data USA, 2020).

Additionally, studies were conducted to find factors to attract people to the construction industry, focusing on gender differences. Perrenoud, Bigelow, and Perkins (2020) examined the factors that attract people in the electrical construction industry depending on gender. Male and female workers commonly reported salary as an influential factor. Additionally, male workers reported the family was the following influential factor while women stated career opportunities as the following factor.

Work environments in the construction industry vary, such as office and field, and can influence the decision to work in the construction industry. Therefore, it is important to examine influences and barriers for each workplace type, field vs. office, to attract and retain women in the construction field.

Methods

Data was gathered through a three-step process. First, a categorization of what jobs are considered field vs. office was created. Next, a survey was developed to measure job preference. The survey items were formulated based on literature review, past professional experience, and panel interviews from professional construction organizations geared toward women, including the Professional Women in Building and Women in Construction, and also four national builders were consulted. The developed survey items were primarily for women in the construction industry working in management position. A survey item asked the respondents' experience working in the office, field, or both. The next questions were about the factors that influenced them to work in either office or field and barriers to prevent them from working in the one they did not prefer. The list of influences and barriers is provided in the result section. The respondents were asked to choose all that apply. The online survey was distributed to females who currently work or have worked in the construction industry to collect their experience and preference on working in the office vs. field. These surveys were distributed to national construction associations databases, such as the National Association of Women in Construction, Professional Women in Building, Design-Build Institute of America, national builders, and construction management faculty and students via email between July 2017 and October 2017.

Results

A total of 95 females participated in the survey. From the survey data, 6% of respondents had an experience in working in the field, 31% of respondents in the office, while 63% of respondents worked in both the field and office (Figure 2).

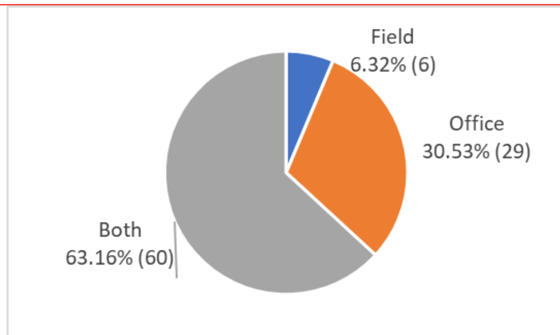

Figure 2. Experience of the Respondents

The difference of preference for experience regarding site or office yielded statistically significant results ($n = 95$, $df = 2$; Likelihood Ratio Chi-Square = 27.660, $p < .0001$). As seen in Table 1 below, women who had experience only in the field preferred the field, women who only had experience in the office preferred the office. Still, interestingly, over 70 percent of women who had experience in both field and office preferred the field to the office.

Table 1

Percent of women who prefer the field or the office

Experience Location	Prefer Field	Prefer Office	Total
Field	5 (83.33%)	1 (16.67%)	6 (100%)
Office	4 (14.81%)	23 (85.19%)	27 (100%)
Both	44 (70.97%)	18 (29.03%)	62 (100%)

A total of 53 respondents preferred to work in the field, and choices were given in the survey as to why the respondent's preference was the field (Table 2). These choices were as follows: the work environment, job schedule, I like being outside, working with tools, interacting with the workforce, casual dress instead of office wear, hands-on work, learning opportunities, I do not like being confined to an office, personal satisfaction, and other. From all the reasons listed, interacting with the workforce was the number one reason why respondents preferred the field, with the job schedule being the least reason. Any barriers that prevented one from working in the office were asked with the following choices: lack of education, lack of experience, job availability, work schedule, No, I just prefer the field, and others. In this scenario, about 66% of the respondents chose they just preferred the field with the least barrier being tied between work schedule and lack of education.

Table 2

Influences to working in the field and barriers to working in the office (n of respondents = 53)

Influences (*n of responses = 287)*	%	Barriers (*n of responses = 59)*	%
Interacting with the workforce	71.70%	No, I just prefer the field	66.04%
The work environment	64.15%	Job availability	11.32%
I do not like being confined to an office	64.15%	Lack of experience	9.43%
Personal satisfaction	64.15%	Lack of education	3.77%
I like being outside	62.26%	Work schedule	3.77%

Learning opportunities	56.60%	Others	16.98%
Hands-on work	54.72%		
Casual dress instead of office wear	39.62%		
Working with tools	32.08%		
Job schedule	15.09%		
Others	16.98%		

A total of 42 respondents reported that they preferred to work in an office. Choices were also given in the survey as to why the respondent preferred the office (Table 3). These choices were as follows: indoor plumbing, the work environment, job scheduling, interacting with the workforce, working with computers, dressing in business attire, learning opportunities, conceptual nature of work, I like having personal workspace, I like being inside, personal satisfaction and fulfillment, and others. Of all the reasons listed, the work environment was the number one reason why respondents preferred the office, with others (not given) being the least reason. Any barriers that prevented one from working in the field were asked with the following choices: lack of education, lack of training, physical limitations, job availability, none, I just prefer the office, or other. In this scenario, about 57% of the respondents chose they just preferred the office, with the least barrier being job availability.

Table 3

Influences to working in the office and barriers to working in the field (n=42)

Influences (*n of responses =137)*	%	Barriers (*n of responses = 47)*	%
The work environment	45.24%	None, I just prefer the office	57.14%
Working with computers	38.10%	Lack of training	14.29%
Learning opportunities	33.33%	Physical limitations	9.52%
Personal satisfaction and fulfillment	30.95%	Lack of education	7.14%
Conceptual nature of work	30.95%	Job availability	0%
I like having a personal workspace	28.57%	Others	23.81%
Job schedule	26.19%		
Interacting with the workforce	23.81%		
I like being inside	23.81%		
Indoor plumbing	16.67%		
Dressing in business attire	16.67%		
Others	11%		

Discussion and Conclusion

Women are traditionally placed in secretarial, administrative, and clerical roles in the construction industry but rarely in the field. The results of the study indicate that women who have experience working in the field prefer the field, those that work in the office prefer the office. Still, women who have experience with both the field and office overwhelmingly prefer the field. In order to attract more women to the construction field, it is important to encourage them to be exposed to and experience fieldwork. Furthermore, women in the field can provide different perspectives and ideas. According to case studies, women help improve team performances when involved in the workforce. It was noted that women offer new or alternative solutions to approach challenges in the workplace. Teams comprised of males and females had higher intelligence overall (Goodman, 2016). Women will bring more diversity in the workforce and further encourage innovation with new ideas for the construction market and thereby benefit the whole industry.

The findings of this study highlight that the overwhelming majority of women who have experienced both working in the field and the office preferred working in the field. Women who prefer the field expressed that interacting with the workforce is one of the main reasons for their preference of the field. They also liked the outdoor work environment, learning opportunities, and hands-on work in the field. On the other hand, women who chose to remain in the office noted that the work environment contributed to their work preference. While it is known that challenges faced by on-site female professionals were physical strength, behavior at the workplace, unisex sanitary standards, and limited promotion opportunities (Elmer, 2014), both groups who preferred the field vs. office stated that no real barriers kept them from either the field or the office positions in the construction industry; it was rather a personal preference. After that, lack of training was the most significant barrier to working in the field. Thus, providing more formal training, such as employee training and job rotation, or informal training, such as mentorship, can help alleviate the training barrier.

This cross-sectional study poses several limitations. First, the majority of the survey respondents were in managerial positions, including superintendents, site engineers/inspectors, construction managers, and consultants. Thus, “field” jobs refer to these different levels of managerial engagement in the field rather than skilled trade positions. Considering that there is a great shortage of skilled workforce in the construction section, it would be interesting to understand the challenges and opportunities to attract more women in those skilled trades. Second, due to the scope of the study, the use of advanced technologies and new employment opportunities for women to work with advanced technologies in the construction field are not included in this study. However, it is expected to see more diverse job opportunities and changes of how work is done related to advanced technologies, from modular construction, pre-fabrication (including 3D printing), construction 4.0, to construction robotics. In addition, the female workforce may engage in these different parts of construction innovation processes. Additionally, a larger sample size will benefit the statistical power of the study results. Lastly, a deeper investigation of employee turnover rates and necessary training and skills to work in the field would supplement the findings of this study.

Importantly, the direct measure of discrimination and harassment on the job is not assessed in this study; however, the matter of sexual harassment and gender-based discrimination should be properly assessed in future studies given the ingrained male-dominant culture at the construction work sites. These two factors affect women in several different ways: job satisfaction, physical, mental, and social health and well-being. Ultimately, companies should provide equal opportunities to women to encourage them and pass on the message that they are welcome and needed in this field. As found in the survey results, women want to work in the construction industry, more importantly in fields. More should be done to get these women in the workforce.

References

Alvanchi, A., Lee, S., & AbouRizk, S. (2012). Dynamics of working hours in construction. *Journal of Construction Engineering and Management*, *138*(1), 66–77. https://doi.org/10.1061/(asce)co.1943-7862.0000384

Bigelow, B. F., Saseendran, A., & Elliott, J. W. (2018). Attracting students to construction education programs: An exploration of perceptions by gender. *International Journal of Construction*

Education and Research, *14*(3), 179–197. https://doi.org/10.1080/15578771.2017.1280101

Dabke, S., Salem, O., Genaidy, A., & Daraiseh, N. (2008). Job satisfaction of women in construction trades. *Journal of Construction Engineering and Management*, *134*(3), 205–216. https://doi.org/10.1061/(ASCE)0733-9364(2008)134:3(205)

Dainty, A. R., & Lingard, H. (2006). Indirect discrimination in construction organizations and the impact on women's careers. *Journal of Management in Engineering*, *22*(3), 108–118. https://doi.org/10.1061/(asce)0742-597x(2006)22:3(108)

Data USA. (2020). *Construction management: Contains STEM majors*. https://datausa.io/profile/cip/construction-management#demographics

Dizaho, E. kadarko, Salleh, R., & Abdullah, A. (2017). Achieveing work life balance through flexible work schedules and arrangements. *Global Business & Management Research*, *9*(1), 455–465.

Elmer, V. (2014). Report: Women still face barriers in construction trades. *The Washington Post*. https://www.washingtonpost.com/blogs/she-the-people/wp/2014/06/11/report-women-still-face-barriers-in-construction-trades/

Goodman, J. (2016). *Women are a growing force in construction: Female executives are breaking new ground in the building industry*. Builder. http://www.builderonline.com/builder-100/people/women-are-a-growing-force-in-construction_o

Hill, E. J., Jacob, J. I., Shannon, L. L., Brennan, R. T., Blanchard, V. L., & Martinengo, G. (2008). Exploring the relationship of workplace flexibility, gender, and life stage to family-to-work conflict, and stress and burnout. *Community, Work and Family*, *11*(2), 165–181. https://doi.org/10.1080/13668800802027564

Kotera, Y., Green, P., & Sheffield, D. (2020). Work-life balance of UK construction workers: Relationship with mental health. *Construction Management and Economics*, *38*(3), 291–303. https://doi.org/10.1080/01446193.2019.1625417

Lingard, H., Brown, K., Bradley, L., Bailey, C., & Townsend, K. (2007). Improving employees' work-life balance in the construction industry: Project alliance case study. *Journal of Construction Engineering and Management*, *133*(10), 807–815. https://doi.org/10.1061/(ASCE)0733-9364(2007)133:10(807)

Malone, E. K., & Issa, R. R. A. (2013). Work-life balance and organizational commitment of women in the U.S. construction industry. *Journal of Professional Issues in Engineering Education & Practice*, *139*(2), 87–98. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000140

Menches, C. L., & Abraham, D. M. (2007). Women in Construction—Tapping the Untapped Resource to Meet Future Demands. *Journal of Construction Engineering and Management*, *133*(9), 701–707. https://doi.org/10.1061/(ASCE)0733-9364(2007)133:9(701)

Merlino, L. A., Rosecrance, J. C., Anton, D., & Cook, T. M. (2003). Symptoms of musculoskeletal disorders among apprentice construction workers. *Applied Occupational and Environmental Hygiene*, *18*(1), 57–64. https://doi.org/10.1080/10473220301391

U.S. Bureau of Labor Statistics. (2013). *Occupational employment projections to 2022*. Montly Labor Review. https://www.bls.gov/opub/mlr/2013/article/occupational-employment-projections-to-2022.htm

U.S. Bureau of Labor Statistics. (2019). *Women in the labor force: A databook*. BLS Reports #1084. https://www.bls.gov/opub/reports/womens-databook/2019/home.htm

U.S. Bureau of Labor Statistics. (2020). *Census of fatal occupational injuries summary, 2019*. https://www.bls.gov/news.release/cfoi.nr0.htm

Watts, J. H. (2009). “Allowed into a man’s world” meanings of work-life balance: Perspectives of women civil engineers as “minority” workers in construction. *Gender, Work and Organization, 16*(1), 37–57. https://doi.org/10.1111/j.1468-0432.2007.00352.x

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Mental and Physical Health for Construction-related Employees: Effects of Work from Home (WFH) and Demographic Indicators

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The rapid and broad shift to Work from Home (WFH) caused by the COVID-19 creates great changes for construction-related employees, which may impact their mental and physical health and further influence organizational management. Demographic indicators are also critical factors influencing mental and physical health. However, the impacts of WFH on mental health were unclear. Also, limited studies explored specific health-related symptoms and demographic differences for construction-related employees considering WFH. This study aims to explore the mental and physical health of construction-related employees considering WFH and demographic indicators using an online survey in the U.S. Based on responses from 73 construction-related employees, two-way Analysis of Variance (ANOVA) results showed that age had a significant impact on depression, pain in the neck, shoulders, or back, and eyestrain symptoms, while WFH, gender, and marital status were not significant factors. Employees between 40 – 59 years old had worse mental and physical health, while participants older than 60 years old reported the best mental and physical health. The potential reason is the differences in pressures, abilities, and past experiences among age groups. The findings contribute to the theoretical understanding of construction-related employees' health and its related factors. The study also helps construction-related employees to improve mental and physical health under the WFH arrangements considering demographic differences and prepare them for future challenges.

Key Words: Mental health, Physical health, Work from home, Construction-related employees, Demographic indicators.

Introduction

Since the breakout of COVID-19, most people have had to work from home (WFH) because of the stay-at-home orders. Over 148,383 employees worked from home in January 2021 (U.S. Bureau of Labor Statistics, 2021). Some companies even plan to apply the WFH arrangement after the pandemic. WFH creates great changes in both work and life environments for employees, which may have significant effects on both their mental and physical health (Suratkon & Syahmina Azlan, 2021).

Employees experienced anxiety, stress, fatigue, pains, etc. during WFH (Oakman et al., 2020), which have become national public health concerns. In particular, employees' mental and physical health is one of the top concerns in the construction industry (Simpeh & Amoah, 2021). Some construction workers reported declined mental well-being during WFH (Pirzadeh & Lingard, 2021), while others had better mental health due to less stress during WFH (Ruff, 2020). The conflicting findings require further exploration. Then, construction-related employees' physical health declined during WFH (Suratkon & Syahmina Azlan, 2021). Many employees even considered the transition to other industries (Alsharef et al., 2021). But limited studies examined the specific physical health symptoms. In addition, demographic indicators, such as gender, age, and marital status, also impact employees' mental and physical health (Oakman et al., 2020; Shockley et al., 2021; Ustun, 2020). Therefore, this paper aims to explore the mental and physical health of construction-related employees of different demographic indicators under the effects of WFH.

Literature Review

The literature review first discussed the studies on the impacts of WFH on physical health and mental health, respectively. Then, the effects of demographic indicators were reviewed. Finally, the limitations were summarized.

Existing studies identified the impacts of WFH on physical health. Changing work environments may decrease physical health (Guo & Chen, 2020). Palumbo (2020) found that remote workers may have increased work-related fatigue and physical exhaustion. Then, there were more screen-related activities during WFH, increasing the prevalence of eyestrain (Ganne et al., 2020). Next, pains in different body parts during WFH are key problems (Ekpanyaskul & Padungtod, 2021). Majumdar, Biswas, and Sahu (2020) indicated that employees experienced physical symptoms, such as headache and discomfort of the neck, shoulder, and back, due to chronic stress, sedentary postures, and confined activities. For construction-related employees, overall physical health was decreased during WFH (Suratkon & Syahmina Azlan, 2021). However, limited work considered the specific symptoms of construction-related employees.

Existing work illustrated the mixed effects of WFH on mental health. Some studies showed that employees had better mental health during WFH, such as more job-related positive affective well-being (Anderson et al., 2015) and lower depression scores (Ustun, 2021). On the contrary, some employees experienced depression, anxiety, and sleep disorders (Arlinghaus & Nachreiner, 2014) due to the workload extension during WFH (Wu & Chen, 2020). Construction-related employees reported mental health problems during WFH, such as anxiety, stress, depression, etc. (Pamidimukkala & Kermanshachi, 2021), while another study indicated that WFH reduced the stress of workers and improved their mental well-being (Ruff, 2020). There is a need to further explore the impacts of WFH on mental health for construction-related employees.

In addition, the effects of demographic indicators on mental and physical health were discussed. During WFH, women, especially married women with children at home, showed a lower level of mental health (Shockley et al., 2021). Also, younger adults and women experienced more stress during WFH (Pieh et al., 2020). Construction-related employees of different genders, ages, and marital statuses also suffered different levels of mental and physical issues (Yang et al., 2021). But limited work explored these demographic differences among construction-related employees.

Overall, both physical and mental health are major challenges for construction-related employees during WFH (Suratkon & Syahmina Azlan, 2021). Although current studies identified the effects of

WFH on mental and physical health, studies focused on construction-related employees are emerging. In particular, limited work discussed the specific symptoms and demographic differences. This study aims to fill the gaps by exploring the specific health-related symptoms of construction-related employees under the effects of WFH considering demographic indicators.

Research Methodology

The conceptual model, as shown in Figure 1, was developed to explore the relations between WFH, mental health, physical health, and demographic indicators for construction-related employees using three hypotheses. First, existing studies identified the impacts of WFH on physical health. H1 indicates that WFH has a significant relation to physical health (four symptoms). Second, although there are conflicting findings, existing work indicated the impacts of WFH on mental health. H2 shows that WFH has a significant relationship with mental health (depression). Finally, current studies indicated demographic indicators may impact mental and physical health. H3 explains the moderation effect of demographic indicators (including gender, age, and marital status) on mental and physical health considering WFH.

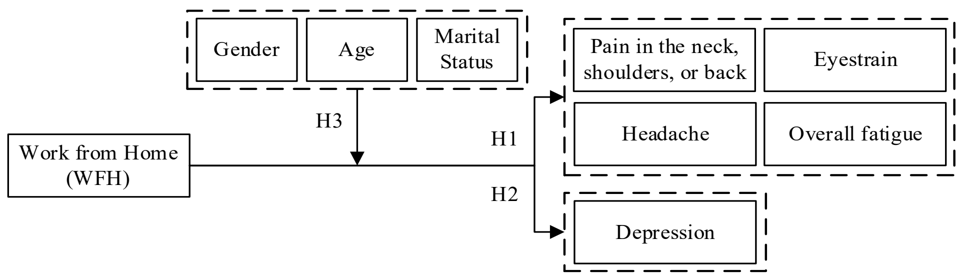

Figure 1. Conceptual model of the study

Then, an online survey was developed. After providing demographic information, each participant needed to provide two sets of responses for both (a) before WFH (i.e., regularly work on-site or in the office) and (b) during WFH (i.e., WFH during the COVID-19 pandemic) for the same variables. Four major variables were measured as follows. *Work-from-home* was dummy coded, where 0 indicates not WFH (i.e., mainly work in the office or on-site), and 1 indicates WFH. *Demographic indicators* included four factors. Gender was dummy-coded, with 1 representing man and 0 representing woman. Also, marital status was a dummy variable (0 means single or divorced, while 1 means married or lived together). Finally, based on the exact ages, age was a categorical variable (0 – 4 represent the 20-29, 30-39, 40-49, 50-59, and older than 60 age groups, respectively). *Mental health* was operationalized as depression, which is a common mental health problem. The single-item measure is an effective way to measure depression (Lefevre et al., 2012). In this study, depression was also measured using a single item: "Please rate the frequency of which you have the depression symptom before and during WFH." The participants were asked to respond on a five-point Likert-like scale, where 1 indicated "very rare" and 5 indicated "very often." *Physical health* was measured by top symptoms for employees ranked in the European working conditions survey (Eurofound, 2017), including (1) pain in the neck, shoulders, or back, (2) headache, (3) eyestrain, and (4) overall fatigue. They were measured by a similar single-item as depression: "Please rate the frequency of which you have the following symptoms before and during WFH." with the same five-point Likert-like scale.

To collect data, the survey was distributed to construction-related employees in the U.S. from May 7th to May 28th, 2020. In this study, construction-related employees covered the workers from

Architecture, Engineering, Construction, and Operation (AECO) industries and educational professionals related to the construction field (e.g., construction management, civil engineering, etc.). Participants were invited in three ways: individual emails, social media, and professional associations and universities. After removing participants who were outside the U.S., provided all N/A, and were not related to the construction industry/education, there were 73 participants. 13 participants already had a full WFH arrangement (more than 5 days/week) before the COVID-19 pandemic, whose responses for (a) before WFH were removed. Another 4 participants did not have any WFH experiences, whose responses for (b) during WFH were removed. Then, the single imputation method was used to impute the item-level missing data by mean values. Finally, there were 129 responses ($129 = 73 \times 2 - 4 - 13$) from 73 participants.

Among the 73 participants, there were 58 men (81.69%) and 14 women (19.72%). One participant did not specify the information. Then, participants from the age groups of 20-29, 30-39, 40-49, 50-59, and older than 60 years were 21 (28.77%), 23 (31.51%), 10 (13.70%), 11 (15.07%), and 8 (10.96%), respectively. In addition, 50 participants were married or lived together with a significant other (70.42%), while 21 participants were single or divorced (29.58%). Two participants did not disclose this information. As for the occupations, there were 35 industry workers (47.95%, including project engineers, BIM managers, civil engineers, etc.), 19 researchers (26.03%), and 17 professors (23.29%).

The data analysis included descriptive analysis and two-way ANOVA. Two-way ANOVA aimed to explore the impacts of WFH and demographic indicators (e.g., gender, age, and marital status) on the mental and physical health of construction-related employees. Interaction plots were obtained to further show the significant differences. The PROC GLM package in SAS software was applied.

Results and Discussions

Descriptive Analysis

Participants worked from home 2.07 days/week on average before the pandemic, which changed to be 4.41 days/week during the pandemic. Although some participants can work from home even before the pandemic, such as educational professionals, COVID-19 indeed caused broad shifts to WFH. Table 1 showed the descriptive analysis of health-related variables. Participants had worse mental health (i.e., more frequent depression) and more eyestrain symptoms during WFH, while pain in the neck, shoulders, or back, headache, and overall fatigue were reduced during WFH. According to the differences in means, overall fatigue improved more obviously than other symptoms.

Two-way ANOVA Results

To test the three hypotheses, two-way ANOVA tests were performed. The results are shown in Table 2. Because WFH, gender, marital status, WFH*gender, WFH*age, and WFH*marital status did not show significant impacts on all five symptoms ($p > 0.05$), WFH, gender, and marital status were insignificant factors, and all the interaction items did not have significant impacts on all the mental and physical health symptoms. But age had a significant impact on depression ($F = 2.74$, $p = 0.03$), pain in the neck, shoulders, or back ($F = 3.33$, $p = 0.01$), and eyestrain symptoms ($F = 3.19$, $p = 0.02$). Thus, H1 and H2 were not supported, which indicated that WFH did not have significant relations to mental and physical health symptoms. H3 was partially supported: age was a significant factor, while gender and marital status did not have significant impacts.

Table 1

Descriptive analysis of variables before and during WFH [Mean (S.D.)]

Variables	Depression	Pain in the neck, shoulders, or back	Headache	Eyestrain	Overall fatigue
Before WFH	1.80 (1.08)	2.54 (1.32)	2.16 (1.36)	2.80 (1.38)	2.82 (1.40)
During WFH	1.92 (1.18)	2.48 (1.18)	2.02 (1.14)	2.85 (1.35)	2.62 (1.31)

Table 2

Two-way ANOVA for WFH and demographic indicators

DVs	IVs	*F*	*P*	IVs	*F*	*P*	IVs	*F*	*P*
Depression	WFH	0.27	0.60	WFH	0.34	0.56	WFH	0.43	0.51
	Gender	0.51	0.48	Age	2.74	**0.03**	Marital Status	0.14	0.71
	WFH* Gender	2.21	0.14	WFH* Age	0.40	0.81	WFH*Marital Status	0.65	0.42
Pain in the neck, shoulders, or back	WFH	0.01	0.90	WFH	0.07	0.79	WFH	0.04	0.84
	Gender	1.52	0.22	Age	3.33	**0.01**	Marital Status	0.01	0.93
	WFH* Gender	0.04	0.85	WFH* Age	0.12	0.98	WFH*Marital Status	0.07	0.79
Headache	WFH	0.08	0.77	WFH	1.03	0.31	WFH	0.17	0.68
	Gender	0.29	0.59	Age	1.45	0.22	Marital Status	0.81	0.37
	WFH* Gender	0.35	0.56	WFH* Age	0.43	0.78	WFH*Marital Status	0.44	0.51
Eyestrain	WFH	0.66	0.42	WFH	0.01	0.91	WFH	0.00	1.00
	Gender	0.03	0.87	Age	3.19	**0.02**	Marital Status	0.00	1.00
	WFH* Gender	1.60	0.21	WFH* Age	0.33	0.85	WFH*Marital Status	0.00	0.97
Overall Fatigue	WFH	3.18	0.08	WFH	1.25	0.27	WFH	0.75	0.39
	Gender	0.10	0.76	Age	1.82	0.13	Marital Status	0.01	0.91
	WFH* Gender	2.58	0.11	WFH* Age	0.39	0.82	WFH*Marital Status	0.02	0.89

To further illustrate the impacts of age, Figures 2a – 2c showed the interaction plots for age, WFH, and the above three symptoms. The higher the line is, the more frequent the group had the symptoms. In Figures 2a and 2c, group 2 showed the most frequent symptoms, while group 3 had the most frequent symptom in Figure 2b. Then, group 4 had the least frequent symptoms in all three figures. In addition, eyestrain symptoms showed more variances between groups than the other two symptoms. Overall, participants between 40 – 49 years old (group 2) and 50 – 59 years old (group 3) reported more frequent depression, pain in the neck, shoulders, or back, and eyestrain, while participants older than 60 years old (group 4) showed the smallest frequency of all three symptoms.

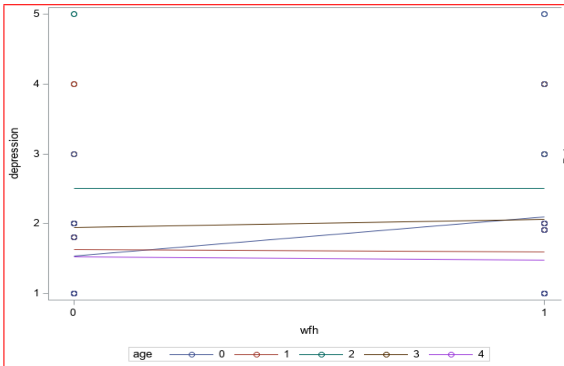

Figure 2a. Interaction plot for depression, age, and WFH

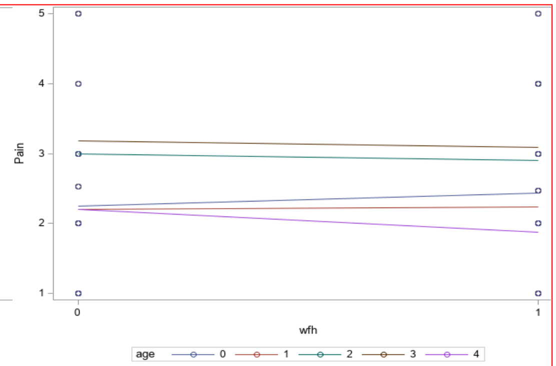

Figure 2b. Interaction plot for pain, age, and WFH

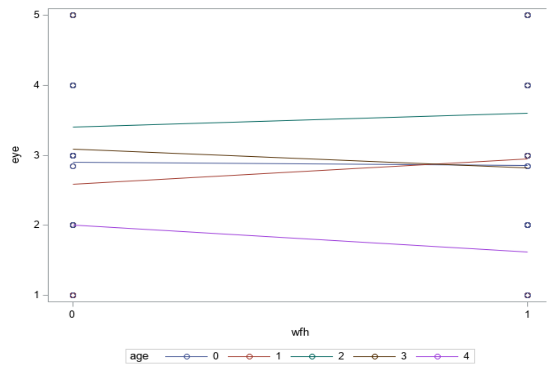

Figure 2c. Interaction plot for eyestrain, age, and WFH

Discussions

The major finding is that age was a major factor impacting the mental and physical health of construction-related employees. On the one hand, employees between 40 – 59 years old showed more frequent depression, pain in the neck, shoulders, or back, and eyestrain symptoms than participants with ages between 20 – 39 years old. Older employees had more frequent depression symptoms than younger ones due to the more possible losses in work, life, and health increased with age (Mirowsky & Ross, 1992). Also, old people were the vulnerable population during the pandemic, which may also increase their depression level. Moreover, the pain in the neck, shoulders, or back increased with age and even became chronic pains due to the accumulated work hours (Cassou et al., 2002). In addition, elder employees showed lower visual performance in digital reading tasks (Ziefle, 2001). They needed more time to finish the same visual task than younger employees, which increases their burdens in the eyes. Thus, older employees had more frequent eyestrain symptoms than younger workers, which is supported by previous findings (Zayed et al., 2021). On the other hand, participants older than 60 years old experienced the least frequent depression, pain in the neck, shoulders, or back, and eyestrain symptoms. The possible reason is that the eldest group had most past work and life experiences to deal with these health-related issues (Nwachukwu I et al., 2020).

But WFH did not show a significant impact on mental and physical health. One possible reason is that many tasks in the construction-related fields required face-to-face interactions and on-site work, which reduced their workload (Biswas et al., 2021). Although WFH created various challenges, the reduced workload offset some negative impacts, resulting in null impacts. Similarly, gender and marital status did not show significant relations to any symptoms. It might be because that WFH allows more free time for women and married employees in the construction-related area to take on household responsibilities and balance work and life (Purwanto et al., 2020). The health-related pressure and symptoms for them during regular work were alleviated by WFH to reduce the differences in gender and marital status, leading to no significant results. Also, this study covered limited women and single participants. Significant differences will be hard to be identified.

Conclusions

WFH caused by the COVID-19 has changed the work and life environments, which impacts both the mental and physical health of employees. To explore the mental and physical health of construction-related employees considering WFH and demographic indicators, the study applied an online survey and two-way ANOVA tests. There are several key findings. First, age had a significant impact on the mental and physical health of construction-related employees. Then, employees between 40 and 59 years old showed more frequent depression, pain in the neck, shoulders, or back, and eyestrain symptoms, while participants older than 60 years old experienced the least frequent symptoms. In addition, WFH, gender, and marital status did not impact mental and physical health significantly.

As for the contribution, the results provide new insights into the impacts of WFH on the mental and physical health of construction-related employees considering specific symptoms and demographic differences. Also, the study can help improve mental and physical health under the WFH arrangements and prepare construction-related employees for future challenges. However, the study has two limitations: limited sample size and single-item measurement of health. Although the current sample size satisfied the requirement of the ANVOA test, more participants can increase the reliability of the results. Future work should also explore matrixes to measure mental and physical health more comprehensively.

References

Alsharef, A., Banerjee, S., Uddin, S. M. J., Albert, A., & Jaselskis, E. (2021). Early impacts of the COVID-19 pandemic on the United States construction industry. *International Journal of Environmental Research and Public Health*, *18*(4), 1559. https://doi.org/10.3390/ijerph18041559

Anderson, A. J., Kaplan, S. A., & Vega, R. P. (2015). The impact of telework on emotional experience: When, and for whom, does telework improve daily affective well-being? *European Journal of Work and Organizational Psychology*, *24*(6), 882–897. https://doi.org/10.1080/1359432X.2014.966086

Arlinghaus, A., & Nachreiner, F. (2014). Health effects of supplemental work from home in the European Union. *Chronobiology International*, *31*(10), 1100–1107. https://doi.org/10.3109/07420528.2014.957297

Biswas, A., Ghosh, A., Kar, A., Mondal, T., Ghosh, B., & Bardhan, Dr. P. K. (2021). The impact of COVID-19 in the construction sector and its remedial measures. *Journal of Physics: Conference Series*, *1797*(1), 012054. https://doi.org/10.1088/1742-6596/1797/1/012054

Cassou, B., Derriennic, F., Monfort, C., Norton, J., & Touranchet, A. (2002). Chronic neck and shoulder pain, age, and working conditions: Longitudinal results from a large random sample in France. *Occupational and Environmental Medicine*, *59*(8), 537–544. https://doi.org/10.1136/oem.59.8.537

Ekpanyaskul, C., & Padungtod, C. (2021). Occupational health problems and lifestyle changes among novice working from home workers amid the COVID-19 pandemic. *Safety and Health at Work*. https://doi.org/10.1016/j.shaw.2021.01.010

Eurofound. (2017). *Sixth European Working Conditions Survey – Overview report*. Publications Office of the European Union.

Ganne, P., Najeeb, S., Chaitanya, G., Sharma, A., & Krishnappa, N. C. (2020). Digital eye strain epidemic amid COVID-19 pandemic - A cross-sectional survey. *Ophthalmic Epidemiology*, 1–8. https://doi.org/10.1080/09286586.2020.1862243

Guo, X., & Chen, Y. (2020). Evaluation of occupant comfort and health in indoor home-based work and study environment. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *12429 LNCS*, 480–494. https://doi.org/10.1007/978-3-030-59987-4_34

Lefevre, T., Singh-Manoux, A., Stringhini, S., Dugravot, A., Lemogne, C., Consoli, S. M., Goldberg, M., Zins, M., & Nabi, H. (2012). Usefulness of a single-item measure of depression to predict mortality: the GAZEL prospective cohort study. *The European Journal of Public Health*, *22*(5), 643–647. https://doi.org/10.1093/eurpub/ckr103

Majumdar, P., Biswas, A., & Sahu, S. (2020). COVID-19 pandemic and lockdown: cause of sleep disruption, depression, somatic pain, and increased screen exposure of office workers and students of India. *Chronobiology International*, *37*(8), 1–10. https://doi.org/10.1080/07420528.2020.1786107

Mirowsky, J., & Ross, C. E. (1992). Age and Depression. *Journal of Health and Social Behavior*, *33*(Spetember), 187–205.

Nwachukwu I, Nkire N, Shalaby R, Hrabok M, Vuong W, Gusnowski A, & Surood S. (2020). *Covid-19 pandemic: Age-related differences in measures of stress, anxiety and depression in Canada*. 1–10. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7503671/pdf/ijerph-17-06366.pdf

Oakman, J., Kinsman, N., Stuckey, R., Graham, M., & Weale, V. (2020). A rapid review of mental and physical health effects of working at home: how do we optimise health? *BMC Public Health*, *20*(1), 1–13. https://doi.org/10.1186/s12889-020-09875-z

Palumbo, R. (2020). Let me go to the office! An investigation into the side effects of working from home on work-life balance. *International Journal of Public Sector Management*, *33*(6–7), 771–790. https://doi.org/10.1108/IJPSM-06-2020-0150

Pamidimukkala, A., & Kermanshachi, S. (2021). Impact of Covid-19 on field and office workforce in construction industry. *Project Leadership and Society*, *2*, 100018. https://doi.org/10.1016/j.plas.2021.100018

Pieh, C., Budimir, S., & Probst, T. (2020). The effect of age, gender, income, work, and physical activity on mental health during coronavirus disease (COVID-19) lockdown in Austria. *Journal of Psychosomatic Research*, *136*(June), 110186.

Pirzadeh, P., & Lingard, H. (2021). Working from home during the COVID-19 pandemic: Health and well-being of project-based construction workers. *Journal of Construction Engineering and Management*, *147*(6), . https://doi.org/10.1061/(ASCE)CO.1943-7862.0002102

Purwanto, A., Asbari, M., Fahlevi, M., Mufid, A., Agistiawati, E., Cahyono, Y., & Suryani, P. (2020). Impact of work from home (WFH) on Indonesian teachers performance during the COVID-19 pandemic: An exploratory study. *International Journal of Advanced Science and Technology*, *29*(5), 6235–6244.

Ruff, K. (2020). *Analysis of Working from Home vs Working at the Office, as a Construction Company in the Bay Area*. https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1461&context=cmsp

Shockley, K. M., Clark, M. A., Dodd, H., & King, E. B. (2021). Work-family strategies during COVID-19: Examining gender dynamics among dual-earner couples with young children. *Journal of Applied Psychology*, *106*(1), 15–28. https://doi.org/10.1037/apl0000857

Simpeh, F., & Amoah, C. (2021). Assessment of measures instituted to curb the spread of COVID-19 on construction site. *International Journal of Construction Management*, 1–19. https://doi.org/10.1080/15623599.2021.1874678

Suratkon, A., & Syahmina Azlan, A. (2021). Working from Home (WFH): Challenges and practicality for construction professional personnel. *International Journal of Sustainable Construction and Technology*, *12*(4), 11–19. https://doi.org/10.30880/ijscet.2021.12.04.002

U.S. Bureau of Labor Statistics. (2021). *Labor Force Statistics from the Current Population Survey*. https://www.bls.gov/cps/demographics.htm#age

Ustun, G. (2021). Determining depression and related factors in a society affected by COVID-19 pandemic. *International Journal of Social Psychiatry*, *67*(1), 54–63. https://doi.org/10.1177/0020764020938807

Wu, H., & Chen, Y. (2020). The impact of work from home (wfh) on workload and productivity in terms of different tasks and occupations. *International Conference on Human-Computer Interaction*, *12427 LNCS*(2020), 693–706. https://doi.org/10.1007/978-3-030-60152-2_52

Yang, Y., Chan, A. P. C., & Chung, J. W. Y. (2021). Physical and mental health of construction workers: A worse status? In *Advances in Science, Technology and Innovation* (pp. 149–155). Springer Nature. https://doi.org/10.1007/978-3-030-48465-1_26

Zayed, H. A. M., Saied, S. M., Younis, E. A., & Atlam, S. A. (2021). Digital eye strain: prevalence and associated factors among information technology professionals, Egypt. *Environmental Science and Pollution Research*, *2000*. https://doi.org/10.1007/s11356-021-12454-3

Ziefle, M. (2001). Aging, visual performance and eyestrain in different screen technologies. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *45*.

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Using Historical Bid Data for Enhanced Conceptual Estimating

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Several small and medium-size contractors store bid day data regarding potential projects creating large datasets of bid day information without meaningful utilization. Many of these companies fail to leverage the archived bid day data because of their format or lack of effort to use historical data. Thus, most conceptual estimates are done using personal judgment and experience with little to no historical data support. Because of this approach, many small and medium-sized companies lack a data-driven approach to develop conceptual estimates. As such, this study aims at leveraging historical bid data to build a data-driven approach for creating conceptual estimates. This objective is achieved by presenting a framework for one company's historical bid day data to develop a conceptual cost estimating model. The framework uses bid day data for the past 45 years to build a data-driven conceptual estimating model using a case-based reasoning approach. The model allows estimators to retrieve the most similar projects from a historical database to create an informed conceptual estimate for potential projects. It is expected that this research will help many small and medium-size contractors leverage their historical bid data by utilizing it.
Key Words: Conceptual estimating, project comparison, data analytics, preconstruction services

Introduction

The American Association of Cost Engineers (AACE) classifies cost estimates into five distinct classes in which class 5 estimate is used for concept screening, and class 1 is used for bidding purposes. The level of accuracy for each cost estimate class is expected to increase with more information regarding the project definition and deliverables (AACE RP 18R-97 2020). When project estimators approach a potential project, they would typically develop a conceptual estimate before creating a detailed cost estimate for screening purposes. This process will help project estimators determine whether a project is feasible for bidding. As such, developing a reliable conceptual cost estimate to evaluate projects from a bidding feasibility perspective is crucial. Most construction firms store a vast amount of historical bid data, which can generate conceptual estimates for future projects. Although many companies realize the importance of leveraging historical data for estimating purposes, many find it challenging because of their business scale, the way the data is stored, or their willingness to spend resources on development efforts. Therefore, many small and medium-sized firms have not fully utilized their historical cost data continuing to rely on their personnel experience to develop conceptual estimates for projects. This study aims to demonstrate how small and medium-sized construction firms can utilize historical bid data to assist project estimators in developing conceptual estimates. This objective is achieved by creating a user-friendly tool to help establish conceptual estimates using the project comparison method. The tool is developed based on historical bid day data for hundreds of projects.

First, the authors compiled historical bid day data estimates to form one database that contains historical bid data. Most projects' bid data were stored in a spreadsheet containing the cost for each division and general information about the project (i.e., size, duration, profit, and contingency). Second, the authors compiled the bid day data for all projects using Python to create one unified spreadsheet. The spreadsheet contains all relevant information such as bid date, project location, bid total, amount of general condition, profit, contingency, project size in square feet, construction duration, market type, and project type. After compiling all bid day data in one spreadsheet, the authors used the project comparison method to develop the conceptual estimating tool. The project comparison method compares the attributes of a new project against the attributes of historical projects to produce a similarity score. The similarity score is calculated for each project in the database and considers four matching attributes: market type, project type, project size, and project duration. The similarity score is then used to rank all historical projects based on their similarity to a new project. Then, project estimators can easily retrieve the data for the most similar historical project to develop an accurate conceptual estimate using the project comparison methods. Finally, two domain experts validated the developed tool by retrieving similar projects for multiple hypothetical projects. It is expected that this paper will benefit a significant sector of small and medium-sized contractors to utilize historical data to develop cost estimating models actively.

Literature Review

Several research studies have focused on estimating construction costs, whether conceptually or detailed. For example, Kim et al. (2012) developed a hybrid conceptual cost estimating model to estimate the construction costs for mixed-used buildings. The conceptual estimating model presented uses two methods: assembly-based and historical data-based estimating to increase the accuracy of the estimating model. The study focuses mainly on improving conceptual cost estimates for mixed-used buildings since not much historical data is available on this type of project. The model also considers the estimator's role in the estimating process by giving them the flexibility to select the most similar historical projects to develop the cost estimate. However, there are some limitations of the model created, such as the number of assemblies included in the model and historical data available.

Choi et al. (2014) also developed a conceptual cost estimating model for public road planning using case-based reasoning, rough set theory, and genetic algorithms. The goal of the model developed is to help government officials estimate the cost of public road work at early stages during the planning phase for budget allocation and investment decisions. The study used data for 207 projects with 17 attributes (e.g., type of project, road length, number of lanes, etc.) to create the conceptual estimating model. Similar to other conceptual estimating models, the authors stressed the lack of historical data and limited project definition to develop a conceptual cost estimate. Thus, the authors aimed at developing conceptual cost estimating to estimate the cost of road projects accurately. It is worth noting that conceptual cost estimating models are inherently inaccurate because of the level of definition of the project. Thus, the model developed aimed at improving the accuracy of conceptual estimates to better estimate project contingencies.

Mahamid (2011) also developed a conceptual estimating model to estimate the cost of road construction using multiple regression techniques. The model was developed using data from 131 road construction projects. Intuitively, the author indicated that models that use bid quantities generate more accurate results than models that use project attributes such as road length, number of lanes. Zima (2015) also developed a conceptual estimating model using fuzzy case-based reasoning to estimate the costs of sports facilities. The model uses criteria such as field type, the quantity of work, other attributes related to the sports facility.

Abdelaty et al. (2020) developed multiple estimating models to predict the cost of preconstruction services for bridges. The authors used artificial neural networks, regression analysis, and case-based reasoning to predict the engineering hours and consultant's fees for preconstruction services. The authors looked at possible 33 bridge design attributes but only used 15 design attributes because they were determined to be well-known during the planning phase. The prediction model is built based on historical data for 67 projects. The study concludes that statistical methods such as neural networks and regression analysis provide practitioners meaningful insights. However, conceptual estimates are inherently inaccurate, and historical data may be inconsistent with generating reliably statistical prediction models. As such, the authors suggested that a case-based reasoning model may be more effective in helping project estimators develop conceptual estimates rather than using statistical methods with a high margin of error.

Data Collection

Bid day data for almost 500 projects spanning between 1975 and 2019 were collected from one construction company. Most projects included in the development of the model were successfully awarded. However, because the data ranged for more than 45 years, it was difficult to determine if specific projects were awarded. Each bid day datasheet contains information regarding the project as follows:

- Project name
- Location (i.e., city and state)
- Type of the project (i.e., new construction, tenant improvement, tenant finish, addition)
- Total area in square foot
- Owner
- Bid date
- Total bid amount
- Percentage of general conditions
- Profit
- Risk
- Duration in months
- Award status (i.e., whether the project was awarded)

Since the data spanned approximately 45 years, the bid day datasheet had different formats, which is challenging to compile all this together in one database. Therefore, a Python script was developed to retrieve project parameters from bid day datasheets and store them in one spreadsheet. The script loops through all the historical bid day data files. Afterward, the script reads each file to extract the attributes described earlier. Finally, it writes the project attributes in a separate spreadsheet to compile the historical bid data.

The final compiled spreadsheet contains bid date, project location, bid total, amount of general condition, profit, contingency, project size in square feet, construction duration, market type, and project type. The market type attribute is a new parameter introduced to classify projects into nine categories: banking, commercial, education, gas station, healthcare, industrial, municipality, restaurants, and retail. The project type attribute classifies projects into three main categories: new construction, addition, and tenant improvement/finish. Finally, the award status attribute indicates whether the contractor was awarded the project. This attribute provides the estimator with more confidence when developing a conceptual estimate.

Methodology

The research methodology used in this study is case-based reasoning. In case-based reasoning, every new project is compared against the historical projects based on a similarity score. The similarity score consists of four terms representing four matching attributes which are listed as follows:

- Market type
- Project type
- Project area
- Project duration

Domain experts selected these four attributes because they are readily available information for any new project and can be easily retrieved with little effort. For each matching attribute, a numeric similarity score is calculated. For example, the market type similarity score is binary, meaning that every historical project will receive a score of one point if the project's market type matches the market type of the project under study. The same concept applies to the project type attribute. However, project size and duration are continuous variables. Because of that, the matching scores of project size and construction duration are calculated using multiple steps. First, the difference between the duration or size of the project under study and the historical project's duration or size is calculated, respectively. Then, based on the difference in project size and duration, historical projects are ranked in ascending order, in which projects with the lowest difference are ranked first. Finally, based on the rank for each historical project, a normalized score with a value between zero and one is computed. Projects ranked first with receiving the highest normalized score, while projects ranked last will receive no points.

A weighted total matching score is computed after the scores are calculated for each matching attribute. The total matching score is calculated by summing up the attribute weight of importance multiplied by its matching score. Finally, historical projects are ranked based on the total matching score, and the most similar historical projects are retrieved to develop conceptual estimates. Users can then use the retrieved historical data to develop a more accurate conceptual estimate after adjusting the bid value for time and location. The remainder of this section explains the detailed procedure set to calculate the project similarity score.

The first term is the market type score (MTS_i) compares the market type of a new project to the market type of every historical project in the database. Equation 1 calculates the market type similarity score as follows:

$$MTS_i = \begin{cases} 1, & MT_v = MT_{iv} \\ 0, & MT_v \neq MT_{iv} \end{cases} \qquad (1)$$

Where MTS_i is the market type score for project i in the database and MT_v is the market type value for the project under study and MT_{iv} is the market type value for project i in the database. As explained earlier in this section, the MTS_i is a binary variable. For example, if two projects share the same market type, then a score of one will be assigned. On the other hand, if two projects have two different market types, a score of zero will be given.

Similarly, the second term of the project similarity score is the project type score (PTS_i) which is calculated according to equation two as follows:

$$PTS_i = \begin{cases} 1, & PT_v = PT_{iv} \\ 0, & PT_v \neq PT_{iv} \end{cases} \qquad (2)$$

Where PTS_i is the project type score for project i in the database and PT_v is the project type value for the project under study and PT_{iv} is the project type value for project i in the database. The PTS_i is also a binary variable with possible values of zero or one.

The third term of the similarity score is the project size score (PS_i), which is calculated according to a two-step process as shown in equations three and four. The first step calculates the absolute difference between the square footage of a new project and every single project in the database. The square footage difference is computed according to equation three as follows:

$$PS_{di} = |PS - PS_{\mathrm{i}}| \qquad (3)$$

Where PS_{di} is the absolute value of the project size difference for project i, PS is the project size in square feet for the project under study, and PS_{i} is the project size in square feet for the project i in the database. The second step includes ranking projects using the PS_{di} in ascending order. For example, the lowest project size difference is ranked first, and the highest is ranked last. This is done in ascending order to projects with the least difference receive the highest similarity score. The rankings are then normalized to calculate a project size score which is a continuous variable with any value between zero and one. The project size score is calculated as follows:

$$PS_i = \frac{RS_i - \min(RS_1, \ldots, RS_i)}{\max(RS_1, \ldots, RS_i) - \min(RS_1, \ldots, RS_i)} \qquad (4)$$

Where PS_i is the project size match score for project i in the database, RS_i is the project rank based on PS_{di}. Projects with the lowest size difference receive the first rank. Similarly, a project duration score is calculated using a two-step process, as shown in equations five and six.

$$PD_{di} = |PD - PD_{\mathrm{i}}| \qquad (5)$$

Where PD_{di} is the absolute value of the project duration difference for project i, PD is the project duration in months for the project under study, and PD_{i} is the project duration in months for the project i in the database

$$PD_i = \frac{RD_i - \min(RD_1, \ldots, RD_i)}{\max(RD_1, \ldots, RD_i) - \min(RD_1, \ldots, RD_i)} \qquad (6)$$

Where PD_i is the project duration match score for project i in the database, RD_i is the project rank based on PD_{di}. Projects with the lowest duration difference receive the first rank. If the difference PD_{di} has the same value for multiple projects, the same rank is assigned to these projects

Finally, the model calculates a total weighted similarity score (SS_i) based on the four scores and the weights of importance of each score. The SS_i is calculated as follows:

$$SS_i = MTS_i \times W_{MT} + PTS_i \times W_{PT} + PS_i \times W_{PS} + PD_i \times W_{PD} \quad (7)$$

Where SS_i is the total weighted matching score for project i in the database;
W_{MT} is the weight of importance of market type;
W_{PT} is the weight of importance for project type;
W_{PS} is the weight of importance for project size; and
W_{PD} is the weight of importance of project duration.
The total score of W_{MT}, W_{PT}, W_{PS}, and W_{PD} must equal 100%.

Conceptual Estimating Model

The methodology described in the previous section is implemented by using data from one construction company. Historical bid day data were cleaned and compiled using Python script, and the estimating model was built using Microsoft Excel. Figure 2 shows the user interface once they open the conceptual estimating model.

	Value	Weight of Importance
Market Type*	Retail	25%
Project Type*	New Construction	25%
Project size (sf)	100000	25%
Project duration (mo.)	5	25%

** All dollar values in this workbook are not adjusted for inflation. Bid value and other monetary figures corresponds to the value of money on the project's bid date.

*Unspecified market or project type means that type was not recorded in LKC bid day worksheet

Figure 2. Conceptual estimating model user interface

Estimators are required to enter the values for all four parameters: 1) market type, 2) project type, 3) project size in square feet, and 4) project duration in months. Afterward, estimators can change the default weight of importance for each parameter to increase or decrease the influence of one parameter on the project retrieval process. The estimating model retrieves the most similar 20 projects based on the matching attributes and their weight of importance for each historical project. The following project attributes are provided to assist project estimators in building their conceptual estimates.

- Project rank
- Project number
- Filename
- Year
- Project name
- Location
- Project and market type
- Owner
- Bid Date
- Bid Total
- General conditions amount
- Markup
- Gross profit
- Project size in square foot

- Construction duration in month
- Total bid per square foot
- Percentage of general conditions
- Markup and profit percentage
- The risk or contingency percentage
- General conditions amount per month
- Markup or profit per month

The retrieved attributes assist project estimators in developing a quick conceptual cost estimate using the project comparison method. In case project estimators need more data about one of the similar historical projects, they can retrieve the complete information of the project (i.e., estimate per division) using the filename attribute.

Conclusions

This paper presents a framework for small and medium-sized construction firms to utilize historical cost estimating data to develop an efficient and reliable way for conceptual estimating. The paper uses historical data from one construction company to create a conceptual estimating model using project comparison. First, bid day data for almost 500 projects were combined using a Python script in one database. Second, the authors developed an algorithm that retrieves similar projects based on market type, project type, project size, and construction duration. Third, the algorithm calculates a similarity score between the new project and every project in the historical database for a new project under study. Fourth, historical projects are ranked from the most similar to the least similar projects using the computed similarity scores. Finally, the algorithm retrieves the most similar 20 projects, which can then be used to develop a conceptual estimate by the project estimators. It is worth noting that project costs stored in the spreadsheet are not adjusted to present value. As such, project estimators should adjust the actual costs after retrieving the most similar projects.

Two domain experts validated the model by using the spreadsheet several times to retrieve historical data. For every spreadsheet run, the domain experts compared the historical data retrieved by the model to what they thought would be similar projects. The validation process was done to try different project types, market types, construction duration, and project size. It is observed that the retrieval process was significantly beneficial to the contractor because of the following:

- Significant time saving on retrieving similar projects.
- Having a methodological approach to retrieve projects instead of relying on personal judgment.
- The ability to see how retrieved historical projects are different compared to the project under study.
- The ability to see the project bid information quickly, such as percentage of general conditions, contingency, and profit.

The research presented in this paper paves the way for many small and medium-sized construction companies to utilize historical data to develop data-driven conceptual estimates instead of relying on personnel experience. The framework and model presented significantly boost the productivity of project estimators by automating the historical project retrieval process instead of relying on personnel memory and experience. Additionally, the project retrieval process presented in this paper is more consistent and reliable when compared to manual retrieval. There is a lot of potentials to improve the efficiency and reliability of preconstruction tasks performed by small and medium-sized companies. Future research should focus on increasing the efficiency of these construction firms that represent a significant portion of the construction industry. Many of these companies can move from personnel experience-based decisions to data-driven decisions. This will only be achieved through the utilization of historical data.

References

AACE Technical Board, AACE Recommended Practice No. 18R-97, Cost Estimate Classification System. AACE International.

Abdelaty, A., Shrestha, K. J., & Jeong, H. D. (2020). Estimating Preconstruction Services for Bridge Design Projects. Journal of Management in Engineering, 36(4), 04020034. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000793

Choi, S., Kim, D. Y., Han, S. H., & Kwak, Y. H. (2014). Conceptual Cost-Prediction Model for Public Road Planning via Rough Set Theory and Case-Based Reasoning. Journal of Construction Engineering and Management, 140(1), 04013026. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000743

Kim, H.-J., Seo, Y.-C., & Hyun, C.-T. (2012). A hybrid conceptual cost estimating model for large building projects. Automation in Construction, 25, 72–81. https://doi.org/10.1016/j.autcon.2012.04.006

Mahamid, I. (2011). Early cost estimating for road construction projects using multiple regression techniques. The Australasian Journal of Construction Economics and Building, 11(4), 87–101. https://doi.org/10.3316/informit.772369219553131

Zima, K. (2016). Fuzzy case-based reasoning in sports facilities unit cost estimating. AIP Conference Proceedings, 1738(1), 200008. https://doi.org/10.1063/1.4951980

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E-procurement Practices in the U.S. Construction Industry

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E-procurement has been a part of several industries for more than three decades now. Although the construction industry is commendable for its wonders, there are few studies about the current applications of E-procurement in construction. The main objective of this research is to survey the construction companies to collect the current practices of E-procurement in construction. A survey was developed and distributed to the construction industry in the U.S., and 409 responses were obtained. The researchers used the survey responses to document the current practices of the companies that use E-procurement. It is expected that documenting the current practices of E-procurement in construction could help enhance construction companies' use of E-procurement successfully to improve their business. Further, the companies that already use E-procurement may optimize their practices. E-procurement can positively impact the construction industry by saving time, money and resolving disputes with suppliers.

Key Words: E-procurement, Construction Technology, Supply Chain

Introduction

Due to the rapid competition between companies in the modern world, industries are adopting advanced and robust tools and technologies to enhance their efficacy to meet customers' versatile demands, which can also reduce cost (Fernandes et al., 2015). A successful procurement and supply chain model is deemed to be vital to the profitability of any business. Procurement is important to every kind of business, for example, manufacturing, retails, and services. One such case is the advent of E-procurement in the supply chain model, which has left indelible effects on the construction industry in modern times. E-procurement can be defined as the buying and selling of goods over the internet (Cherian et al., 2020). It is a digitized system that can support the sourcing of suppliers (requesting quotation) and managing the inventory in real-time. It is an evolutionary method of procurement rather than the conventional method of paper-based procurement, which is error-prone (Oh et al., 2014). The use of E-procurement has brought simplicity, transparency, and efficiency to the overall supply chain management model. E-procurement adoption in the construction industry is not as broad. There has been minimal research into the current practices of E-procurement in construction. As a result, the purpose of this study is to address a knowledge gap by looking into the factors that influence the application of E-procurement using data from a questionnaire survey of 409 construction companies in the U.S.

Literature review

E-procurement in General

Many researchers investigate E-procurement applications in different industries. Makali (2015) described the implementation of internet procurement and its capabilities to increase performance in the retail market. This study was based on collecting data from the retail supermarkets to find how they achieved a competitive advantage using E-procurement. By creating a questionnaire, the author decided to target 40 supermarkets to measure the situation and concluded that the acceptance rate of E-procurement in Kenya is as low as 56%. According to Samoei and Ndede (2018), the main problem faced by the Ministry of Education, Science, and Technology in Kenya was poor information and communication technology integration, among others. The objective of E-procurement was to notice the improvements and effects in e-tendering, e-sourcing, e-ordering, and e-information within the ministry. The research findings showed that E-procurement has a significant effect on financial performance, and it helped the ministry connect efficiently with their stakeholders and previous buyers and all the purchases at one platform. Chirchir (2018) effectively investigated the effects of E-procurement on the supply chain and its benefit in Kenya. With the help of purposive and proportional sampling, he targeted the population of 4200 respondents from 12 different firms. The data was collected through different mediums like questionnaires and interviews through various levels of management. The overall outcome on the buying performance by adopting E-procurement was increased by 0.4. Therefore, he advised firms to adopt E-procurement and modify the supply chain for increased productivity and performance.

Baladhandayutham and Venkatesh (2012) focused on the factors that affect the effective implementation of E-procurement. The research results revealed that factors like workers' competency, management participation, and dedication had a positive impact on the E-procurement, but on the other hand, factors like cost had a negative impact. They concluded that retail markets should focus on their employees' performance and cost management to notice an increased positive rate in their profits and performance. Wankwe (2017) used a descriptive design to collect data. Methods like mean, median, mode, and percentages were used, which gave the effective performance relationship ratio between suppliers and management. The results reflected that between capacity and propensity to adopt, the researcher saw a strong positive relationship. Moreover, the author mentioned that there could be instances where the relationship could be affected due to supplier propensity and attitude to adopt E-procurement or not. Mwangi and Kagiri (2016) used a descriptive research method to collect random samples from the group of 112 members from various levels in the Sarova chain of hotels. Data was collected through questionnaires and analyzed with the help of SPSS (Statistical Package for the Social Sciences). The multivariate regression method was used to analyze each variable's importance, which concluded that the right quantities are present on shelves using e-tendering and e-sourcing. The study recommends using E-procurement to reduce cost and increase flexibility for the business in the hospitality sector.

Awadallah and Saad (2018) further researched the adoption of E-procurement in the hospitality sector. The research instrument for gathering primary data was a self-administered questionnaire with purchasing managers. Fifteen surveys were delivered to the fifteen hotels under investigation; 15 of the surveys were legitimate for analysis (100%); nevertheless, ten of the hotels undertook an E-procurement process. The researchers concluded that the advantages of E-procurement deployment include improved quality of goods and services, increased customer satisfaction, and time and cost savings for hotels. Aikins et al. (2014) also investigated the E-procurement practices and their benefits towards the better performance for the hotel sector in Kumasi. The research data was collected using questionnaires and was analyzed using SPSS software. Examining, categorizing, and tabulating the evidence to answer the study's objectives is what data analysis entails. The researchers concluded that a significant reduction in the cost of processing an order, shorter lead times, and faster delivery of products and services are just a few of the benefits of E-procurement in the hospitality sector. Hassan et al. (2014) examined E-procurement applications in the Information Technology (I.T.) sector in New Zealand. The researchers collected data from 151 senior managers in different I.T. companies. Their conclusions show that all the E-procurement features are in use, particularly those that rely on widely available technologies. Complex E-procurement systems, such as e-auctions, are, nonetheless rare.

Chang and Wong (2010) talked about speeding the acceptance of E-procurement and involvement in e-marketplaces. A two-stage investigation was used, which included both a qualitative and quantitative method. Following the distribution of a research questionnaire, data assessment and testing were performed. The results showed that firms that embraced E-procurement were more likely to participate in the e-marketplace, which improved the overall firm's performance. Bhadaoria and Karande (2020) did a study among big-scale enterprises in India. The investigation used a descriptive technique to determine the practices that influence the performance of E-procurement programs. A total of 38 responders were chosen from a list of 233 significant manufacturing companies. The information was gathered via distributing a questionnaire to the responders. Using SPSS (Statistical Package for the Social Sciences), the data was thoroughly examined and presented in tables. The study concluded that most of the large-scale manufacturers in India have welcomed E-procurement with various practices of e-procurement such as online advertising of tenders, online shortlisting of vendors, online tenders' submission among other items.

Nzuve (2013) used a semi-structured questionnaire to collect primary data from the health sector about E-procurement. Frequencies, mean, standard deviation, factor analysis, and multivariate linear regression were used as the primary analysis methods in SPSS. It was suggested that private hospitals look for ways to improve collaboration within the health sector and with medical suppliers to speed up the adoption of E-procurement. Pasiopoulos et al. (2013) did a cross-sectional study to determine how health providers felt about implementing E-procurement procedures in Greek public hospitals. The providers' attitudes were investigated using the Technology Acceptance Model (TAM). Two hundred eighty-three selected administrative workers of procurement units and head/deputy physicians from all Greek public hospitals participated in the study. 94.7% of the employees and physicians both thought E-procurement was helpful, according to the findings. Tai et al. (2010) conducted a questionnaire survey of 137 Taiwanese enterprises that have all engaged in E-procurement programs. The study proposed a supply chain orientation-based Web-based E-procurement impact model. The findings show that computerized execution of purchase processes enhances both operational efficiency and strategic effectiveness. Gupta and Narain (2012) conducted a survey to determine the current state of E-procurement and its adoption in India. The information was gathered from 36 big Indian organizations. According to the survey's findings, Indian companies are utilizing E-procurement to boost production flexibility and cost savings, improve customer happiness, improve delivery, improve inventory management, and offer a wider selection of products.

E-procurement in Construction

Ibem et al. (2016) researched the factors that influence E-procurement adoption using data from a questionnaire survey of 213 businesses in the construction industry in Nigeria. The data were analyzed using descriptive statistics, factor, and categorical regression analysis. The findings reveal that improving project delivery efficiency, eliminating geographic barriers, and better communication among project team members were the main barriers to E-procurement adoption. Tutu et al. (2019) assessed the important criteria for E-procurement implementation in Ghana. A poll of 60 procurement specialists was surveyed, and the mean score ranking test was then used to evaluate which criteria were important in E-procurement deployment. The findings demonstrated that internet availability, power stability, procurement officer capacity enhancement, and infrastructure availability were all essential critical variables in the deployment of E-procurement. Nawi et al. (2017) conducted a survey of 120 Malaysian construction enterprises, all of which have progressed beyond the fundamental phases of E-procurement. According to the findings, the usefulness of E-procurement is often restricted to operational and tactical gains. These empirical data provide helpful suggestions for construction companies looking to begin their E-procurement journey.

A systematic questionnaire was created by Cherian et al. (2020) to investigate the elements that influence material E-procurement in the cement sector. The researchers collect data from 126 employees of five cement businesses. The researchers used descriptive research and factor analysis to determine the most important factors in E-procurement. Aguiar et al. (2015) used Building Information Modeling (BIM) as a novel approach to help construction companies apply E-procurement. This paper presents an innovative approach to E-procurement in construction, which uses building information models (BIM) to support the construction procurement process. The result is an integrated and electronic instrument connected to a rich knowledge base capable of advanced operations and able to strengthen transaction relationships and collaboration throughout the supply chain. Vasudevan et al. (2021) studied the adoption, implementation barriers, and implementation strategy for BIM and E-procurement systems in the Malaysian construction industry. The responses of 100 people were analyzed, and the information was discussed and tabulated. The findings reveal that most respondents are aware of BIM and E-procurement systems and their benefits and challenges in Malaysia. The study concluded that both BIM and E-procurement are still in the early stages of application in the Malaysian building industry. Only a little research has been found on the E-procurement application in construction. This paper aims to bridge this gap by looking into the current practices of E-procurement in the U.S. construction industry. The following section will discuss the survey process and results.

Current Practices Survey

The survey targeted people from various age groups, different experiences, and different job titles. Survey Monkey has been used to generate and distribute the survey. The first set of questions was demographic (4 questions). The second set of questions was technical and targeted current practices used in the construction industry (11 questions). The survey was distributed to the construction industry in the U.S., and 409 responses were collected. The survey results are shared below.

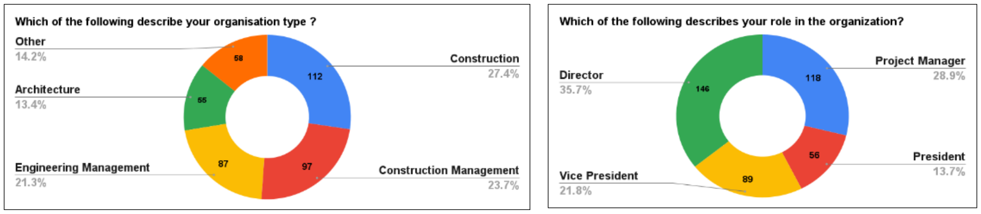


Figure 1.A (left) & 1.B (right). Respondents' organization types and organizational role

Figure 1.A illustrates responders from different companies answered the survey questions. Responders from construction companies represent 51.1% of the respondents' population, followed by 21.3% from engineering companies. Figure 1.B shows that the organization's Director represents 35.7% of the respondents, while 28.9% have a project manager role.

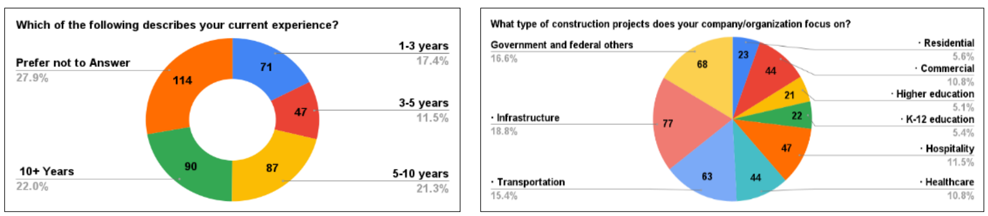


Figure 2.A (Left) & 2.B (right). Respondents' experience and construction project types

Figure 2.A shows that 22% of the respondents have 10+ years of experience, followed by 21.3% who have 5-10 years of experience. Figure 2.B shows that 18.8% of the participants work in heavy infrastructure construction companies, followed by 16.6% who work for the government.

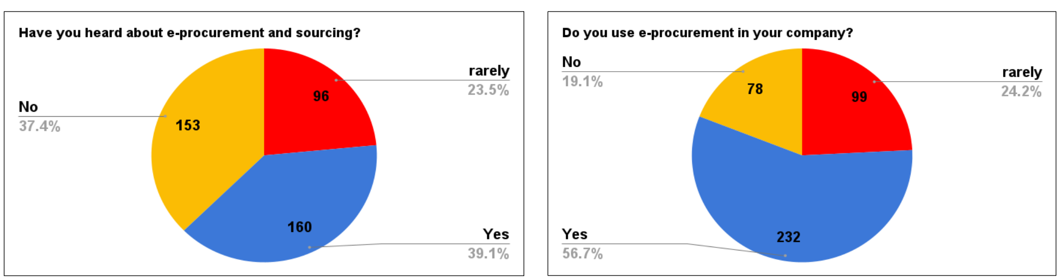


Figure 3.A (left) & 3.B (right). Respondents' familiarity of E-Procurement

Figure 3.A depicts that 39.1% of the respondents have heard about E-procurement, although some of them responded negatively while others preferred not to say about it. Figure 3.B illustrates that 56.7% of the respondents already use E-procurement, however, some of the companies still use the traditional method of procurement.

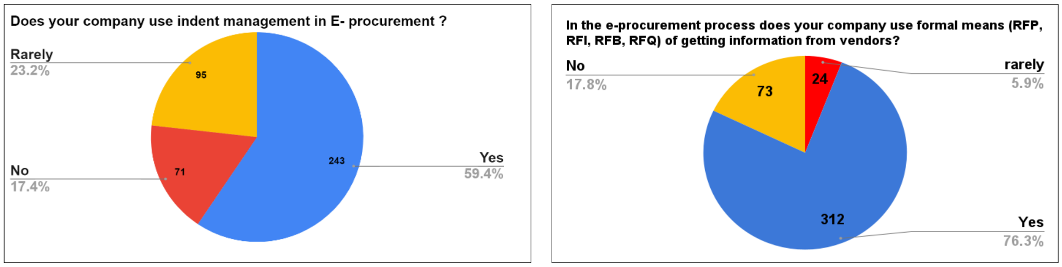


Figure 4.A (left) & 4.B (right). Respondents' familiarity with indent management and formal means of E-procurement

Figure 4.A shows that 59.4% of companies use indent management in E-procurement, only 17.4% percent of responders answered that they don't use indent management. Figure 4.B shows that 76.3% of the companies use E-procurement formal means (i.e., RFP, RFI, RFB, RFQ).

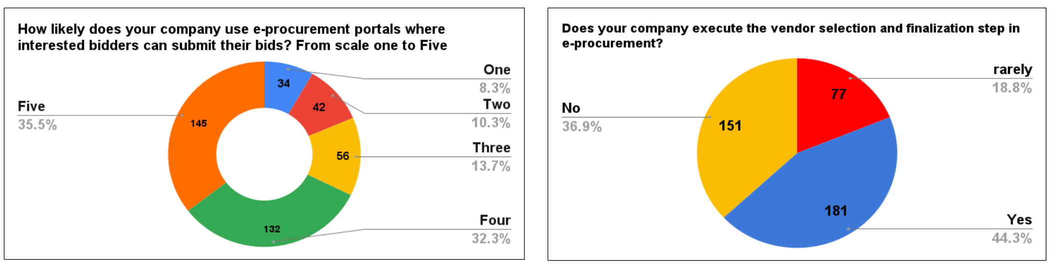


Figure 5.A (left) & 5.B (right). The likelihood of using portals and vendor selection using E-procurement.

Figure 5.A illustrates that 32.3% of the responders state that their companies are likely to use portal platforms for E-procurement, while 35.5% say that their companies are very likely to use the portals. Figure 5.B shows that 44.3% of the companies use E-procurement to finalize vendor selection. However, some of the companies still use a traditional methodology of selecting a vendor.

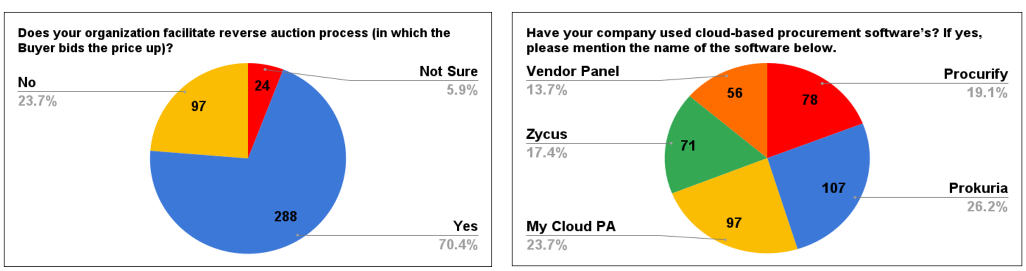
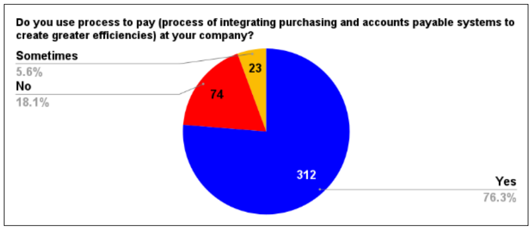


Figure 6.A (left) & 6.B (right). The likelihood of using reverse auction and cloud-based E-procurement.

Figure 6.A depicts that about 70.4% of the companies are involved in the reverse auction process while 23.7% don't use a reverse auction. Figure 6.B shows that 100% of the respondents use cloud-based E-procurement tools and the most common tools are Prokuria, My Cloud PA, and Procurify.



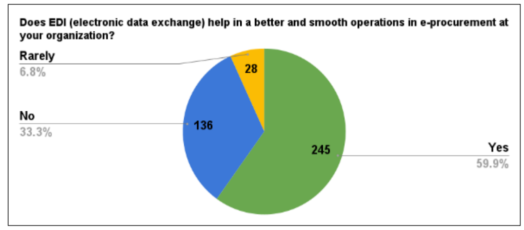


Figure 7.A (left) & 7.B (right). The integration of E-procurement with Account Payable/Purchasing for Electronic Data Exchange

Figure 7.A illustrates that 76.3% of the companies that use E-procurement integrated their E-procurement system with their Account Payable/Purchasing systems. Figure 7.B shows for the majority of companies, Electronic Data Exchange (EDI) has been helpful when it comes to operations in E-procurement.

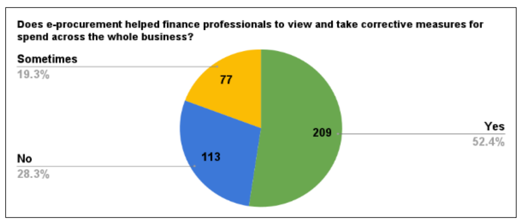


Figure 8. utilization of E-procurement for cost controls

Figure 8 shows that 52.4% of the participants stated that E-procurement had been used effectively to help finance professionals take corrective actions to control spending in the organizations.

Conclusion

This study has provided construction companies with an in-depth analysis of the current practices in E-procurement. The study results carry more weight because the responses given by the people have first-hand experience, and many fall in the role of top management in construction, such as Project Managers, Directors, and Vice Presidents. Further, most of the responders have more than ten years of experience in the construction industry. E-procurement is a relatively novel platform for doing business, and its usage has been increased over time. E-procurement is more than just a system for making purchases online. The system has been implemented to achieve significant benefits such as product delivery, getting different business requests for proposals, and quotations from vendors. Similarly, many companies found indent management useful, implying that they can order, track, and monitor their resources in real-time. Survey responses show that most companies have adopted E-procurement for their selection of vendors. Also, from the survey, it can be inferred that many companies allow reverse auctions in their supply chain model to save costs and ensure greater transparency. Also, responders stated that E-procurement helped them control cost and has enabled finance professionals to do the financial transactions with greater transparency. One of the reasons the use of E-procurement has been increased is because of its easiness and flexibility. Not only is it ideal for large corporations, but small and medium enterprises can also easily adapt to E-procurement. In a nutshell, the study shows that the use of E-procurement in construction is indispensable, and its scope will be widened with the passage of time.

References

Aguiar, A., Grilo, A. (2015). BIM-based E-procurement: An innovative approach to construction E-procurement. *The Scientific World Journal*, Volume 2015, Article ID 905390, 1-15. http://dx.doi.org/10.1155/2015/905390

Aikins, I., Osei, A., Duah, P. A., Adjei, H., Broni, A. O., & Christian, A. O. A. (2014). E-procurement an Emerging Supply–Chain Management System in The Hospitality Industry: Perspectives of Hoteliers in The Kumasi Metropolis. *European Journal of Business and Social Sciences*, 2(12), 71-88.

Awadallah, N., Saad, S. (2017). E-procurement as a New Trend in Hospitality Industry: A Descriptive Study in Egyptian Hotels. *Journal of Hotel & Business Management, 6(1)*, 1-7.

Baladhandayutham, T., Shanthi Venkatesh, D. (2012). Construction industry in Kuwait–an analysis on E-procurement adoption with respect to supplier's perspective. *International Journal of Management Research and Development* (IJMRD), *2(1),* 1-17

Bhadaoria, S., Karande, K. K. K. (2020). Decisive factors for the adoption of E-procurement in manufacturing firms in India. *Psychology and Education Journal*, 57(9), 6124-6132.

Chang, H.H., Wong, K.H. (2010). Adoption of E-procurement and participation of e-marketplace on firm performance: Trust as a moderator. *Information Management, 47(2)*, 262-270.

Cherian, T. M., Munuswamy, S., & Jasim, K. M. (2020). E-procurement practices to improve the efficiency of vendor transactions in Indian cement companies. *International Journal of Procurement Management*, 13(4), 443-461.

Chirchir, E. K. (2018). Structural Equation Modeling of Supply Chain Management Practices on Relationship Between Adoption Of E-Procurement and Supply Chain Performance in Manufacturing Firms In Kenya. *International Journal of Economics, Business and Management Research.* 2(5), 70-87.

Fernandes, T., Vieira, V. (2015). Public e-procurement impacts in small-and medium-enterprises. *International Journal of Procurement Management, 8(5),* 587-607.

Gupta, M., Narain, R. (2012). A survey on adoption of E-procurement in Indian organisations. *International Journal of Indian Culture and Business Management*, *5(1),* 76-109.

Ibem, E. O., Aduwo, E. B., Tunji-Olayeni, P., Ayo-Vaughan, E. A., & Uwakonye, U. O. (2016). Factors influencing E-procurement adoption in the Nigerian building industry. *Construction Economics and Building*, *16(4),* 54-67.

Makali, S. N. (2015). E-procurement and procurement performance of supermarkets in Nairobi [Unpublished Doctoral dissertation, University of Nairobi].

Nawi, M.N., Deraman, R., Bamgbade, J.A., Zulhumadi, F., & Riazi, S.R. (2017). E-procurement in Malaysian construction industry: benefits and challenges in implementation, *International Journal of Supply Chain Management, 6(5)*, 209-213.

Mwangi, E. W., Kagiri, A. (2016). Effects of E-procurement on procurement performance in hospitality industry in Kenya: Case of Sarova chain of hotels*. International Academic Journal of Procurement and Supply Chain Management*, *2(2)*, 1-19.

Nzuve, M. K. (2013). Implementation of E-procurement practices among private hospitals in Nairobi, Kenya [Unpublished Doctoral dissertation, University of Nairobi].

Oh, S., Yang, H., & Kim, S.W. (2014). Managerial capabilities of information technology and firm performance: role of e-procurement system type. *International Journal of Production Research*, *52(15)*, 4488-4506.

Pasiopoulos, A., Siskou, O., Galanis, P., Prezerakos, P., Moisoglou, I., Theodorou, M., & Kaitelidou, D. (2013). The Implementation of E-procurement System in Health Sector in Greece: Attitudes of Potential Users and Implications for Hospital Management, *International Journal of Health Research and Innovation*, *1(1),* 15-23.

Samoei, A. K., Ndede, F. (2018). Adoption of E-procurement and financial performance of ministry of education, science and technology, *Kenya. International Academic Journal of Economics and Finance*, 3(2), 385-409.

Wankwe, S. (2017). An Assessment of The Effects Of E-procurement Adoption on Procurement Management: A Case of Tuskys Supermarket. [Unpublished Thesis, Kisii University].

Tai, Y. M., Ho, C. F., & Wu, & W. H. (2010). The performance impact of implementing web-based E-procurement systems, *International Journal of Production Research*, *48(18),* 5397-5414. DOI: 10.1080/00207540903117915

Tutu, S. O., Kissi, E., Osei-Tutu, E., & Desmond, A. (2019). Evaluating critical factors for the implementation of E-procurement in Ghana. *International Journal of Procurement Management*, *12(1),* 1-14.

Vasudevan, G., Wei, C. C. (2021). Implementation of BIM with Integrated E-procurement System in Malaysian Construction Industry. *Advances in Civil Engineering Materials*, *10(15),* 165-171.

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Empirical Analysis of Lump Sum Pay Item Prices for Highway Projects

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Cost estimates for Lump Sum (LS) pay items are typically completed using historical information from similar projects or knowledge from subject matter experts. Since LS pay items are mainly unitless and do not have a consistent relationship with their quantities, it imposes a critical burden on estimating accurate prices of LS pay items for highway projects. State highway agencies (SHAs) often encounter significant variations in prices of LS pay items throughout the project development process. Inaccuracies of prices of LS pay items can cause significant cost escalation, project delay, and scope change. However, the current literature indicates that few studies have focused on exploring factors affecting the prices of LS pay items for highway projects. Thus, the overarching objective of this study is to identify and analyze factors affecting the prices of LS pay items used for highway projects. This study analyzed Traffic Control Lump Sum (TCLS) and Grading Complete Lump Sum (GCLS) pay items collected in the state of Georgia, using statistical analysis. This study identified the relationships between the prices of the LS pay items and important project-related factors, such as construction cost, estimated contract time, and major projects. The findings of this study help SHAs estimate more accurate prices of LS pay items and develop more accurate construction costs for highway projects.

Key Words: Big Data, Lump Sum Items, Regression Analysis, Tukey-Kramer Post-hoc Analysis

Introduction

State highway agencies (SHAs) in the United States often encounter inaccuracy of cost estimates for their highway projects during the project development process (PDP) because of a lack of reliable and complete project information. Since the project scope and design are not complete during the PDP, cost estimators/engineers in state highway agencies (SHAs) have difficulties in developing accurate cost estimates for pay items of a highway project. Inaccuracy of cost estimates during the PDP can trigger significant cost discrepancies, scope changes/creep, project delays/cancellations. SHAs use pay items to represent works following the agencies' standard specifications for highway construction and contract documentation (Baek et al. 2016; Baek and Ashuri 2021). During the PDP, the detailed quantities and specific pay items that are representative of projects' scope and design should be determined to ensure accurate cost estimates of projects. Thus, it is critical to develop accurate cost estimates for individual pay items, which produces total construction costs for highway projects.

Several studies have focused on identifying factors affecting pay items of construction projects to improve the accuracy of construction costs. For instance, Wilmot and Cheng (2003) studied 2,827 highway and bridge contracts, collected in the state of Louisiana to estimate the cost of highway projects using key pay items, such as embankment, concrete pavement, and asphalt pavement. The authors utilized a regression analysis in developing multiplicative formulations of key pay items for forecasting the future construction cost. This study also showed that item prices are significantly influenced by several factors, such as the quantity of a pay item and the location of contracts. Chou et al. (2006) developed a preliminary cost-estimating system by analyzing 2,222 projects, collected in the state of Texas. This study estimated the total cost of a project using the predicted quantities of the major work items (e.g., excavation, flexible base, and work zone pavement markings). Shrestha et al. (2014) study 151 road projects in the state of Nevada to determine the correlation between the bid costs of unit price items and quantities of items. The author developed regression models to forecast bid costs of unit price items and showed that the quantities of items have a critical impact on estimating bid costs of unit price items.

A study conducted by Ilbeigi et al. (2015) analyzed 841 highway projects in the state of Georgia to evaluate the impact of price adjustment clauses on the unit bid price of asphalt line items. The authors developed regression models and identified several important variables that affect the bid price of asphalt line items, such as the quantity of the line item, total contract price, and the asphalt cement price index. Cao et al. (2018) used more than 1,400 highway projects to predict the unit prices bids for resurfacing projects. The authors identified 20 most important features through the Boruta analysis, such as geographical characteristics of a project location (e.g., terrain, region), the quantities of bid items, and the number of asphalt cement plants around a project location and used them in developing a forecasting model for unit price bids. In follow-up work, Baek and Ashuri (2019) analyzed the submitted unit price bids for major asphalt line items used for resurfacing and widening projects let in the state of Georgia between 2008 and 2015. The authors developed a random parameter model to estimate the unit price bids for asphalt line items while taking into account unobserved heterogeneity of the geographical location and time of a project. The authors identified important factors affecting the unit price bids for asphalt line items, such as the quantity of the item, total contract price, and pavement length.

Although the current literature shows that a wide range of factors affects cost estimates for pay items that are the unit basis, few studies focus on Lump Sum (LS) pay items, such as Clearing & Grubbing, Grading Complete, Mobilization, and Traffic Control. Cost estimates for LS pay items are typically completed using historical information from similar projects or knowledge from subject matter experts. LS pay items are mainly unitless and do not have a consistent relationship with their quantities (Shrestha et al. 2017), which can cause significant variations in the prices of LS pay items. Furthermore, the relationships between project-related factors and LS pay items prices are not clearly defined through an empirical study. Therefore, the objective of this study is to identify and analyze important factors that affect cost estimates of LS pay items, including Traffic Control and Grading Complete using statistical analysis.

Research Methodology and Data Collection

The overarching objective of this study is to identify and analyze factors affecting the prices of LS pay items used for highway projects. Thus, this study conducts statistical analysis, including Pearson correlation analysis, Tukey Kramer Post-hoc analysis, and multiple regression analysis, to identify important project-related factors for prices of LS pay items. This study analyzed Traffic Control and Grading Complete LS pay items developed at the final design development of PDP. The descriptive statistics for the LS pay items used for highway projects in the state of Georgia are provided in Table 1. A Traffic Control Lump Sum (TCLS) pay item represents work for managing mobility and safety impact within a project work zone and addressing traffic safety and control through the work zone using several items such as Guardrails, traffic signals, and pavement markings. And a Grading Complete Lump Sum (GCLS) pay item is for earthwork on highway or road including excavating of all materials (e.g., ditches and undesirable materials), hauling, formatting, embankments, construction shoulders, subgrades, etc.

Table 1

Descriptive Statistics of Lump Sum Items

Lum Sum Pay Items	N	Minimum	Maximum	Mean	Std. Deviation
Price for TCLS Pay Item	309	$ 10,500.000	$ 5,826,501.000	$ 309,223.965	$ 643,675.805
Price for GCLS Pay Item	267	$ 5,000.000	$ 8,739,752.000	$ 665,817.711	$ 1, 287,034.798

In addition, project-related factors were collected from the Georgia Department of Transportation (GDOT) project development documents, including GDOT Concept Report, Field Plan Review (FPR) Reports, and Preconstruction Status Reports (PSR). The list of potential variables is provided in Table 2.

Table 2

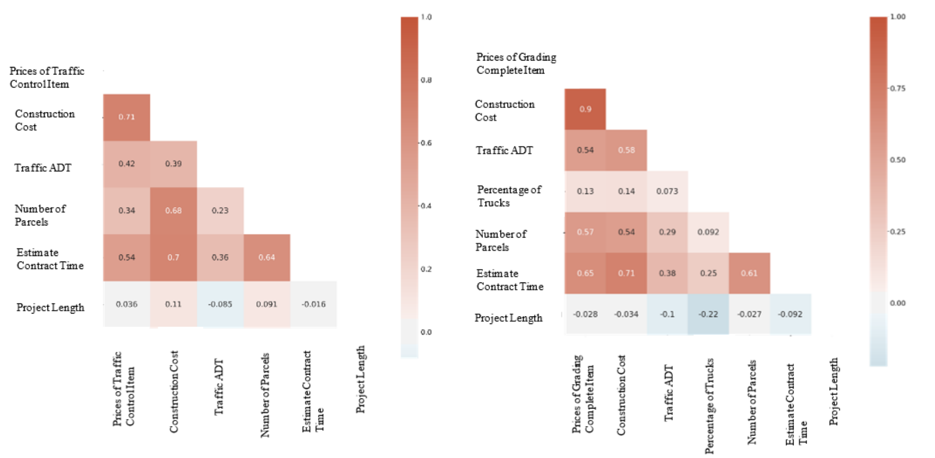
List of Potential Variables for TCLS and GCLS Pay Items

Variables	Descriptions (Sources)	Units
Construction Cost	The total amount of all pay items for a project (GDOT Concept Report)	$
Traffic Volume (ADT)	Average daily traffic (ADT) represents the total volume of vehicle traffic on a highway or road (Field Plan Review Reports)	Number
Percentage of Trucks	The Percentage of Trucks on a highway or road (Field Plan Review Reports)	%
Number of Parcels	Number of parcels for the right of way (Field Plan Review Reports)	Number
Estimate Contract Time	Estimate contract duration (Field Plan Review Reports)	Month
Traffic Control Plans	Traffic control plans contain four types for a highway or road, including (Field Plan Review Reports): • Detours • Lane Closures • Lane Closures and Detours • Lane Closures, Detour, and Flagging Operations • Lane Closures and Flagging Operations • Traffic Restrictions • No Traffic Restrictions	Boolean Indicator
Project Types	Project types (Field Plan Review Reports): • New Highway Projects (widening, new location roadways, and interchange reconstruction) • Maintenance Projects (resurfacing, pavement preservation, and restriping) • Bridge Program (maintenance and replacement of an existing bridge)	Boolean Indicator

	• Location Specific Improvements (roundabout, intersections, traffic signal, pedestrian upgrade, lighting, advanced traffic management, etc.) • Systemic Improvements (guardrail, cable barrier, drainage, culvert, and nose wall)	
Major Projects	A project that has significant amounts of right-of-way acquisition, a significant change in travel patterns, or significant social, economic, or environmental effects (Field Plan Review Reports)	Boolean Indicator
Urban	Urban: an area designated by the Bureau of the Census (a population of more than 5000), Rural: an area designated by the Bureau of the Census (a population of less than 5000) (Field Plan Review Reports)	Boolean Indicator
Project Length	Length of the project (Preconstruction Status Report)	Miles
MPOs	Areas with a population greater than 50,000, defined by the U.S. Census (Preconstruction Status Report)	Boolean Indicator
Environmental Document Types	Environmental Documentation Process Types (Preconstruction Status Report): NEPA [the National Environmental Policy Act] is for projects involving federal funds or projects requiring a USDOT action. GEPA [the Georgia Environmental Policy Act] is for projects not involving Federal Funds or a project not requiring a USDOT action.	Boolean Indicator
GDOT Districts	GDOT Seven Districts (District 1-District 7) (Preconstruction Status Report)	Boolean Indicator

Results and Discussions

Pearson correlation analysis is conducted to identify significant correlations between LS pay item price and continuous variables. For the TCLS pay item, five continuous variables, including construction cost for a project, traffic volume average daily traffic (ADT), number of parcels, estimate contract time, and project length. For the GCLS pay item, six variables, including construction cost for a project, traffic volume (ADT), percentage of trucks, number of parcels for Right of Way, estimate contract time, and project length are used. The null hypothesis of Pearson correlation analysis is that there is not a significant correlation between LS pay item prices and explanatory in the population. The alternate hypothesis is that there is a significant correlation between LS pay item prices and explanatory in the population. Figure 1 shows the results of the Pearson correlation analysis for LS pay items. The results concluded that total prices of pay items for a project and estimated contract time are significantly correlated with the prices of TCLS pay items at a significant level $\alpha = 5\%$. In addition, the construction cost for a project, traffic volume (ADT), number of parcels for Right of Way, and estimated contract time are significantly correlated with the GCLS pay item prices at a significant level $\alpha = 5\%$.



(a) Pearson Correlation for TCLS Pay Item (b) Pearson Correlation for GCLS Pay Item

Figure 1. Results of Pearson Correlation Analysis for TCLS and GCLS Pay Items

This study evaluated mean differences of LS item prices between each pairwise combination of groups using a Tukey-Kramer Post-hoc Test. Group variables for TCLS pay items are traffic control plans, project types, major projects, urban, MPOs [metropolitan planning organization], environmental document type, and GDOT seven districts. The null hypothesis of the Tukey-Kramer Post-hoc test is that the two group means of LS pay item price are not significantly different, while the alternate hypothesis is that two group means of LS pay item price are significantly different. Table 3 and 4 provides the results of Tukey-Kramer Post-hoc tests for LS pay items that show pairs that have significant differences between two pairs of groups at a significant level α = 5%. The Tukey-Kramer Post-hoc test revealed that the prices of TCLS pay item of a project that uses lane closures, detour, and flagging operations are significantly higher than the prices of a project that have other traffic control plans, including lane closures, traffic restrictions, or no traffic restrictions at a significant level α = 5%. Also, there are no significant mean differences in the prices of TCLS pay items for the following comparisons of type of traffic control plans, including lane closures, detours, traffic restrictions, and no traffic restrictions. In addition, the prices of TCLS pay items for new highway projects are significantly higher than the prices for bridge programs, location-specific improvement projects, and systemic improvement projects at a significant level α = 5%. However, there are no significant mean differences in the prices of TCLS pay items for the following comparisons of project types, including bridge programs, location-specific improvements, maintenance projects, and systematic improvements. The prices of TCLS pay item for major projects are significantly higher than the prices for minor projects at a significant level α = 5%. The prices of TCLS pay items for projects, located in MPO areas are significantly higher than the prices for projects, located in non-MPO areas at a significant level α = 5%. Interestingly, group variables, including environmental document types and GDOT districts are not defined as significant group variables in terms of mean differences of TCLS pay item prices within different groups.

Table 3

Results of Tukey-Kramer Post-hoc Test for Traffic Control Lump Pay Item

Group Variables	Group 1	Group 2	Mean Difference	Lower	Upper	*P*-Value
Traffic Control Plans	Lane Closures	Lane Closures, Detour, and Flagging Operations	638768.302	139066.582	1138470.000	0.003*
	Lane Closures, Detour, and Flagging Operations	Traffic Restrictions	690957.216	91274.420	1290640.000	0.012*
	Lane Closures, Detour, and Flagging Operations	No Traffic Restrictions	751749.731	213003.791	1290496.000	0.001*
	Lane Closures and Flagging Operations	No Traffic Restrictions	480564.121	34440.099	926688.100	0.025*
Project Types	New Highway Projects	Bridge Program	698078.062	448411.500	947744.600	0.001*
	New Highway Projects	Location Specific Improvement Projects	659615.121	422419.900	896810.400	0.001*
	New Highway Projects	Systemic Improvements	797848.507	417764.200	1177933.000	0.001*
Major & Minor	Major Projects	Minor Projects	790575.182	633757.166	947393.198	0.001*
Urban & Rural	Rural	Urban	144721.047	654.678	288787.415	0.049*
MPO & Non MPO	Non MPOs	MPOs	218091.116	72275.884	363906.347	0.004*

Note: * indicates that null hypothesis is rejected at a significant level α = 5%.

Moreover, Table 4 provides the results of the Tukey-Kramer Post-hoc Test for the GCLS pay item. The results showed that the prices of GCLS pay items for new highway projects are significantly higher than the prices of the LS pay items for bridge program, location-specific improvement projects, systemic improvement projects at a significant level α = 5%. Besides, the prices of GCLS pay items for major projects are significantly higher than the prices for minor projects at a significant level α = 5%. The prices of GCLS pay items for projects, located in urban areas are significantly higher than the prices for projects, located in rural areas at a significant level α = 5%. The prices of GCLS pay items for projects, located in MPO areas are not significantly different from the prices for projects, located in non-MPO areas at a significant level α = 5%. However, there is no statistical evidence that the prices of GCLS pay items for projects are significantly different in group variables, including terrain types, environmental document types, and GDOT districts, at a significant level α = 5%.

Table 4

Results of Tukey-Kramer Post-hoc Test for Traffic Control Lump Pay Item

Group Variables	Group 1	Group 2	Mean Difference	Lower	Upper	*P*-Value
Project Types	New Highway Projects	Bridge Program	2086340.000	1578257.000	2594424.000	0.001*
	New Highway Projects	Location Specific Improvement Projects	2194930.000	1686847.000	2703014.000	0.001*
	New Highway Projects	Systemic Improvements	2382542.000	1790288.000	2974796.000	0.001*
Major & Minor Projects	Major Projects	Minor Projects	2377093.000	2037808.000	2716379.000	0.001*
Urban & Rural	Rural	Urban	482987.326	177396.650	788578.002	0.002*
MPO & Non MPO	Non MPOs	MPOs	549516.558	236715.178	862317.938	0.001*

Note: * indicates that null hypothesis is rejected at a significant level α = 5%.

Lastly, this study conducted a regression analysis to estimate the relationship between the prices of LS pay items and explanatory variables. The null hypothesis of regression analysis is that there is no statistically significant relationship between the prices of LS pay items and an explanatory variable, while the alternate hypothesis is that there is a statistically significant relationship between the price of an LS pay item and an explanatory variable. Through Pearson correlation and Tukey-Kramer Post-hoc tests, input variables for developing regression models for LS pay items were identified. Seven variables used for developing an exploratory model for the prices of TCLS pay items include construction cost for a project, estimate contract time, traffic control plans, project types, major projects, urban areas, and MPO areas. In addition, in developing an exploratory model for the prices of GCLS pay items, eight variables, including construction cost for a project, ADT, number of parcels for Right of Way, estimate contract time, project types, major projects, urban areas, and MPO areas.

Table 5 provides the results of regression analysis for the prices of TCLS pay items. Through the stepwise feature selection process, five variables are included in the exploratory model for traffic control items. The result indicates that there is a positive relationship between the prices of TCLS pay items and construction cost for a project while holding other variables in the model constant. In other words, as the project size increases, the price of the traffic control item increases. Also, bigger projects are more likely to have a greater price for traffic control. As the project size is one of the major attributes affecting traffic management plans for all road projects, larger projects require a greater number of traffic management plans for the projects because the larger projects typically have a higher impact on the public (e.g., traffic delays and safety concerns). In addition, estimated contract time has a positive relationship with the prices of TCLS pay items, while holding other variables constant. The result indicates that as the duration of a project increases, the price of TCLS pay item for a project increases.

Moreover, the prices of TCLS pay items for major projects tend to be higher than the prices of TCLS pay items for minor projects, where have fewer project requirements such as amounts of right-of-way acquisition, changes in travel patterns, and social, economic, or environmental effects. A binary variable of lane closures, detours, and flagging operations, one of the binary variables of traffic control plans, is identified as an important variable in a regression model. On average, the price of the TCLS pay item for a project that contains the traffic plans, including lane closures, detours, and flagging operations, is higher than the price of the traffic control items for a project that contains fewer traffic control plans. The more the traffic control plans in a project, the higher the price for the TCLS pay item for a project. Next, projects located in MPO areas tend to have higher prices of TCLS pay items for projects than the prices for projects located in non-MPO areas. As projects in the MPO areas are expected to have greater impacts on the traveling public, the risk to works, and the volume of traffic, it requires greater attention for traffic control, which increases the price of the traffic control item in a project.

Table 5

Result of Regression Analysis for Price of Traffic Control Lump Sum Pay Item

Model	**Unstandardized Coefficients**		**Standardized Coefficients**	***P*-Value**	**Collinearity Statistics**
	B	Std. Error	Beta		VIF
(Constant)	-196716.665	73523.111		0.008*	
Construction Cost	0.024	0.003	0.428	0.000*	1.698
Estimated Contract Time	12161.674	3997.874	0.183	0.003*	2.033
Major Projects	190416.482	92135.094	0.119	0.040*	1.861
Lane Closures, Detours, and Flagging Operations	313923.198	128213.564	0.105	0.015*	1.038
MPO Areas	126478.013	55900.437	0.096	0.024*	1.017

Note: * indicates that the Null Hypothesis is rejected; VIF indicates the variance inflation factor; B indicates unstandardized coefficients.

Table 6 shows the results of regression analysis for the prices of the GCLS pay item. Through the stepwise feature selection process, six variables were included in the model. The result of an exploratory model of the GCLS pay item indicates that there is a positive relationship between the price of the GCLS pay item and construction cost for a project while holding other variables constant. As the project size increases, the price of the GCLS pay item increases. The bigger the project size, the more the earthwork required. It results in an increase in the price of the GCLS pay item for a project. In addition, on average, the price of the GCLS pay item for new highway projects is higher than the price for other project types (e.g., bridge program, maintenance projects, and improvement projects). Traffic volume (ADT) also shows a positive relationship with the prices of GCLS pay items. The larger traffic volume on a project location is the higher prices for GCLS pay items. Similarly, the number of parcels for Right of Way is determined as an explanatory variable with a negative relation with the prices of GCLS pay items. The higher the number of parcels for Right of Way the higher the prices of GCLS pay items. Furthermore, it is found that estimated contract time for a project has a positive relationship with the prices of GCLS pay items. The result shows that the project duration is a critical factor for estimating the prices of GCLS pay items. Lastly, the prices of GCLS pay items for major projects are, on average, more likely to be higher than those for minor projects.

Table 6

Result of Regression Analysis for Price of Grading Complete Lump Sum Pay Item

Model	Unstandardized Coefficients		Standardized Coefficients	*P*-Value	Collinearity Statistics
	B	Std. Error	Beta		VIF
(Constant)	-264155.499	116887.453		0.025*	
Construction Cost	0.053	0.007	0.356	0.000*	
New Highway Projects	564605.462	179503.375	0.155	0.002*	1.786
Traffic Volume (ADT)	13.128	2.848	0.192	0.000*	1.961
Number of Parcels	3665.681	1731.439	0.108	0.035*	1.393
Estimated Contract Time	19824.413	7528.615	0.137	0.009*	2.096
Major Projects	472497.495	191502.680	0.129	0.014*	2.177

Note: * indicates that the Null Hypothesis is rejected; VIF indicates the variance inflation factor; B indicates unstandardized coefficients.

The results of the Analysis of Variance (ANOVA) tests are provided in Table 7. The null hypothesis is rejected at a 1% significance level indicating that overall, a combination of the identified variables used to build the stepwise regression models for both TCLS and GCLS pay items is statistically significant for explaining variation in the prices of TCLS and GCLS pay items. The adjusted R-squared for a regression model for the TCLS pay item is 0.454 (45.4%). The developed model explained 45.4% of the variance of the prices of TCLS pay items. Furthermore, the adjusted R-squared value for a regression model of the GCLS pay item is 0.670 (67%), which indicates that the developed regression model can be considered a good fit for observed prices of GCLS pay items. Therefore, it is concluded that the developed regression models for the prices of TCLS and GCLS pay items performed well in explaining the variation of the collected data of the LS pay items.

Table 7

Summaries of Regression Models for TCLS and GCLS Pay Items

TCLS Pay Item						
		Sum of Squares	**DF**	**Mean Square**	***F*-Value**	***P*-Value**
ANOVA	Regression	59094066467380.500	5	11818813293476.100	52.267	<.001
	Residual	68516044544274.000	303	226125559552.059		
	Total	127610111011654.000	308			
Adjusted R Square = 0.454 (45.4%)						
GCLS Pay Item						
		Sum of Squares	**DF**	**Mean Square**	***F*-Value**	***P*-Value**
ANOVA	Regression	298364091822523.000	6	49727348637087.100	90.888	<.001
	Residual	142253887845632.000	260	547130337867.814		
	Total	440617979668154.000	266			
Adjusted R Square = 0.670 (67%)						

Note: DF indicates the degree of freedom

Conclusions

The primary objective of this study is to identify and analyze factors that affect the prices of LS pay items for highway projects. This study used prices of Traffic Control Lump Sum (TCLS) and Grading Complete Lump Sum (GCLS) pay items used for highway projects in the state of Georgia. To achieve the goal of this study, Pearson correlation analysis, Tukey-Kramer Post-hoc test, and multiple regression analysis were conducted. The Tukey Kramer Post-hoc revealed that the prices of TCLS and GCLS pay items are significantly different in four common group variables including project types, major projects, urban areas, and MPO areas. Furthermore, multiple regression analysis for TCLS and GCLS identified the best combination of variables, such as construction cost, estimate contract time, and major projects, for estimating the prices of the LS pay items. The regression analysis revealed that construction cost and estimate contract time have positive relationships with the prices of TCLS and GCLS pay items. The projects that contain traffic control plans including lane closures, detour, and flagging operations are significantly higher prices of TCLS pay items than those that contain fewer traffic control plans. In addition, it can be concluded that more complex projects, represented by major projects, tend to have higher prices for the LS pay items.

The primary contribution of this study to the body of knowledge is that this study explored project-related variables that have not been used in previous research and identified the relationships between the prices of the LS pay items and important project-related factors. SHAs can use the identified variables to estimate the prices of LS pay items, which enables them to develop more accurate cost estimates for projects.

References

Baek, M., Mostaan, K., and Ashuri, B. (2016). Recommended practices for the cost control of highway project development. In Construction Research Congress 2016 (pp. 739-748).

Baek, M., and Ashuri, B. (2019). Analysis of the variability of submitted unit price bids for asphalt line items in highway projects. Journal of Construction Engineering and Management, 145(4), 04019020.

Baek, M., and Ashuri, B. (2021). Synthesis of Practices and Tools for Cost Estimation and Cost Management for Transportation Projects. Journal for the Advancement of Performance Information and Value, 13(1), 22-22.

Cao, Y., Ashuri, B., and Baek, M. (2018). Prediction of unit price bids of resurfacing highway projects through ensemble machine learning. Journal of Computing in Civil Engineering, 32(5), 04018043.

Chou, J. S., Peng, M., Persad, K. R., and O'Connor, J. T. (2006). Quantity-based approach to preliminary cost estimates for highway projects. Transportation Research Record, 1946(1), 22-30.

Wilmot, C. G., and Cheng, G. (2003). Estimating future highway construction costs. Journal of Construction Engineering and Management, 129(3), 272-279.

Ilbeigi, M., Ashuri, B., and Shayegh, S. (2016). Price adjustment clauses and submitted bid prices for major asphalt line items in highway projects. Journal of Construction Engineering and Management, 142(5), 04015103.

Shrestha, P. P., Pradhananga, N., and Mani, N. (2014). Correlating the quantity and bid cost of unit price items for public road projects. KSCE Journal of Civil Engineering, 18(6), 1590-1598.

Shrestha, K. J., Jeong, H. D., and Gransberg, D. D. (2017). Multidimensional highway construction cost indexes using dynamic item basket. Journal of Construction Engineering and Management.

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Empirical Analysis for Modeling Spatial Variation in Right of Way Acquisition Durations

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The objectives of this research are to analyze empirical Right of Way (ROW) acquisition process records to quantitatively determine key project features influencing ROW acquisition durations and examine the spatial variation of the features' effects. This research used database of 495 projects that finished ROW acquisition process between the year 2010 and 2019 by Georgia Department of Transportation. The multiple linear regression is performed to identify significant variables that impact acquisition duration. Then, the geographically weighted regression analysis is conducted to examine spatial variations of variables' effects across the geographical locations. Acquisition durations tend to increase as the number of parcels and the average cost estimate per parcel increases, the design is completed by consultant or regional office, and the type of work is roadway and widening projects. The analysis results indicate that variables' effects vary throughout areas of the state. Therefore, ROW practitioners should consider giving different weights to project features depending on the project's location when setting the ROW acquisition schedule to reduce risks of schedule delays and cost overruns. It is anticipated that findings of this research will provide insights to ROW practitioners on how to improve ROW acquisition timeline estimations and better manage the risks.

Key Words: Right of Way, Geographically Weighted Regression, Spatial Analysis, Project Management

Introduction and Background

The Right of Way (ROW) acquisition is to acquire real properties that are required for transportation projects. It is critical to complete acquiring ROW in a timely manner so that the transportation project can move forward in the scheduled time (Aleithawe, 2017). Failing to acquire required ROW on time can directly affect the schedule of construction and cause delays and cost overruns in transportation projects (Jeong et al., 2016). Therefore, it is important to accurately estimate the ROW acquisition duration to mitigate the risk of project being delayed. However, estimating ROW acquisition timeline beforehand is often difficult because of the complex nature of the process (Chung et al., 2021; Dyke et al., 2020). Specific project characteristics and unique surroundings make it challenging to precisely forecast ROW acquisition timeline (Sohn et al., 2009).

Because transportation projects are different in many dimensions, their unique project features should be considered when setting the acquisition timeline. For example, the number of parcels and number of relocations would directly affect the amount of workload to complete acquisition process (Chung et al., 2021). The location of projects, such as urban or rural areas, would generate different challenges in the acquisition projects (Jeong et al., 2016). The project type (e.g., widening, bridge, intersection improvement, etc.) is an important feature because the type of parcels to acquire would differ (Sohn et al., 2014). It is needed to understand how unique project characteristics affect the ROW acquisition duration to better estimate timelines of the process. Previous studies contributed to identify the barriers that impede facilitation of ROW deliveries and to improve the estimation of the ROW acquisition duration.

Gibson et al. (2006) examined detailed records of 45 projects, including letters, faxes, appraisal reports, negotiation reports, and communications between internal and external entities, to find which factors caused delays in the ROW acquisition process. The following incidents were found to cause delays in ROW acquisition: (1) disputes on compensation and pricing; (2) title curative problems; (3) third-party delays; (4) parcel characteristics, and owner-initiated and improvement delays; (5) environmental sensitivity and expert witness delays; (6) legal activity causing delays; (7) utility delays; (8) design change or revision delays; and (9) terrain features dispute causing delays.

Jeong et al. (2016) conducted surveys and interviews to identify barriers that exist in the ROW acquisition process. The authors found that the barriers that transportation agencies faced were caused by four roots: (1) uncooperative work environment; (2) lack of tools and methods; (3) distrust of property owners; and (4) adverse effect of eminent domain law.

Waters (2000) found the barriers and obstacles that hinder expedient ROW acquisition process, by conducting a survey of transportation agencies. The barriers and obstacles found were (1) late design and ROW plan changes and revisions; (2) unrealistic project schedule; (3) problems in coordination between agencies; (4) insufficient trained ROW staff; (5) consultant problems; and (6) ineffective use of technology applications.

Chung et al. (2021) conducted survey of ROW representatives in thirty-six State Department of Transportations (DOT) to identify current management practices developed and explore possible ways to expedite the process. A part of their survey was dedicated to find the importance of factors considered in setting the ROW acquisition timeline. The survey results indicated that the top five factors considered important are (1) number of parcels to acquire, (2) needs for relocation assistance, (3) project size in monetary value, (4) needs for appraisers, and (5) project type.

Aleithawe et al. (2012) performed regression analysis using previous Mississippi Department of Transportation highway construction projects to identify the factors contributing to acquisition duration. The authors found that the significant factors that increased the acquisition duration were: (1) number of parcels; (2) number of parcels acquired by condemnation; and (3) number of revisions. The authors also developed a regression model using the identified factors to estimate the ROW acquisition durations.

Multiple researches have been conducted to identify factors that affect the ROW acquisition duration and find ways to make the acquisition process more efficient and expedient. However, only limited studies have been done to empirically identify which project features affect the ROW acquisition duration and quantitatively measure the importance of variables. Moreover, gaps in knowledge remains on finding if the effects of variables would vary depending on the projects' locations. The objective of this research is to analyze empirical ROW acquisition process records to quantitatively determine key project features influencing the ROW acquisition durations and examine the spatial variation of the effect of variables. The methods introduced in this paper can be applied by any transportation agencies to evaluate which project features affect their ROW acquisition duration and examine how the effects vary throughout locations. Quantitatively evaluating the influence of key project features and their spatial variation throughout locations will give transportation agents insights on how to improve their ROW acquisition estimation models so that they can better manage ROW acquisition risks.

Research Methodology

Data Preparation

This research used the database of 495 projects that finished ROW acquisition process between the year 2010 and 2019 by Georgia Department of Transportation (GDOT). The project descriptions were found in the GDOT Preconstruction Status Report. The duration required to perform ROW acquisition process was used as the dependent variable. Literature review and discussion with subject matter experts associated with GDOT have been done to identify the factors that affect the ROW acquisition timeline. Thirteen variables were selected to be the explanatory variables for the analysis in this research. The descriptions of the variables and justification of the selections are listed in Table 1.

Table 1

Description of variables selected for the analysis

Variable	Descriptions	Source
Number of Parcels	The number of parcels required to acquire for a project is a significant factor to estimate the workload and duration. It was also used for building models to predict acquisition timeline in previous research.	Aleithawe et al. 2012; Chung et al. 2021; Sohn et al. 2014
Number of Relocations	The number of relocations provides the number of parcels that need relocation assistance. This factor was found to be essential when setting the acquisition timeline.	Gibson et al. 2006; Sohn et al.2014
Number of Condemnations	This variable describes the number of condemnations needs to be filed. Filing condemnation can significantly affect the acquisition duration and cause delays in the acquisition duration.	Aleithawe et al. 2012; Caldas et al. 2011
Average Cost Estimate Per Parcel	This represents the average cost estimate per parcel. The cost estimate per parcel would affect the duration depending on the funds available for the ROW acquisitions. The annual ROW budget was found to be one of the key drivers affecting ROW acquisition duration.	Sohn et al. 2014
Environment Document	The level of environmental document needed to be completed (National Environmental Policy Act; Georgia Environmental Policy Act). It was found that the type of environmental document needed to be completed affects the ROW acquisition timeline.	Waters 2000
Design	It defines which office completed the design process (central office; regional office; consultant). The quality of designs would influence the ROW acquisition duration because the revisions in design was found to be one of the significant factors that contributed to delays in ROW acquisition. An	Aleithawe et al. 2012; Gibson et al. 2006

	assumption was made that the quality of design is dependent on the office that prepares the design.	
Urban Location?	This variable indicates if the project is held at urban location or not. The acquisition timeline has been found to be impacted by the geographic location (e.g., urban, suburban, or rural) because the acquisition environment would differ depending on the location of a project.	Jeong et al. 2016
District	This identifies which DOT district the project is held in (District 1 to 7). The characteristics of district, such as district ROW staff size and district annual ROW budget, would impact the duration it takes to acquire ROW.	Sohn et al.2014
Type of Work	The work type of project (bicycle/pedestrian facility; bridges; interchange; intersection improvement; operational improvement; roadway project; roundabout; signal; widening; others) would affect the types of parcels that need to be acquired.	Chung et al. 2021; Sohn et al. 2014
Program Type	This variable provides information about the program type of the project (enhancement; new construction; reconstruction; replacement; maintenance; safety). The type of projects was identified to be a significant factor in setting the ROW acquisition timeline.	Sohn et al. 2014
Length of Projects	The physical length would determine the variations in the surrounding environments and in the types of parcels. Higher variations in the project environment may increase the complexity of the acquisition process and cause longer durations.	Discussion with subject matter experts
Acquired by Central Office?	This variable indicates if the ROW acquisition process was performed by the central office or the regional office. The durations might depend on which office performs the acquisition.	Discussion with subject matter experts
Let with Other Projects?	This variable indicates if a project is planned to be let with other projects. If two or more projects are planned to be let together, their schedule may be influenced by one another.	Discussion with subject matter experts

After selecting the variables for the analysis, the multicollinearity between explanatory variables were examined. Substantial degree of multicollinearity exists between variables when those are related to each other (Bowerman et al., 2005). High multicollinearity can inflate the variances of affected variables and generate less certain results among the variables. The multicollinearity can be measured using the Variance Inflation Factor (VIF) value. The variables with VIF value larger than 10 were considered to have severe degree of multicollinearity (Bowerman et al., 2005) so that they were removed from the analysis. The removed variables were reconstruction and replacement from the program type and bridges from the type of work.

The dependent and explanatory variables were standardized for the data analyses. Standardization adjust each variable’s scale and unit into a common scale and unit (Karlaftis et al. 2010). The importance of explanatory variables to explain the variance of dependent variable can be found by comparing magnitudes of standardized coefficients.

Data Analysis

The multiple linear regression and geographically weighted regression were conducted to examine the relationship between the project features and the ROW acquisition durations. The significant variables were found from the multiple linear regression and evaluated how those variables affect the acquisition durations. With those identified significant variables, the geographically weighted regression was performed to capture the spatial variation of relationships between the dependent and explanatory variables. The coefficients calculated from the geographically weighted regression were adjusted throughout the geographical locations to build regression models for local variables (Düzgün H., and Kemeç S. 2008). Plotting the varying coefficients of significant variables helps to find how the effect of explanatory variable changes throughout the locations.

Results and Discussions

The model generated from the multiple linear regression and the geographically weighted regression is defined as the following equation.

$$\begin{aligned} ROW\ Acquisition\ Duration = {} & a_0 + a_1[Number\ of\ Parcels] \\ & + a_2[Average\ Cost\ Estimate\ Per\ Parcel] + a_3[Consulatnt\ Design] \\ & + a_4[Local\ Design] + a_5[Roadway\ Project\ (Type\ of\ Work)] \\ & + a_6[Widening\ (Type\ of\ Work)] \end{aligned}$$

where, a_0 is a constant and a_i is a coefficient of the i-th explanatory variable. The coefficients computed from the multiple linear regression are global, meaning that the coefficients apply for projects at all locations, while the coefficients found from the geographically weighted regression vary throughout the locations. Since the variables were standardized, it means that the dependent variable changes in a_i standard deviation when the i-th variable is changed by one standard deviation. The adjusted R-squared values for the multiple linear regression model is 0.449 while it is 0.454 for the geographically weighted regression.

Multiple Linear Regression

The global coefficients of significant variables identified from the multiple linear regression are listed in Table 2. The acquisition duration is found to increase as the number of parcels and the average cost estimate per parcel increases. In addition, the duration tends to increase as designs are prepared by the consultant or regional office compared to when it was completed by the GDOT central office. Furthermore, the roadway project and widening type of works significantly affect the duration to take longer than other types. The order of significance among variables is: (1) number of parcels, (2) average cost estimate per parcel, (3) consultant design, (4) roadway project, (5) regional office design, and (6) widening.

Table 2

Multiple linear regression analysis results

Significant Variables	Coefficient	Standard Error	P-Value	VIF
Number of Parcels	0.553	0.085	< 0.001	6.419
Average Cost Estimate Per Parcel	0.105	0.039	0.0075	1.379
Consultant Design	0.234	0.089	0.0085	1.544
Regional Office Design	0.302	0.150	0.0443	4.160
Roadway Project	0.594	0.232	0.0107	1.960
Widening	0.285	0.145	0.0499	2.241

The higher number of parcels increasing the acquisition duration aligns with the findings from the previous studies. The survey results and data analyses from previous studies found that the number of parcels is one of the significant variables that influence the ROW acquisition duration (Aleithawe 2012; Caldas et al. 2006; Chung et al. 2021; Hakimi and Kockelman 2005; Sohn 2014). Increment in number of parcels to acquire for a project would increase the overall workload including valuation, negotiation and possibly relocation and condemnation.

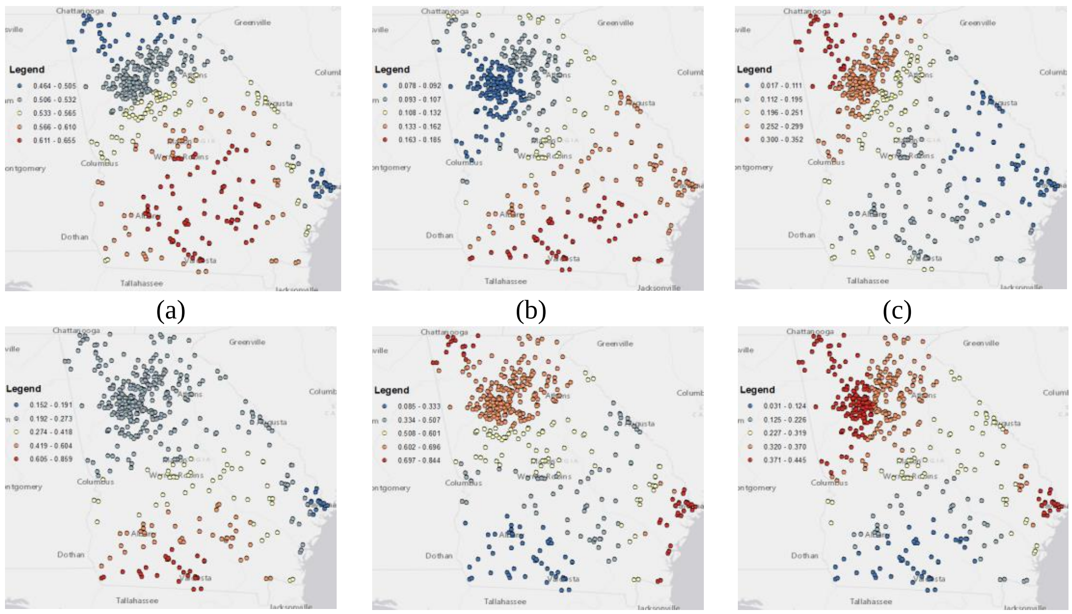
The acquisition duration tends to be lengthier as the average cost estimate per parcel increases. The requirement for an appraisal may be waived for low valued parcels to save a substantial amount of time to prepare the appraisals (Jeong et al. 2016). The GDOT allows appraisals for non-complicated parcels value lower than $15,000 can be waived (GDOT, 2018). The ROW acquisition durations may be estimated differently depending on the requirement of preparing appraisals. Furthermore, high price of ROW acquisition can generate a problem due to the funding limitation, which was found to be one of the key drivers that affect the acquisition schedule (Sohn et al. 2009). Sohn et al. (2014) found that the available district annual budget to purchase ROW was a factor that impact the duration to acquire parcels.

The acquisition duration would increase as the designs are prepared by consultant or regional offices compared to when designs are prepared by the central office. From a survey conducted by Waters (2000), all 36 state survey respondents considered that the revisions to the design is a major issue that hinders ROW acquisition process. Moreover, Aleithawe et al. (2012) identified that the ROW acquisition duration increases as the number of revisions increments from conducting data analysis with the historical data collected from the Mississippi Department of Transportation. It is apparent that the maintaining high quality of design is important for minimizing the number of revision and results in expediting the ROW delivery. The information about the number of revisions made for each project was unavailable for this research. The authors made an assumption that the quality of designs would be dependent on the office that performs design process. It would be worthwhile to conduct a further research to examine the number of revisions required for designs prepared by different offices and how those revisions directly or indirectly impacted the acquisition duration.

The roadway and widening projects were found to significantly take longer duration than other projects. The type of parcels and the location of parcels would depend on the type of projects. This result aligns with the findings from previous qualitative studies. The project type was found to be the fifth most important factor when considering the ROW acquisition timeline from the survey with thirty-six state DOT representatives conducted by Chung et al. (2021). Sohn et al. (2014) identified that the project type is one of the drivers that impact the acquisition durations by conducting workshops with forty-three practitioners who are responsible for ROW acquisition related tasks. Further research would be needed to find which characteristics of roadway and widening projects cause longer duration than the other projects.

Geographically Weighted Regression

The local coefficients of the significant variables found from the geographically weighted regression analysis are shown in Figure 1. As it is shown in the figure, the magnitudes of significant variables coefficients vary throughout the projects' locations.



(a) (b) (c)

(d) (e) (f)

Figure 1. Local coefficients of the significant variables found from the geographically weighted regression: (a) number of parcels; (b) average cost estimate per parcel; (c) consultant design; (d) regional office design; (e) roadway project; (f) widening. (Generated from Esri ArcGIS 2020)

The number of parcels and the average cost estimate per parcel tend to have higher impact at the southern part of the state. The consultant design increases the duration at the northern part of the state while the regional office design increases the duration at the southern part. The roadway and widening projects have the highest influence around the Atlanta and Savannah metropolitan areas. The potential reasons for higher impacts of variables on specific areas would include shortage on human resources, limited available funding, quality of design, performance of district office, difficulty of purchasing parcels to widen or improve existing roadways, and more. The limitation of this research was that the available data did not contain detailed information about the progress of ROW acquisition process for individual project. Therefore, it was difficult to identify which factors are the key drivers that generate the spatial variation of the variables' coefficients. Further research of examining the progress of ROW acquisition process held in multiple areas would be required to clearly understand which factors mainly drive the spatial variation of the variables' effects.

Conclusions

The 495 transportation project data was evaluated to identify which project features should be considered when estimating the ROW acquisition timeline. Among the thirteen variables used in the analysis, the number of parcels, average cost estimate per parcel, design, and project type were found to be significant for explaining the variation of the ROW acquisition timeline. Two categories in both design and project type were found to significantly influence the acquisition duration. In summary, six variables that were found to significantly affect the acquisition duration are (in the order of significance): (1) number of parcels, (2) average cost estimate per parcel, (3) consultant design, (4) roadway project, (5) regional office design, and (6) widening. The analysis results suggest that the acquisition duration tends to increase as the number of parcels and the average cost estimate per parcel increase. Moreover, the acquisition durations would take longer when the design is prepared by consultant or regional offices and if the project type is roadway or widening project.

From the geographically weighted regression analysis results, it is evident that the amount of influence of variables to the acquisition duration vary throughout different areas of the state. Therefore, rather than using a one-size-fits approach to create a baseline timeline for ROW acquisition tasks, setting ROW acquisition timelines differently depending on the project's location can help reduce the risks. Examining the progress of ROW acquisition process held in different areas might help us to identify the key drivers that generate spatial variation of the variables' impacts to the acquisition durations. It is anticipated that the findings of this research will provide insights to ROW practitioners on how to improve methods to estimate ROW acquisition timeline and mitigate the risk of project being delayed. Furthermore, the methods introduced in this paper would provide ideas on how records of other tasks related to transportation infrastructure projects can be evaluated to effectively manage project risks.

References

Aleithawe, I., Sinno, R.R., & McAnally, W.H. (2012). Right of Way Acquisition Duration Prediction Model for Highway Construction Projects. *Journal of Construction Engineering and Management, 138(4)*, pp. 540–544.

Aleithawe, I. (2017). Right-of-Way Acquisition Workflow Model to Reduce Acquisition Duration. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction.*

Bowerman, B., O'Connell, R.T., & Koehler, A.B. (2005). Forecasting, Time Series, and Regression. *Thomson Brooks/Cole, California.*

Caldas, C. H., Zhang, Z., Kockelman, K. M., Persad, K. R., Medina, D. V., & Chung, E. J. (2006). Synthesis of Best Practices in Right-of-Way Valuations and Negotiations. *Center for Transportation Research., University of Texas at Austin*.

Caldas, C. H., Zhang, Z., Kockelman, K. M., Persad, K. R., Al Halabi, R., & Kincaid, E. (2011). Development of Best Practices for Right-of-Way Valuations and Negotiations in Transportation Projects. *Journal of the Transportation Research Forum*.

Chung, F., Baek, M., & Ashuri, B. (2021) Improving the Management Practices for Right-of-Way Acquisition Process. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction.*

Düzgün H., & Kemeç S. (2008). Spatial and Geographically Weighted Regression. *In: Encyclopedia of GIS.* doi: 10.1007/978-0-387-35973-1_1242.

Dyke, C.V., Gibson, B., Baskette, R., Jasper, J., Wallace, C., & Kreis, D. (2020). Kentucky Transportation Cabinet Right of Way Process Review (Phase I). *Kentucky Transportation Cabinet*.

Georgia Department of Transportation (GDOT). (2018). Right of Way Manual. *Georgia Department of Transportation*.

Gibson, E.G., O'Connor, J.T., Chang, R.G., Hedemann, S.M., & Chong, W.K. (2006). Durations for Acquiring Roadway Right-of-Way and Assorted Expediting Strategies. *Texas Department of Transportation*.

Hakimi. S., and Kockelman, K.M. (2005). Right of Way Acquisition and Property Condemnation: A Comparison of U.S. State Laws. *Journal of the Transportation Research Forum.*, 44(3), pp. 45–58.

Jeong, D., Gransberg, D.D., Park, H., & Shelar, N. (2016). Barriers to Right-of-Way Acquisition and Recommendations for Change. *Minnesota Department of Transportation.*

Karlaftis, M. G., Mannering, F. L., & Washington, S. (2010). Statistical and Econometric Methods for Transportation Data Analysis. *Taylor & Francis.*

Sohn, T. (2009). Determining durations for right-of-way acquisition and utility adjustment on highway projects. *The University of Texas at Austin*.

Sohn, T., Azambuja, M., O'Connor, J.T., & O'Brien, W. J. (2014). Empirical Study on the Key Drivers Affecting Durations for Right-of-Way Acquisition on Highway Projects. *Journal of Management in Engineering.*, 30(3), Art. no. 04014009.

Waters, T. (2000). NCHRP Synthesis 292: Innovative Practices to Reduce Delivery Time for Right of Way in Project Development. *National Cooperative Highway Research Program.*

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Evaluation of the Engineering and Design Scope of Services for State DOT Infrastructure Projects

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Transportation agencies across the United States (U.S.) are under increasing pressure to deliver the project more efficiently and effectively. To meet expectations, the agencies are increasing the rate of procurement of professional consultant services as they are facing various challenges in project scoping process (PSP). Since the scope of services (SOS) and PSP are related to each other, this study is focused on evaluation of the available data addressing the comprehensiveness of the SOS across different states. The authors focused on the design SOS and evaluated 49 documents from 8 state departments of transportation (DOTs). The authors then developed a series of criteria for assessing the comprehensiveness of these selected DOTs. Data analysis indicated significant variations across the states in terms of the criteria. Further, weights were assigned to the identified criteria and sub-criteria using the analytic hierarchy process (AHP) and the SOS documents were ranked for their comprehensiveness. Comprehensive score indices (CC_i and CC_e) were calculated using the level of comprehensiveness and the level of importance derived from actual SOS document pages and AHP respectively.

Keywords: Scope of Services (SOS), Project Scoping Process (PSP), Analytic Hierarchy Process (AHP), Department of Transportation (DOT).

Introduction

In recent years, the transportation industry has witnessed an increase in the use of professional services consultants for engineering and design professional services to meet rising demand. This increased demand has elevated both the number of projects for states' Department of Transportation (DOT) and the need for on-time delivery to meet the increased need for transportation projects (Gen & Kingsley, 2007). Compounding the challenge is that DOTs are facing shortage of skilled and seasoned employees to keep up with the increasing demands as thousands of workers are expected to retire over the next 5 to 10 years (Nambisan, Hallmark, & Albrecht, ; Vandervalk, Cronin, & Thompson, 2020).

According to the American Road & Transportation Builders Association's (ARTBA) seventh annual analysis of the latest U.S. DOT's National Bridge Inventory (NBI) database, more than one-third, or 220,000, of the nation's 618,000 bridges need structural repair, rehabilitation work or replacement

(TOP 10 takeaways, 2017). The USDOT categorizes the condition of bridges as good, fair, and poor (structurally deficient). Of the total bridges that need structural repair, rehabilitation work or replacement, 45,000 of them are classified as structurally deficient. At the current pace, it would take nearly forty (40) years to repair the rising backlog of structurally deficient bridges, according to the report (TOP 10 takeaways, 2017). Moreover, many transportation projects have experienced significant delays in schedules over the last three years (Quattlebaum & Dee, 2019). The majority of the delays were caused by deficiencies related to projects' scopes of work (SOW).

To address the increasing burden of transportation projects aggravated by the lack of seasoned employees, the DOTs have increased the rate of procurement for engineering and design professional services. In order to avoid procurement delays, particularly related to insufficient project details associated with inadequate project scopes, a comprehensive and well-developed project scope is essential. The objective of this study is to evaluate the components of professional consultant scope of services (SOS) for state DOT projects. This paper elucidates essential engineering and design SOS criteria identified from relevant SOS documents collected from different state DOTs.

Literature Review

A well-defined project scoping process (PSP) is essential for a state Department of Transportation (DOT) to effectively meet the infrastructure needs of their state. The lack of consistent project scoping definition makes the pre-contract scoping processes challenging for the state transportation agencies (STAs). According to a study conducted on pre-contract PSP by Hamed Zamenian et al., the Indiana DOT had to face problems due to inconsistency in the scoping process across different units within the agency. This problem was also associated with lack of resources for coordination and long-term planning (Zamenian & Abraham, 2016). The authors could not identify a pattern for such inconsistencies in the scoping practices, but support was identified to link it to the absence of formal policy to assess the quality and effectiveness of their scoping procedures (Zamenian & Abraham, 2016).

In developing the PSP framework, Kermashachi et al., highlighted that the lack of scope definition and lack of details associated with project scoping often resulted in cost and time overruns. The authors also indicated that transportation projects are often programmed before defining the scope sufficiently which resulted in delays and increased costs (Kermanshachi, Anderson, Goodrum, & Taylor, 2017). Moreover, inaccurate estimates result in changes associated with project budgeting and schedule causing the DOTs to adjust in the scope definition of transportation projectss (Hessami, A. R., Sun, D., Odreman, G. J., Nejat, A., & Saeedi, M., 2017). The level of scope definition has considerable influence on the cost and schedule of a project and can hinder the ability to control project change orders (Kermanshachi, Safapour, Anderson, Goodrum, & Taylor, 2020; Le et al., 2009).

Kermanshachi et al. also developed a multi-level project scoping model for transportation projects. The authors used the integrated definition modeling technique to develop the scoping process. The development of this technique led to the adoption of appropriate best practices and strategies which reduced scope changes and prevented unnecessary delays for infrastructure projects (Kermanshachi et al., 2019). The authors also identified major activities associate with the PSP which were classified into four categories: environmental, right-of-way (ROW)/utilities, design, and construction. The study of these categories indicated that collectively all four categories are critical dimensions of an effective PSP (Kermanshachi et al., 2020).

An internal report on reducing scoping deficiencies to improve the delivery of transportation projects for the South Carolina Department of Transportation (SCDOT), identified eight major obstacles that delayed projects from advancing to the construction phase of work (Quattlebaum & Dee, 2019). The analysis showed 495 events of delays in different phases of work across a span of over three years. The delays that were evaluated ranged from 90 days to over 1700 days. Among the eight obstacles identified, scoping deficiencies attributed to 45% of the delays. These deficiencies included any modifications to the original design criteria established to meet the purpose of the project (Quattlebaum & Dee, 2019).

At present, few, if any, detailed investigations have been undertaken to evaluate the comprehensiveness of scope of services (SOS) related to development of engineering and design elements. This study is intended to bridge this gap and assist state DOTs in the development of the tasks and subtasks necessary to identify the SOS criteria which is important to achieve a comprehensive SOS.

Research Methodology

A five-step research method was used to investigate and evaluate development of consultant scope of services (SOS).

Step 1: Data Collection

The first step in the research methodology was to collect data that was relevant to the scope of services (SOS) for professional services consultants. To initiate this step, the authors further divided this step into three sub-steps.

Conduct a literature review – Scientific databases such as Google Scholar, Transportation Research Board (TRB) database, FHWA, and other scholarly publications that include American Society of Civil Engineers' (ASCE) Construction Research Congress (CRC), and SAGE Publications were searched to retrieve relevant literature data. A total of 37 publications based on various topics including PSP and related studies were retrieved from these sources.

Investigate each of the 50 state DOT websites for relevant data –Twenty-six (26) states had a variety of documents related to professional SOS ranging from templates, requests of proposal (RFP), and contracts with actual project scopes. These documents were available in the public domain. Published documents were not available on the DOT's website for the remaining 24 states. Some of these remaining states did have a consultants' page on their respective agency websites but the documents were not publicly accessible. The 26 states that had information available are California, Nevada, Utah, Colorado, Texas, Oklahoma, North Dakota, Wisconsin, Iowa, Missouri, Louisiana, Mississippi, Tennessee, Kentucky, Ohio, Florida, Georgia, South Carolina, North Carolina, Virginia, New York, North Hampshire, Maine, New Jersey, Vermont, and Minnesota.

Collection of data from secondary sources – This includes the data collected from the industry consultants' websites.

Step 2: Data Organization

Based on the website search of state agencies, the authors identified 155 documents relevant to the study. These documents included templates, contracts, and RFPs. The documents were studied for their content and organized according to the services provided. The organization of these documents was done in the following manner:

State-wise listing of documents – The documents collected were arranged according to the state.

Organize the documents – After development of a comprehensive listing, the documents across states were re-arranged based on the document name/title. Documents with similar titles were grouped together.

Categorize the documents – Once the documents were organized, they were placed into their appropriate group or "service categories". This task aimed to process the raw data into a more meaningful form for detailed study within the defined service categories. Each service category represented the type of service the documents provided. This process was repeated until all 155 available documents were grouped into their most suitable categories.

Step 3: Develop SOS criteria for evaluation

Considering the influence that engineering design elements have on the scoping process (Burati, Farrington, & Ledbetter, 1992; Kirby, Furry, & Hicks, 1988) the focus of the research effort was strictly limited to the category of 'engineering design/design' SOS only . This resulted in reduction of the candidate state DOTs from twenty-six (26) down to eight (8) as the other state DOTs lacked published SOS documents related to engineering design. Among these eight (8) states DOTs, a total of forty-nine (49) design SOS documents were available for evaluation. In Step 3, the elements of design SOS were compared to develop criteria for evaluation. Each SOS had two (2) elements – task, and subtask. The documents with a similar type of SOS were compared to identify common tasks and subtasks between them. Similar tasks and subtasks were then grouped into the most suitable criteria. For example, Engineering Design & Analysis criterion had all design-related activities from various SOS documents. This comparison was made across all eight states to determine the criteria.

The eight (8) essential criteria identified were:

- Project Organization & Management
- Engineering Design & Analysis
- Survey & Mapping
- Plans, Specifications, and Estimates (PS&E)
- Right-of-Way (ROW)
- Utilities & Railroad Coordination
- Environmental Studies/Documentation/Permits
- Public Information

In addition to the SOS tasks and subtasks, there are additional criteria that are relevant to evaluate the comprehensiveness of a state DOT's SOS development process (Jin, Haidary, Bausman, & Chowdhury, 2021). They included the following:

SOS Document Year – To evaluate the comprehensiveness of the SOS, it was essential to determine the year when the documents were published by the DOTs. Having a recent SOS is a key indicator that the document identifies current DOT policies and processes for the agency.

Improvements - Value engineering (VE) means adding value to the project in various possible ways including but not limited to reducing overall project cost, improving the design delivery process, make construction simpler, reduce the project duration, improve safety and quality, and consider environmental goals (Jin, Haidary, Bausman, & Chowdhury, 2021). According to Tiendung Le et al., Risk Management (RM) and scope definition are crucial elements of the project development process (PDP) as it allows to identify the risks at their sources (Jin, 2021; Le et al., 2009). PDP consists of various components and PSP is one of the important components of it. Incorporating risk management criteria built into the SOS allows the DOTs and the consultants to identify, analyze, and mitigate the risks during the design phase.

Step 4: Weighting SOS criteria using AHP model.

After identifying the criteria for evaluation, the next step was to weight the criteria. To address this step, the authors adopted AHP as the most appropriate method to weight the criteria (Jin, Haidary, Bausman, & Chowdhury, 2021). AHP allows judgment in assigning weights to criteria that are incommensurable. The goal was to assign an importance score to each of SOS criteria. The steps utilized to determining the comprehensiveness of PDP were consistent with a prior study (Jin, Haidary, Bausman, & Chowdhury, 2021). For this study, the problem was divided into main criteria: SOS components, SOS document year, and other improvements as shown in both Tables 1 and 2.

Once the hierarchical structure was developed, the authors performed a pairwise comparison which involved comparison of each criterion with the remaining criteria to calculate the weight with respect to one another. Table 1 shows the process of assigning weights to each criterion relative to other criteria using pairwise comparison matrix. The weights were assigned to each criterion with respect to another using the AHP rating scale. By definition, the comparison matrix has two distinct properties: (1). it is a symmetrical matrix, and (2). all the diagonal elements are one, as the relative importance of a criterion with respect to itself is one.

Table 1
Pairwise Comparison Matrix for assigning criteria weights

		Criterion Number							
Criterion	**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Project Organization & Management	**1**	1	2/9	3/9	3/9	3/9	4/9	2/9	5/9
Engineering Design & Analysis	**2**	9/2	1	6/2	9/9	8/4	4/1	9/9	9/3
Survey & Mapping	**3**	9/3	2/6	1	1/3	5/5	4/2	1/5	6/2
PS&E	**4**	9/3	9/9	3/1	1	6/3	6/2	1/3	1/2
ROW	**5**	9/3	4/8	5/5	3/6	1	4/2	1/3	6/2
Utilities & railroad Coordination	**6**	9/4	1/4	2/4	2/6	2/4	1	1/3	4/4
Environmental Studies/ Documentation/ Permits	**7**	9/2	9/9	5/1	3/1	3/1	3/1	1	8/2
Public Involvement	**8**	9/5	3/9	2/6	2/1	2/6	4/4	2/8	1

The weighting of criteria consisted of: (1). assigning weights to each criterion with respect to another to develop a pairwise comparison matrix; as explained above; (2). normalizing the comparison matrix; and (3). calculating the weights of each criterion by averaging the normalized values in each row. To validate the accuracy of the criteria weights, consistency index (C.I.) and consistency ratio (C.R.) were calculated.

$$C.I. = (\lambda_{max} - n) / (n - 1), \text{ and } C.R. = C.I. / R.I.$$

where, λ_{max} is calculated by dividing all the elements of the weighted sum matrices by each criterion weight, n is the total number of criteria, and RI is the C.I. for a randomly generated matrix.

Assigning the pair-wise scores was a subject task that incorporated the perception and understanding of subject matter experts (SMEs) in design and construction management. The final outcome of this step was a series of importance levels (γ) for each criterion. Specific (γ) values for each criterion are presented and discussed in the Results and Findings section.

Step 5: Ranking the comprehensiveness of SOS.

The final step in the development of evaluation method was to measure the comprehensiveness (ε) of the SOS documents. While there could be several numerical and categorical approaches to do this, one convenient metric is the number of pages with each document that is allocated to each criterion. To that end, each SOS document was closely observed, and the number of pages allotted to each criterion was calculated. It must be noted that the absolute number of pages is misleading. For example, a criterion could be 9 pages in 200 page document vs. in a 20 page document. To resolve this matter, the team defined two distinct approaches to measure (ε) by: (1). Calculating internal comprehensiveness (ε_i) by normalizing the criterion's number of pages by the total number of pages in the document, and (2). Calculating external comprehensiveness (ε_e) by the criterion's number of pages by the total number of pages of the same criterion across all the SOS documents.

Data Analysis

Based on the data collected, the authors conducted data analysis to investigate SOS criteria and their occurrence in the documents collected from various states. A total of 49 SOS documents from eight (8) states were studied. The findings are presented in Table 2.

Table 2

Basic Criteria of Engineering and Design Scope of Services (SOS) (n = 49)

Criteria		**Min.**	**Mean**	**Max.**	**SD**
Documentation year of SOS document		2008	2018	2021	3.5
SOS Components	Total number of document pages	3	56.7	312	67
	The number of tasks in the SOS	1	15.7	39	15.1
	The number of pages of project organization & management	0	6.3	33	8.5
	The number of pages of engineering design & analysis	0	18.5	101	23.9
	The number of pages of survey and mapping	0	3.4	14	4.9
	The number of pages of PS&E	0	2.7	12	3.5
	The number of pages of ROW	0	0.5	4	0.8
	The number of pages of utilities & railroad coordination	0	2.7	19	3.4
	The number of pages of environmental studies/documentation/permits	0	4.1	48	7.3
	The number of pages of public information	0	1.3	10	2.2
Other Improvements	Value engineering	0	0.2	1	0.4
	Risk management	0	0.2	1	0.4

As shown in Table 2, the combined mean of document pages and number of SOS tasks were 56.7 and 15.7 respectively, whereas the state with the highest number was Florida with a mean of 106 pages and 33 tasks. This proves that there was a significant variation between the states.

Results And Findings

Based on AHP, the weights of criteria were calculated to evaluate the comprehensiveness of design SOS. The criteria weights were then used to rank the comprehensiveness of each SOS document. To validate the accuracy of criteria weights, the authors measured the consistency index (C.I.) and consistency ratio (C.R.). Upon calculation, the authors concluded that (C.R. = 0.07568 < 0.10) the matrix was reasonable consistent. Table 3 shows the weights of each criterion and sub-criterion. It was found that SOS components were the most important criteria (72.35%) when compared with other improvements (19.32%) and documentation year (8.33%). Among the sub-criterion of SOS components, environmental studies/ documentation/ permits, engineering design & analysis, and PS&E ranked higher in terms of their weights with 19.14%, 14.82%, and 10.64% respectively. This indicates that the sub-criteria had a high level of importance in terms of tasks and subtasks in the SOS. After establishing weights for each criterion and sub-criterion, the internal and external comprehensiveness score (i.e., CC_i and CC_e) SOS documents across the states were completed.

Table 3

Weight of each criterion

Criterion	Weight	Sub-criterion	Weight
Documentation Year	8.33%	Year of publication	8.33%
SOS Components	72.35%	Project organization & management	2.79%
		Engineering design & analysis	14.82%
		Survey & mapping	6.99%
		Plans, Specifications, & Estimates (PS&E)	10.64%
		Right-of-Way (ROW)	7.82%
		Utilities & railroad coordination	4.42%
		Environmental studies/ documentation/ permits	19.14%
		Public information	5.72%
Other Improvements	19.32%	Value engineering	9.66%
		Risk assessment	9.66%
Sum	100%		100%

Figure 1 shows the comprehensive score indices for internal and external comparison of the SOS documents. The (CC_i) is the product of weighted average of level of comprehensiveness and the level of importance within each document, and the (CC_e) is the product of level of comprehensiveness and the level of importance across all the documents. Based on Figure 1, the authors found the following:

- The comprehensive scores indices are highly variable for both internal (CC_i) and (CC_e).
- The highlighted boxes in Figure 1 show the number of documents from respective states. The FDOT documents in Figure 1 have a significantly consistent comprehensive score index when compared to the rest of the documents. Further, the overall score index for FDOT is the highest among others. This indicates that the FDOT document range in Figure 1 has both consistency and comprehensiveness.
- Again, FDOT ranked first in terms of the average number of SOS tasks with 32.76 (~33) tasks per document.

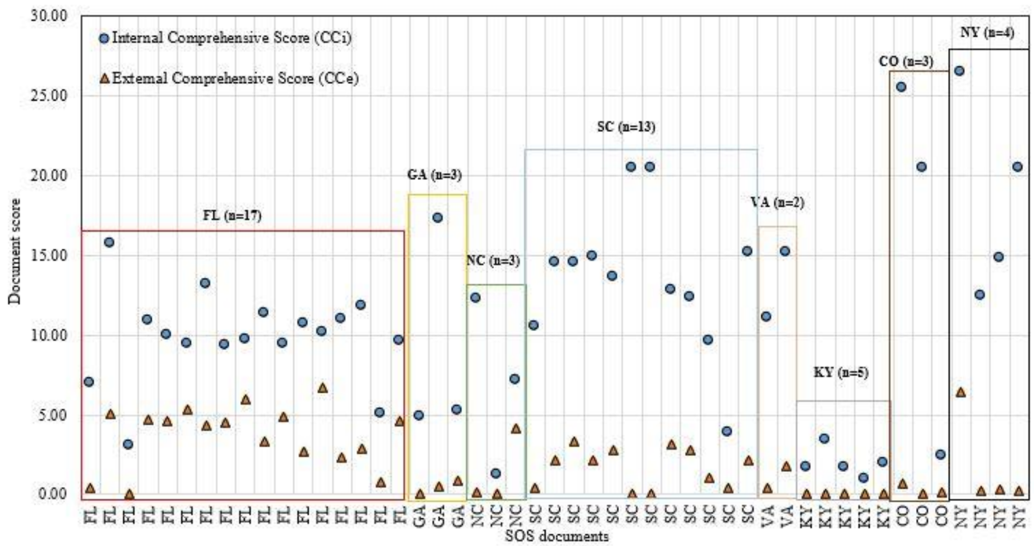

Figure 1. Comprehensive Score Index

Conclusion

To meet the ever increasing demand of infrastructure projects across the U.S., the state transportation agencies need to avoid procurement delays and issues related to insufficient scope development. In order to address the issues related to lack of detailed scope, it is necessary that the state DOTs develop a comprehensive design SOS which can be modified according to the project's need. However, it can only be possible through a detailed evaluation of design SOS components. Therefore, this research paper is aimed at evaluating the engineering and design SOS and measuring the comprehensiveness of the identified criteria. Based on the comprehensive score indices for internal and external SOS documents, it was found that FDOT had both consistency in their SOS documents as well as comprehensiveness when compared with the other seven (7) state DOTs. The key takeaways from this study are:

- Out of the 26 state DOTs that have SOS documents published on their websites, only 8 state DOTs have SOS documents related to engineering design.
- The state DOTs should focus on developing a standard scope language for environmental studies, engineering design & analysis, and PS&E as they contribute 61.64% of the total SOS components.
- Also, a very few state DOTs had documented value engineering and risk assessment in the SOS documents.

Future Research

Based on the evaluation of design SOS, the authors aim to develop a baseline template for design SOS that can be used by all DOTs in procuring consultants. To achieve this goal, the authors will conduct a series of interviews with the industry consultants and candidate states identified in this study.

References

Burati, J. L., Farrington, J. J., & Ledbetter, W. B. (1992). Causes of quality deviations in design and construction. *Journal of Construction Engineering and Management, 118*(1), 34-49. doi:10.1061/(ASCE)0733-9364(1992)118:1(34)

Gen, S., & Kingsley, G. (2007). Effects of contracting out engineering services over time in a state department of transportation. *Public Works Management & Policy, 12*(1), 331-343. doi:10.1177/1087724X07302585

Hessami, A. R., Sun, D., Odreman, G. J., Nejat, A., & Saeedi, M. (2017). Project Scoping Guidebook for Metropolitan Planning Organization Transportation Projects (No. 0-6929-P1). Texas A & M University.TOP 10 takeaways. (2017, Aug 06,). Sun (London, England : 1964) Retrieved from https://search.proquest.com/docview/1926307708

Jin, W., Haidary, T. A., Bausman, D. C., & Chowdhury, M. (2021). Evaluation of project development process at state transportation agencies. *Transportation Research Record, 2675*(3), 326-337. doi:10.1177/0361198120971260

Kermanshachi, S., Anderson, S. D., Goodrum, P., & Taylor, T. R. B. (2017). *Project scoping process model development to achieve on-time and on-budget delivery of highway projects* SAGE Publications. doi:10.3141/2630-18

Kermanshachi, S., Safapour, E., Anderson, S. D., Goodrum, P., & Taylor, T. R. B. (2020). *Establishment of effective project scoping process for highway and bridge construction projects* American Society of Civil Engineers (ASCE). doi:10.1061/(asce)sc.1943-5576.0000427

Kermanshachi, S., Safapour, E., Anderson, S., Goodrum, P., Taylor, T., & Sadatsafavi, H. (2019). Development of multi-level scoping process framework for transportation infrastructure projects using IDEF modeling technique. In Proceedings of Transportation Research Board 98th Annual Conference.

Kirby, J. G., Furry, D. A., & Hicks, D. K. (1988). Improvements in design review management. *Journal of Construction Engineering and Management, 114*(1), 69-82. doi:10.1061/(ASCE)0733-9364(1988)114:1(69)

Le, T., Caldas, C. H., Gibson Jr, G. E., & Thole, M. (2009). Assessing scope and managing risk in the highway project development process. Journal of Construction Engineering and Management, 135(9), 900-910.

Nambisan, S., Hallmark, S., & Albrecht, C.*Preparing tomorrow's transportation workforce: A midwest summit*

Vandervalk, A., Cronin, B., & Thompson, C. (2020). *Project final report acknowledgment of sponsorship*

Zamenian, H., & Abraham, D. M. (2016). *Pre-contract project scoping processes: Synthesis of practices* Purdue University. doi:10.5703/1288284316192

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Construction Project Level-based Environmental, Social, and Governance (C-ESG): A Review

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Sustainable business has been shed light on as a new way of business success by emphasizing global and local responsibility of environment, community, society, and economy in the industry and company levels. Environmental, social, and governance (ESG) factors of construction companies have often been evaluated by aggregating sustainability performance of their projects. However, the ESG is still underperforming in the project level. Therefore, the objective of this research is to propose the concept of the construction project level ESG (C-ESG) for facilitating sustainability practices in the construction industry. C-ESG intends to guide the valuation of non-financial performance in ESG and to achieve a higher level of sustainable development goals (SDG) for the construction project. A comprehensive literature review was conducted to consolidate evaluation metrics and key concepts in ESG, and adapt the ESG framework to the construction project context. In the project levels, three conceptual applications of the ESG framework can be considered: identifying priority public investment projects, supporting the bid/no-bid decisions, and monitoring and evaluating project progress. This research identified the needs and opportunities of C-ESG. In the future, further studies will be conducted to define key performance indicators (KPIs), metrics, and quantification methods in the three C-ESG types.

Key Words: Environment, Social, and Governance (ESG), Construction Project-level ESG (C-ESG), Sustainable Development Goals (SDG), Construction Management

Introduction

The United Nations (UN) established sustainable development goals (SDG) for promoting the wealth of each country while they pursue to protect the earth. The SDG is a high-level of goals for achieving a sustainable future for all countries, communities, and individuals on the planet (United Nations, 2020). A total of 17 SDGs addresses the significant challenges (e.g., climate change, energy, and industry innovations) for a sustainable future. In 2020, about 72% of the G250, the world's largest 250 companies, connected their business activities to the SDG in their corporate reporting system (KPMG, 2020). By referring to the SDGs, the companies have been trying to develop sustainability programs that can help to communicate their stakeholders including investors and shareholders in a transparent manner (Huber, Comstock, & Smith, 2018; KPMG, 2020). The developed programs consider both financial and non-financial elements for managing the companies and support the achievement of the SDG for the companies. Particularly, institutional investors such as pension and sovereign wealth foundations are interested in the non-financial aspects in their business, such as sustainability and ethical goals of their investment (Huber et al., 2018). They also include environmental, social, and governance (ESG) factors considered as the sustainable financing for maintaining the sustainability of companies' business. To promote sustainable financing, the UN Environment Program Finance Initiative (UNEP-FI) presented three investment principles for responsible investment (PRI); sustainable insurance (PSI); responsible banking (PRB). Based on these principles, Sustainable Accounting Standards Board (SASB) provides a standard guideline for assessing the ESG framework of companies and consequently achieving sustainable financing (SASB, 2018a). The SASB standard helps to identify which non-financial elements that can influence the performance of financial conditions of the companies, regardless of the industry domains (SASB, 2017). Particularly, there is no exception for the construction industry. This domain has been considering ESG for sustainable development of companies as well as the industry itself, for example, they have established the program for leadership in energy and environmental design (LEED) for certifying the green building systems.

In particular of workforce health and safety, the construction industry has been focusing on the defect and safety-related work costs by managing their jobsites and laborers. Likewise, the contractors recently have been trying to incorporate the ESG values into their business for pursuing the SDG. Since the construction sectors usually have a negative social footprint, such as generating heavy construction wastes, high carbon emission levels, and losing the lives of laborers, the ESG indicators should be specially considered as core elements for enhancing their industry images as well as maintaining the sustainability of each company in the construction sector.

However, the level of SDG in this industry is still low because assessing the ESG is still underperforming in the construction project level as well as company level for their financial and non-financial performance (Kreander, Gray, Power, & Sinclair, 2005). Therefore, the main goal of this study is to review the literature related to the ESG adoption to the construction section and to propose the concept of the construction project level ESG (C-ESG) for achieving a higher level of SDG for the construction project as well as the company's better financial and non-financial performance. There were only a few scientific studies in the field of ESG in construction. However, this paper tried to collect the related information, find the departure of the problem, and propose the concept of C-ESG for further studies in this domain.

ESG Integration for Sustainable Financing

ESG framework should begin with defining the scope of evaluating an organization's ESG responsibility in the context of environmental, society, and governance, then understand material sustainability issues. Every business is intertwined with environmental, social, and governance (ESG) concerns (Henisz, Koller, & Nuttal, 2019). Three elements of ESG can be defined as environmental criteria including energy used, waste discharges, and resources needed by business operations, and impacts of living beings (Henisz et al., 2019); social responsibility of the organization's transparent and ethical activities and behaviors for people, institutions, and communities (Henisz et al., 2019; ISO, 2010); and internal systems to govern a business, to make decisions in ethics and compliance with the law, and to satisfy external stakeholders (Henisz et al., 2019). ESG Materiality can be defined as sustainability issues that have material impacts on the companies' financial condition and operating performance (SASB, 2017). Three metrics: revenue/costs, assets/liabilities, cost of capital/risk profile (SASB, 2017), were defined to evaluate the financial impacts. Materiality Map shows material sustainability issues by industry based on investors' interest and impacts on companies (SASB, 2021) . Based on the material sustainability issues of a company, the company will be able to create a valuation model to forecast financial impacts by transforming its actions and practices. The financial value of non-financial-driven activities will be quantified so that it improves returns to stakeholders and business operations while contributing to sustainable development. Figure 1 describes the process of integrating ESG and assesses the impacts on the company values.

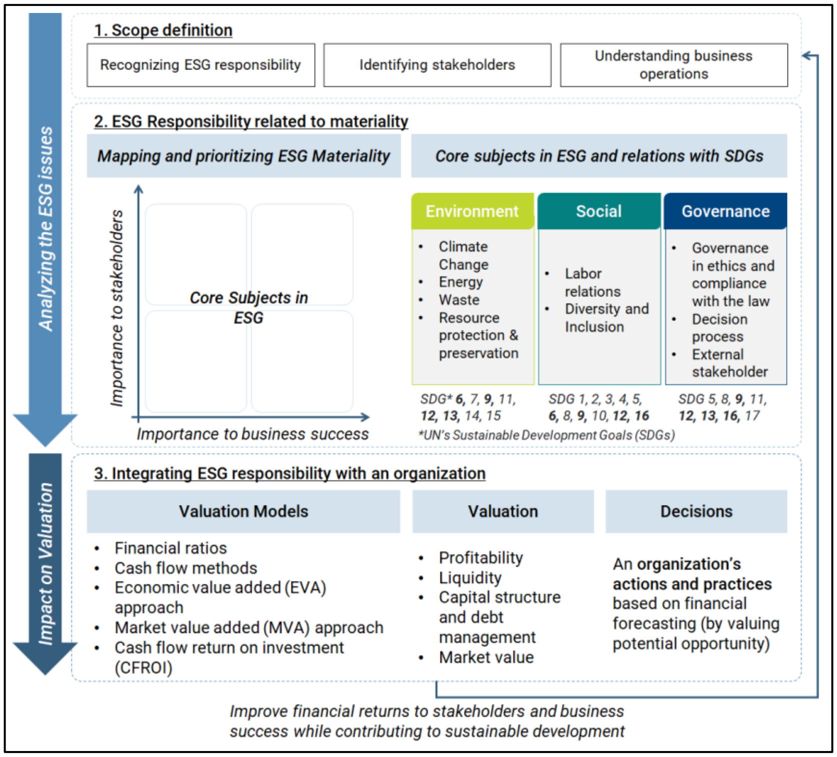

Figure 1. ESG integration framework (Referred to Berenberg, 2018; Henisz et al., 2019; ISO, 2010; Skaug Saetra, Wynsberghe, Bolte, & Nachid, 2021; Stankeviciene, 2012; United Nationas Global Compact, 2016)

Based on the framework, investors have been asking the ESG integrations for sustainable financing of the companies, and they have been using the ESG portfolios for screening their investment projects (Melas, Nagy, & Kulkarni, 2017). Also, ESG criteria have been integrated into investment decision processes (Kaiser, 2020). Hence, the companies accepted their requests by expanding the diversity of their business into ESG domains. For example, Netflix has decided to raise a creative development fund of about 20 million USD for the next 5 years, to strengthen their business diversity (Netflix, 2020). Clorox has also established a strategy of reducing virgin plastic usage by about 50% by 2030, to respond to the requests from their investors (Clorox Company, 2021). One of the largest global petroleum companies, ExxonMobil Inc. has utilized the ESG framework to develop a new business. This company has partnered with the U.S. government to develop the technology to capture and store carbon, and they invested in biomass technology to reduce greenhouse gases (ExxonMobil, 2020).

Also, the ESG framework includes climate changes, natural resources and energy, human resources, social responsibility, and organizational changes throughout the three components. Many companies have integrated those non-financial components to enhance their sustainability and their financial profits. ESG indicators can be measured as sustainable development of economic entities (Zhao et al., 2018). Companies need to assess materiality issues in the context of ESG which affects the financial significance and performance of their business (Steinbarth & Bennett, 2018). According to research analyzing relationships between investment factors and ESG scores of the stock market, stocks with high ESG scores have shown stable earnings, lower accruals, and higher profitability (Melas et al., 2017). Therefore, companies have been opening their non-financial as well as financial data to the public by complying with international standards and the ESG framework (Buchholz et al., 2020; Lee, 2020).

However, the integration and application of ESG investment criteria are difficult to be universally accepted across countries and industries (Kaiser, 2020). The construction industry has unique and intrinsic features. Since different types of business, such as transportation, mechanics, and finance are connected in a single construction project, ESG in the construction industry should be adapted by considering its organization and management mechanism during the construction project life cycle.

ESG in the Construction Industry and Its Limitations

The construction industry often serves as an economic driver by hiring a workforce (Kim, Chang, & Castro-Lacouture, 2020) and activating multiple economic sectors such as the primary sector for extracting natural resources, secondary sector for manufacturing building materials and components, and tertiary sector for providing consultant services (e.g., design, engineering, and management) (Pheng & Hou, 2019). Many different parties, owners, contractors, and designers should be involved in the construction works (Ofori, 1990) and provide different professional practices which lead to a complicated organizational structure in the industry (Pheng & Hou, 2019). Although the team organization is temporary for a particular product (Pheng & Hou, 2019), collective efforts across organizations are required to reduce management costs and increase its profit during their collaboration (Kim, Han, Yi, & Chang, 2016).

With the emphasis on ESG integration, the construction industry has been focusing on establishing the future strategy for increasing their ESG scores. For example, Samsung Construction and Engineering Corporation declared that they will not invest the coal-related projects, such as thermal power plant construction or mining coal projects anymore after completing all the related projects currently ongoing. At the same time, they are planning to expand their business into eco-friendly or renewable projects (Park, 2021). Hyundai Construction Company is focusing on the development of smart safety technologies by adopting various information and communication technologies (ICT), and they aggressively invest the new renewable energy-related projects, such as hydrogen fuel-related facility construction, bio-gas-related, and tidal power generation projects for enhancing their business sustainability (Hyundai Engineering & Construction, 2020).

However, there is still a huge argument that the adoption of ESG components or sustainable financing into the construction has significant effects on the performance of the organization or their profits (Hoepner, Rezec, & Siegl, 2011; Siew, 2017) Kreander et al. (2005) found that there is no significant difference in the performance or investment when the construction companies returned the social and environmental responsibility to the society and community (Kreander et al., 2005). In addition, the adoption of ESG would lead to underperformance of the construction project as well as companies' financial performance in the construction industry (Siew, 2017). Poelloe (2010) surprisingly investigated that the construction companies' social responsibilities, such as reducing carbon, greenhouse gases, and construction waste or sharing the profits with the communities have a negative correlation with companies' financial and market performance (Poelloe, 2010). Another limitation is that the project managers are against emphasizing the construction companies' ESG-related activities and their responsibilities for society. They do not think of them as beneficial components to increase the financial performance of the business (Butković, Tomšić, & Kaselj, 2021).

Hence, to resolve the problems, Lovrenčić Butković et al (2021) emphasized that the construction firm should pay attention to collaborative ESG activities (e.g., reducing Carbon dioxide emissions, managing safety and health, reducing construction waste, increasing the return to the public and community, during the construction management and operations for obtaining the favorable business reputations from the public. Therefore, the construction project management should consider both non-financial and financial components including various trades, work processes, work processes, waste management, and workforce safety that can impact the sustainability of contractors' business. Figure 2 shows the relationships of the ESG adoption in construction management and the success of the business of the construction companies in terms of their sustainability.

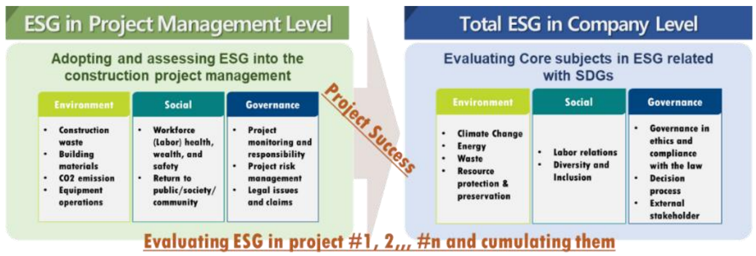

Figure 2. Relationship between ESG adoption to project and company levels

According to SASB, companies in engineering and construction services have significant materiality issues on ecological impacts in the environment dimension, product quality & safety in the social capital dimension, employee health & safety in the human capital dimension, product design & lifecycle management in the business model & innovation dimension, and business ethics in leadership & governance dimension (SASB, 2018b). The companies should measure six (6) sustainability topics: environmental impacts of project development, structural integrity & safety, workforce health & safety, life cycle impacts of buildings & infrastructure, climate impacts of business mix, and business ethics for their active projects, commissioned projects and total backlog (SASB, 2018a).

Proposing a Construction project level-based ESG (C-ESG)

The systematic and effective management during the project should aim to complete and deliver the product to the customer successfully by utilizing the knowledge, skills, and well-structured organization. It will contribute to providing an acceptable level of project safety, quality, and profits, hence sustainability is a very critical part of construction project management (Erdogan, Šaparauskas, & Turskis, 2019) and consequently the companies' success. Therefore, this study defines the C-ESG as the decision-making process leading to the success of construction management as well as the entire business by considering ESG criteria. Considering both stakeholders and business success, example of materiality subjects in C-ESG is shown in Figure 3 for valuation.

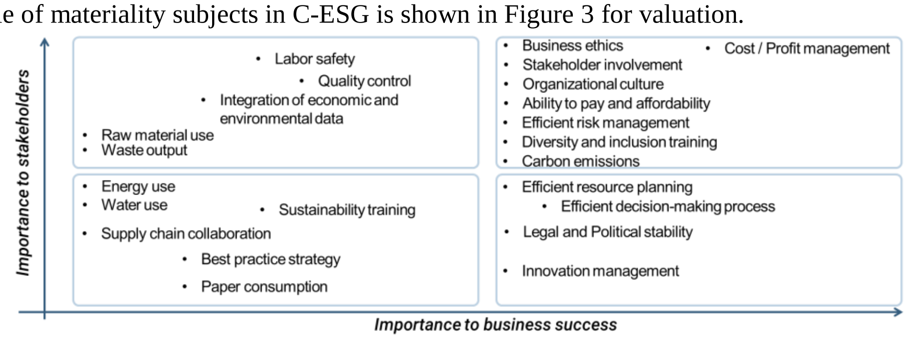

Figure 3. Example of Materiality Subjects in C-ESG for Valuation (ARUP, 2018; Stanitsas, Kirytopoulos, & Leopoulos, 2021)

Strategies to implement C-ESG

To implement the C-ESG, three main components should be elaborated: (1) government owners should identify the priorities for their public investment projects as well as establish the ESG criteria for the project before advertising the bid; (2) general contractors should identify and consider the ESG framework that the government provided for supporting their decision-making to participate the bid or not; and (3) both subjects should manage and monitor how the project management runs for achieving the ESG goals. Figure 3 illustrates the concept of C-ESG between the public and private sectors.

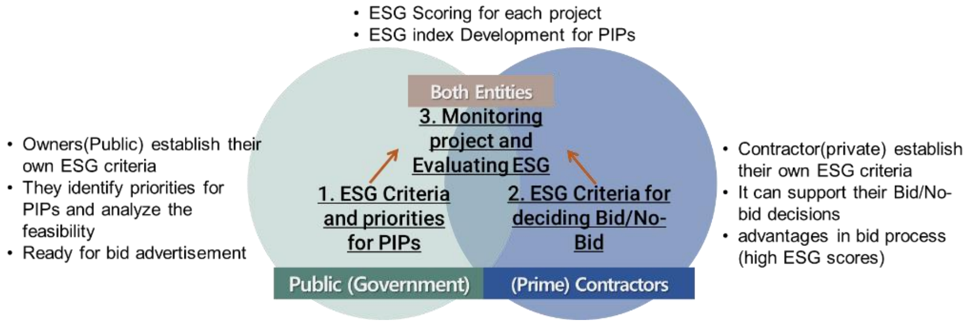

Figure 4. Concept of C-ESG

Government: Identifying Priority for Public Investment Projects Through Well-Defined the ESG criteria

The government as the owner of the public investment projects (PIP) generally provides the systematic process and scope for the project contractors in the public-private partnership (PPP). Typical public investment planning requires identifying the priorities for the PIP to decide a go or no-go based on its feasibility evaluation. Even the prime contractor participating in the PIP is assessed in terms of ESG in recent, they do not have any systematic ESG framework provided by the government. The project owner should establish the ESG framework for their construction project and their contractors, especially in the case of the PPP. The public entity can set up their ESG-focused strategies, establish ESG-connected project goals, conduct ESG-driven feasibility and cost-benefit analysis, and provide well-planned bid advertisements for the contractor candidates. Since all context should be under the legal framework, it might result in promoting the implementation of ESG into the construction projects in a practical way.

General Contractor: Identifying ESG Criteria for deciding the Bid/No-bid Decisions

One of the important components in the C-ESG concept is how the contractor can decide to participate in the PIP bid or not based on reviewing and identifying the ESG criteria that the owner provided. Based on the review, the contractor can establish their ESG strategy that can be implemented into their construction project management. This might provide a more objective decision-making tool for contractors can complete the project or not by referring to the ESG criteria that they should follow within the legal framework. This tool can be utilized as another feasibility analysis methodology in non-financial components for the contractor.

Both: Monitoring and Evaluating of Construction Project

Generally, contractors have their project monitoring process and plans for their project management; however, it is very difficult to assess the non-financial components during the project. Based on the ESG framework, both entities in PPP must have their ESG criteria to evaluate the values of sustainable finance aspects. The owner can monitor the construction process as well as assess the potential market values of the product (e.g., road, airport, or bridge) and profits. Also, they can establish their asset visions and management plans for the product. The private contractors can evaluate their non-financial performance, convert it into financial performance, and identify their final profits from this project. Thus, the contractor can stack their historical sustainable financial information for their construction project, and it can be utilized as their decision-making tool for future projects. Finally, the C-ESG can contribute to developing the systematic company ESG index as well as gaining higher ESG scores.

Discussion and Conclusion

This study provided the concept of C-ESG to promote a higher level of sustainability for the public project owners as well as the private contractors within the PPP. The main challenge in integrating the ESG framework is considering it from the companies' business management perspectives in the construction industry since this domain should have different characteristics regards the business structure as well as intrinsic features of construction projects. Therefore, the ESG framework must be designed by project level-based rather than the companies' entire business. First, the owner should have their ESG criteria for evaluating the feasibility and priorities of their public investment project. Second, the contractors (usually prime contractors) should also have their ESG criteria for considering both financial and non-financial feasibilities for deciding the participation of project bids or not. Third, both entities must assess their project and management process by utilizing their ESG framework. Then, the C-ESG index or framework will be developed for systematically evaluating the sustainable finance of construction projects, and the companies can obtain cumulative ESG scores for their business operations in the construction industry. This study still documents significant challenges. First, the number of literature used for review was very small. So, this study reviewed various types of literature including magazines, reports, and scientific papers, then the departure of the problem was established. The results should be further formalized and analyzed scientifically by expanding the knowledge about construction project-level ESG in the future. The suggested C-ESG concept is still required a scientifically formalized process through utilizing defining key performance indicators (KPI) and their importance based on the questionnaire responses and established C-ESG index referring to the general ESG framework. Further studies can also identify the critical factors influencing the performance of ESG in the construction project and analyze how they are taking actions under different scenarios through system dynamics simulation. Then, it is possible to promote establishing the C-ESG for enhancing the sustainability level of entities in the construction industry.

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References

ARUP. (2018). *Sustainable Development Report 2017/18*. Retrieved from https://www.arup.com/perspectives/publications/promotional-materials/section/sustainability-report

Berenberg. (2018). *Understanding the SDGs in Sustainable Investing*. KG: Hamburg, Germany. Retrieved from https://www.berenberg.de/files/ESG News/SDG_understanding_SDGs_in_sustainable_investing.pdf

Buchholz, H., Eberle, T., Klevesath, M., Jürgens, A., Beal, D., Baic, A., & Radeke, J. (2020). Forward Thinking for Sustainable Business Value: A New Method for Impact Valuation. *Sustainability 2020, Vol. 12, Page 8420*, *12*(20), 8420. https://doi.org/10.3390/SU12208420

Butković, L. L., Tomšić, D., & Kaselj, S. (2021). Collaborative Strategic View in Corporate Social Responsibility – Construction Industry Case. *Business Systems Research : International Journal of the Society for Advancing Innovation and Research in Economy*, *12*(1), 144–163. https://doi.org/10.2478/bsrj-2021-0010

Erdogan, S. A., Šaparauskas, J., & Turskis, Z. (2019). A Multi-Criteria Decision-Making Model to Choose the Best Option for Sustainable Construction Management. *Sustainability 2019, Vol. 11, Page 2239*, *11*(8), 2239. https://doi.org/10.3390/SU11082239

Henisz, W., Koller, T., & Nuttal, R. (2019). *Five ways that ESG creats value*.

Hoepner, A. G. F., Rezec, M., & Siegl, K. S. (2011). Does Pension Funds' Fiduciary Duty Prohibit the Integration of Environmental Responsibility Criteria in Investment Processes?: A Realistic Prudent Investment Test. *SSRN Electronic Journal*. https://doi.org/10.2139/SSRN.1930189

Huber, B. M., Comstock, M., & Smith, H. (2018). UN Sustainable Development Goals—The Leading ESG Framework for Large Companies. In *The Harvard Law School Forum on Corporate Governance*. The Harvard Law School Forum on Corporate Governance. Retrieved from The Harvard Law School Forum on Corporate Governance website: https://corpgov.law.harvard.edu/2018/10/04/un-sustainable-development-goals-the-leading-esg-framework-for-large-companies/

Hyundai Engineering & Construction. (2020). *2020 Hyundai Engineering & Construction Sustainability Report*. Retrieved from https://www.hdec.kr/kr/company/library_03.aspx?

ISO. (2010). *ISO 26000 Social Responsibility*. Retrieved from https://www.iso.org/iso-26000-social-responsibility.html

Kaiser, L. (2020). ESG integration: value, growth and momentum. *Journal of Asset Management*, *21*(1), 32–51. https://doi.org/10.1057/S41260-019-00148-Y

Kim, S., Chang, S., & Castro-Lacouture, D. (2020). Dynamic Modeling for Analyzing Impacts of Skilled Labor Shortage on Construction Project Management. *Journal of Management in Engineering*, *36*(1). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000720

Kim, Y.-W., Han, S.-H., Yi, J.-S., & Chang, S. W. (2016). Supply chain cost model for prefabricated building material based on time-driven activity-based costing. *Canadian Journal of Civil Engineering*, *43*(4). https://doi.org/10.1139/cjce-2015-0010

KPMG. (2020). *The KPMG Survey of Sustainability Reporting 2020*. Retrieved from home.kpmg/sustainabilityreporting

Kreander, N., Gray, R. H., Power, D. M., & Sinclair, C. D. (2005). Evaluating the Performance of Ethical and Non-ethical Funds: A Matched Pair Analysis. *Journal of Business Finance & Accounting*, *32*(7–8), 1465–1493. https://doi.org/10.1111/J.0306-686X.2005.00636.X

Lee, J. (2020). *기업의 사회적 가치와 커뮤니케이션 (Corporates' social value and communications)*. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/kr/Documents/insights/deloitte-korea-review/11/kr_insights_deloitte-korea-review-11_06.pdf

Melas, D., Nagy, Z., & Kulkarni, P. (2017). Factor Investing and ESG Integration. *Factor Investing: From Traditional to Alternative Risk Premia*, 389–413. https://doi.org/10.1016/B978-1-78548-201-4.50015-5

Ofori, G. (1990). *The Construction Industry: Aspects of Its Economics and Management*. Singapore University Press.

Park, G. (박근홍). (2021). [ESG's 왓] 삼성물산, 친환경 행보 눈길…총수 이슈·안전 문제는 약점.

Http://Www.Sisaon.Co.Kr/. Retrieved from https://www.sisaon.co.kr/news/articleView.html?idxno=125309
Pheng, L. S., & Hou, L. S. (2019). The Economy and the Construction Industry. In *Construction Quality and the Economy* (pp. 21–54). Springer Nature Singapore Pte Ltd. https://doi.org/10.1007/978-981-13-5847-0_2
Poelloe, A. (2010). *Is there a trade-off between social responsibility and financial performance?* (Master thesis in Erasmus University Rotterdam.). Master thesis in Erasmus University Rotterdam. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.866.197&rep=rep1&type=pdf
SASB. (2017). *SASB Conceptual Framework*. Retrieved from https://www.sasb.org/wp-content/uploads/2020/02/SASB_Conceptual-Framework_WATERMARK.pdf
SASB. (2018a). *Engineering & Construction Services*. Retrieved from https://www.sasb.org/standards/download/
SASB. (2018b). SASB Materiality Map. Retrieved from Sustainability Accounting Standards Board website: https://materiality.sasb.org/materiality.html
SASB. (2021). Exploring Materiality. Retrieved from Sustainability Accounting Standards Board website: https://www.sasb.org/standards/materiality-map/
Siew, R. Y. J. (2017). Critical evaluation of environmental, social and governance disclosures of Malaysian property and construction companies | Construction Economics and Building. *Construction Economics and Building*, *17*(2), 81–91. Retrieved from https://search.informit.org/doi/abs/10.3316/informit.947578197095696
Skaug Saetra, H., Wynsberghe, van, Bolte, L., & Nachid, J. (2021). A Framework for Evaluating and Disclosing the ESG Related Impacts of AI with the SDGs. *Sustainability 2021, Vol. 13, Page 8503*, *13*(15), 8503. https://doi.org/10.3390/SU13158503
Stanitsas, M., Kirytopoulos, K., & Leopoulos, V. (2021). Integrating sustainability indicators into project management: The case of construction industry. *Journal of Cleaner Production*, *279*, 123774. https://doi.org/10.1016/J.JCLEPRO.2020.123774
Stankeviciene, J. (2012). Methods for valuation of restructuring impact on financial results of a company. *Economics and Management*, *17*(4), 1289–1295. https://doi.org/10.5755/J01.EM.17.4.2990
Steinbarth, E., & Bennett, S. (2018). Materiality Matters: Targeting the ESG Issues that Impact Performance. In *https://corpgov.law.harvard.edu/*. The Harvard Law School Forum on Corporate Governance. Retrieved from The Harvard Law School Forum on Corporate Governance website: https://corpgov.law.harvard.edu/2018/05/10/materiality-matters-targeting-the-esg-issues-that-impact-performance/
United Nationas Global Compact. (2016). *Practical Guide to ESG Integration*. Retrieved from https://www.unglobalcompact.org/
United Nations. (2020). *The Sustainable Development Goals Report 2020*. New York. Retrieved from https://unstats.un.org/sdgs/report/2020/
Zhao, C., Guo, Y., Yuan, J., Wu, M., Li, D., Zhou, Y., & Kang, J. (2018). ESG and Corporate Financial Performance: Empirical Evidence from China's Listed Power Generation Companies. *Sustainability 2018, Vol. 10, Page 2607*, *10*(8), 2607. https://doi.org/10.3390/SU10082607

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Impact of COVID-19 on Construction Project Performance in the US

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Coronavirus disease (COVID-19), which was declared as a global health emergency by World Health Organization (WHO) had a profound impact on the construction industry. The disruptions created due to the shutdown of construction projects, manufacturing facilities, and major international transportation hubs because of the pandemic impacted the construction industry which is still unfolding. The goal of this study was to investigate the effect of COVID-19 on construction project performance using metrics previously established by the Construction Industry Institute (CII). Data was collected through surveys from construction professionals in the US across various sectors of the industry provided valuable insights about the immediate impact of COVID-19 on project performance. Project performance was measured in terms of the CII's five metrics: cost, schedule, rework, changes, and safety. Out of them, cost, schedule, and changes were significantly impacted due to the pandemic. The survey responses also revealed the measures adopted by companies to abate the effects of COVID-19 on project performance and the steps taken to enhance project performance during this period.

Key Words: COVID-19, Project performance, Cost, Schedule, Changes, Rework, Safety

Introduction

World Health Organization (WHO) identified the Coronavirus disease (COVID-19) as a global health emergency on January 30, 2020. It forced everyone to make changes to their ways of life and impacted the global economy. Filho, Brandli, Salvia, Rayman, and Platje (2020) reported that the impact of COVID-19 on the global economy will unfold gradually and is estimated to be more challenging than the financial crisis of 2007–2009. Many trends in architecture and urban design that we see today were derived from measures taken before COVID -19 to ensure the health, hygiene, and comfort of urban residents (Megahed & Ghoneim, 2020).

The rapid spread of COVID-19 cases engendered many countries to declare complete national lockdowns. Lockdown was a cautionary measure against the swift spreading virus. This decision restricted the movement of people and resulted in partial or complete shutdown of many businesses across many sectors. The construction industry in the US was affected by statewide lockdown orders issued by different states. During this time, most construction projects and developments were postponed. The construction industry is an industry where workers are typically on-site daily to either perform construction activities or to ensure work is carried out in accordance with the plans and specifications. The extensive lockdown caused by COVID-19 disrupted the construction processes and thereby impacted project performance. Measurement of project performance is defined as a process of assessing performance relative to a defined goal (Ali & Rahmat, 2010). To ensure construction project performance satisfaction, projects are managed with the aim of meeting the required standards predetermined and expected by all stakeholders (Gyadu-Asiedu 2014). Project performance is achieved in any given project when the aim and goals of different parties involved in the project are met. Financial and non-financial metrics can be used to measure performance of construction projects.

The goal of this study was to investigate the effect of COVID-19 on construction project performance. Existing literature investigating the effect of COVID-19 has mostly utilized exploratory strategies to gather the perceptions of industry professionals (Filho et. al, 2020, Alsharef et. al, 2021, Pamidimukkala & Kermanshachi, 2021). This study, on the other hand, used a structured survey with established metrices of project performance to measure the effect of COVID-19 on construction projects. Metrics used in this study to measure performance were developed and vetted by the Construction Industry Institute (CII). The specific metrics used were cost, schedule, rework, changes, and safety. Study participants recruited from various sectors within the US construction industry were surveyed to understand the impact of COVID-19 on the construction projects' performances based on the five metrices. The respondents identified cost, schedule, and changes as the three metrics out of the five that were significantly impacted during COVID-19. While the construction companies implemented new safety protocols to ensure safety of the workers from COVID, occupational safety as a performance metric was not affected during this period. To cope with the disruptions caused due to the pandemic, respondents reported practicing more off-site construction to make it easier to abide by safety guidelines and enhance quality and productivity.

Literature Review

According to Associated General Contractors of America (2021), the construction industry is comprised of over 680,000 employers with over 7 million employees and produces nearly $1.3 trillion worth of structures each year. Historically, changes from the original contract's time and cost are considered cardinal performance measurement metric (Konchar & Sanvido, 1998). Measuring construction project performance is an integral part of project management/project controls process. Gransberg and Buitrago (2002) explained that the metrics focused on changes from the original contract's time and cost are well known, however they suffer from lack of clarification regarding project success. They are generally represented as either a positive or negative percentage of original contract requirements, but they do not indicate the reason for the change from original, nor do they assign responsibility for that change.

Measurement metrics can be beneficial to companies; performance measurement over time assist managers to identify explanatory reasons for good/poor performances. Also, measurement metric is useful to track the implications of certain managerial and technological implementations. With a standard and acceptable performance metrics, companies can compare their policies and procedures with peers/competitors to improve their own efficiency and become more competitive. Despite the importance attached to measuring project performance in the construction industry, several researchers and experts have identified shortcomings attached to the different approaches to performance measurement and doubt whether the primary purpose of the measurement would be eventually achieved if implemented. Some researchers believe performance should be measured at the company level, while others believe performance should be measured at the project level. Traditional benchmarking models were developed for the manufacturing industry and are difficult to adapt to the construction industry due to the nature of industry participants, projects, and methods of execution. (Lee, Thomas, & Tucker, 2005).

Gyadu-Asiedu (2014) pointed out different problems associated with existing performance assessment philosophies, concepts, and paradigms. He identified problems with success/failure definition, problems with the performance assessment procedure, and problems with the use of lagging measures. Various studies have provided strong evidence indicating a causal linkage between the application of performance measurement and business excellence. To enhance productivity and quality in the construction industry, an acceptable way of measuring performance must be implemented. To resolve the controversies surrounding project performance, the Rethinking Construction report (Egan, 1998) suggested rethinking: capital cost, construction time, predictability, defects, accident, productivity and turnover, and profit as a set of suitable performance measurement metrics. Additionally, institutes such as the Department of Environment, Transport, and Regions (DETR) and the Construction Industry Institute (CII) have developed metric to measure performance suitable for their own assessments. The DETR suggested cost, quality, time, client satisfaction, change order, business performance, and health and safety, while CII proposed cost, schedule, rework, change order, and safety (Kpi Group, 2000).

Performance Metrics

The CII benchmarking and metrics (BM&M) was created in 1995 with four main goals: (1) to establish a common set of metric definitions in the construction industry, (2) to provide performance norms to the industry, (3) to quantify the use and value of best practices, and (4) to help focus CII research and implementation efforts (Costa, Formoso, Kagioglou, Alarcón, & Caldas, 2006). The performance metrics regarding cost, schedule, safety, changes, and rework in the construction industry have been studied since 2001 by researchers in academia and industry. Previous research carried out on performance measurement has shown that performance measurements can be done in terms of financial and non-financial measures, or the combination of both. This study focused on the impact of COVID-19 on project performance at the project level using the CII metrics, which are designed to measure at the project level. These metrics have been vetted and established as robust metrics to measure project performance over the years.

COVID 19 and Project Performance

The construction industry professionals have experienced various degrees of impacts due to the COVID-19 depending on the local and state responses to the pandemic. The construction industry members will need to address both short-term and long-term challenges posed by COVID-19.

According to Occupational Safety and Health Administration (2020), the COVID-19 exposure risk levels associated to various construction tasks vary. Low exposure risk tasks are associated with tasks where employees remain six feet apart with little contact with the public, visitors, or customers. Construction tasks associated with medium exposure risks are tasks that require workers to be within six feet with customers, visitors or public. Entering an indoor site occupied by someone suspected of having or known to have COVID-19 is regarded as high exposure risk level. It is worthy to note that, offsite construction is especially beneficial in the fight against COVID-19 due to its capability for rapid delivery of projects, decentralized working system, and reduced dependencies between project activities (Gbadamosi, Oyedele, Olawale, & Abioye, 2020).

The impact of the COVID-19 on the US construction industry created immediate effects. Faced with cancelled projects, supply chain disruption, and uncertainties due to pandemic, approximately 40% of U.S. construction firms reported layoffs by the end of April 2020 (Engineering.com, 2021). Three suggested actions for post COVID-19 era success from industry experts are:

- Fortify supply chains; recognize vulnerabilities and find options to counter them before being faced with a shortage.
- Readjust business priorities; capital and resources may need to be deployed elsewhere.
- Consider preassembly options; a controlled environment provides numerous benefits.

Research Method

This study adopted a survey method to collect data from construction professionals comprising of construction managers, cost estimators, project managers, superintendents, and project engineers in the United States. For this study, construction managers and project managers were listed as two distinct roles. Construction managers are those contracted by the project owner and represents their interest (CMAA, 2020) while project managers are employees of the general contractor assigned to a project (PM.com, 2020). They were selected based on their roles and involvement in construction operations and day-to-day activities on the job site. According to the U.S. Bureau of Labor Statistics (2021), the U.S. construction industry consist of 476,700 construction managers, 214,200 cost estimators, 288,451 project managers, 209,346 superintendent and 211,595 project engineers. Convenience sampling was implemented to identify possible participants by job title from the researchers' U.S. LinkedIn network. The industry professionals were then recruited using the LinkedIn email and direct message features. Regional or state location was not a consideration for this study due to the national impact of COVID-19 on the construction industry.

An online questionnaire was created and sent to participants who were assured of confidentiality and anonymity in their feedback. Given the metrics for this study were established and vetted by CII and the questions about actions taken aligned with previous industry research (Engineering.com, 2021), the questionnaire used for this study was not independently vetted. The questionnaire included four sections with different types of questions: one with demographic questions, one with Likert scale questions, and two with 'yes' or 'no' questions. The first section consisted of three demographic questions about the participants role in the industry; number of years in the industry; and sectors of projects. In section two, questions were designed using the CII metrics (cost, schedule, safety, rework, and changes) and asked participants to identify the impact of COVID-19 on the company's projects being constructed during the pandemic. A Likert scale of 1-5 was used with 5 being 'most significant impact'; 4 being 'fairly significant impact'; 3 being 'significant impact'; 2 being 'slightly significant impact'; and 1being 'no impact'. The following CII definitions were provided for each metric:

- Cost - Expense incurred by a contractor for labor, material, and equipment
- Schedule - Project schedule outlines project milestones and activities involved in construction sequentially.
- Rework - Act of redoing or correcting work that was not carried out effectively the first time and prevalent on construction job sites.
- Safety - State of being safe, freedom from the occurrence/risk of injury, danger, or loss.
- Change - Refers to work deleted or added to from the original scope of work of a contract, which changes the original contract amount and/or completion date.

Section three was designed to collect data about the different construction methods and processes that the company may have implemented to keep workers safe and healthy to abate the effects of COVID-19 on project performance. Participants were provided with the list shown in Table 3 and were asked to answer 'yes' or 'no' if the new measure was implemented. In section four participants were asked to respond 'yes' or 'no' to the 10 questions shown in Table 4 about project performance monitoring strategies and on-site changes made due to COVID-19.

A total of 209 surveys were sent and 94 responses recorded, indicating an initial response rate of 45%. The process of cleaning the data was implemented to detect and correct any errors in the database. The data from this study was cleaned to identify and delete any incomplete data within the dataset, as a result the responses from nine participants were identified as incomplete and thus deleted reducing the response rate to 41%. The remaining data was then organized and analyzed using descriptive statistics.

Findings

Table 1 shows the background information of the participants. Among the respondents, a little more than one third were project managers, and the remaining were project engineers, cost estimators, superintendents, and construction managers. More than half of the respondents had between five to 10 years of industry experience (Table 1). The respondents had experience of working in various sectors of the construction industry such as multifamily residential, institutional, commercial, etc. Almost one third of them had experience of working in the commercial sector, and the others worked in the multifamily residential, institutional, infrastructure, and healthcare (see Table 1).

Table 1

Background information of the participants

	Categories	**N (%)**
Participants' Titles	Project Manager	30 (35)
	Project Engineers	18 (21)
	Cost Estimators	17 (20)
	Superintendent	15 (18)
	Construction Managers	5 (6)
Participants' number of years in the industry	5-10 years	45 (53)
	Less than 5 years	24 (28)
	Over 10 years	16 (19)
Participants' company sectors	Commercial	27 (32)
	Commercial & Multifamily residential	16 (18)
	Multifamily residential	15 (18)
	Infrastructure and Heavy construction	11 (13)
	Healthcare	9 (11)
	Institutional	7 (8)

This study included five of the construction sectors in the United States but combined the sectors into one group to reflect the design of items in Table 3 and Table 4. Six sectors were available to select from with one being a combination of Commercial and Multi-family Residential as shown in Table 1. Measures adopted to abate for the impact on project performance, and measures adopted to enhance project performance were designed by industry experts as post COVID-19 strategies for all sectors to practice in the evaluation of project performance.

Followed by the background information, the survey requested the participants to select the CII performance metrics (cost, rework, schedule, changes, safety) based on how those were impacted on the company's projects being constructed during the pandemic. The CII metrics were implemented because they were designed to measure performance at project level not company level and performance was measured at the project level for this study. Project level metrics provide an effective way to evaluate project process and guides project objectives with the aim of tracking performance and enhances improvement when needed (Sham, 2013). Table 2 shows the impact of the pandemic on each performance metric according to the participants in the study. Thirty of the 85 participants (35%) selected cost as the metric most significantly impacted by COVID-19. Whereas on the other end of the scale, 28 participants (33%) selected safety as the metric for which there was no significant impact because of COVID-19. It is worth mentioning here that safety as performance metric specifically refers to occupational accidents and incidents on projects. Based on Table 1, if the levels of impact are categorized into two groups: more significant (combining 'most significant', 'fairly significant', and 'significant') and less significant (combining 'slightly significant' and 'not significant'), then "change of project scope" appears to be the metric most significantly affected (62% respondents). The other significantly affected metrics were schedule (54%) followed by cost (53%). Safety remained the least impacted metric (39%).

Table 2

Impact on performance metrics due to COVID (five-point Likert scale)

Performance Metrics	**Level of Impact**				
	Most Significant N (%)	Fairly Significant N (%)	Significant N (%)	Slightly Significant N (%)	Not Significant N (%)
Cost	**30 (35%)**	10(12%)	13(15%)	19(22%)	13(15%)
Rework	21(25%)	11(13%)	15(18%)	**23(27%)**	15(18%)
Schedule	16(19%)	**27(32%)**	11(13%)	16(19%)	15(18%)
Changes	13(15%)	15(18%)	**34(40%)**	9(11%)	14(16%)
Safety	5(6%)	22(26%)	12(14%)	18(21%)	**28(33%)**
Total (%)	85 (100%)	85 (100%)	85 (100%)	85 (100%)	85 (100%)

Table 3 presents the responses to the dichotomous questions asked about the measures implemented to abate the effects of COVID on project performances. The measures had been recommended by industry experts and represent seven actions for project success in the future (Engineering.com, 2021). Practicing more off-site construction to achieve a controlled environment to make it easier to abide by safety guidelines, quality enhancement and to increase productivity is the most effective measure to reduce impact of COVID-19 on project performance. The fortification of supply chain process through the identification of vulnerabilities and finding options to counter them before being faced with a shortage was identified as the least applicable measure needed to subside COVID-19's impact on project performance.

Table 3

Measures taken by companies to abate the effects of COVID-19 on project performance

Adopted measures	**Yes N (%)**	**No N (%)**
Practicing more off-site construction to achieve a controlled environment to make it easier to abide by safety guidelines, quality enhancement and to increase productivity.	74 (87%)	11 (13%)
Incorporation of new safety protocols.	69 (81%)	16(19%)
Investing in employees and the company culture by providing and training employees on new tools and technologies.	63 (75%)	22 (25%)
Preparing allocation of resources across projects with the ability to quickly identify and respond by incorporating technologies with real-time transparency.	62 (73%)	23 (27%)
Fortification of the supply chain process through the identification of vulnerabilities and finding options to counter them before being faced with a shortage.	60 (70%)	25 (30%)

Due to page limitations, only the top six measures implemented by participants to enhance project performance are shown in Table 4. The questions were designed to collect project level data from the company with the expectation that participants may not have the responsibility to initiate or perform the measures but would have knowledge as to whether the measures were taken by the company. According to survey analysis, making changes to jobsite rules in response to COVID 19 guidance is the highest rated measure to ensure performance is attainable. The complete list of questions and results are available upon request.

Table 4

Measures taken by companies to enhance project performance during COVID-19 disruptions

Adopted measures	**Yes N (%)**	**No N (%)**
Did you make changes to jobsite rules in response to COVID 19 guidance?	75 (88%)	10 (12%)
Do you have to revisit contract terms around delays, unforeseen circumstances, excusable conditions, time extension, and liquidated damages?	71 (84%)	14 (16%)
Do you perform scheduled or time impact analysis, which include the examination of the status of material procurement to identify potential delays in the schedule?	70 (82%)	15 (18%)

Do you understand the resourcing trend on a real-time basis to be able to forecast changes to productivity compared to the plan?	61 (72%)	24 (28%)
Did you assess the cost impact of the reduced workforce, enhanced cleaning, and other modification germane to COVID 19 guidance?	60 (71%)	25 (29%)
Did you review insurance policies to understand whether the impact caused by pandemic (COVID-19) on construction programs is covered?	60 (71%)	25 (29%)

Conclusions

Data collected from participants in this this study provided valuable insight about the immediate impact of COVID-19 on project performance related to cost, rework, schedule, changes, and safety. The study also revealed the measures adopted by companies to abate the effects of COVID-19 on project performance and the measures adopted to enhance project performance due the disruption caused by the pandemic. As might be expected, all participants reported COVID-19 had a significant or greater impact on cost, rework, schedule, and changes. The shutdown of construction projects, manufacturing facilities, and major international transportation hubs during the early months of the pandemic in 2020 slowed or stopped projects across the country. Once the lockdown was lifted and projects restarted many were operating with a reduced workforce due to CDC guidelines and the high infection rate among workers. The disruption impacted the workforce and supply chain, which had a direct impact on project performance. Seventy percent (70%) of participants reported that measures were adopted to fortify the supply chain process through the identification of vulnerabilities and options to counter them before being faced with a shortage. However, the adoption of measures to enhance project performance was less with 63% of participants completing a proactive analysis of efficiency impacts due to labor shortages and 65% completed a risk analysis on disruptions to the supply chain. Due to the inherent nature of the construction industry's reliance on a project-based supply chain the impact of COVID-19 on project performance was significant.

In contrast to cost, rework, schedule, and changes, only 46% of participants reported COVID-19 had a significant or greater impact on project performance. Keeping in mind that project performance is measured across the duration of a project, 87% adopted measures to practice more off-site construction to make it easier to abide by safety guidelines and 81% incorporated new safety protocols. Also, 88% of participants made changes to jobsite rules in response to CDC guidelines.

While the study revealed findings from companies working across a variety of construction sectors, it was limited in two areas. First, it was limited to US construction companies and did not consider the impact of COVID-19 on project performance in other countries. Also, all the survey questions were closed ended and did not provide participants with the opportunity to elaborate on their responses. Future research that includes international companies could provide useful comparisons and insights related to project performance metrics. However, this study revealed the immediate impact of COVID-19 on US project performance and provided insight into steps taken to abate the impact and enhance project performance. It appears that the measures adopted related to safety on the project may have reduced the impact of COVID-19 on that metric. Whereas the cost, rework, schedule, and changes metrics can be linked to the workforce and supply chain shortages. Lessons learned from the impact of COVID-19 on the workforce and supply chain could change how the industry manages both in the future.

References

Ali, A. S., & Rahmat, I. (2010). The performance measurement of construction projects managed by ISO-certified contractors in Malaysia. *Journal of Retail and Leisure Property*, *9*(1), 25–35. https://doi.org/10.1057/rlp.2009.20

Alsharef, A., Banerjee, S., Uddin, S. M., Albert, A., & Jaselskis, E. (2021). Early impacts of the COVID-19 pandemic on the United States construction industry. International journal of environmental research and public health, 18(4), 1559.

Associated General Contractors of America. (n.d.). Retrieved March 5, 2021, from https://www.agc.org/learn/construction-data

Costa, D. B., Formoso, C. T., Kagioglou, M., Alarcón, L. F., & Caldas, C. H. (2006). Benchmarking Initiatives in the Construction Industry: Lessons Learned and Improvement Opportunities. *Journal of Management in Engineering*, *22*(4), 158–167. https://doi.org/10.1061/(ASCE)0742-597X(2006)22:4(158)

Egan, R. (1998). Rethinking Construction, United Kingdom Construction Task Force. Retrieved March 5, 2021 from https://constructingexcellence.org.uk/wp-content/uploads/2014/10/rethinking_construction_report.pdf

Engineering.com, *Long-Term Effects of COVID-19 in the Construction Industry*. (n.d.). Retrieved March 5, 2021, from https://www.engineering.com/story/long-term-effects-of-covid-19-in-the-construction-industry

Filho, W. L., Brandli, L. L., Salvia, A. L., Rayman-Bacchus, L., & Platje, J. (2020). COVID-19 and the UN sustainable development goals: Threat to solidarity or an opportunity? *Sustainability (Switzerland)*, *12*(13), 1–14. https://doi.org/10.3390/su12135343

Gbadamosi, A. Q., Oyedele, L., Olawale, O., & Abioye, S. (2020). Offsite Construction for Emergencies: A focus on Isolation Space Creation (ISC) measures for the COVID-19 pandemic. *Progress in Disaster Science*, *8*. https://doi.org/10.1016/j.pdisas.2020.100130

Gransberg, D. D., & Buitrago, M. E. V. (2002). Construction project performance metrics. *AACE International. Transactions of the Annual Meeting*, *August*.

Gyadu-Asiedu, W. (2014). Construction Project Performance Measurement: A Review of the Philosophies, Concepts and Paradigms. *AFRICA DEVELOPMENT AND RESOURCES RESEARCH INSTITUTE (ADRRI) JOURNAL ADRRI JOURNAL*, *5*(5), 74–91.

Konchar, M., & Sanvido, V. (1998). Comparison of U.S. Project Delivery Systems. *Journal of Construction Engineering and Management*, *124*(6), 435–444. https://doi.org/10.1061/(ASCE)0733-9364(1998)124:6(435)

Kpi Group. (2000). KPI Report for The Minister for KPI Report for The Minister for Construction. *Department of the Environment, Transport and the Regions*, *January*, 34.

Lee, S.-H., Thomas, S. R., & Tucker, R. L. (2005). Web-Based Benchmarking System for the Construction Industry. *Journal of Construction Engineering and Management*, *131*(7), 790–798. https://doi.org/10.1061/(asce)0733-9364(2005)131:7(790)

Megahed, N. A., & Ghoneim, E. M. (2020). Antivirus-built environment: Lessons learned from Covid-19 pandemic. *Sustainable Cities and Society*, *61*(June), 102350. https://doi.org/10.1016/j.scs.2020.102350

Occupational Safety and Health Administration. (n.d.). *COVID-19 - Control and Prevention - Construction Work* | Retrieved March 5, 2021, from https://www.osha.gov/coronavirus/control-prevention/construction

Pamidimukkala, A., & Kermanshachi, S. (2021). Impact of Covid-19 on field and office workforce in construction industry. Project Leadership and Society, 2, 100018.

U.S. Bureau of Labor Statistics. (n.d.). Retrieved April 21, 2021, from https://www.bls.gov/

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A Review of Genetic Algorithm as a Decision-Making Optimization Tool in Project Management

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Project Management requires a lot of decision-making, with chances of making a better decision increasing with an increase in available data. However, decision-making becomes increasingly difficult and complex as available data increases. The problem that this paper address is the lack of the ability of the rational human mind to process a large amount of data within a short period, thereby making poor decisions that could be influenced by lots of biases and reducing the chances of finding an optimal solution. This presents the need for optimization in decision-making with the aid of non-human intelligence/Artificial Intelligence. Therefore, the objective of this paper is to access the impact of Genetic Algorithms as a tool that can facilitate decision-making without sacrificing useful data that could optimize decision making. This study provides a review of genetic algorithms as an optimization tool for decision-making in project management. A comprehensive study is conducted on relevant literature from reputable journal databases. The study highlights the concept and benefits of genetic algorithm, followed by the drivers, as well as the barriers to its adoption. Findings from this paper will provide an insight into the research trend, level of adoption, and potential research areas in the use of genetic algorithms as a decision-making optimization tool. This study is expected to help project managers make a more informed decision in the adoption of decision-making optimization tools as using the right decision tool will free the human mind from mundane tasks to perform more creative tasks.

Key Words: Genetic Algorithm, Project Management, Decision-making, Intelligent Decision

Introduction

Decision-making is the process of considering different options and ideas and arriving at a judgment to take deliberate action on how to allocate resources to achieve the desired goal (Haidar, 2015). Project management is a difficult decision-making process including constant time and cost constraints. The majority of project management issues revolve around planning and scheduling decisions (Gonçalves et al., 2008). The success of a project is determined to a large extent by the quality of decisions made by project managers throughout the project life cycle. The more data available, the better the chances of making an optimal decision by the project manager. However, decision-making becomes increasingly difficult and complex as available data increases hence, presenting a need for an intelligent decision-making support system. Intelligent decision-making generally refers to the application of Artificial Intelligence (AI) in making decisions. One of the major Intelligent optimization tools in decision making is Genetic Algorithm (GA).

A Genetic Algorithm (GA) is a search algorithm based on the mechanics of natural evolution. It loops through available possibilities to select the best combination of variables for optimum or near optimum decisions. It is an efficient optimization system for solving problems with many constraints, uncertainties, and an abundance of feasible solutions. GA is suitable where fast decisions are needed due to its ability to use successive evolution of two acceptable solutions to form the best features. Problem-specific knowledge can also be incorporated to guide the search and decision process of a GA (Haidar, 2015; Katoch et al., 2021).

The objective of this paper is to access the impact of Genetic Algorithms as a tool that can facilitate decision-making without sacrificing useful data that could optimize decision-making. The study provides information on the current level of adoption and application of Genetic algorithm in project management decision-making, the research trend, and the limitations which are potential research areas to improve its adoption. The problem that this paper address is the lack of the ability of the rational human mind to process a large amount of data (big data) within a short period, thereby making poor decisions that could be influenced by lots of biases, reducing the chances of finding an optimal solution.

Background

A study by Janssen et al (2017) identified the main challenge in decision-making with big data as the inability to understand and use the data to create value by dealing with the complexity of the data and making meaning out of it. Big data analysis is a time-consuming task that requires the use of advanced cognitive systems (Gupta et al., 2018). This analysis reveals relationships, trends, and patterns that the human mind may not be able to unravel. In the present data-driven society, big data analysis avail organizations the power to make better decisions and stay competitive (Shamim et al., 2019). This presents the need for a more efficient system capable of processing such big data to assist the human mind in decision-making. Also, making decisions with the human mind is impaired by biases such as irrelevant socio-cultural constraints and cognitive bias when dealing with incomplete datasets (Parry et al., 2016). An AI decision-making system is free from such biases, thereby portraying a true description of the dataset by letting the data speak for itself. This is suitable for the dynamics of construction projects especially in dealing with the planning of cost, time, and human resources. AI is simply the ability of machines to perform human-like activities by learning from experience. GA is the AI decision-making optimization tool considered in this study.

GA has demonstrated its potential as an optimization tool through its application in multiple constraint scheduling, time-cost trade-offs, critical path problem, resource leveling, facility layout, and finance-based scheduling (Ancveire & Poļaka, 2019; Gonçalves et al., 2011; Haidar, 2015; Katoch et al., 2021; Milios et al., 2013; Ramzan et al., 2012; Zhu et al., 2011). The current success in the use of GA as a decision-making optimization tool could be attributed to its drivers such as the ability to process multiple solutions simultaneously, fast output, ability to select solutions based on the fitness value assigned to each chromosome, ability to find the global optimum and avoid becoming stuck in a local optimum, ability to solve poorly understood problems, and the ability to change fitness functions depending on the desired solution (L. Chen et al., 2019; Haidar, 2015).

Despite the above-listed GA benefits, there are still some setbacks that limit the application of GA as a decision-making optimization tool. A major limitation of GA is the cost of developing a robust GA optimization model because of its complexity and the amount of time needed for its development

(Haidar, 2015). Also, solution coding with GA could be problem-specific with architecture that may not be easily applicable to another problem (Ancveire & Poļaka, 2019).

Methodology/Approach

The systematic review method was used in this study. This method is primarily concerned with planning, identifying, and evaluating existing literature to obtain and analyze data from them (Ayodele et al., 2020). Systematic reviews answer specific questions, instead of providing generic literature summaries on the research area (Khan et al., 2003). The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) method of system review was adopted. PRISMA method was adopted for this review because it can be used to report a wide array of systematic reviews and is suitable for assessing the benefits and disadvantages of a method/technology. Peer-reviewed journal articles were obtained from Scopus and ASCE databases. Relevant articles were also obtained from Google Scholar. Only articles related to Construction Management and Project Management are considered in this study. Due to the rapid evolution in technology, only materials from 2000 are considered to ensure that current information is obtained. The following keywords were used to search for relevant articles on the databases listed above "Genetic algorithm" AND ("Decision making" OR "Decision-making") AND ("Construction" OR "Project Management"). Fig. 1 shows the research process

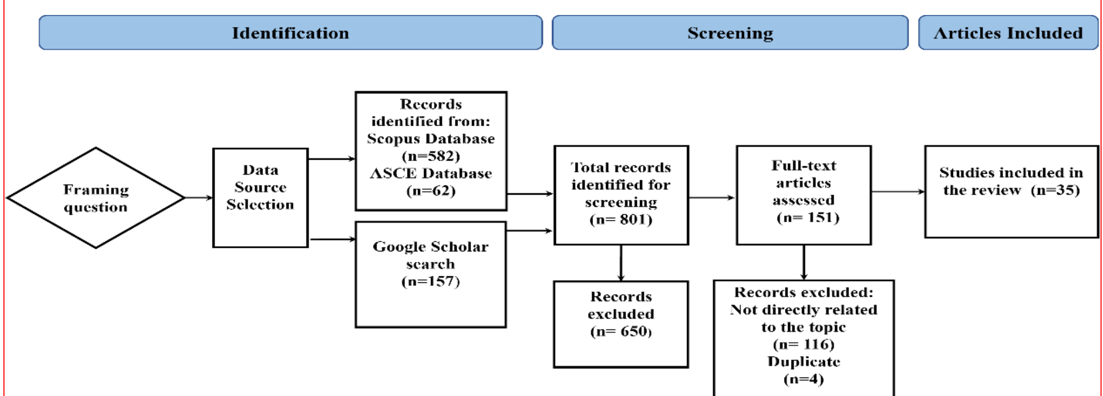

Fig. 1. Systematic review process using the PRISMA method

Analysis and Results

Concept of Genetic Algorithm in Decision-making

Inspired by the biological evolution process, Genetic Algorithm (GA) are search algorithms based on the principles of natural selection and proposed by J.H Holland in 1975 with features like chromosome representation, operators, crossover, selection, and fitness selection (Andre et al., 2001; Sivanandam & Deepa, 2008). The operators are biologically inspired and emulate the Darwin survival theory by selecting chromosomes based on their fitness value (Haidar, 2015; Katoch et al., 2021; Scully & Brown, 2009). GA can efficiently use previous information on new search points to project higher performance when randomized by combining strings containing partial solutions. GA differs from other decision-making optimization tools because they regulate variable representation and exploit similarities among high-performance strings, making them difficult to fool even for challenging functions (Haidar, 2015; Sivanandam & Deepa, 2008). Fig 2 represents the process of the genetic algorithm where A and B are the parent chromosomes and A' and B' are the offspring (next generation) chromosomes. a_{1-4} and b_{1-4} represent the genes contained in the chromosomes.

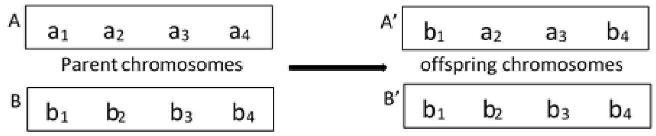

Fig. 2. Genetic Algorithm process

The initial generation of GA is the starting point for optimization with each chromosome assigned a fitness value by the fitness function based on its capacity to solve a given problem (Katoch et al., 2021). The Pareto fitness function called the maximum fitness function is a popular multi-objective fitness function for genetic algorithms and is represented mathematically by equation 1 (Elaoud et al., 2007). On each iteration of the GA, the generation passes through a series of random processes before forming a new generation. Consider two different chromosomes a and b from the same generation

$$F(x_a) = \max_{a \neq b} \left[\min_{1 \leq s \leq k} \{ f_s(x_a) - f_s(x_b) \} \right] \quad (1)$$

Where a and b and two distinct designs in a particular generation and $F(\chi_a)$ represents the fitness of the a^{th} design

The process of GA optimization is controlled by several operators such as selection, mutation, crossover, encoding, and adaptation. Encoding is the process of converting the available information to a format easily recognizable by the GA such as binary and octal. Crossover is the random combination of two or more fittest parent chromosomes to form an offspring chromosome. Mutation ensures that genetic variation is maintained from one population to the next, while the selection operator determines which strings that will participate in the formation of a new generation (Katoch et al., 2021; Sivanandam & Deepa, 2008b). The workflow of GA involves selecting the initial population by the fitness function based on their fitness values. Reproduction is the next step which involves the crossover of parent chromosomes and the mutation of genes of the offspring chromosomes to ensure that the fittest genes are selected. If the output at this stage is satisfactory for the problem, the process ends, if not, the output serves as the new population, and the process is repeated until satisfactory solutions are obtained.

Applications of Genetic Algorithm in Project Management Decision-making

GA has been applied in different fields of engineering (Katoch et al., 2021). This section reviews the common areas of project management where GA has been successfully applied.

Time-Cost Tradeoff

The Time-Cost tradeoff analysis is a crucial part of construction project planning with the aim of selecting the best resources and procedures to complete a project within the required timeframe and at the lowest possible cost (Haidar, 2015). Time-Cost Tradeoff Problems (TCTP) generally arise when the timeframe for a segment of a project has to be reduced to accommodate unanticipated setbacks to meet up with the set deadline (Mokhtari et al., 2011). Wuliang & Chengen (2009) proposed a GA-based solution to Discrete time-cost tradeoff problems (DTCTP). The DTCTP supposes that project activities' durations are distinct, non-increasing functions of a single amount of non-renewable resource. This study proposed a solution to a well-known project scheduling problem—DTCTP to help project managers balance project duration, cost, and available resources. Their approach is based on predefining the resource price, renewable resources related to the project cost including direct and indirect cost, every activity can be performed in a crashing way with the project direct cost used to shorten the duration of each activity. This model developed by the authors balanced three constraints—time constraints, renewable resource constraints, and cost constraints.

Resource Leveling and Resource Constraint Scheduling

Resource leveling in project management is a method used to maintain a smooth flow of construction resources and to avoid daily fluctuation in resource demand (Haidar, 2015). Resource-constrained project scheduling problem (RCPSP) deals with a situation in which the workforce available to perform tasks are limited, with each job having a deadline and a penalty for failing to meet the deadline (Cavalcante et al., 2013; Lova et al., 2009). Gonçalves et al., (2011) proposed a GA approach for RCPSP. The method involves the combination of biased random-key-based GA, a schedule generation scheme, an improvement procedure, and a chromosome adjustment procedure. The main role of GA in their approach is to evolve the chromosomes, which represent the priorities of the activities. The result indicated that the approach performed well against other algorithms and even yielded new best-known solutions for several benchmark test cases.

Material Delivery Schedule

An optimized material delivery schedule has the potential to reduce costs in construction. Fung et al. (2008) applied GA to multi-storey tower block construction by optimizing storage, distribution, and transportation. The test result showed a reduction of 15% in the total transportation cost. Anvari et al., (2016) developed a multi-objective GA-based optimization tool for manufacturing, transportation, and assembly of precast construction projects with the main objective of reducing project completion time. The authors believe that it is necessary to assess the cost and time decision implications from manufacturing up to assembly. This GA algorithm compared to other algorithms can capture real-life situations because of its high degree of flexibility. It is expected to help project managers select the best methods for different levels of prefabrication bearing in mind the total cost and time. This GA algorithm proved to be better than other heuristics when compared in small and medium-size instances but not in large instances.

Finance-Based Scheduling

Availability of cash at the right time during a construction project execution is a common challenge faced by contractors which significantly alters the project schedule. This in turn affects the profitability of a construction project (Fathi & Afshar, 2010). It is necessary to maintain a good and realistic cash flow scheduling throughout a project to avail contractors with funds when needed. A finance-based schedule entails adjusting the project schedule to meet up with constraining cash flow. GA has been applied by researchers because GA is less problem-dependent and enables project managers to arrive at sub-optimal solutions in situations where dynamic programming fails (Yu et al., 2012) itemize finance-based scheduling problems (Alghazi et al., 2013; Ali & Elazouni, 2009; Fathi & Afshar, 2010). Fathi and Afshar (2010) proposed a GA-based multi-objective optimization model for finance-based construction project scheduling that facilitates the decision-making process for the best cash procurement line of credit using the general concept of non-dominated sorting genetic algorithm with elitism. The model selects optimum solutions from a set of optimal nondominated solutions based on the defined order of priority of the objectives. In some situations, however, finance-infeasible offspring chromosomes arise when the traditional crossover and mutation operations are performed (Alghazi et al., 2013). To boost GA's performance by addressing the issue of reproducing finance-infeasible offspring chromosomes, Alghazi et al. (2013) developed a repair algorithm that works by changing the start times of activities to ensure that cash flow never shows higher finance needs compared to the cash limitation. The repair algorithm outperformed the other two treatment methods for finance-infeasible chromosomes—discarding and penalizing the infeasible chromosomes.

Multiple Constraint Scheduling

Project scheduling is a complex process with a lot of considerations for successful project delivery with different short and specific approaches for each scheduling constraint, thereby requiring the combination of multiple heuristic rules for decision making. GA, however, offers a single heuristic solution to such problems. Chen & Shahandashti (2009) proposed a hybrid GA and simulated annealing (SA) method for generic multiple projects scheduling with multiple resource constraints. Due to the random searchability of the GA-SA hybrid, the model can be applied to various kinds of optimization problems. Dawood & Sriprasert (2006) also applied GA in Multiple Constraint Scheduling. The authors considered four major construction constraints: Contract constraint (time, cost, quality, special agreement); Physical constraint (technological dependency, space); Resource constraint (availability, capacity, perfection); and Information constraint (availability and perfection). To resolve these constraints, they employed the techniques of Resource allocation (to reschedule projects to efficiently utilize the limited resources) and Resource leveling (adjusting task dates, duration, and resource allocation, to fix the overallocation of resources while maintaining the original project duration).

Drivers of Genetic Algorithm in Project Management Decision-making

The GA operators—selection, mutation, and crossover, which are based on the laws of evolution give GA its competitive edge over other optimization methods (Fourie & Perold, 2003; Katoch et al., 2021). Its adoption for decision-making optimization in project management is driven by its unique advantages that include genetic mutation, excellent parallel compatibility, suitability for large-scale optimization problems, efficiency in handling noisy functions, and generates multiple global optimal solutions (Ancveire & Poļaka, 2019; Haidar, 2015; Ko & Wang, 2010; Sivanandam & Deepa, 2008). Traditional optimization methods like the physical, schematic (graphs and charts), and linear programming methods usually become infeasible when there are multiple constraints and uncertainties in achieving an optimal/near-optimal solution, hence, a need for an intelligent method for decision-making optimization such as GA (Haidar, 2015; Sivanandam & Deepa, 2008a).

Table 1

Comparison of Genetic Algorithm with Traditional Optimization Methods

Genetic Algorithm	Traditional Optimization Algorithms
• Designed for both continuous and discrete optimization problems.	• Designed for either continuous or discrete problems
• More robust because they search for solutions from a sample population.	• Less robust as they mostly search from a single point
• Not easily confused as they work with encoded parameters and not the actual parameters	• Can be fooled by problems with complex parameters
• Uses objective function.	• Uses derivatives
• Are based on probabilistic modeling.	• Based on deterministic modeling

Linear programming uses mathematical/analytical techniques to solve optimization problems with different linear constraints (Haidar, 2015). The ability of GA to be initiated with a population of solutions makes it possible for a global optimum to be obtained with a GA. GA differs from other optimization methods in the sense that the properties of its fitness function are not bound by any mathematical constraints and is designed to maximize tradeoff by exploring new search locations and utilizing already obtained information (Sivanandam & Deepa, 2008). Table 1 summarizes the unique benefits of GA compared to other optimization techniques.

Challenges of Genetic Algorithm in Project Management Decision-making

Despite the numerous unique benefits provided by this innovative decision-making optimization tool, there are still some barriers affecting its adoption in project management decision-making in the construction industry. Some of the challenges include the amount of time needed to develop GA for a particular project, the complexity, the possibility of premature convergence, and its inability to guarantee a single best solution.

Rate of convergence and speed are considered important factors in determining the performance of an algorithm. A GA converges when there is no change in the chromosomes from one iteration to the next. Premature convergence occurs when the optimization problems coincide too early, leading to the algorithm being trapped in a local optimum and generating poor results (Andre et al., 2001). A smaller generation may result in the GA converging too early, hindering the chances of the GA to reach optimal/suboptimal solutions (Haidar, 2015). Andre et al. (2001) proposed a solution to premature convergence in GA by introducing scale factor and adaptive study interval. The method showed an improvement in convergence but negatively affected the speed of the algorithm.

Selecting an appropriate initial population is necessary for the use of GA in decision-making as the output depends on the initial sample population. Typical examples of such situations in construction project management include the inability to identify the level of knowledge of a team member required to complete a particular task, keeping up with the skill development of team members, and the inability to prioritize activities involved in a project (Ancveire & Poļaka, 2019; Li & Dong, 2018). A very large population could increase the processing time of a GA while a very small population could lead to a poor output (Katoch et al., 2021).

Conclusion

Project management is mostly about decision-making and with the advent of big data, which is aimed at making more informed decisions, it has become increasingly difficult for the human mind to process such data without the aid of non-human intelligence. The study showed that GA has proven to be efficient through its practical application in project management situations like time-cost tradeoff, finance-based scheduling, multiple constraint scheduling, resource leveling, and material delivery. The success of GA in these contexts could be attributed to its operators—selection, mutation, and crossover, that mimic the biological evolution process. GA differs from other traditional optimization algorithms mainly because it can be applied to both discrete and continuous optimization problems and can also search for solutions from a sample population and not a single point, thereby greatly reducing the possibility of getting trapped in a local optimum. GA however has its downside like the complexity required for its development and the possibility of premature convergence when an inappropriate initial sample population is selected. GA has demonstrated to be efficient despite its few limitations. Further research on the challenges of GA could address the current setbacks faced by GA in decision-making.
The contribution of this paper is a comprehensive review of GA with a focus on the area of Project Management decision-making. A simplified concept of GA and its applications in project management are discussed.

References

Alghazi, A., Elazouni, A., & Selim, S. (2013). Improved Genetic Algorithm for Finance-Based Scheduling. *Journal of Computing in Civil Engineering*, *27*(4), 379–394.

Ali, M. M., & Elazouni, A. (2009). Finance-based CPM/LOB scheduling of projects with repetitive non-serial activities. *Construction Management and Economics*, *27*(9), 839–856.

Ancveire, I., & Poļaka, I. (2019). Application of Genetic Algorithms for Decision-Making in Project Management: A Literature Review. *Information Technology and Management Science*, *22*(0), 22–31.

Andre, J., Siarry, P., & Dognon, T. (2001). An improvement of the standard genetic algorithm fighting premature convergence in continuous optimization. *Advances in Engineering Software*, *32*(1), 49–60.

Anvari, B., Angeloudis, P., & Ochieng, W. Y. (2016). A multi-objective GA-based optimisation for holistic Manufacturing, transportation and Assembly of precast construction. *Automation in Construction*, *71*, 226–241.

Ayodele, O. A., Chang-Richards, A., & González, V. (2020). Factors Affecting Workforce Turnover in the Construction Sector: A Systematic Review. *Journal of Construction Engineering and Management*, *146*(2), 03119010.

Cavalcante, V. F., Cardonha, C. H., & Herrmann, R. G. (2013). A Resource Constrained Project Scheduling Problem with Bounded Multitasking. *IFAC Proceedings Volumes*, *46*(24), 433–437.

Chen, L., Wang, Y., & Guo, G. (2019). An Improved Genetic Algorithm for Emergency Decision Making under Resource Constraints Based on Prospect Theory. *Algorithms*, *12*(2), 43.

Chen, P.-H., & Shahandashti, S. M. (2009). Hybrid of genetic algorithm and simulated annealing for multiple project scheduling with multiple resource constraints. *Automation in Construction*, *18*(4), 434–443.

Dawood, N., & Sriprasert, E. (2006). Construction scheduling using multi-constraint and genetic algorithms approach. *Construction Management and Economics*, *24*(1), 19–30.

Elaoud, S., Loukil, T., & Teghem, J. (2007). The Pareto fitness genetic algorithm: Test function study. *European Journal of Operational Research*, *177*(3), 1703–1719.

Fathi, H., & Afshar, A. (2010). GA-based multi-objective optimization of finance-based construction project scheduling. *KSCE Journal of Civil Engineering*, *14*(5), 627–638.

Fourie, C. J., & Perold, W. J. (2003). Comparison of genetic algorithms to other optimization techniques for raising circuit yield in superconducting digital circuits. *IEEE Transactions on Applied Superconductivity*, *13*(2), 511–514.

Fung, I., W. H., Wong, C. K., Tam, C. M., & Tong, T. K. L. (2008). Optimizing Material Hoisting Operations and Storage Cells in Single Multi-storey Tower Block Construction by Genetic Algorithm. *International Journal of Construction Management*, *8*(2), 53–64.

Gonçalves, J. F., Mendes, J. J. M., & Resende, M. G. C. (2008). A genetic algorithm for the resource constrained multi-project scheduling problem. *European Journal of Operational Research*, *189*(3), 1171–1190.

Gonçalves, J. F., Resende, M. G., C, Mendes, J. J., & M. (2011). A biased random-key genetic algorithm with forward-backward improvement for the resource constrained project scheduling problem. *Journal of Heuristics*, *17*(5), 467–486.

Gupta, S., Kar, A. K., Baabdullah, A., & Al-Khowaiter, W. A. A. (2018). Big data with cognitive computing: A review for the future. *International Journal of Information Management*, *42*, 78–89.

Haidar, A. D. (2015). *Construction Program Management – Decision Making and Optimization Techniques*. Springer.

Janssen, M., van der Voort, H., & Wahyudi, A. (2017). Factors influencing big data decision-making quality. *Journal of Business Research*, *70*, 338–345.

Katoch, S., Chauhan, S. S., & Kumar, V. (2021). A review on genetic algorithm: Past, present, and future. *Multimedia Tools and Applications*, *80*(5), 8091–8126.

Khan, K. S., Kunz, R., Kleijnen, J., & Antes, G. (2003). Five steps to conducting a systematic review. *Journal of the Royal Society of Medicine*, *96*(3), 118–121.

Ko, C.-H., & Wang, S.-F. (2010). GA-based decision support systems for precast production planning. *Automation in Construction*, *19*(7), 907–916.

Li, H., & Dong, X. (2018). Multi-mode resource leveling in projects with mode-dependent generalized precedence relations. *Expert Systems with Applications*, *97*, 193–204.

Lova, A., Tormos, P., Cervantes, M., & Barber, F. (2009). An efficient hybrid genetic algorithm for scheduling projects with resource constraints and multiple execution modes. *International Journal of Production Economics*, *117*(2), 302–316.

Milios, D., Stamelos, I., & Chatzibagias, C. (2013). A genetic algorithm approach to global optimization of software cost estimation by analogy. *Intelligent Decision Technologies*, *7*(1), 45–58.

Mokhtari, H., Kazemzadeh, R., & Salmasnia, A. (2011). Time-Cost Tradeoff Analysis in Project Management: An Ant System Approach. *Engineering Management, IEEE Transactions On*, *58*, 36–43.

Parry, K., Cohen, M., & Bhattacharya, S. (2016). Rise of the Machines: A Critical Consideration of Automated Leadership Decision Making in Organizations. *Group & Organization Management*, *41*(5), 571–594.

Ramzan, M., Jaffar, A., Iqbal, A., Anwar, S., Rauf, A., & Shahid, A. A. (2012). Project scheduling conflict identification and resolution using genetic algorithms (GA). *Telecommunication Systems*, *51*(2–3), 167–175.

Scully, T., & Brown, K. N. (2009). Wireless LAN load balancing with genetic algorithms. *Knowledge-Based Systems*, *22*(7), 529–534.

Shamim, S., Zeng, J., Shariq, S. M., & Khan, Z. (2019). Role of big data management in enhancing big data decision-making capability and quality among Chinese firms: A dynamic capabilities view. *Information & Management*, *56*(6), 103135.

Sivanandam, S. N., & Deepa, S. N. (2008a). Genetic Algorithms. In S. N. Sivanandam & S. N. Deepa (Eds.), *Introduction to Genetic Algorithms* (pp. 15–37). Springer.

Sivanandam, S. N., & Deepa, S. N. (2008b). Introduction to Genetic Algorithms. In S. N. Sivanandam & S. N. Deepa (Eds.), *Introduction to Genetic Algorithms* (pp. 15–37). Springer.

Wuliang, P., & Chengen, W. (2009). A multi-mode resource-constrained discrete time–cost tradeoff problem and its genetic algorithm based solution. *International Journal of Project Management*, *27*(6), 600–609.

Yu, L., Wang, S., Wen, F., & Lai, K. K. (2012). Genetic algorithm-based multi-criteria project portfolio selection. *Annals of Operations Research*, *197*(1), 71–86.

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Situational Impact on Leadership Styles with Emerging Construction Managers

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Leadership in the construction industry can determine the success of a project. However, many emerging construction managers do not understand the different styles of leadership. Three common leadership styles are Autocratic, Democratic, and Laissez-faire. Adapting leadership styles to the situation will have an immediate impact on the success of the leader. The objective of this study was to examine the impact that the situation has on leadership styles with early-career construction managers. Forty-five early career construction managers participated with the study and examined their preferred leadership styles in two different situations. The survey examined the differences in their responses with the two situations. The preferred leadership style that the participants selected was democratic, however in the second situation that presented more stress the participants were more likely to demonstrate Autocratic leadership.

Key Words: Leadership, Autocratic, Democratic, Laissez-faire, Leadership Training

Introduction

There are several leadership styles that a construction manager can display on the job. The three most discussed leadership types are Autocratic, Democratic, and Laissez-faire. Often, leaders can move from one type of style to another. It is important to understand the advantages and disadvantages of each type of leadership style to ensure that one is utilizing the best leadership style for the circumstances. The construction job site presents many different situations, and they call for some adaptability with leadership. As with the different leadership styles, there are many different types of followers in construction, some of which will respond to certain leadership styles better than others. Becoming aware of ones' preferred leadership styles is an important aspect of leadership training. Understanding how the situation may impact a leader's preferred leadership styles will help build their awareness to reduce negative impacts on those that follow them. This paper aims to investigate the difference between leadership styles and two different project situations with construction managers. Forty-five early-career project managers participated in the study and identified the impact that the situation has on leadership styles.

Literature Review

Emerging construction managers must learn to become good leaders to have a positive impact on the workforce. Some take a heavy-handed approach, while others prefer to be less involved. Styles fluctuate, as does their effectiveness at the workplace. Several leadership styles are studied; however, three core leadership styles are prevalent in leadership research; autocratic, democratic, and laissez-faire (Mills and Jung 2012; Khan & Khan, 2015). The autocratic style is one in which the manager retains as much power and decision-making authority as possible. This style clearly defines the leader's role as the boss but may cause a disconnected relationship with employees to form. Autocratic individuals are solely focused on the task at hand and how to complete it. Laissez-faire leadership is on the other end of the spectrum. It is one in which the manager provides little or no direction and gives their employees as much freedom as possible. All authority or power is given to the employees, and they can determine goals, make decisions, and resolve problems on their own. In the middle of these two leadership styles is the democratic leader. Democratic leaders focus on building working relationships with coworkers. This style shares the power and focuses on building trust with their employees that promote a collaborative work environment. It encourages employees to give input, but the final decision still lies with the manager (Sundar, 2019). Democratic may be useful because collaboration in the workplace can help promote a team mindset (Bresnen et al, 1986). Figure 1 presents the continuum of leadership behaviors first presented by Tannenbaum and Schmidt (1973), which presents who controls decision-making power between the leader and their employees or followers.

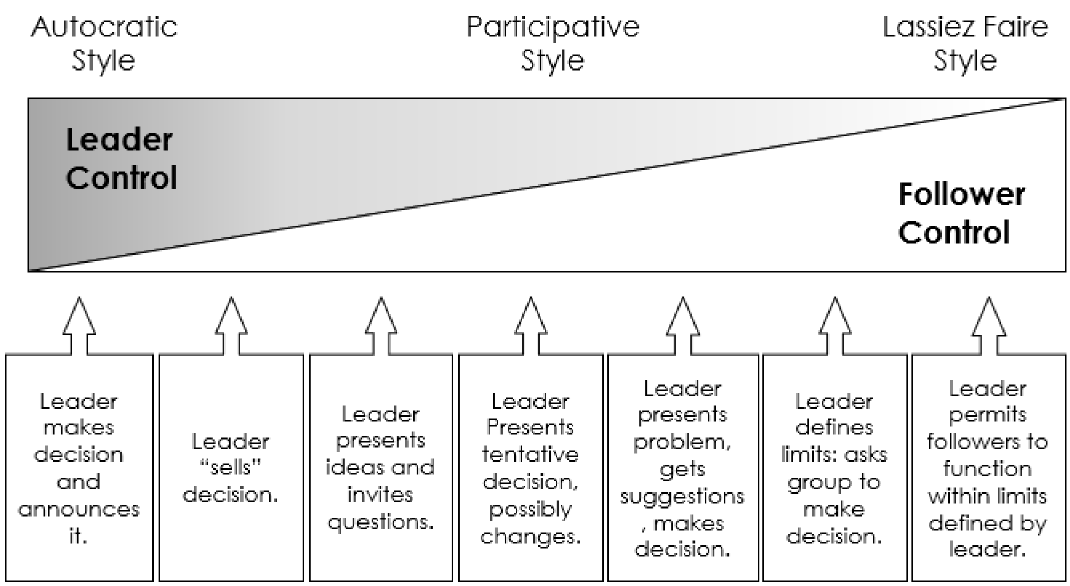

Figure 1. The Continuum of Leadership Behavior (Adopted from Tannenbaum and Schmidt, 1973)

In 2012, Thomas Mills and Younghan Jung sent out a questionnaire to 94 construction workers on the construction job site to find their opinions on which leadership style was most preferred. It was found that most workers strived to use a democratic approach. However, the researchers believed that project executives, project managers, superintendents, office engineers, and field engineers should use different leadership styles dependent on their roles and responsibilities. They inferred that the traditional style of leadership in which the leader demonstrates a strong autocratic leadership style may not be the ‘best’ style and that leaders should employ a mix of various styles to succeed. (Mills and Jung, 2012). Mills and Jung recommend that further research is needed on leadership styles in construction as it has a large impact on organizational success. Another researcher, Shalini Sundar (2019), recognized the democratic approach as the most dependable on the construction job site. Sundar studied the impact that leadership style has on employee satisfaction in the construction industry and found that out of the three styles, democratic and laissez-faire were found to have a direct positive effect on job satisfaction. The two styles focus on building coworker relationships and inviting positive conversations as opposed to autocratic which does not bother. However, some articles outright reject the laissez-faire styles on the construction job site. One study focused on how leadership styles impact construction site safety and the researchers warned against laissez-faire leadership style (Grill et al. 2018). This was because the study found a correlation between laissez-faire leadership styles and unsafe construction sites.

The situation can have an immediate impact on the leadership style that one demonstrates. For example, a stressful project may largely impact leadership skills on a construction site. Construction managers have one of the heaviest workloads in construction, making their position very prone to stress. Mentally, stress may lead to depression, anxiety, poor decision-making, and poor work performance (Djebarni, 1996). Djebarni (1996) found that construction leaders were more successful in stressful situations when they demonstrated autocratic behaviors. This was due to the autocratic leaders focusing more on the task or project and focusing less attention on building their relationships with their team members. Another study agreed that the autocratic leadership style was better on a stressful job site; however, they also found that the Construction managers who focused more on building good relationships with their team members had better overall worksite performance (Bresnen et al, 1986). The pros and cons of each style vary, and one should not solely seat themselves within one style. Flexibility is key as one never knows what the situation will bring.

Methodology

The objective of this study was to examine the impact that the situation has on leadership styles with early-career construction managers. In 2021, 45 emerging project managers were identified for leadership training. They are composed of early career (5-10 years of experience) construction managers within a large construction company in North America. Before training on leadership styles, a survey was conducted with the participants to identify their preferred leadership styles. The portion of the survey that studied participant leadership styles was composed of five questions. Unbeknownst to the participants, the five questions would be asked in two distinct situations. Situation 1 was a Regular Project (RP) in which the project team was efficient, and the project was on schedule. After answering the five questions for Situation 1, Situation 2 was presented. Situation 2 was composed of a stressful project, it was described as follows “*In contrast to Situation 1, the project team members seem to lack awareness about their responsibilities, the owner is frustrated, and this project has fondly been named the "Project from Hell" (PFH). It is plagued with all kinds of problems: delayed schedule, low morale, safety issues, design omissions, inexperienced subcontractors, government audits, and many scope changes.*

The participants responded to the questions with categorical responses that scaled across Autocratic, Democratic, and Laissez-Faire leadership styles; this method has been used in a previous study examining leadership styles among construction managers (Jung et al, 2014). Categorical variables were designed for the five questions to determine preferred leadership styles. These categorical responses across leadership styles presented a 3-point scale, similar to the Tannenbaun and Schmidt (1973) study, which distinguishes leader/follower control between the three main leadership styles, see Figure 1. The following five questions were used to test participant leadership styles, their categorical response options can be observed in Tables 1 through 5.

1. How would you seek input from the project team on tough Project Management decisions?
2. How would you make the tough Project Management decisions?
3. How would you manage the project team member responsibilities?
4. How would you define and monitor project team member performance?
5. Who should drive the project team members?

To study the differences between the two situations. The null hypothesis for this study is that the project managers would select the same leadership styles for each of the two situations. The Alternative Hypothesis is that the project managers would select different leadership styles dependent on the situation. Both visual inspection and a paired sample t-test were conducted on the data to test the hypothesis.

Data Analysis

The survey responses are presented in Tables 1-5. These unique tables were modified from tables presented in past research comparing leadership styles (Jung et al, 2014). These tables present the data in a way that provides a visual analysis of the differences between the two situations. Table 1 presents the first question and the percent of project managers that responded with the categorical response for Autocratic, Democratic, and Laissez-Faire. The differences between the two situations between the Regular Project (RP) and the Project from Hell (PFH) can be analyzed visually. As can be seen in Table 1, the Mean for the RP was 2.51, meaning the responses were between a Democratic and Laissez-Faire leadership style. However, the mean decreased to 2.07 in Situation 2. Upon visual inspection, a difference appears to exist with preferred leadership styles between the two different situations with all five questions.

Table 1

Question 1 Situational Difference with Seeking Project Team Input

How would you seek input from the project team on tough Project Management decisions?

Available Responses	I wouldn't seek input from any of the project team members.	I would present solutions and invite input from all team members.	I would seek input from all team members on possible solutions.		
Scale	1	2	3		
	Autocratic	Democratic	Laissez-Faire	Mean	Stand. Dev.
Situation 1 RP	0%	49%	51%	2.51	0.50
Situation 2 PFH	20%	53%	27%	2.07	0.67

Table 2

Question 2 Situational Difference with Decision Making

How would you make the tough Project Management decisions?

Available Responses	I would make necessary PM decisions and be sure that the team understands why I made the decision.	I would get input from the team, but I would retain the final decision-making authority.	I would seek input from all team members on possible solutions.		
Scale	1	2	3		
	Autocratic	Democratic	Laissez-Faire	Mean	Stand. Dev.
Situation 1 RP	20%	73%	7%	1.87	0.50
Situation 2 PFH	36%	62%	2%	1.67	0.52

Table 3

Question 3 Situational Difference with Managing Team Member Responsibilities

How would you manage the project team member responsibilities?

Available Responses	I would assign the responsibilities to each team member and make a schedule for them to complete the items.	I would assign the responsibilities to each team member and ask each team member if they agree with their responsibilities or if we need to change any of them.	I would communicate what responsibilities are needed for the project and the team members knowing their strengths and weaknesses would decide on their responsibilities individually.		
Scale	1	2	3		
	Autocratic	Democratic	Laissez-Faire	Mean	Stand. Dev.
Situation 1 RP	33%	47%	20%	1.87	0.72
Situation 2 PFH	60%	22%	18%	1.58	0.77

Table 4

Question 4 Situational Difference with Defining and Monitoring Performance

How would you define and monitor project team member performance?

	I would define team member performance expectations and I would monitor their performance.	I would have the team members define their performance expectations and have them monitor their individual performance and report their performance to me.	I would have the team members define and monitor their performance with little to no supervision from me.		
Scale	1	2	3		
	Autocratic	Democratic	Laissez-Faire	Mean	Stand. Dev.
Situation 1 RP	49%	51%	0%	1.51	0.50
Situation 2 PFH	80%	20%	0%	1.20	0.40

Table 5

Question 5 Situational Difference with Driving Performance

Who should drive the project team members?

	I believe as the PM, I need to drive team members to work hard.	I believe team members should be self-driven and as the PM, I should only monitor progress.	I believe team members can drive themselves without any monitoring from myself as the PM.		
Scale	1	2	3		
	Autocratic	Democratic	Laissez-Faire	Mean	Stand. Dev.
Situation 1 RP	29%	71%	0%	1.71	0.50
Situation 2 PFH	62%	38%	0%	1.38	0.48

Upon conducting the paired two sample t-Test a significant difference between the responses for Situation 1 and Situation 2 was found in all five questions, see Table 6. The t stat was greater than the t-critical for all 5 questions, which means that we can reject the null hypothesis. The p-value was greater than 0.05 in all five tests, supporting the rejection of the null hypothesis. This means that a clear change of leadership style preference exists between the two situations.

Table 6

t-Test: Paired Two Sample for Means

	Question 1		Question 2		Question 3		Question 4		Question 5	
	RP	*PFH*	*RP*	*PFH*	*RP*	*PFH*	*RP*	*PFH*	*RP*	*PFH*
Mean	2.51	2.07	1.87	1.67	1.87	1.58	1.51	1.20	1.71	1.38
Variance	0.26	0.47	0.25	0.27	0.53	0.61	0.26	0.16	0.21	0.24
Observations	45	45	45	45	45	45	45	45	45	45
Pearson Correlation	0.292		0.518		0.578		0.489		0.497	
Hypot. Mean Diff.	0		0		0		0		0	
df	44		44		44		44		44	
t Stat	4.114		2.659		2.789		4.458		4.690	
P(T<=t) two-tail	0.000		0.011		0.008		0.000		0.000	
t Critical two-tail	2.015		2.015		2.015		2.015		2.015	

Discussion

Although many construction projects don't go exactly as planned, situation one presents a project that is going as planned. The response to Situation 1 gives a base understanding of the preferred leadership style of the 45 participants. From the data analysis, we can infer that project managers prefer the Democratic leadership style. These findings align to the Mills and Jung (2012) study. Questions one and two are similar in that they deal with getting information to make difficult decisions in the workplace. Often, a project manager will seek decision making input as team diversity may help bring well rounded answers. The democratic style shares some of the authoritative power and focuses on building trust in their employees with decision making. In the ideal situation, the managers chose to get input on decision-making from their team members. Interestingly, many of the responses in questions one and two reflected Laissez-Faire leadership styles which contrasts with some research that suggests that a Laissez-faire leadership style is not appropriate in construction. This may be due to the nature of these two questions. Instead of dealing with hard productivity decisions, they instead only seek input. The PMs do not have to use any input given to them from their team, and no matter what they retain power in question one and two. Questions three and four reflected that the Laissez-Faire leadership style is not appropriate for assigning and monitoring individuals' roles and responsibilities. PMs should be more involved with assigning roles and responsibilities. Project managers use a democratic and autocratic approach to set obtainable goals and help provide feedback when needed. This democratic leadership approach will improve trust within their team members which will lead to higher commitment and increased job satisfaction. When the questions focus shifted to highlight aspects of a project which can heavily affect the team, such as providing feedback, PMs sought to maintain project control no matter the situation.

One can see that the 'Project from Hell' worksite situation had a large impact on the categorical responses with the early-career construction managers. When participants were asked about the PFH, the mean shifted towards the Autocratic leadership style on all five questions. PMs prefer a

Democratic leadership style; however, when the project objectives are threatened, it forces them to be more task-focused and demonstrate autocratic characteristics. In both tables one and two, the answers still favor democratic, though autocratic percentages do substantially increase. This reflects that when things get stressful, PMs do not seek as much input from others. As stated above, they may still ask their team members and use a democratic approach; however, final decision authority is theirs alone. During the PFH, PMs elected to retain more control on assigning responsibilities. This means followers are not going to have the ability to decide job responsibilities when the project objectives are threatened. When the project becomes stressful, the survey participants seem to rely heavier on their personal experiences. Finally, the perception that the construction manager must maintain motivation with their followers shifted from a team's responsibility to the leader's responsibility. The perception is that the leader needs to drive and motivate their team members on a stressful project. One can see this substantial shift in leadership ideology in the latter three questions. Although the autocratic leadership style will allow for quicker decisions in a stressful project there are several negative impacts that will impact their team members. The first negative impact on the team will be the morale, in contrast to the past, autocratic leadership is less acceptable for the younger workforce. Another negative impact will be the level of dependency on the leader will increase. By becoming more controlling, the PMs are giving up collaboration with their team members in favor of ensuring tasks are completed in a certain manner. Seasoned workers will be less likely to provide input in situations in which their voice is not heard.

Conclusion

There is little research available in the construction industry with regards to the impact that leadership styles have on construction projects. A review of the past research on leadership styles in construction found three prior studies. Historically the construction manager has led with an autocratic leadership style, even though research has shown that the democratic leadership style is a more effective approach in construction. In addition, the preferred leadership styles have been studied with certain job roles, democratic leadership was found to be the preferred leadership style within the project management role, while autocratic leadership styles have been preferred with superintendent or safety positions. This paper presents the first study of how the situation impacts preferred leadership styles on the construction jobsite. Although the survey pool is limited to 45 early career project managers and the situations are hypothetical, the data provides a better understanding of the behaviors that will likely change when a project gets stressful. Further research can help contractors understand how the stressful nature of a project will impact leadership styles and combat the negative outcomes of leaders under stress.

The situation has an immediate impact on the preferred leadership style of emerging construction managers. This study examined two situations, one was a project that was going as planned and the other situation was referred to as the 'Project from Hell'. The objective was to find if there was a difference between preferred leadership styles in the two situations. There clearly was a difference between the two situations. The hypothesis that leadership styles differ between project situations was found to be true. The preferred leadership style includes a Democratic approach that incorporates team members strengths on the project. Construction Managers prefer that their team members are involved in decision making and selecting their responsibilities. The desire is that team members are motivated and want to be collaborative in the construction process. A more collaborative team has been found to be more successful and experience higher levels of employee satisfaction. However, in the more stressful project this study found that construction managers shifted their leadership style to a more Autocratic leadership style. The 'Project from Hell' observed more autocratic responses with seeking input from team members, making tough project decisions, managing team member responsibilities, monitoring performance, and driving the project team members. Although the leader will focus more on the task at hand, the benefits of democratic leadership will decrease.

References

Bresnen, M. J., Bryman, A. E., Ford, J. R., Beardsworth, A. D., & Keil, T. E. (1986). "*LEADER ORIENTATION OF CONSTRUCTION SITE MANAGERS"*. J. Constr. Eng. Manage.

Djebarni, Ramdane. (1996). The Impact of Stress in Site Management Effectiveness. Construction Management and Economics. 14. 281-293. 10.1080/014461996373368.

Jung, Y., Jeong, M. G., & Mills, T. (2014). Identifying the preferred leadership style for managerial position of construction management. *International Journal of Construction Engineering and Management*, *3*(2), 47-56.

Jung, Y., & Mills, T. (2012). A Survey of Construction Managerial Leadership Styles. *48th ASC Annual International Conference Proceedings*, 1–9. https://doi.org/http://ascpro0.ascweb.org/archives/cd/2012/paper/CPRT138002012.pdf

Khan, M., & Khan, I. (2015). The Styles of Leadership: A Critical Review. *Public Policy and Administration Research*, *5*(3), 87–92. https://doi.org/https://www.iiste.org/Journals/index.php/PPAR/article/viewFile/20878/21131

Nielsen, K., Grill, M., Grytnes, R., Pousette, A., & Törner, M. (2018, November 23). *The leadership practices of construction site managers and their influence on occupational safety: An observational study of transformational and passive/avoidant leadership*. Taylor & Francis. Retrieved from https://www.tandfonline.com/doi/full/10.1080/01446193.2018.1526388.

R. Tannenbaum and W. H. Schmidt, "How to choose a leadership pattern," Harvard Business Review, vol. 51, pp. 162-180, 1973.

Singh, A. (2009, September 15). Organizational power in Perspective *Leadership and management in Engineering,* Vol 9, No 4. Leadership and Management in Engineering. Retrieved September 19, 2021, https://doi.org/10.1061/(ASCE)LM.1943-5630.0000018

Sundar, S. (2019, August 25). *(PDF) leadership style of managers in construction industries and its relationship with employee's job satisfaction*. ResearchGate. Retrieved from https://www.researchgate.net/publication/335392322_Leadership_Style_of_Managers_in_construction_industries_and_its_Relationship_with_Employee%27s_Job_Satisfaction.

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Blockchain Applications through the Lens of Project Managers

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This paper succinctly addresses the initial results of the first phase of a study aiming at the application of blockchain technology in project management. In the first stage, the perception of project managers toward the application of blockchain technology in professional areas was explored. After briefly reviewing the concepts of blockchain technology, smart contracts, and integration of the BIM and blockchain, a blockchain network is introduced as a case application in project management. This paper shows that blockchain is a viable system for governing project contracts by automating the consequences of each transaction and maintaining a tamper-proof record of project progress, which would be valuable in any kind of dispute resolution. In addition, the familiarity of project managers with potential applications of blockchain in project management was investigated through a quantitative method via a survey distributed to project managers. The results indicate that the advent of blockchain sets a platform for further integration of technology in various project management areas. The results also show that practical knowledge of project managers through blockchain-based cryptocurrencies correlates with their perceptions toward blockchain applications. The results suggest project managers can plan accordingly to embrace blockchain potentials along with other industries.

Keywords: Project Management, Blockchain, Smart Contract, Construction

Introduction

Construction projects include a horizontally and vertically complex supply chain coming together to realize a project's objectives. Multiple parties, often with conflicting interests, enter into contractual relationships that often lead to adversarial dispute resolution due to the nature of the work and the contracts supporting it. Innovative procurement and contracting models, Building Information Modeling (BIM), and other technological advances have been proposed and implemented to reduce the tension and improve the efficiency of the construction processes. However, construction still has a long way to get to an optimal point compared to other industries. Blockchain technology uses a decentralized peer-to-peer system to govern the relationship between different parties involved in a network. This approach is against the typical centralized business networks used in most cases. A lot of efforts, such as cloud BIM have been made to integrate the procurement network of construction projects. However, in all of them, there are different segments or parties that are left out. The complex structure of a construction project very well matches the peer-to-peer structure of blockchain technology. Furthermore, it can work as a platform where all the parties involved in a project are included in an integrated framework of project management to increase the efficiency of the project as well as reduce the hostility and possible conflicts in it. This paper discusses the blockchain technology and possibilities for its adaptation in the project management process, which is then followed up with results of a survey and follow-up discussions.

Literature Review

Blockchain

Blockchain is a decentralized transaction and data management system technology that has mainly been used for cryptocurrency and the financial service sector. Blockchain can be described as a digital list of transactions that is recorded and distributed across the entire network of computer systems. Throughout this chain, every block contains a number of transactions. In this system, every time a new transaction initiates, a record of that transaction is added to every participant's list.Blockchain allows everyone in the network to see every aspect of information with no one person being in control. Applying blockchain into construction could solve many challenges, including trust between different parties working on a project, transparency, and time issues. Potential applications of blockchain could be notarization-related, transaction-related, and provenance-related. Blockchain can eliminate the verification time of documents' authenticity, and every document can be stored in a distributed ledger. The time and cost it takes to dispute payments, technology transfer, equipment leasing, etc., can be decreased with all the processes being automated and neutral on the blockchain. The supply of each product or service can easily be traced through a blockchain ecosystem allowing for transparency from all parties. Blockchain can also be used in combination with other technologies already used throughout construction, such as BIM, IoT, and cloud computing. The co-evolution of these technologies and blockchain could lead to beneficial applications in construction, such as information management, payments, procurement, regulations and compliance, supply chain management, dispute resolution, construction management and delivery, and technological systems. Overall, the use of blockchain in the construction industry could help improve the time, costs, and disputes of the final project.

Blockchain in Project Management

Blockchain technology has emerged in the project management realm in recent years, and different purposes and applications have been identified to employ the technology. Amoah and Oh (2020) reviewed different models and proposed applications of blockchain in project management and stated that blockchain-based BIM and smart contacts are two applications of the technology in construction project management. In addition, project management offices PMOs can benefit blockchain-based applications through creating and managing digital records, coordinating the tasks between stakeholders, and reinforcing acceptable performances. El Khatib et al. (2021) reviewed six different blockchain-based cases in which different aspects of project management were evaluated and concluded that automation of the process, transparency, enhanced stakeholder management, and cost management are among the advantages of the blockchain in project management. In another whitepaper published by Blockchain Research Institute (Williams et al., 2019), payments, provenance, and data management were specified as early days of blockchain applications while followed by smart contracts and supply chain management. Blockchain as a distributed, encrypted, immutable, time-stamped, and secure platform helps PMOs to decrease project monitoring and controlling while improving overall project efficiency (Budeli, 2020). While many studies have explored various applications of blockchain in project management, areas consisting of multiple entities or processes are potential fields to employ blockchain technology (World Economic Forum, 2020; Tezel et al., 2020; Backman et al., 2017).

Blockchain in Construction

The construction supply chain can be divided into seven categories: Clients, Architects, Engineers, General Contractors, subcontractors (trades), Suppliers (including manufacturers), and Authorities. In most projects, different entities represent one role (i.e., sub-contractor, supplier) which means in each project organization, more than ten entities are routine;y interacting. The current paper contracts require a paper trail for every administrative task, which makes the process cumbersome, slow, and error-prone while making the document management of each project a dreadful task. In contrast, a blockchain network can easily connect all different parties together digitally while governing the transactions between the entities through smart contracts, which can result in a level of automation that is not possible through other currently available means. The transactions will be chained together through the secured hashes and leave an immutable trail of events that can be used to instantly solve any conflict. Furthermore, the blockchain network can be integrated with a BIM model to create a seamless digital twin construction environment, where all parties are using the same live model for design and construction purposes to achieve a higher level of integration and efficiency (Shojaei et al., 2019a). In order to create such a network, a public blockchain (such as Ethereum) or a private blockchain platform such as Hyperledger Fabric can be used. A public network would provide higher security, but the scalability issues and the costs associated with each transaction can become a major barrier. On the other hand, a private network such as Hyperledger Fabric can provide the right balance of versatility, scalability, security, and operation cost to the construction projects. This integration can be done by assigning a unique ID number that can be generated using the MD5 hashing algorithm and integrating those IDs into the smart contract, and tracking its progress in the project. The use of MD5 hash means that any change to the initial component would result in a different hash which can be easily flagged out by comparing it to the previous blocks. Three main elements in the Hyperledger Fabric network need to be defined: network model, business logic, and access control limitation. The network model is the foundation of the blockchain network where all different parties, types of transactions, assets, and events are defined. Business logic is smart contacts algorithms that will govern the relationship between the parties and decide if a transaction is valid or not. The access control limitation would define the access privileges for each entity to different types of information. Any type of construction project, regardless of its delivery method, supply chain complexity, and objectives, can be easily adapted to such a network structure. Furthermore, the use of this network in construction can be extended to improving the sustainability of the built environment through facilitating the embodied carbon and energy calculations (Shojaei et al., 2019b) or even making a greater impact by getting us closer to making a circular economy a reality (Shojaei et al., 2021). These objectives will be easily achievable by adopting a blockchain network as a foundation for a construction project's total supply chain management.

Methodology

The main purpose of this study was to explore the perception of project management professionals toward potential uses of blockchain in project management areas with a glance at the construction industry. Blockchain technology is a novel and emerging technology that is finding its path into non-financial contexts. Since these non-financial areas have just started to study the feasibility of blockchain applications, any deductive analysis is channeled with reliability issues. Therefore, in this study, construction management is assumed under the general project management umbrella. In the first stage of this study, project management professionals in different sectors in Mississippi participated in an educational module that overviews the different applications of blockchain. Project Management Institute (PMI), as the leading not-for-profit professional membership association for the project management profession, delivers values to more than 2.9 million professionals working around the world (PMI, 2021). PMI strives to enhance project managers' careers, improve organizational success, and further mature the profession. The first stage of this study was conducted through the PMI chapter meeting in which project management professionals convened to interactively pursue the discussion on the blockchain application in project management. As the first part of this educational module, a survey was designed and distributed to the participants to further explore their perceptions toward different aspects of blockchain and its potentials in project management. The data obtained from the survey were then organized and structured to create a data model. Different descriptive analyses were performed to analyze the data. The results of these analyses are described in the next sections.

Results

The data obtained through the survey were organized, modeled, and analyzed in statistical software. Seventeen project management professionals participated in the first round of the survey. Female participants comprised 65% percent of the participants, and the rest were male professionals. Participants also reported other demographic information, as shown in Figures 1-3.

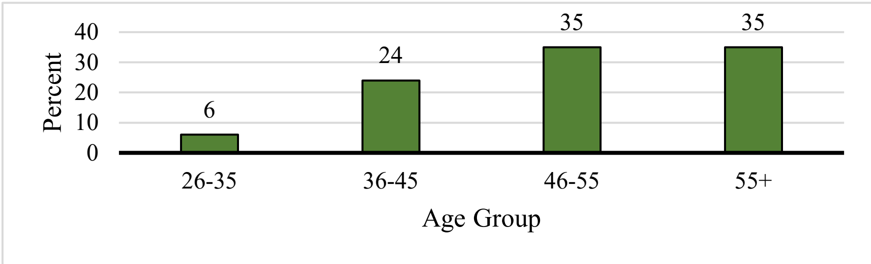

Figure 1: Participants age groups

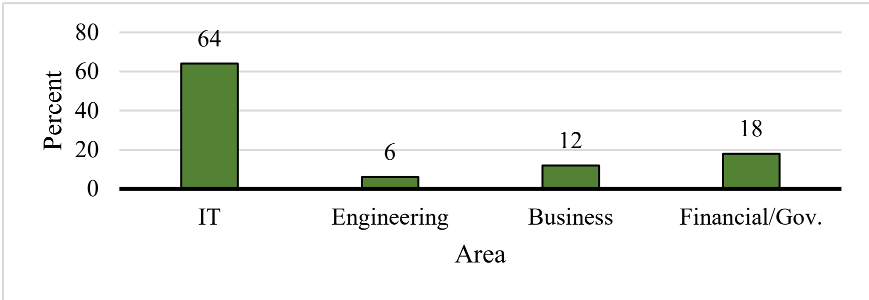

Figure 2: Participants area of expertise

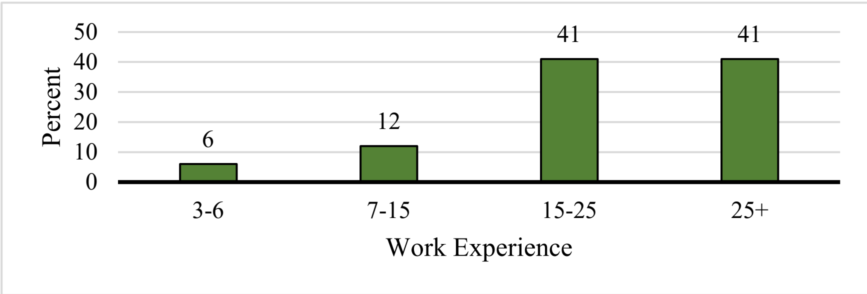

Figure 3: Participants work experience

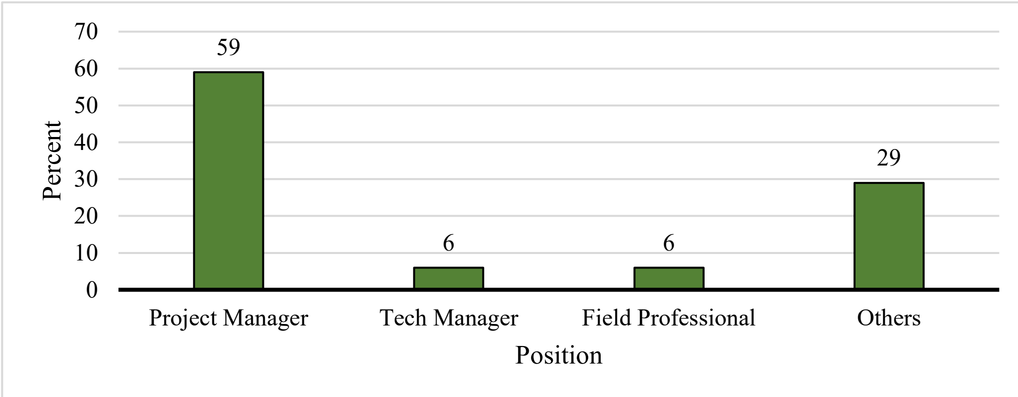

Figure 4: Participants position

Also, participants reported that, on average, they are directly working on 2-5 projects (76%) and 6-10 (24%) at a time. In the next section, participants were asked if they were familiar with any cryptocurrency other than Bitcoin and if they own any cryptocurrency. The majority of participants reported that they were familiar with altcoins, and about one-fourth of participants owned one or more cryptocurrencies. The percentage of each group is shown in Figure 5.

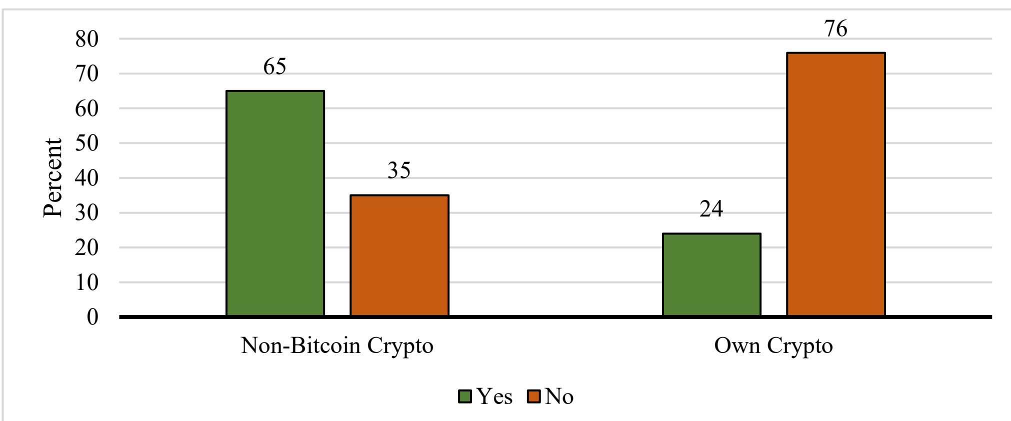

Figure 5: Participants and Cryptocurrencies

In the next section, participants were asked to rate to what extent they believed the blockchain technology could be used in project management, using a five-level Likert scale (1: Very Low; 5: Very High). While 18% of participants stated that the blockchain has low potential to be used in project management, the majority of participants rated the application of blockchain as moderate or higher.

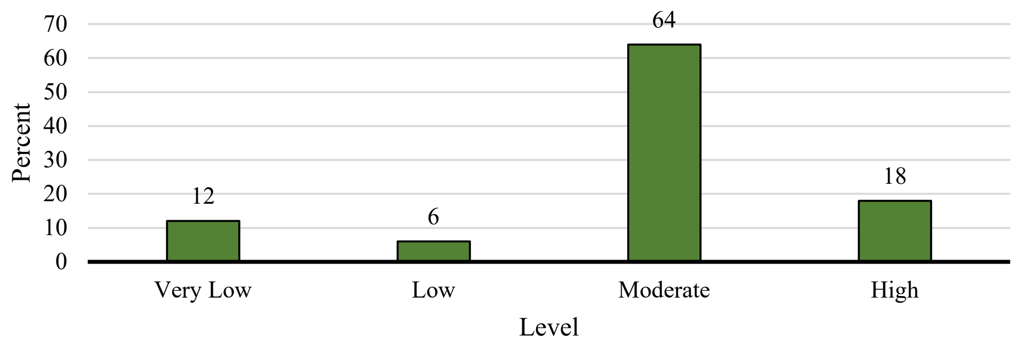

Figure 6: Participants perception toward blockchain in PM

In the next section, a group of possible applications for blockchain technology was provided to participants to be evaluated. Participants were asked to what extent they evaluated the potential of blockchain in different subjects, including medical records, e-notary, tax collection, smart contracts, supply chain management, insurance, and energy. These areas were derived from the literature review in which the emergence of blockchain technology is conceptualized through different applications or frameworks. A five-level Likert scale was used to rate the potential of areas to exploit blockchain. All these areas received weighted average scores above the mid-point, which indicated the positive attitude toward the use of blockchain; however, among these areas, smart contract and supply chain management was rated above others. The percentage of levels for each area is shown in Figure 7.

Analysis of Associations

The analysis of the association between gender and blockchain potentials revealed that female participants displayed higher scores in areas that can utilize blockchain. A similar trend can be seen between the two groups of “crypto owners” and “non-owners.” This means, possessing any cryptocurrency has a positive association with the perception of blockchain in different areas of project management. With five-level Likert scale (1-5), the weighted average of each areas’ score (out of 5) is shown in Table 1.

Table1: Weighted average score of blockchain potentials

Gender	Blockchain in PM	Medical Records	E-notary	Tax Collection	Smart Contracts	Supply Chain	Insurance	Energy
Male	2.67	3.33	2.83	3.33	3.67	3.83	3.00	3.33
Female	3.00	3.36	3.36	3.73	3.82	3.73	3.45	3.64
Crypto Owners	3.25	3.75	3.75	3.75	4.00	4.00	3.50	3.50
Non-owners	2.77	3.23	3.00	3.54	3.69	3.69	3.23	3.54

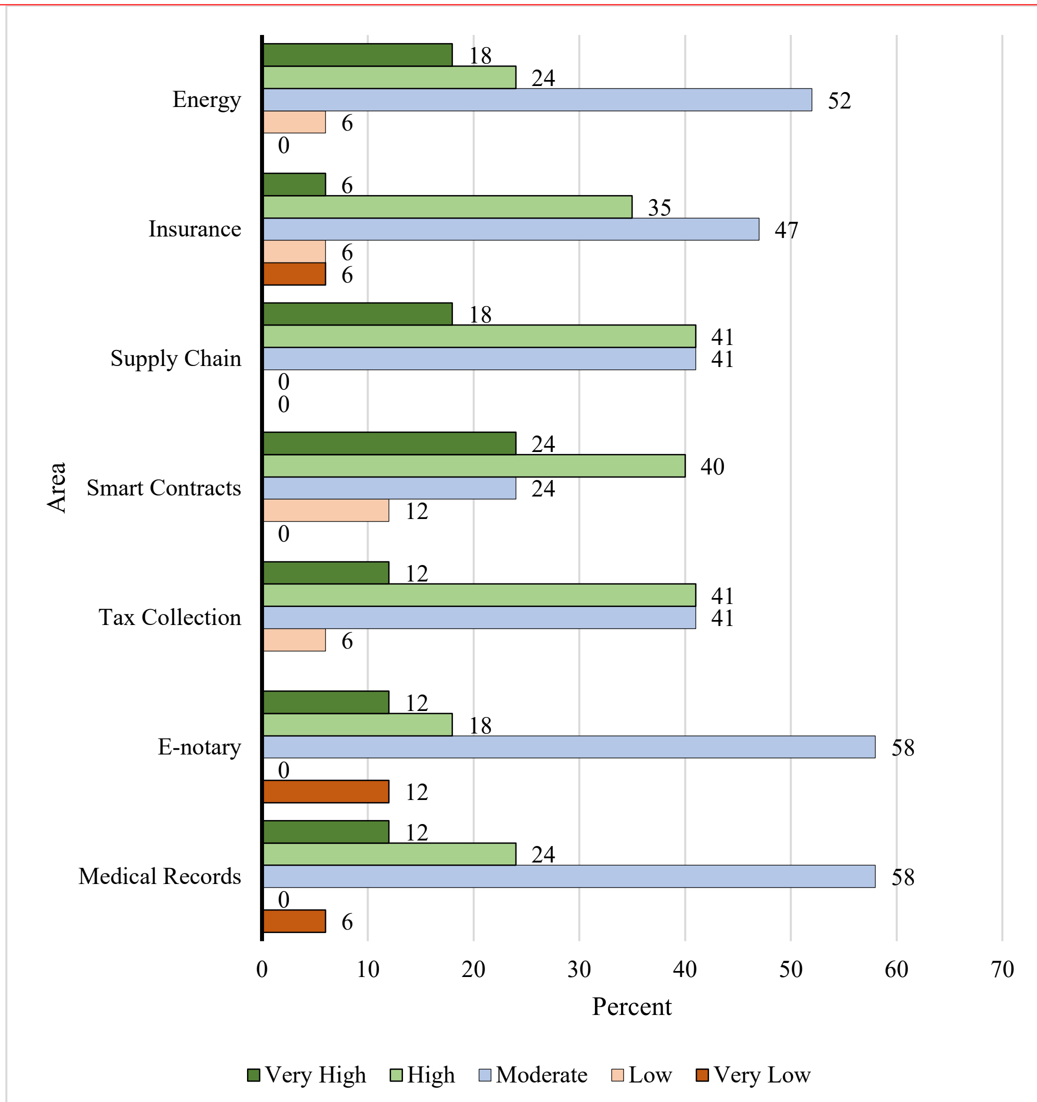

Figure 7: Participants perception toward Blockchain in different PM areas

Discussion

Blockchain as new technology has crossed its initial boundaries in cryptocurrencies. This technology is emerging in various professional and technical fields. It is shown that various frameworks and models can adopt blockchain and provide better services or products in a distributed system. One of the areas that blockchain technology can enhance is project management which itself includes many sectors. Conducted research in recent years has suggested various applications for blockchain in managing projects. There are even some instances of such applications to prototype the model. Despite these, the project management body of knowledge is still untapped, and project management professionals are not fully aware of blockchain potentials in their professions. One of the steps to start the feasibility review of potentials is to explore the perception of project managers toward different aspects of blockchain, which is the goal of this study. In the first stage, reported in this paper, a group of PMI's affiliated project managers was surveyed, and the descriptive analysis of the data was provided in the result section. Reviewing the results indicates that project managers, even those who had a background in IT, reported relatively low familiarity with blockchain. As reflected in Figure 5, the details of blockchain and its application in project management were not known for all participants. While it is expected that project managers are among those who explore new technologies to apply this, a lack of familiarity can delay the adoption process. This issue might be intensified in construction project management due to its characteristics. This fact necessitates large discussions and explorations of blockchain in construction project management. The next point, derived from the results, was the positive attitude of project managers toward blockchain. As a consistent issue in the blockchain and cryptocurrency domain, trust has been a pivotal point in the success of the technology. Without public trust, which is central to the concept of the blockchain, none of its applications can flourish. Therefore, if a positive attitude toward blockchain is seen, it indicates a constructive direction for trust-building. While trust is impacted by numerous factors and has a lengthy process to reach a reliable threshold, any positive move can facilitate it. Generally, positive attitudes stemming from internal feelings or external sources smooth the road for trust. The average scores of the applicability of blockchain in various areas were above the mid-point. These scores were given without any prior technical presentations or discussions. The next point that underscores the importance of proper blockchain technology for project managers was the association between the previous familiarity and attitudes toward the subject. Owning cryptocurrencies provides opportunities to technical learn the nitty-gritty of blockchain, which in turn results in positive perceptions of professionals toward potentials of the technology. It should be emphasized that the factors discussed here are among the external ones and can positively or negatively impact the speed of blockchain adoption in project management. Internal and technical factors are outside the scope of this research and need more thorough studies to be explored. Another interesting observation is the relationship between the gender and applicability score, specified in Table 1. However, this trend does not imply a causal relationship, and a larger sample size and repeated measures are required to draw any generalized conclusion.

Conclusion

This paper succinctly discussed the applications of blockchain technology in project management and presented pilot survey results to illustrate the state of knowledge among the project managers on the fundamentals and possible applications of blockchain in this area. Blockchain technology can bring different parties involved in a project closer together, increase the efficiency of the project processes through automation by smart contracts and faster access to any desired information, increase transparency through the protected distributed ledger, which results in fewer conflicts, and increase the security of the project information. Specifically, construction projects can benefit from the integration of blockchain technology on an organizational level. The survey results show that project managers are not very well-versed in the application of blockchain in project management, and educating them while producing different tools and applications to facilitate the integration of this technology with project management is a critical step. The number of participants can be named as a limitation of this study which entails conducting the survey using a larger population as future work in this line of research. Furthermore, more empirical investigation and research and development are needed to integrate different aspects of project management processes with blockchain technology.

References

Amoah, E., & Oh, J.-Y. (2020). BLOCKCHAIN IN IoT AND PROJECT MANAGEMENT. *Issues in Information Systems, 21*(3), 268-278. doi:https://doi.org/10.48009/3_iis_2020_268-278

Backman, J., Valtanen, K., Laikari, A., & Vallivaara, V. (2017). *Blockchain Review.* VTT, Finland: VTT Technical Research Centre of Finland Ltd.

Budeli, L. (2020). Improving project monitoring and control performance using Blockchain technology. *PM World Journal, IX*(VII).

Hijazi, A. A., Perera, S., Al-Ashwal, A. M., & Neves Calheiros, R. (2019). Blockchain adoption in construction supply chain : a review of studies across multiple sectors. *Constructing Smart Cities: Proceedings Of The 22Nd Cib World Building Congress (Cib2019), 17-21 June 2019, The Hong Kong Polytechnic University, Hong Kong, China*. Retrieved from https://site.cibworld.nl/dl/publications/WBC19/WBC_Proceedings_June2019_Complete.pdf

Jennifer Li, Mohamad Kassem. Applications of distributed ledger technology (DLT) and Blockchain-enabled smart contracts in construction. Automation in Construction. Volume 132, 2021, 103955, ISSN 0926-5805, https://doi.org/10.1016/j.autcon.2021.103955.

Jun WANG, Peng WU, Xiangyu WANG, Wenchi SHOU. The outlook of blockchain technology for construction engineering management. *Front. Eng*, 2017, 4(1): 67–75 https://doi.org/10.15302/J-FEM-2017006

Khatib, M. M., Beshwari, F., Beshwari, M., & Beshwari, A. (2021). THE IMPACT OF BLOCKCHAIN ON PROJECT MANAGEMENT. *ICIC International*, *15*, pp. 467-474. doi:DOI: 10.24507/icicel.15.05.467

PMI. (2021). *Learn About PMI*. Retrieved from Project Management Institute: https://www.pmi.org/about/learn-about-pmi

TEZEL, A., PAPADONIKOLAKI, E., YITMEN, I., & HILLETOFTH, P. (2020). Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions. *Front. Eng. Manag.* doi:https://doi.org/10.1007/s42524-020-0110-8

Shojaei, A., Flood, I., Moud, H. I., Hatami, M., & Zhang, X. (2019a). An implementation of smart contracts by integrating BIM and blockchain. In Proceedings of the Future Technologies Conference (pp. 519-527). Springer, Cham.

Shojaei, A., Wang, J., & Fenner, A. (2019b). Exploring the feasibility of blockchain technology as an infrastructure for improving built asset sustainability. Built Environment Project and Asset Management.

Shojaei, A., Ketabi, R., Razkenari, M., Hakim, H., & Wang, J. (2021). Enabling a circular economy in the built environment sector through blockchain technology. Journal of Cleaner Production, 294, 126352.

Williams, A. D., Vargas, R. V., Conforto, E. C., & Oumarou, T. A. (2019). *BLOCKCHAIN AND THE PROJECT MANAGEMENT OFFICE.* Mountain View, CA: BLOCKCHAIN RESEARCH INSTITUTE.

World Economic Forum. (2020). *Redesigning Trust: Blockchain Deployment Toolkit.* World Economic Forum.

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Success Factors in the Implementation of Flow Scheduling

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Planning and scheduling are two essential functions leading to the successful management of a construction project. With more complex projects, more sophisticated clients, and shorter timeframes for project development from inception to completion, new scheduling techniques emerge building on the successes and learning from the failures of previous efforts. One of the relatively new scheduling techniques benefiting from lean construction principles and the application of concepts such as Last Planner and Reverse Phase Scheduling is Flow scheduling. Flow scheduling is becoming gradually a mainstream technique in the scheduling of projects with aggressive schedules. It builds on the concept of Takt, Location Based Management System (LBMS), and Pull scheduling where each participating performer looks at the workflow allowing for the activity to start on time when all the required resources are lined up based on discussions and compromises among project team members. Several factors can enhance or impede the successful implementation of Flow. This paper addresses some of these factors and illustrates the successful use of Flow scheduling through a case study.

Key words: Takt, Flow, Lean Scheduling, Success Factors.

Introduction

High competition and shrinking margins of profits, added to increasing project complexity and higher levels of specialty are factors driving the construction industry in a more progressive and collaborative direction. The adoption of Lean Construction principles is becoming mainstream within the domestic and international construction industry. Tools and techniques ranging from reverse phase scheduling (RPS) and the use of Last Planner to the adoption of better supply chain management and collaborative contracting such as Integrated Project Delivery (IPD) are gaining ground among construction professionals and project owners alike. The focus in scheduling has switched from long term planning spanning the whole project duration to shorter term planning covering time windows from six to eight weeks at a time. This change resulted from increasing amounts of uncertainties in the long term, and a closer focus on the throughput of operations leading to productivity and production improvements rather than local optimization of construction activities. This also resulted in a switch from a predominantly “Push” mode of scheduling, where each activity is driven by its predecessor, to a "Pull" model taking the end product into consideration and allowing the activities to be completed at the last responsible moment to ensure meeting project deadlines. This move attempted to adapt concepts and techniques that have a proven success track record in the manufacturing industry to the construction industry. One of these concepts is Takt time, which is defined as "the division of available work time per shift by the customer demand rate per shift" (Rother and Shook, 1998). It is also defined as "the unit of time within which a product must be produced in order to match the rate at which that product is needed" (Frandson et al., 2013). Flow planning is an interactive and collaborative process where Last Planners (usually foremen of different subcontract trades) work together to create a detailed construction schedule. The goal is to generate a workable construction schedule and to validate that the schedule meets the project milestones, while gaining consensus and alignment from all the Last Planners involved. Recent industry delays caused by Covid-19 and the supply-chain disruption necessitate the move from traditional planning to a more agile and resilient approach. Flow can contribute to improving productivity, and can therefore be used as a mitigating factor against future unforeseen disruptions

History and Background

Since its introduction in its more recent form in the late nineties, the concept of lean scheduling has witnessed a wealth of research around the theory and implementation of Lean and Takt planning in construction scheduling. Ballard and Howell (1998) drew the comparison and contrast between the manufacturing industry and the construction industry with respect to the motion of product (object) versus the motion of labor (subject) and concluded that the construction process time and space are interlinked and co-dependent. Dlouhy et al. (2014) identified the concept of establishing Standard Space Units (SSU), which they defined as "a small and independent unit according to structural and manufacturing characteristics to divide the functional area of work into spatial areas that can be finished independent of one another". Seppanen (2014) compared Takt time planning to traditional Location Based Management Systems (LBMS) and concluded that they can be combined resulting in a reduction of the project duration if the project's critical path went through the locations and tasks following Takt time. Daniel et al. (2018) investigated the influence of procurement methods on the successful implementation of lean scheduling using the Last Planner System (LPS) and concluded that a mindset change towards collaboration among different project stakeholders is fundamental to successful LPS implementation. Similarly, Mossman (2014) concluded that LPS can be used with any project delivery system, especially Integrated Project Delivery (IPD) which is based on an initial assumption of trust that is regularly verified. Frandson et al. (2013) identified Takt planning as a "work structuring method, which serves as part of a production system design, and developed an iterative six-step process for its implementation: (1) Data gathering, (2) Zone definition, (3) Trade sequence generation, (4) Individual trade duration, (5) Workflow balancing, and (6) Production schedule finalization". In another publication, Frandson et al. (2015) explored the similarities and differences between Location Based Management Systems (LBMS) and Takt Time Planning (TTP) and concluded that both focus on creating a balanced production schedule with a predictable timing of work while also preventing spatial interference between trades. Their work focused primarily on comparing TTP to the Line of Balance (LOB) technique. One of the major differences is that LOB required identical, or almost identical repetitive steps (e.g., floor plan or footprint), whereas TTP can allow for a variation in that footprint provided that "Balanced Zones" or "Densities" are established. Both techniques support buffers to prevent interference among different trades. These buffers could include (1) time, (2) capacity, (3) space, and (4) workable backlog.

Flow Builds on Takt Planning System

Flow takes into consideration the interaction of the three variables that must be solved for: Areas of work or zones, Takt or tempo, and sequence of work. Zones separate the project work into similarly dense areas, which are not necessarily identical, but require similar balance of crews and intensity of work. Columns, walls, joints, or other distinguishable features can delineate the demarcation lines separating zones. Takt is the rhythm or tempo at which work within the zone will be completed. The most common Takt in construction is a working week, or 5 working days. It can be shorter, allowing for a time buffer to complete any workable backlog. Takt time longer than 5 working days is not desirable as it breaks that tempo, and zones must be reduced accordingly to fit that Takt. The third element is work sequence, which defines the repeatable steps or tasks needed to complete an area or work (e.g., wall studs, MEP rough in, Insulation, hanging drywall). This sequence will be repeated in different zones. The determination of zones and Takt are more of an art than a science and can be perfected through an iterative process. Sequences may be dictated by hard logic (only one-way of doing the work) or a soft logic (a preferred method among many possibilities). It can also be affected by internal or external constraints.

Preparation for Flow Planning

For the successful implementation of Flow planning, several structured steps must be conducted in an orderly fashion. These steps include:

1- Determine the area(s) / Task(s) to be flowed
2- Perform quantity take-offs of the scopes that will be longest to perform (HVAC duct, Electrical, Drywall, etc.). Calculating these quantities will be conducive to negotiating durations with the subs based on the simple formula: Duration = Quantity / Production rate.
3- List all tasks (activities) for the typical zone (area to be flowed)
4- Based on the calculated quantities and the subcontractors' production rates, durations can be calculated determining how long it will take a typical crew to perform each activity across a whole floor.
5- Each floor will be broken into areas or zones of reasonably similar densities (similar durations) to establish the Takt time. Some areas (stairwell, elevator shafts, Mechanical rooms, etc.) may be intentionally left out of the zone calculations as they will have a different Takt and serve as workable backlog.
6- Verify that all the other activities can be performed within the selected Takt.
7- Check for crew balancing which can be achieved iteratively by moving the zone boundaries until such balance is reached

Once these pre-planning steps are achieved, meetings with the key subcontractors are conducted, especially if they are new to the Flow concept, to explain the logic and get their buy-in and commitment. This may result in another review of the Takt and the zones. Color-coded Post-it sheets are used to illustrate the interactions among the key subcontractors and the flow of their work through different work zones. The main two factors to be addressed in this meeting are crew sizes needed to meet the Takt and the proper sequence of work steps. Once the key subcontractors agree to this work plan, the rest of the subs can keep up with the work, as it will need fewer resources. Once the schedule is prepared, it is distributed to all subs for final review and comments. Once revised, it will be approved and posted to all subs.

Success factors for Flow implementation

Many factors can contribute to a smooth and successful implementation of Flow scheduling. Some of these factors are discussed hereunder. Some projects may lend themselves to more or less of these factors.

1- **Project delivery method / Client Buy-in:** Although it has been reported that Flow and Takt planning can be adapted to any project delivery method (Design-Bid-Build, Design-Build, Integrated Project Delivery, etc.) with different types of contracts and payment methods (Firm lump sum, Unit price, Guaranteed Maximum Price, etc.). Nevertheless, more progressive clients who understand lean processes and collaborative contracting are easier to be on-board of Flow planning and scheduling. Clients that are more traditional may resist the idea, as they are used to more conventional top-down methods of planning and scheduling.

2- **Design and construction modularization and preassembly:** Modularization helps with the standardization of the work zones and densities, whereas preassembly can ensure better quality, less rework, and shorter installation time. To maintain lean elements for the project, preassembled units (Bathroom pods, precast elements, etc.) should be delivered on a just in time (JIT) basis to avoid storage needs and double handling on-site.

3- **Team Harmony and Learning Curve**: Building long-term alliances with the key subcontractors results in working with the same group of subs, which helps create more trust among the key performers, thus expediting the learning curve and fostering better communication. New team members can be brought on-board faster, and their buy-in can be achieved easier once they see a couple or more of the performers familiar with the system and trusting its results.

4- **Selection of the trades that can be flowed:** Although, theoretically, any trade can be flowed, most of the recorded success has been with the finishing trades. Some trades lend themselves much easier to flow than others. Structural steel contractors, for example, have a relatively tight schedule, and are used to their own pace and method of work. Reinforced concrete, on the other hand, can be easily broken into zones and smoothly flowed and coordinated with other external enclosure activities.

5- **Zone selection and establishing densities:** As mentioned earlier, this is more art than science. It has a reciprocal role with the selected Takt and the geometrical layout of the work areas, as it affects and is affected by the Takt time. Establishing the correct zones helps with the work balance and crew allocation. Figure 1 displays an example of proper selection of balanced zone densities.

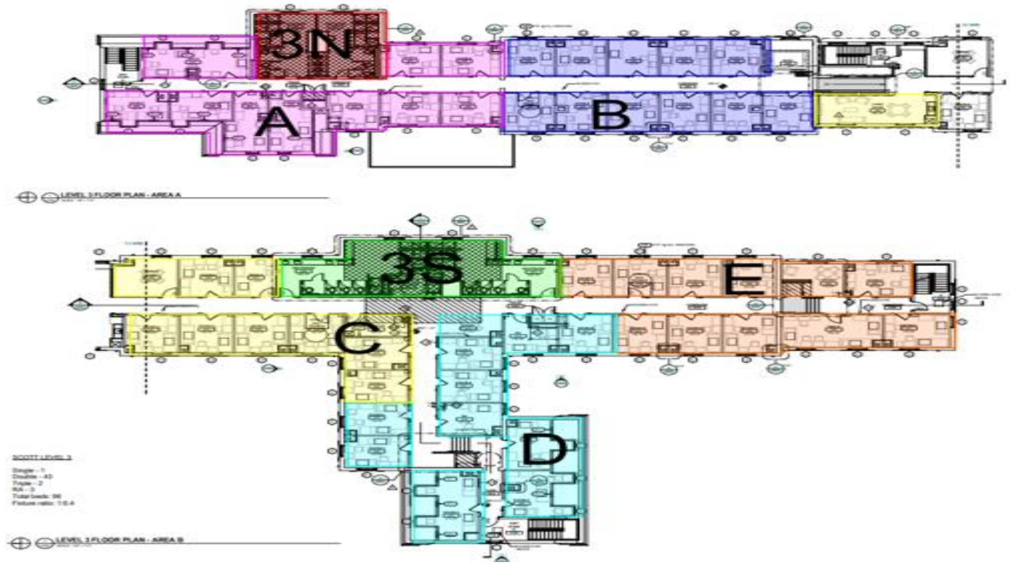

Figure 1. Establishing zones of equivalent densities

6- **Space Availability / Crew Balancing:** Balancing the workload for different trades and crew balancing are important ingredients for any work schedule, and especially so for Flow. Adjusting the crew size may take several attempts until we reach a balance that allows for optimum employment and productivity for the available crews without the need to start/stop/resume work, which may prove hard to recall crews that have been dismissed.

7- **Prototyping / Mockups:** The first of multiple repeated zones or work areas can serve as an in-place mockup to resolve any possible kinks in the process. This works especially well for interior work. Exterior mockups on the other hand may be a bigger challenge due to the external exposure to the elements and the longer lead-time. Figure 2 shows a sample mockup for façade and window details.

Figure 2. Mockup

8- **Standard visual aids:** Standard post-it sheets that are color-coded by trade or discipline provide more familiarity with the process and can lead to better visual inspection of the plan. It also helps the participants see the timing and location of their involvement. These visual aids can also provide both planning and control tables and graphs that enable to participants to observe any deviation from the plan and the need for rebalancing/recalibration. The key, as with any other plan, is regular updating. Figure 3 displays some of the visual aids used on-site with color coding for different responsibilities.

9- **Gemba walks:** This is the way to gather information through observation and interaction with the field performers where value is created. Its main purpose it to observe deviations from the plan and to implement the proper corrective action when needed. Weekly Gemba walks are essential to monitoring and controlling the successful implementation of the plan. It helps get input from the actual performers, thus implementing feasible and actionable change. If the Takt is less than a working week, the Gemba walk schedule needs to be synchronized with the shortened Takt to avoid any backlog and accumulation of errors.

10- **Workable backlog on areas that cannot be easily flowed:** Pulling these areas into the flow is key to the success of the plan. These areas become a “reserve” for moving workers off the flow path and then pulling them back in. It requires special attention from the project manager and can be perfected with time. Examples include mechanical rooms and other congested areas with a heavier worker concentration.

Figure 3. Visual aids for color-coded responsibilities and Weekly Work Plan

11- **Working with, not against, CPM:** Flow scheduling is not a complete substitute for the critical path method (CPM). Both can work together to improve each other. A milestone schedule is prepared in the traditional CPM fashion to get client approval on major project dates and milestones. Flow schedules focus more on the short term, six to eight weeks periods. Upon their completion, flow schedules can be presented in the easily understood Gantt chat format, as this is the easiest and most straightforward mode of schedule communication among different stakeholders. Dedicated flow scheduling software, such as V-Planner, may be used in conjunction with regular CPM scheduling software to coordinate and communicate to the different stakeholders. Figure 4 displays a Phoenix schedule together with a V-Planner schedule for the same activities.

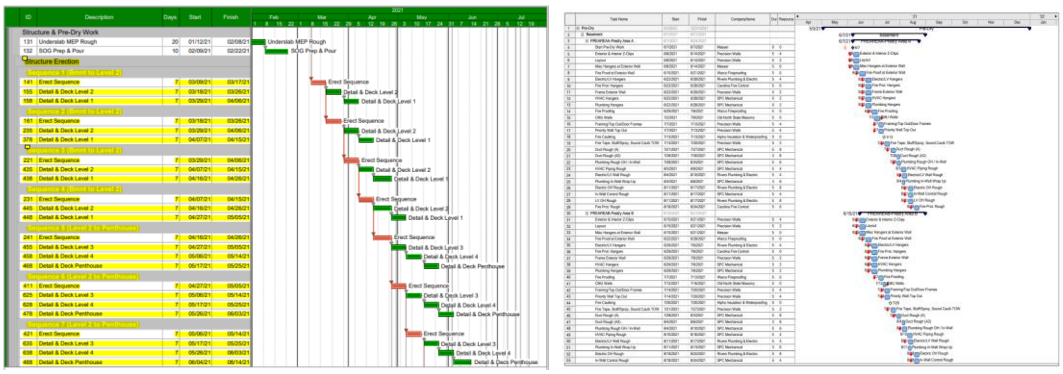

Figure 4. Traditional CPM (left) and V-Planner Flow schedules (Right)

Case Study

A qualitative case study is listed hereunder highlighting the implementation of most of these success factors on a project consisting of two identical high-rise towers in Columbus, Ohio. The Construction Manager @ Risk (CM@R) was a reputable organization based in the Midwest, with an annual volume of work exceeding $1 Billion. The first tower (East Tower) was executed through a crew of contractors and subcontractors following the traditional scheduling and organization approach, whereas the second tower (North Tower) was executed and coordinated using the flow method of planning and scheduling. Some of the comments of the executing team on the East Tower include:

1. Floors were congested with workers. Project continuously struggled with multiple trades on top of each other in each condo unit.
2. Floors were congested with multiple contractor's material.
3. Excess material was left behind on each floor. Subs would order new material rather than see the remaining material that they had on the job to utilize.
4. Missing framing for ceiling lights, access panels, etc. The drywall contractor was always jumping around floors addressing "loose ends".
5. Shaft walls were not done ahead of time. Created "leave out" areas on every floor that forced the drywall hangers and finishers to return and complete.
6. Quality was difficult to manage as the work was spread out and different trades and people were doing the same tasks on multiple floors.

Whereas the comments from the team working on the North Tower included:

1. Easier to deliver product to the site from the shop. Deliver by floors vs half floor, partial floor, etc. Makes the shop much more productive and efficient.
2. There is no room on site to store material, so this was a significant improvement from Parks Edge East.

3. Easy to manage the work since only one subcontractor was in each area at a time.
4. No congestion on floors. Implementation of the 5S became a priority to all the subs.
5. Makes ordering material easier. Can easily see what's left and what is needed on each floor.
6. Establishes clear expectations on crew productivity. The crews can see exactly what they need to get done in each day to meet the takt time.
7. All shaft walls done ahead of production framing a. making Inspections easier to manage
8. Quality Control Plan much more defined and communicated – easier to identify issues with less congestion on the floor/area
9. Better and much more focused approach towards quality.
10. REPETITION – use the same person(s) to do the same tasks with repetition. Less chance for errors.
11. Less overtime, unless the work fell behind. Late work completed through workable backlog.

Figure 5 displays a space comparison between the East Tower (right) versus the North Tower (Left)

Figue 5. Space comparison between East and North Towers

The North tower was completed on schedule and on-budget, with a work force averaging 82 workers. The East tower used twenty percent more resources with an average workforce of 104 workers.

Conclusion

The implementation of Flow in scheduling and executing projects leads to better coordinated activities on site, resulting in higher project efficiencies, and leading to a safer environment to operate. Long term alliances and working with trusted project partners accelerates the learning curve and allows for transfer of the team experience from one project to the other. Several factors can affect the successful implementation of Flow and other principles of lean construction. Flexibility in establishing densities and work zones reduces the magnitude and severity of unexpected disruptions. Increasing project complexity necessitates looking into innovative teaming agreements and buy-in to allow for earlier contractor involvement and valuable input in project planning and execution. Modularization, work packaging, preassembly, and mockups are different proven tools leading to reducing the project team footprint and allowing for better use of available limited space. Not every project or every activity can be flowed: Flow when you can, and use "unflowable" areas as buffers for workable backlog. Contractors who experience flow for the first time and can see its benefits act as ambassadors for the concept and help propagate it to subcontractors on other projects. Following lean processes such as the Gemba walk, 5 S, reverse phase scheduling and simple visual aids can enhance teams' understanding of the concepts and the techniques involved therein. Flow is not a complete replacement for the traditional critical path method, as milestones and stage gates can still be scheduled using traditional CPM software, and translated into Gant Charts for ease of communication, especially with project owners.

References

Ballard, G., Howell, G., (1998), *What kind of production is construction*, Proceedings of the 6th Annual Conference of the International Group for Lean Construction, Guaruja, Brazil.

Daniel, E., Pasquire, C., Dickens, G., and Masarini, R., (2018), *Empirical Study on the Influence of Procuremnt Methods on Last Planner System Implementation*, Proceedings of the 26th Annual Conference of the International Group for Lean Construction, Chennai, India.

Dlouhy, J., Binninger, M., Oprach, S., and Haghsheno, S., (2016), *Three Level Method of Takt Planning and Takt Control – A New Approach for Designing Production Systems in Construction*, Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA.

Frandson, A., Seppanen, O, and Tommelein, I., (2015), *Comparison between Location Based Management and Takt Planning*, Proceedings of the 23rd Annual Conference of the International Group for Lean Construction, Perth, Australia.

Frandson, A., Berghede, K., and Tommelein, I., (2013), *Takt time planning for construction of exterior cladding*. Proceedings of the 21st Annual Conference of the International Group for Lean Construction, (IGLC21), Fortaleza, Brazil.

Mossman, A., (2014), "*Last Planner: 5+1 Crucial and Collaborative Conversations for Predictable Design and Construction Delivery*", Http://bit.ly/LPS-5cc.

Rother, M., Shook, J., (1998), *Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA*, Lean Enterprise Institute, Cambridge, MA.

Seppanen, O., (2014), *A Comparison of Takt Time and LBMS Planning Methods*, Proceedings of the 22nd Annual Conference of the International Group for Lean Construction, Oslo, Norway.

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Case Study: Construction Site Utilization Planning for Custom Multifamily Residential Developments

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Previous research studies on the best practices for Construction Site Utilization Planning (CSUP) have been generic leaving decisions about the project-type specific delineation methods to the developers of site utilization plans (SUPs). This case study explored how construction industry professionals working in custom multifamily residential sector implement CSUP. The research objectives were twofold: 1) identifying the factors that affect CSUP for custom multifamily residential developments, and 2) determining the best CSUP practices for custom multifamily residential developments. Six industry professionals working for a custom multifamily residential developer were interviewed in this study. The research findings indicated that CSUP for custom multifamily residential projects should begin during early preconstruction phase, an integrated approach for CSUP should be used, and incorporation of hauling routes and typical temporary facilities at medium level of detail was critical. Some of the best CSUP practices included holding regular meetings with all stakeholders to discuss SUP, its associated updates, and enforcement policies. The interviewees suggested the SUP's efficacy should be monitored regularly depending on size and complexity of the project. The study findings are significant as they can help construction industry professionals develop more robust SUPs that are unique to the needs of custom multifamily residential developments.

Key Words: Site logistics, Site utilization planning, Multifamily, Residential

Introduction

Construction site utilization planning (CSUP), also known as construction site logistics planning, is an important preconstruction planning task that affects safety, duration, environmental impacts, and budgetary performance of construction projects (Deshpande & Whitman, 2014; Elbeltagi et al., 2004; Ning et al., 2011). The objective of CSUP is to spatially plan jobsite for predicted construction activities and their associated elements to enhance safety and reduce project duration and cost (Mawdesley et al., 2002). CSUP depends on the project type, size, and location. CSUP is especially critical in vertical construction projects where space is considered one of the major constraints (Whitman et al., 2021). Also, comprehensive CSUP requires a development procedure to identify the need for temporary facilities, type of temporary facilities, their locations, space requirements, and on-site routes (Song et al., 2016; Whitman et al., 2021). Location of temporary facilities and placement of equipment are directly related to the construction sequencing and performance of a project. According to Akinci et al. (1998), comprehensive CSUP may decrease the amount of ineffective work that is associated with poor site planning. On the other hand, poor CSUP and poor implementation of site utilization plans (SUPs) can lead to schedule delays, misplacement and improper handling of materials, financial loss, and unsafe work conditions (Mincks & Johnston, 2010).

Over the years, researchers have developed various models that utilize GIS, CAD-based tools, and mathematical techniques that help with the creation and optimization of SUPs (Mincks & Johnston, 2010; Osman et al., 2003; Xu & Song, 2015; Hammad et al., 2016; Song et al., 2016; RazaviAlavi & AbouRizk, 2017). Despite revolutionary advancements in theoretical modeling and optimization of SUPs, review of the related literature reveals an important gap. As discussed by Whitman et al. (2021), there is a need for a comprehensive study of CSUP best practices applied by industry professionals. Recognizing this gap, Zolfagharian and Irizarry (2014) emphasized the need for a rule-based evaluation system that industry professionals could use in their decision-making process for CSUP. While this system offers insight into the variables related to SUPs, it lacks the rigor of integrating best CSUP practices identified by industry professionals (Whitman et al., 2021). Whitman's study (2014) identified general best practices related to CSUP. However, as stated earlier, CSUP depends on the project type, size, and location. Literature review indicates that there are very limited studies on best CSUP practices for custom multifamily residential developments. Therefore, this case study aimed to understand how construction industry professionals working in custom multifamily residential sector implement CSUP. The specific research objectives included:

1. Identifying the factors that affect CSUP for custom multifamily residential developments.
2. Determining the best CSUP practices for custom multifamily residential developments.

It should be noted that in this study CSUP stands for Construction Site Utilization Planning and refers to the process of planning and developing site utilization plans (SUPs), while SUP refers to a product or outcome of CSUP.

Literature Review

CSUP overlaps with other planning tasks such as budgeting, scheduling, procurement, anticipation of on-site personnel, and mobilization and demobilization of construction equipment (Elbeltagi, 2008). Therefore, for creating an effective SUP, the SUP developer should have a clear understanding of the elements associated with CSUP and the construction execution plan. In other words, in order to develop optimal SUPs, the developer should create alternative site layouts that enhance the flow of construction project resources such as personnel, equipment and materials while satisfying project constraints (Whitman, 2014). Additionally, the SUP developers should be completely familiar with elements such as space constraints on the project site, safety requirements, and temporary facilities (Whitman, 2014). According to Whitman et al. (2021), the majority of industry professionals begin CSUP in pre-bid stage of the project while some practitioners develop the SUP once the project is awarded. However, the same study concluded that the majority of industry professionals considered CSUP a continuous process over the duration of the project.

Typically, project managers are responsible for CSUP (Osman et al., 2003; Whitman et al., 2021). However, due to the complexity of CSUP, designers and SUP developers are often contracted to develop a SUP on behalf of the project owner or the general contractor (Song et al., 2018). Whitman (2014) stated that prior to the start of the project, the developed SUPs should be reviewed by project superintendents, foremen, and contractors since they have vast knowledge of material storage, material handling, and equipment operation. According to Whitman et al. (2021), project managers typically seek input from structural, foundation, electrical, plumbing, and HVAC contractors during the CSUP process. In this process, contractors can significantly help project managers by providing information such as equipment and the type of tools that will be used on site, required storage space, and the anticipated number of personnel on site. Furthermore, project managers can incorporate critical information, such as preferred access points to the site, existing site conditions, construction traffic routes, and environmental concerns of owners, universities, and municipalities, into SUPs. However, the majority of construction industry professionals prefer medium level of detail to be incorporated into SUPs since medium level of detail includes essential temporary facilities and storage locations (Whitman et al., 2021).

Location of the construction site plays a major role in determining the space constraints. In urban areas, less space is available for construction activities as the structure itself encompasses the majority of the site. Therefore, for an efficient execution of the construction activities, space planning should be carefully handled. In contrast, space planning for large construction sites tends to be overlooked during project planning phase due to space abundance. In these cases, SUP developers place temporary facilities randomly within the site boundaries, which reduces the efficiency and safety of the workplace (Mawdesley et al., 2002). Temporary facilities play a major role in supporting construction activities over the duration of a project (Whitman et al., 2021). Type of the project, project location, and complexity of the construction schedule determine the type of temporary facilities required on a jobsite (Whitman et al., 2021). Characteristics such as shape, size, and functionality of each temporary facility should be completely understood prior to the development of a SUP. Incorporating inadequate temporary facilities may significantly impact the productivity levels on site (Elbetltagi, 2008). Development of an efficient SUP that incorporates the aforementioned elements can result in fewer workplace hazards and safety concerns (U.S. Department of Labor, 2013). For instance, incorporating Occupational Safety and Health Administration rules into SUPs reduces workplace fatalities and injuries (U.S. Department of Labor, 2013). Elbeltagi et al.'s study (2004) indicated that the storage locations of material and equipment have a significant impact on construction site safety. Hence, these locations should be carefully selected so that the movement of material and equipment can be minimized (Elbeltagi et al., 2004). In addition, it is crucial to comply with other OSHA requirements such as providing adequate access roads when developing SUPs. Industry professionals responsible for CSUP ranked movement of material, equipment, and on-site personnel as top three priorities when planning access roads to jobsite (Whitman et al., 2021).

As stated earlier, proper implementation of a well-developed SUP is key for improving construction operations (Akinci et al., 1998) and requires all trades to be involved in the project planning and well informed about site space allocation (Whitman et al., 2021). Monitoring the effectiveness and management of SUP is usually the responsibility of the site superintendent that assesses the effectiveness of a SUP by analyzing the flow of construction activities, the ability of trades to access the site and move material, and the time they spend managing contractors (Whitman et al., 2021). A software tool particularly designed for SUP development has not emerged yet; therefore, PDF overlay software such as Bluebeam, and other software such as Autodesk Revit and Computer Aided Design (CAD) are currently being used by industry professionals to develop SUPs. PDF overlay is currently the leading method for creating SUPs since it is noticeably easier to operate and requires less training to use. However, Autodesk Revit is becoming one of the most commonly used software within the construction industry due to the wide range of tools and utilities it offers (Whitman et al., 2021).

Enhancing SUP developer's familiarity with site constraints is identified as one of the CSUP best practices implemented by construction industry professionals (Whitman et al., 2021). Whitman et al. (2021) identified integrated CSUP as the best practice to enhance the effectiveness of SUPs. In other words, involvement of project stakeholders such as owner, contractors, and construction management personnel in development of SUPs is crucial for achieving an effective SUP. Proper implementation of SUPs requires clear communication among all stakeholders on site. In addition to the main elements of SUPs, project stakeholders should consider incorporating weather characteristics and safety regulations into the SUPs. The effectiveness of SUPs should be monitored regularly and considering that SUPs are fluid documents, stakeholders should be kept up to date about any modifications (Whitman et al., 2021).

Methodology

Semi-structured interviews were conducted to accomplish the research objectives. The interview questions were developed by the authors and then reviewed and approved by Colorado State University's Institutional Review Board (IRB) to protect human research participants. Participation in the interviews was voluntary. The participants were asked to sign a consent form that outlined information such as interview duration, potential risks and benefits, and data security. Six participants were recruited for the interviews based on their current role in the company and previous experience with custom multifamily residential projects. Authors interviewed a Director of Construction Operations, a Preconstruction Manager, a Senior Project Manager, a Project Manager, an Assistant Project Manager and a Senior Superintendent, that worked for the same custom multifamily residential general contracting company. The interview instrument consisted of ten open-ended questions. The first set of questions asked about the factors that affected CSUP for custom multifamily residential developments. The second set of questions asked about the best CSUP practices used by industry professionals for custom multifamily residential developments.

Each of the six personal interviews were recorded using voice memo application and immediately transcribed. Interview notes were also taken during each session. Pseudonyms were used to code the data for participant's protection. After transcription, the verbal interview data for each question were manually analyzed to identify patterns, redundancies, and repetitions in answers. Qualitative analysis of interview responses was performed due to the small sample size and open-ended nature of interview questions. For each interview question, redundancies and patterns found in participant answers were used to draw appropriate conclusions. The data were analyzed using a general inductive approach, which helped condense the raw data into a brief summary format. Furthermore, this analysis helped establish links between the research objectives and the research findings, and compare the findings of this case study to the findings of previous research. In the next section, the results are presented separately for each interview question to compare the perceptions of interviewed industry professionals.

Results

Factors that Affect CSUP for Custom Multifamily Residential Developments

When asked about **the main factors affecting CSUP for custom multifamily residential developments,** all respondents indicated space constraints and limitations on hauling routes as the main factors. This was due to the fact that most multifamily residential developments were located in active urban and suburban areas with different municipality requirements. In urban areas, the residential building structure itself encompassed the majority of the site and utilization of any off-site area for construction-related work required special permits from Department of Transportation and

Infrastructure (City and County of Denver, 2021). Participant responses to a question about **the ideal timeframe for SUP development** varied greatly. Four participants (the Preconstruction Manager, the Director of Construction Operations, the Project Manager, and the Assistant Project Manager) stated that SUP development should begin in early stages of the project preconstruction phase because CSUP in the bidding stage of a project enhanced the accuracy of construction schedule and budget. Two participants including the Senior Project Manager and the Senior Superintendent indicated that their preferred time for CSUP was just before the commencement of construction work because the use of an approved set of construction drawings reduced risk and uncertainty associated with CSUP.

Next, the participants were asked about **stakeholders whose input was critical for creation of a SUP**. All participants except the Assistant Project Manager stated that the number of contractors and trades working on site could be a critical factor in CSUP. All participants emphasized the use of an integrated approach for CSUP and indicated that the input from superintendent and the project manager was critical. Two participants (the Project Manager and the Assistant Project Manager) stated that they also sought input from the project owner. According to the Senior Project Manager, the Preconstruction Manager, and the Senior Superintendent, seeking input from contractors was also crucial in CSUP. These three participants mentioned that the contractors who typically contributed to CSUP were from foundation, structural, MEP, and civil/site work teams. Participants were also asked about the **kind of information stakeholders should provide for development of a SUP.** The Senior Project Manager, the Preconstruction Manager and the Senior Superintendent stated that they requested contactors to provide information such as type and size of the equipment that would be on site, number of employees, material delivery time, and amount of space needed for storage and staging. Additionally, the Director of Construction Operations and the Senior Project Manager indicated that requesting information about the sequence of work and duration was crucial for SUP development.

Best CSUP Practices for Multi-family Residential Developments

Participants were asked a series of questions that helped authors determine the best CSUP practices for custom multifamily residential developments. First, participants were asked **to identify the primary elements that should be incorporated into the SUPs**. All participants indicated at least two access points at any time, and access roads that were compliant with local Fire Department and Law Enforcement requirements. Furthermore, participants stated that it was of significant importance to include temporary facilities such as staging and storage areas, erosion control measures, security fencing, trailer, temporary toilets, and trash and recycling dumpsters in SUPs. Furthermore, SUPs should identify location of the source(s) of temporary power on site. When asked about the **level of detail for SUPs**, the Assistant Project Manager stated that the level of detail depended on the complexity of the project, while the other five participants indicated that medium level of detail was sufficient for custom multifamily residential projects.

Next, the participants were asked **how they implemented SUPs in their custom multifamily residential projects.** All six participants stated that regular communication with contractors on site was the key for a successful SUP implementation. All participants mentioned that implementation of SUPs in custom multifamily residential projects was typically the responsibility of the project manager and/or site superintendent because project managers and superintendents ran day-to-day operations on construction sites while ensuring conformance to the schedule.

When asked about **metrics that helped determine the effectiveness of a SUP**, all six participants stated that site safety was a critical measure of the effectiveness of a SUP. The Director of Construction Operations and the Senior Superintendent indicated that conducting monthly inspections to ensure compliance with the approved SUP was also an important method for determining the effectiveness of a SUP. The Assistant Project Manager pointed out that other factors such as accessibility of site for trades, ease of material movement, and efficient equipment operation throughout the site were important for determining the effectiveness of a SUP.

Next, the participants were asked about **software packages they usually used to create SUPs.** All interviewed participants except the Senior Superintendent indicated that, in general, they used software tools to develop SUPs. Participants typically used Bluebeam and Adobe Acrobat software for SUP development while they never utilized Autodesk Revit. However, all respondents except the Director of Construction Operations stated that the use of BIM and Autodesk Revit for all construction related tasks including SUP development would be inevitable in the near future since these processes and tools were becoming frequently used on construction projects.

In order to determine effective methods for developing efficient SUPs for custom multifamily residential projects, participants were asked **to discuss their best CSUP practices**. Common responses included involvement of key stakeholders such as foundation, structural, MEP, and civil/site work contractors, project managers, and superintendents throughout SUP development. Furthermore, being mindful of inclement weather conditions and their effect on site accessibility for trades, equipment, police, and fire department were of significant importance. Participants mentioned that holding regular meetings with all stakeholders involved in SUP implementation on the jobsite and informing them about SUP's associated updates and enforcement policies were some of the most important best practices for successful implementation of SUPs. Furthermore, the SUP should be monitored for effectiveness on a monthly basis. However, according to the Assistant Project Manager, the frequency of monitoring could differ depending on size and complexity of the project.

Discussion

Previous research recognized SUP development as a critical component of most construction projects regardless of space constraints (Whitman et al., 2021). However, our research found that the main reasons for developing SUPs for custom multifamily residential projects were space constraints and hauling route limitations. In other words, it can be implied that development of a SUP for custom multifamily residential projects located in less developed areas where space is not a constraint might be deemed nonessential. This finding aligns with findings of Mawdesley et al. (2002) who found that space planning for large construction sites tended to be overlooked due to space abundance.

Similar to Whitman et al's. (2021) study, opinions of the participants in our study differed in regard to the optimal timeframe for SUP development. In our study, four participants stated that the level of complexity of SUPs could have significant impact on project's budget and schedule suggesting that SUP development should start in early stages of preconstruction. This finding aligns with that of Whitman et al. (2021) that most construction companies considered SUP development part of the estimation phase. As SUP development during estimation phase results in a more accurate budget, companies would have a higher chance of winning the award while maximizing their profit margin (Whitman et al., 2021). The remaining two participants in our study provided a different response; they suggested that developing SUP just before the commencement of the construction work was a better practice due to higher completion and accuracy of the plans and specifications. All six participants agreed that CSUP was a continuous process over the duration of the project.
Similar to the findings of Whitman et al. (2021), our results indicated that construction professionals working on custom multifamily residential projects preferred an integrated CSUP approach. In other

words, involvement of key project stakeholders such as project managers, superintendents, and contractors was crucial for development of an effective SUP. While Whitman et al. (2021) concluded that the majority of owners were involved in SUP development, our study indicated that the owner's input for SUP development was not highly prioritized in custom multifamily residential developments. The reason for this perception might be that three participants including the Senior Project Manager, the Senior Superintendent, and the Project Manager considered CSUP a part of General Contractor's means and methods that should not be altered by other stakeholders. In addition, our study indicated that the implementation of SUPs in custom multifamily residential projects was the responsibility of the project manager and the superintendent. Inclusion of project manager as a party responsible for implementation of SUPs is a new addition to the findings of Whitman et al.'s (2021) study in which only the superintendent was identified as the primary party responsible for SUP implementation.

Our study, similar to the Elbetagi et al. (2004) and Whitman et al. (2021) studies, indicated that information such as type and size of the equipment that would be on site, number of employees, material delivery time, and amount of space needed for storage and staging were critical for SUP development. Key elements that should be incorporated into SUPs for custom multifamily residential projects were similar to elements of SUPs developed for other types of construction projects. In other words, authors did not find a deviation from the temporary facilities required for custom multifamily residential developments as compared to other construction project types as indicated by Whitman et al. (2021). The findings of our study also echoed the results of previous research in regard to the preferred SUP's level of detail. The majority of interviewed industry professionals preferred a medium level of detail with only essential temporary facilities and storage locations incorporated into the plans, which confirms findings of Whitman et al. (2021).

Metrics used for determining the effectiveness of a SUP on custom multifamily residential projects are similar to those identified by Whitman et al. (2021). Our study found that factors such as site safety, site accessibility for trades, ease of material movement, and efficient equipment operation throughout the site could be used to determine the effectiveness of a SUP. These findings align with those of Whitman et al.'s (2021) study focusing on construction industry in general that identified flow of construction activities, ability to access and move material, and the time spent managing contractors as the main measures used for determining the effectiveness of SUPs. Majority of construction industry professionals used software tools to develop SUPs (Whitman et al., 2021). This aligns with the findings of our study that indicated the majority of the participants used Bluebeam to develop SUPs for their custom multifamily residential projects. According to Whitman et al. (2021), PDF overlay software such as Bluebeam was the most frequently used tool for SUP creation; however, the use of Autodesk Revit and Computer Aided Design (CAD) was also very common. This finding is in contrast with our results; our study participants stated they had never used tools such as Autodesk Revit or CAD for SUP development.

Conclusions

Literature review indicated that the previously documented best CSUP practices were generic, leaving the decisions about project-type specific delineation methods to the developers of SUPs. This case study aimed to understand how construction industry professionals working in custom multifamily residential sector implemented CSUP. The two major research objectives were: 1) to identify the factors that affect the CSUP for custom multifamily residential developments, and 2) to determine the best CSUP practices used for SUP creation in this sector. In addition, authors compared their findings to the findings of the previous research in this field. According to the findings of this study, CSUP for custom multifamily residential projects should begin in early stages of the preconstruction phase to help enhance the accuracy of construction schedule and budget planning. Due to large number of trades that participate in custom multifamily residential projects, SUP developers should use an integrated CSUP approach. In other words, involvement of key project stakeholders such as foundation, structural, MEP, and civil/site work contractors, project managers, and superintendents in SUP development is crucial. Incorporating the typical temporary facilities at medium level of detail into the SUP for custom multifamily residential developments is recommended. Additionally, developers of SUPs for custom multifamily residential projects should be mindful of hauling routes due to space and regulatory restrictions unique to urban and suburban areas. Holding regular meetings with all stakeholders involved in SUP implementation on the jobsite and informing them about SUP's associated updates and enforcement policies are some of the most important best practices for successful implementation of SUPs. It is recommended to monitor the effectiveness of SUPs on a monthly basis. However, the frequency of monitoring can differ depending on size and complexity of the project.

This study contributes to the existing body of knowledge by focusing on custom multifamily residential sector. The major contribution is that study findings could help construction industry professionals with development of more robust SUPs that are unique to the needs of the custom multifamily residential developments. This research had the following limitations. The sample for this case study consisted of six industry professionals with extensive background in custom multifamily residential construction projects along the front range of Colorado. In addition, these six professionals worked for the same construction company. Hence, due to the small size and exclusivity of the sample, the findings of this study cannot be generalized. Therefore, future research should utilize a larger sample size. Future study could develop a practical framework for the site utilization planning process specific to custom multifamily residential developments. In addition, future research could focus on developing optimal site utilization plans specific to custom multifamily residential developments and creating their graphical representations.

References

Akinci, B., Fischer, M.A., & Zabelle, T.R. (1998). Proactive approach for reducing non-value adding activities due to time-space conflicts. *Proceedings of IGLC. https://iglcstorage.blob.core.windows.net/papers/attachment-fdd83563-cc2e-4d9d-b67b-310ea966b85e.pdf*

Deshpande, A., & Whitman, J. B. (2014). Evaluation of the use of BIM tools for construction site utilization planning. *Proceedings of Associated Schools of Construction*. http://ascpro0.ascweb.org/archives/cd/2014/paper/CPGT233002014.pdf

Elbeltagi, E. (2008). *Construction site layout planning* [Lecture notes]. Retrieved from Structural Eng. Dept., Mansoura University, Mansoura, Egypt.

Elbeltagi, E., Hegazy, T., & Eldosouky, A. (2004). Dynamic layout of construction temporary facilities considering safety. *Journal of Construction Engineering and Management, 130*(4), 534-541.

Hammad, A., Akbarnezhad, A., & Rey, D. (2016). A multi-objective mixed integer nonlinear programming model for construction site layout planning to minimise noise pollution and transport costs. *Automation in Construction*, *61*, 73-85.

Mawdesley, M. J., Al-jibouri, S. H., & Yang, H. (2002). Genetic algorithms for construction site layout in Project Planning. *Journal of Construction Engineering and Management*, *128*(5), 418-426.

Mincks, W. R., and Johnston, H. (2010). *Construction Jobsite Management*. Albany: Delmar.

Ning, X., Lam, K., & Lam, M. C. (2011). A decision-making system for construction site layout planning. *Automation in Construction*, *20*(4), 459-473.

Osman, H. M., Georgy, M. E., & Ibrahim, M. E. (2003). A hybrid CAD-based construction site layout planning system using genetic algorithms. *Automation in Construction*, *12*(6), 749-764.

RazaviAlavi, S., & AbouRizk, S. (2017). Site layout and construction plan optimization using an integrated genetic algorithm simulation framework. *Journal of Computing in Civil Engineering*, *31*(4), 04017011.

Song, X., Xu, J., Shen, C., & Peña-Mora, F. (2018). Conflict resolution-motivated strategy towards integrated construction site layout and Material Logistics Planning: A bi-stakeholder perspective. *Automation in Construction*, *87*, 138-157.

Song, X., Xu, J., Shen, C., Peña-Mora, F., & Zeng, Z. (2016). A decision making system for construction temporary facilities layout planning in large-scale construction projects. *International Journal of Civil Engineering*, *15*(2), 333-353.

Street Occupancy (2021). Retrieved October 22, 2021, from https://www.denvergov.org

U.S. Department of Labor (2013). OSHA 35-Year Milestone.

Whitman, J. B. (2014). *Construction site utilization planning best practices (Master's thesis)*. Available from AUETD database.

Whitman, J., Deshpande, A., Zech, W., & Perez, M. (2021). Construction site utilization planning: A process based upon industry best practices. *CivilEng*, *2*(2), 309-324. doi:10.3390/civileng2020017

Xu, J., & Song, X. (2015). Multi-objective dynamic layout problem for temporary construction facilities with unequal-area departments under Fuzzy Random Environment. *Knowledge-Based Systems*, 81, 30-45. doi:10.1016/j.knosys.2015.02.001

Zolfagharian, S., & Irizarry, J. (2014). Current trends in construction site layout planning. *Proceedings of Construction Research Congress 2014*. doi:10.1061/9780784413517.176

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A model for delay analysis impact at planning phase of Oil and Gas pipeline projects: A case of Iraq

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Abstract

Project delay and cost overrun are major issues caused by the associated Risk Factors (RFs) in any projects including Oil and Gas Pipeline Projects (OGPPs). This problem is exacerbated by the subjective nature of the identification and quantification of delay factors t at the planning stage. To overcome above issues, this research designs a Delay Analysis Model (DAM) at planning stage of the project by introducing fuzzy logic in delay analysis; hence, systematize and objectify the quantification of the process. The paper presents a step-by-step process of identifying the RFs and quantifying the probability of project delivery. The inputs of the model are the RFs, level of impact, and the estimated maximum and minimum duration of each critical task of the project. The model is integrated with @Risk simulator to quantify the delay impact. The key output of the study is a useful delay analysis tool that help to identify and quantify the potential delay impacts and the confidence level of project deliver in time at the planning stage so that proactive measures could be taken in advance. The model was evaluated using a case study of an OGPP in Iraq. The findings suggested that a potential overall delay at all stages of the project was found around 45 days in the project.

Key Words: Oil and Gas Pipelines, Delay Analysis Model, Monte Carlo Simulation, Project Delay, @Risk simulator

Introduction

Construction delay generates long-term severe economic consequences and environmental impacts for nations, and it is one of the common problems in the construction industry in both developed and developing countries (Shah, 2016). Providing a good knowledge about the Risk Factors (RFs) and their level of impact on the projects at the planning stage could help the stakeholders to make sound decisions in response to risk management (Ruqaishi and Bashir, 2015) to keep the construction delay interruption in the projects to minimum, as much as possible (Kraidi et al., 2020a). The research gap, however, has been the lack of delay analysis tools that can reduce bias and subjectivity. To close this gap, this paper proposes a delay analysis system of risk factors using fuzzy logic theory (Chan et al., 2009), to reduce biasness of relative importance index/values of risk probability and impact on of all risk factors affecting in all critical task/activity in the construction project. The paper designs a Delay Analysis

Model (DAM), which is used to analyze and quantify the construction delay caused by the associated RFs at the planning stage of the projects in an integrated and systematic way. The DAM has been used in the Oil and Gas Pipeline Projects (OGPPs), in Iraq. The functionality of the DAM was evaluated with a case study of oil and gas pipeline project that is under construction in the south of Iraq. The paper concludes that reduction of bias and subjectivity in delay analysis creates a robust decision-making strategy for the management of delay risks

Literature Review

Fallahnejad (2013) and Sweis et al. (2019) used document analysis and a questionnaire survey to identify the main delay factors and analyze their impact on the OGPPs in Iran. Sweis et al. (2019) used a questionnaire survey to identify the root causes of the delay factors in gas pipeline projects in Iran. Ruqaishi and Bashir (2015) investigated the delay factors in the construction of oil and gas projects in Oman as a case study in the Gulf Cooperation Council (GCC) region, which involves United Arab Emirates, Saudi Arabia, Qatar, Oman, Kuwait and Bahrain. Kadry et al., (2017) examined delay risks in areas of high geopolitical environment. However, these studies did not quantify the potential delay in these projects caused by the RFs in a manner that takes care of subjectivity and bias. Moreover, the risk assessment methods used in these studies are limited to their regions of study, which means they cannot be effectively applied to analyze the impact of the delay factors in OGPPs and improve the level of safety of these projects elsewhere.

A study conducted by Kraidi et al., (2020a), is critical to this paper, because it details how a project planning software ASTA BIM can be used to identify activities on the critical path; and use the ASTA ASTA risk simulator to analyze the RFs that cause delays on a case study project. The ASTA risk simulator has only four methods of risk distribution (which are uniform, normal, skewed normal and skewed triangular distribution), but only one distribution method could be applied on time during the process of risk simulation, which does not reflect the reality of the RFs on the duration of the projects. This is one of the limitations of using ASTA risk simulator that quantifies the impact of the RFs on the duration of the projects. In a study done by Assaad et al. (2020), the authors used @Risk simulator to predict project performance in the construction industry. This is because @Risk simulator could enable the researchers to use most of the parametric fitted and theoretical distributions existing in the literature. For instance, normal distribution, which is defined by the mean and the standard deviation. The beta distribution, which is defined by minimum, maximum, alpha1, and alpha2; Dagum distribution, which is a continuous function defined over positive real numbers and is useful in many actuarial statistics or risk management. Kumaraswamy distribution, which is a continuous distribution used for lower and upper bounded variables, that could be used on the [0, 1] interval, and it is like the Beta distribution; but much simpler to implement in simulation studies. Pert distribution, which is a continuous function with a curved density that is a special case of the Beta General distribution and is widely used in risk analysis. Assaad et al. (2020) encouraged researchers to replicate their methodology for other types of projects, such as buildings and infrastructure. Such a methodology has been used in this paper in an infrastructure type of projects, which are OGPPs. Shebob et al. (2012) analyzed the possible minimum, the mean and the maximum duration of a construction project in Libya and the UK using Monte Carlo Simulation. However, the risk assessment methods used by Shebob et al. (2012) are limited to their regions of study, which means they cannot be effectively applied to analyze the impact of the delay factors in oil and gas projects and improve the level of safety of these projects elsewhere. The research question of this study is: what is the impact of the risk factors on the duration of OGPPs and how the study contributes to designing a DAM that expected to determine delay impact due to associated RFs in project? The DAM is integrated with @Risk simulator to quantify the delay impact caused by the associated RFs in the OGPPs considering different risk distribution methods for the same RFs and work activities at the same time, using the fuzzy logic theory to reduce bias. The adopted methodology and specification for the design and development of the DAM is described in the next sessions of this paper.

Research Methodology

This paper uses the mixed research methodology to analyze and quantify the impact of delay factors in the projects and confidence level of project delivery of an oil and gas pipeline project in a simple and systematic way. The focus is to develop a holistic and integrated a Delay Analysis Model (DAM) for the OGP projects. The study has adopted a systematic strategy with mixed research approaches to achieve reliable results from risk analysis in OGP projects. The qualitative approach of this paper refers to the literature review and the subjective and objective analysis of documents collected from the projects. Meanwhile, the quantitative approach of this paper refers to the analysis of the RFs using an industrial survey, the application fuzzy theory and the Monti Carlo algorithm using @Risk.

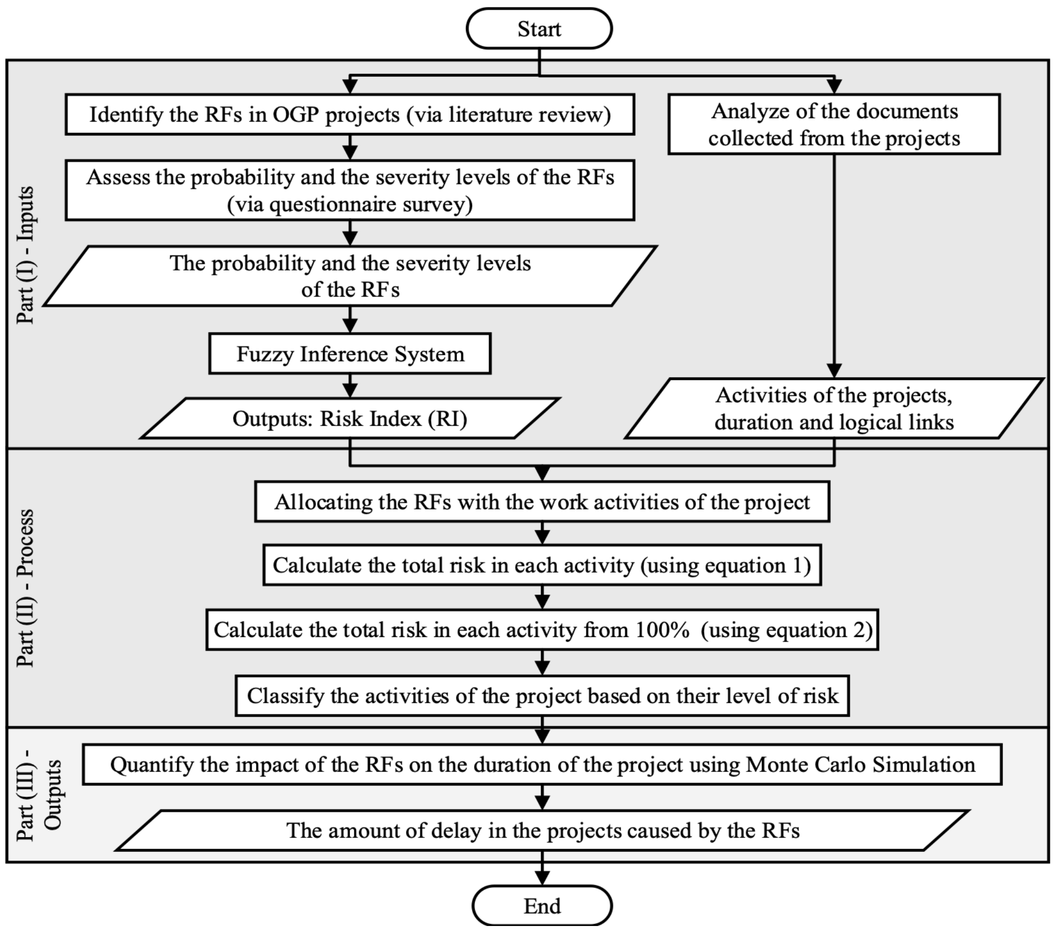

Figure 1. The information flow chart of the Delay Analysis Model (DAM).

The specification of the DAM works under three phases, as follows. (i) Part I, which explains the inputs of the model and how to find them; (i) Part II, which explains the process part of the model and illustrators how to link the RFs to the activities of the projects and calculate the risk level in each critical activity (already identified using project planning software). And (iii) part III, which explains the outputs of the model. Figure 1 presents the information flow diagram of the Delay Analysis Model (DAM) designed and developed in the study

Step 1: Identify the potential RFs in OGPPs: This step involves investigating the published studies that identified and analyzed the risk factors, which may affect the duration of OGPPs worldwide. This part of the DAM explains the process of identifying and assessing the RFs in OGP projects in Iraq. Firstly, the RFs were identified via an extensive literature review about the risks in OGP projects worldwide in order to overcome the problem of data scarcity about the RFs in OGP projects in Iraq (Kraidi et al., 2017). Based on the findings of the literature review, a questionnaire survey was designed and conducted with construction professionals to identify the probability and severity levels of the RFs within OGP projects in Iraq (Kraidi et al., 2019b) and analyze the RFs regards their degree of probability and impact on OGP projects. The outputs of this step are the probability and severity level of potential RFs with Risk Index (RI) values in the projects. See Table1 for details of RFs with respective RI.

Table 1:
The results of identifying and assessing the RFs in OGPPs in Iraq.

List of Risk Factors (RFs)	The findings of the survey (Kraidi et al. 2019b).		Result (Kraidi et al., 2019c, 2018).
RFs (Kraidi et al., 2017 and 2019a).	Probability	Severity	Risk Index (RI)
Sabotage	3.995	4.490	3.99
Corruption	3.717	4.192	3.87
Insecure areas	3.712	4.106	3.76
Low public legal & moral awareness	3.692	3.859	3.80
Thieves	3.687	4.081	3.75
Corrosion & lack of protection against it	3.687	3.990	3.72
Improper safety regulations	3.667	3.949	3.70
Exposed pipelines	3.667	3.682	3.70
Shortage of IT services	3.657	3.652	3.68
Improper inspection & maintenance	3.646	3.924	3.69
Lack of proper training	3.631	3.773	3.71
Weak ability to identify the threats	3.631	3.899	3.67
The pipeline is easy to access	3.626	3.646	0.57
Limited warning signs	3.621	3.571	3.56
Little research on this topic	3.606	3.697	3.55
Lawlessness	3.566	3.682	3.54
Lack of risk registration	3.530	3.697	3.60
Stakeholders' attention	3.495	3.143	3.51
Conflicts over land ownership	3.449	3.611	3.68
Public's poverty & education level	3.333	3.409	3.49
Design, construction & material defects	3.323	3.848	3.64
Threats to staff	3.227	3.399	3.35
Inadequate risk management	3.101	3.505	3.48
Operational errors	2.980	3.611	3.30
Leakage of sensitive information	2.747	3.505	3.38
Geological risks	2.652	3.182	3.17
Natural disasters & weather conditions	2.465	3.066	3.10
Vehicle accidents	2.237	2.712	2.80
Hacker attacks on operating or control	1.894	2.970	3.03
Animal accidents	3.995	4.490	1.95

Step 2: Risk assessment: The RFs were assessed regarding their degree of impact on the projects based on the results of a questionnaire survey and the application of the fuzzy theory for determining the risk index by considering the biasness of the stakeholder's judgement on probability and consequence level. This study has carried out an industrial survey to determine probability and severity of each RFs. The RFs that identified based on the findings of the literature review (see step 1 above) were conducted in a questionnaire survey to identify the probability and severity levels based on the perceptions of the stakeholders (Kraidi et al, 2019). The results of the fuzzy theory used to calculate the RFs' degree of impact on the projects, i.e., the values of Risk Index (RI) of the RFs. Analyzing the risk factors using the fuzzy logic theory has three stages, which are fuzzification, knowledgebase, and defuzzification. Stage 1 Fuzzification provides crisp inputs for the Fussy Inference System (FIS) in MATLAB. The probability and severity levels of the RFs are the two required inputs for the FIS in this paper. Stage 2 Knowledgebase defines the membership functions for the inputs and outputs of the model and the 'If-Then rules' to control the FIS. Stage 3 Defuzzification is about obtaining the final outputs of the model, which is RI in this model. In this stage of the FIS, the value of the RI will be calculated for the risk factors depending on the range of RP and RS of each risk factor and the controlling rules of the model. This step will help in ranking the RFs regarding their degree of impact on the projects.

Step 3: Risk allocation and activities analysis: This step of the model involves using the professional and academic knowledge to allocate the RFs to the activities of the project. The case study project of this paper is a 64 km pipeline that will transport the petroleum products from Badra field to the shipping point on the gulf in Basra. This project has been under planning since May 21, 2019, and the targeted delivery date is January 09, 2023, which means the duration of the project is estimated as 3 years and 238 days (1330 days). Risk allocation and calculating the level of risk in the projects activities was carried out using the following steps. The subjective and objective analysis of technical reports and practical guides such as (FTA, 2019) was used to justify the process of risk allocation because they explained what is required in each activity, the nature of each activity and the potential RFs that could affect that activity based on vast experience and a review of the construction process in OGPPs worldwide. Calculate the algebraic summation to calculate the summation of risk impact and the level of risk in each critical activity of the project, using equation 1 and 2 below.

$$\text{The summation risk of an activity} = \sum \text{RI values of the RFs relevant to that activity} \qquad (1)$$

$$\text{The summation risk of an activity (from 100\%)} = \frac{\text{The summation risk of that activity}}{\sum \text{The summation risk in the project}} \text{X}100\% \qquad (2)$$

The impact levels of the associated RFs on the calculation of the project duration (using ASTA planning software) were set up at five different levels of risk variation as follows. (I) Very High (VH) risk [75% - 125%] varies in a task duration when considering all RFs. Similarly, (II) High (H) risk [80% - 120%], (III) Medium (M) risk [85% -115%], (IV) Low (L) risk [90% - 110%] and (V) Very Low (VL) risk [95% - 105%] variations are considered on each task based on the experts' advice and industry survey findings. The findings of step 3 are the impact level of each project task on task duration, see table 2.

Table 2:
The summation of the risk impact and risk level to the project activities of the case study

Activities	Equation 1	Equation 2	Risk Level
Concept and definitions*	18.11	0.86	VL: 95% - 105%
Life-cycle plan	71.8	3.41	H: 80% - 120%
Choosing the route	76.65	3.64	H: 80% - 120%
Route approval	73.14	3.47	H: 80% - 120%
Design and development	43.44	2.06	M: 85% -115%

Installation procedure	29.28	1.39	L: 90% - 110%
Risk assessment	49.67	2.36	M: 85% -115%
Time schedule	22.08	1.05	L: 90% - 110%
Cost estimation	22.08	1.05	L: 90% - 110%
Communications	25.43	1.21	L: 90% - 110%
Materials order	18.41	0.87	VL: 95% - 105%
Survey, staking and setting out	75.77	3.60	H: 80% - 120%
Clearing and grading the right-of-way	73.46	3.49	H: 80% - 120%
Topsoil stripping	57.88	2.75	M: 85% -115%
Buildings, roads and river crossings	76.63	3.64	H: 80% - 120%
Pipe transportation to site	59.02	2.80	M: 85% -115%
Temporary fencing and signage	51.09	2.43	M: 85% -115%
Trenching	54.05	2.57	M: 85% -115%
Erosion control & side support	57.48	2.73	M: 85% -115%
Pipe set-up	43.84	2.08	M: 85% -115%
NDT tests	32.77	1.56	L: 90% - 110%
Welding, fabrication and installing	36.28	1.72	L: 90% - 110%
Sandblast	32.82	1.56	L: 90% - 110%
Painting	32.81	1.56	L: 90% - 110%
Coating	54.69	2.60	M: 85% -115%
Lowering pipe and backfilling	46.71	2.22	M: 85% -115%
Cathodic protection of the pipe	68.64	3.26	H: 80% - 120%
Final fitting	32.61	1.55	L: 90% - 110%
As-built survey	32.48	1.54	L: 90% - 110%
Hydro, pressure test	29.1	1.38	L: 90% - 110%
Backfilling	36.16	1.72	L: 90% - 110%
Fencing and signage	61.49	2.92	M: 85% -115%
Final clean-up	40.11	1.90	L: 90% - 110%
Right-of-way reclamation	54.03	2.57	M: 85% -115%
Safety barriers	55.53	2.64	M: 85% -115%
Operation within design limits	97.54	4.63	VH: 75% - 125%
Commissioning operation value	97.54	4.63	VH: 75% - 125%
Performance and efficiency	29.26	1.39	L: 90% - 110%
Enhanced performance and efficiency	97.54	4.63	VH: 75% - 125%
Monitoring and inspection	42.57	2.02	M: 85% -115%
Maintenance	59.54	2.83	H: 80% - 120%
Risk control	36.31	1.72	L: 90% - 110%

- **Step 4: Quantify the potential delay in the project.**

This step is about using the findings of the steps above and run the simulation model to quantify the impact of the RFs on the duration of the project, i.e., the delay, using MCS. The final finding of this step is the amount of the potential delay in the project caused by the associated RFs, see figure 2. As explained above, the duration of the project is estimated as 1330 days. The results of risk simulation show that the minimum and maximum duration of the project are 1329.30 days and 1441.84 days, respectively. The project has a chance 5% of been completed of a duration between 1374.94 days to 1349.1 days or between 1404.5 days to 1441.84 days. The project has a probability of 50% to be finished in the mean duration, which is 1374.94 days. And the project has a probability of 90% to be finished between 1349.0 days to 1404.4 days (see Figure 2).

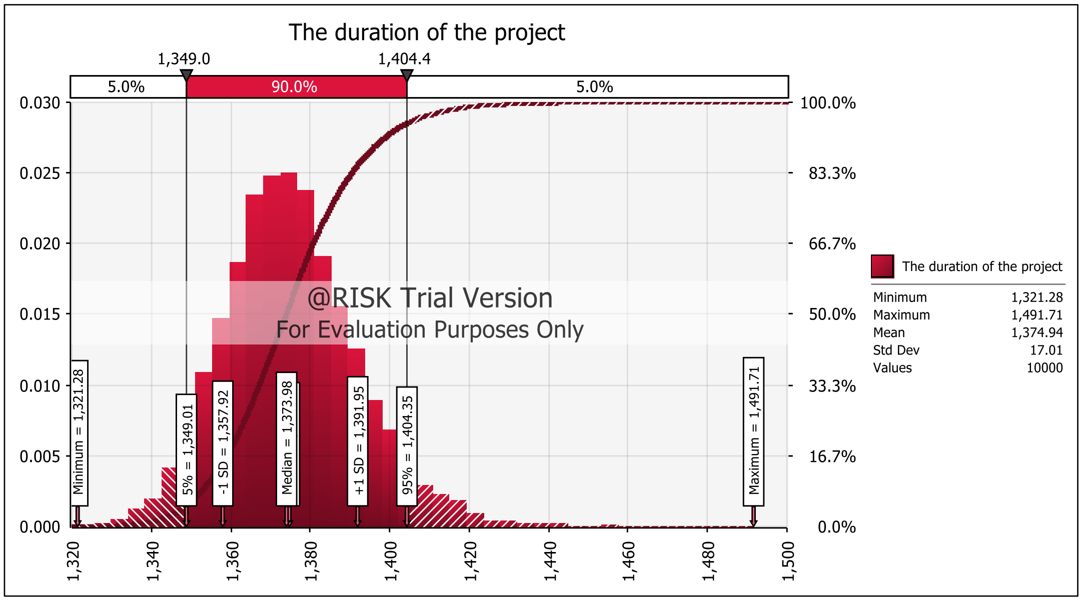

Figure 2. The results of simulating the duration of the project.

Results

The paper has analyzed the delay in the overall duration of the project as well as by the project's stages as explained in table 3 below.

Table 3:
The results of @Risk and the delay in the project considering the impact of the RFs.

Project Stages	Planned duration	@Risk results	Delay#	Standard Deviation
The total duration of the project	1330 days	1374.94 days	44.94* days	17.01
The duration of the planning stage	812 days	796.84 days	-15.16 days	9.39
The duration of the pre-construction stage	200 days	242.12 days	42.13 days	7.78
The duration of the construction stage	213 days	224.45 days	11.44 days	10.75
The duration of the post-construction stage	105 days	111.52 days	6.53 days	5.53

= Delay = the duration of @Risk – planned duration
*44.94 = -15.16+42.13+11.44+6.53. #This stage might be finished before the planned date.

As shown in Table 3 above, the highest delay of the project comes from the pre-construction stage with a delay of 42.13 days. Meanwhile, the results of @Risk revealed that the planning and design stage of the project could be finished 15.16 days earlier than expected. Which means the RFs that associated with the case study project have the highest impact of its duration. Fishburn (1984) defined risk as a bad event. The word risk generally means negative results caused by a bad or an unexpected event (Alali, 2010). Risk is an uncertain incident or situation, which has a positive or negative effect on the project's goals if it happens (PMI, 2013, as cited by Almadhlouh, 2019). Ahmed et al. (2007) defined risk as any unexpected or unplanned event that affects a project in either a positive or a negative way. Which may explain the positive impact of the RFs that associate with the project at the planning stage. As well as it was found that the delay in the pre-construction, the construction and the post-construction stages is around 42.13 days, 11.44 days, and 6.53 days, respectively.

Discussion and Conclusions

Having noticed a gap in the delay analysis system of risk factors, this research introduced Fuzzy logic theory to reduce biasness of relative importance index/values of risk probability and consequences on all risk factors affecting in all critical tasks/activities in the critical path identified using ASTA planning tool. It also used @risk simulator integrated with Monte Carlo simulation to identify and quantify the delay impact on the project duration in an oil and gas pipeline construction project, which is key knowledge contribution in this paper. The key output of the DAM is to determine the possible project durations and associated RFs for the successful delivery, and this is considered as a useful tool. The model was evaluated using a case study of an OGPP in Iraq. The results of the case study project suggested a potential delay might occur if considering the associated RFs. The sources of the RFs listed in this research should not be ignored because they were identified based on international investigations and industry experience. Fuzzy logic theory was used to estimate the RI values of the RFs, which reduces the uncertainty associated with the risk analysis and overcomes the data scarcity problem and the prejudices in stakeholders' judgements about their level of impact Kraidi et al. (2019c and 2020b). @Risk Simulator used these risk distribution methods for each RFs of the project rather than one distribution method at a time, with a degree of impact on the duration of the project. For example, RiskTriang (0,0.7,1) distribution was assigned to the stealing the products and the materials RFs, which is different from assigning Uniform, Normal, Triangular or Skewed Triangular with no degree of impact on the duration of the project. RiskTriang is a function within @Risk simulator and generates a triangular distribution of probabilities.

The average delay in the project after considering the RFs within critical work activities was found as 42 days from the planned duration at pre-construction stages when using four risk distribution methods. A single case study was used in this research to evaluate the DAM that developed in this research. While a single case study was used in this research, the results of this research came from a long pipeline project, which extended for 164 km. The pipeline is crossing 3 different cities, which are Al Kut, Maysan, and Basra in Iraq. It crosses different geographical environments and topographies, like rivers, lakes, roads, residential areas, green areas, etc. Therefore, the results of the case study reflect highly reliable and valid findings. The paper concludes that the developed delay risk analysis model is useful to quantify the potential delay at the starting stage and assist in identifying the causes of delay they might face at execution and operation stages.

The future study involves developing a computer-based model that analyses the potential correlations between the RFs and the activities of the projects. Such proposed model will provide a better understating about different project uncertainties in the construction industry. It is recommended that more case studies with different graphical locations in different country of oil and gas line project need to be conducted and calibrated before implementing as a practical and commercial tool in the oil and gas industry.

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References

Ahmed, A., Kayis, B., and Amornsawadwatana, S. (2007). A review of techniques for risk management in projects. Benchmarking: An International Journal, 14(1), 22–36.

Alali, B. (2010). Post-Project Risk Perception and Systems Management Reaction. Old Dominion University.

Almadhlouh, A. (2019). Risk Management Approaches in Oil and Gas Industry Projects: A Qualitative Study. Colorado Technical University.

Assaad, R., El-Adaway, I. H., and Abotaleb, I. S. (2020). Predicting project performance in the construction industry. Journal of Construction Engineering and Management, 146(5), 04020030.

Chan, A.P.C., Chan, D.W.M., Yeung, J.F.Y., 2009. Overview of the Application of "Fuzzy Techniques" in Construction Management Research. J. Constr. Eng. Manag. Vol.135, pp1241–1252.

Fallahnejad, M. (2013). Delay causes in Iran gas pipeline projects. International Journal of Project Management, 31(1), pp. 136-146.

Fishburn, P. C. (1984). Foundations of risk measurement. I. Risk as probable loss. Management Science, 30(4), 396–406.

FracTracker Alliance (FTA). (2019). Pipeline Construction: Step-By-Step Guide [Online]. Available at https://www.fractracker.org/resources/oil-and-gas-101/pipeline-construction/

Kadry, M., Osman, H., Georgy, M., 2017. Causes of Construction Delays in Countries with High Geopolitical Risks. J. Constr. Eng. Manag. 143, 04016095.

Kraidi, L., Shah, R., Matipa, W., and Borthwick, F. (2018). An Analysis of the Critical Risk Factors in Oil and Gas Pipeline Projects Using a Comprehensive Risk Management Model. This Paper Was Presented as a Working Paper at the ARCOM 34th Conference, 3-5 September. Belfast, UK.

Kraidi, L., Shah, R., Matipa, W., and Borthwick, F. (2019a). Analyzing the critical risk factors associated with oil and gas pipeline projects in Iraq. International Journal of Critical Infrastructure Protection, 24, pp. 14-22.

Kraidi, L., Shah, R., Matipa, W., and Borthwick, F. (2019b). Analyzing Stakeholders' Perceptions of the Critical Risk Factors in Oil and Gas Pipeline Projects. Period Polytech Archit.

Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2017). Analysing the Critical Risk Factors of Oil and Gas Pipeline Projects in Iraq. In the Proceedings of the 3rd BUiD Doctoral Research Conference, British University in Dubai, the 13th of May 2017, Dubai. pp. 133-148.

Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2019c). Application of Fuzzy Logic Theory on Risk Assessment in Oil and Gas Pipeline Projects. In Proceedings of the 55th Annual ASC Conference, 10-13 April. Denver, Colorado, USA.

Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2020a). Quantitative Analysis of the Delay Factors in Oil and Gas Pipeline Projects. In Tom Leathem (editor). Associated Schools of Construction Proceedings of the 56th Annual International Conference. Liverpool, UK, 2020, vol 1, pp. 356–363.

Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2020b). Using stakeholders' judgement and fuzzy logic theory to analyze the risk influencing factors in oil and gas pipeline projects: Case study in Iraq, Stage II. International Journal of Critical Infrastructure Protection, 28, pp. 100337-100346.

Ruqaishi, M., and Bashir, H. (2015). Causes of Delay in Construction Projects in the Oil and Gas Industry in the Gulf Cooperation Council Countries: A Case Study. Journal of Management in Engineering, 31(3), pp 5014017-1-8.

Shah, R. (2016). An Exploration of Causes for Delay and Cost Overruns in Construction Projects: Case of Australia, Malaysia, and Ghana. Journal of Advanced College of Engineering and Management, Vol 2, pp 41-55.

Shebob A, Dawood N and Shah R K (2012), "Development of A New Methodology for Analysing and Quantifying the Impact of Delay Factors Affecting Construction Projects," International Journal of Construction Engineering and Project Management, Vol 2 (3), pp17-29

Sweis, R., Moarefi, A., Amiri, M., Moarefi, S., and Saleh, R. (2019). Causes of delay in Iranian oil and gas projects: a root cause analysis. Inter. Journal of Energy Sector Management, 13(3), pp. 630-650.

World Map. (2014). Iraq Oil Pipelines Map. https://www.mapsofworld.com/iraq/oil-pipelines-map.html

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Assessing the effectiveness of Constructivism and Transformational Leadership on STEM/TEKS through a Construction Summer Experience

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Construction summer experiences in the form of summer camps targeting high school students are becoming more common. These construction summer experiences are critical as they provide high school students the opportunity to learn about construction, career pathways in construction and perhaps motivate them to enroll in one of the nation's university construction programs. Unfortunately, a theoretical framework to develop and implement construction summer experiences did not exist until recently. This study presents the research results of a pilot implementation of a Summer Experience based on Transformational Leadership and Constructivism theories (SumEx-TLC). More specifically, this paper provides the results in Science, Technology, Engineering and Math (STEM), and Texas Essential Knowledge and Skills (TEKS) of a construction transportation infrastructure via summer experience. This one-week hands-on summer experience engaged a small group of minority and economically disadvantaged high school students. During the pilot implementation, data was collected following an exploratory case study with a quasi-experimental design methodology. The pilot study results are encouraging and support the notion of continuing research using similar frameworks with a large-scale implementation.

Key Words: Constructivism, Transformational Leadership, Summer Experience, Construction, Transportation, Infrastructure

Preamble

At least for the last three decades, researchers have documented that in the United States (US), living segregation by race and income is detrimental to the development, well-being, and opportunities of children and their families in the disadvantaged groups (Carr et al., 2008; Duncan et al., 1997; Ellen, 2001; Newman, 2008; Sampson, 2012; Sampson et al., 2002; Sharkey, 2013; Wilson, 2012). Children with economic disadvantage (Poor children) are less likely than their counterparts (never-poor children) to graduate from high school/college and be consistently employed (Ratcliffe, 2015). Thus, the importance of engaging minority and economically disadvantaged high school students in a summer experience provides a pathway to the construction industry. Unfortunately, students, specifically underrepresented minorities in the inner-city High Schools, seldom have the opportunity to learn about existing career opportunities in the construction of transportation infrastructure.

Literature Background

Extensive literature exists on this research project's four main components: Construction of Transportation Infrastructure, Summer Experience, Constructivism Learning Theory, and Transformational Leadership (Figure 1). However, a significant gap exists in the intersection of the four topical areas and, therefore, the need for this research project particularly (in addition to the importance of engaging minority and economically disadvantaged populations). This section intends to summarize the current knowledge of those four components that served as the foundation for the framework to develop Summer Experiences based on Transformational Leadership and Constructivism theories (SumEx-TLC).

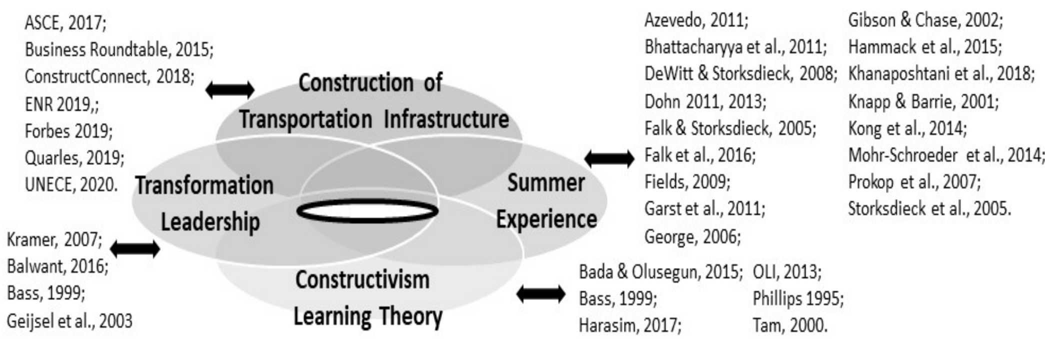

Figure 1. Significant Elements of this Research Project and Sample Literature

Construction of Transportation Infrastructure

Transport infrastructure supports the transport system, including roads/bridges, railways, inland waterways, maritime ports, and airports. The construction of transportation infrastructure is vital because it is the country's backbone and crucial to prosperity and the public's health and welfare (ASCE, 2017).

Summer Experiences

Summer experiences are implemented in multiple settings such as summer camps, professional shadowing during summer, summer field trips, and summer museum visits, among others. Several researchers have argued that this type of setting promotes experiential learning (Azevedo, 2011; Knapp & Barrie, 2001; Prokop et al., 2007). In a pedagogical sense, such learning experiences contribute to active learning and interest development in Science, Technology, Engineering, and Mathematics (STEM), while also increasing their understanding of the topic (DeWitt & Storksdieck, 2008; Garst et al., 2011).

It is also documented that individual career choices are based on interests, perceptions, attitudes, and values (Hammack et al., 2015), and K-12 is where they are established (Bhattacharyya et al., 2011; George, 2006). Historically, summer experiences (or summer camps/summer academy boot camps) have been conducted to assess student perception change in fields relating to STEM (Hammack et al., 2015; Bhattacharyya et al., 2011; Mohr-Schroeder et al., 2014), career interest in the science and engineering fields (Kong et al., 2014), and others. Summer experiences in Construction Management have also shown a positive impact (Table 1).

Table 1. Construction Summer Experiences

Summer Experience	Institution	Key finding	Reference
Women in CM Summer Institute	Colorado State Univ.	Increased participants' perceived knowledge of construction management	Mehany (2019)
Building Construction Summer Camp	Auburn University	Increased the participant's recognition of the professionals that manage construction projects	Redden (2018)
City of Minecraft	Kansas State University	The top 10% of the participant's responses indicated that they learned about civil eng. and construction	Loughmiller (2018)
Visualization, Informatics, Technology Automation, and Learning	Florida International University	Participants were made aware that technology could be applied to construction to solve problems in interesting ways.	Carrasquillo (2017)
Construction Management Academies	Texas A&M University	Made a positive impact on participants career choice	Escamilla (2017)
Construction Summer Camp	California State University	Hands-on learning was an effective tool in promoting STEM and construction management to the participants.	Gaedicke (2016)

Constructivism learning theory

Constructivism learning theory postulates that the experiences and reflection of those experiences by the people impact their understanding and knowledge of the world (Harasim, 2017) (Figure 2).

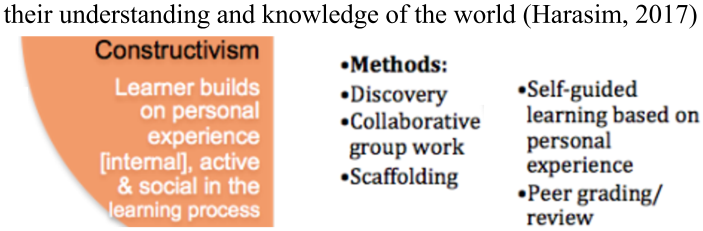

Figure 2. Learning Perspective and Instructional Methods for Constructivism Theory (OLI, 2013)

The constructivism theory was selected as the hands-on activities allowed the participating high school students to discover and collaborate in a self-guided learning environment (Figure 2). The constructivist learning theory was applied in this research because of its applicability to education (especially K-12), the ability of the pedagogy to recalibrate the student's existing perceptions values, and understanding of how things operate and promote an active learning environment (Phillips 1995; Tam, 2000) that stimulates the students (Bada & Olusegun, 2015).

Transformational Leadership

Transformational leadership involves "inspiring followers to commit to a shared vision and goals for an organization or unit, challenging them to be innovative problem solvers and developing followers' leadership capacity via coaching, mentoring, and provision of both challenge and support" (Kramer, 2007). Transformational leadership has broad potential applicability to higher education, and the leadership style is positively associated with students' motivation, satisfaction, perceptions of instructor credibility, academic performance, affective learning, and cognitive learning (Balwant, 2016). The transformational leadership components that were implemented in this summer experience are idealized influence, inspirational motivation, intellectual stimulation, and individual consideration

(Bass, 1999). It was expected that this would bring positive change, engage students, and overlap with active learning resulting in the constructivist learning theory.

Summer Experience Brief Description

The hands-on pilot Construction of Transportation Infrastructure - Summer Experience focused on the construction of infrastructure for the three types of transportation (Land, Air, and Water), had its content directly linked with the Texas Essential Knowledge and Skills (TEKS) in Science, Technology, Engineering and Math (STEM) as well as marketable "Soft" Skills, and in the process, made it unique for Texans. Furthermore, the Construction of Transportation Infrastructure - Summer Experience was grounded on the newly developed Transformational Leadership and Constructivism theories (SumEx-TLC) framework. The hands-on pilot summer experience involved all-day one-week interaction (Monday – Friday) among the researchers and economically disadvantaged and minority high school students. The students had four sessions each day from Monday through Thursday and five sessions on Friday of one hour and 30 minutes. Each session focused on one STEM-TEKS or Marketable "Soft" skill that was contextualized in the construction of the different transportation infrastructure types. Detailed information about the summer experience can be found in the paper published at the ASC 2021 conference titled "Framework for a Summer Experience based on Transformational Leadership and Constructivism " (Langar, S., & Sulbaran, T., 2021).

Research Methodology

The research methodology used in this project was an exploratory mixed research as it allowed the researchers to create knowledge and understanding as well as set a standard for acceptable teaching practices for summer experiences by gaining an understanding through exposure to the particular phenomenon of implementing the summer experience. The theoretical framework is presented in the paper titled "Framework for a Summer Experience based on Transformational Leadership and Constructivism (SumEx-TLC)" in the ASC 2021 Proceedings. The pilot deployment, data collection, data analysis, and lessons learned and presented in this paper (Figure 3).

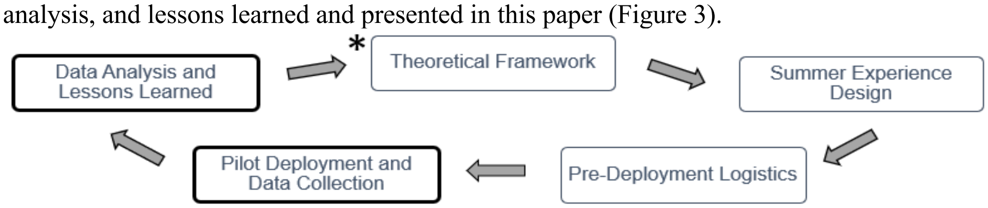

Figure 3. Summer Experience Cycle

Collection and Assessment

The data collection and assessment of SumEx-TLC presented in this study measured the impact on economically disadvantaged high school students' knowledge and perceptions on STEM/TEKS. Assessments and data collection were conducted at the beginning of the summer experience (Pre-assessment), daily in the afternoon (formative), and post-assessment (summative) at the end of the summer experience. All assessments were designed to maintain the student respondents' confidentiality, were conducted online using Qualtrics, and were approved by the Institutional Review Board (IRB) at the University of Texas at San Antonio. Most of the questions were multiple-choice, and responses to the questions were in the form of a five-point Likert scale that assesses the KPI. All data was collected and stored on Qualtrics. After the surveys were deactivated, all responses were downloaded from the Qualtrics to a secured University Computer for Data Analysis to evaluate the

KPI's. Data collected during the pilot implementation from the nine participating students were subjected to descriptive and inferential statistical analysis using SPSS and Jupiter Notebooks. For the descriptive statistics, distribution tables and graphs were created and discussed in the subsequent section. For the inferential statistics, an independent sample t-test was performed

Results

The results from the data collected related to STEM and TEKS are presented below in the following topical areas:

- Science: Use of physics law (TEKS 112.39) to design infrastructure such as bridges
- Technology: Develop 3D Models (TEK 126.43) to communicate transportation infrastructure concepts
- Math: Apply geometry concepts (TEKS 111.41) to quantify materials needed to construct transportation infrastructure

Science - Physics - Newton's Laws - TEKS 112.39

The students' responses regarding knowledge in Newton's Laws (physics) after the summer experience were higher than the responses before the summer experience (Figure 4). The Newton's Laws mean value before the summer experience was 3.67 (between "Average" and "Somewhat Above Average"), and the mean value after the summer experience was 4.38 (between "Somewhat Above Average" and "Far Above Average), (Table 2). This improvement is encouraging and indicates positive perception change among participating students post-summer camp.

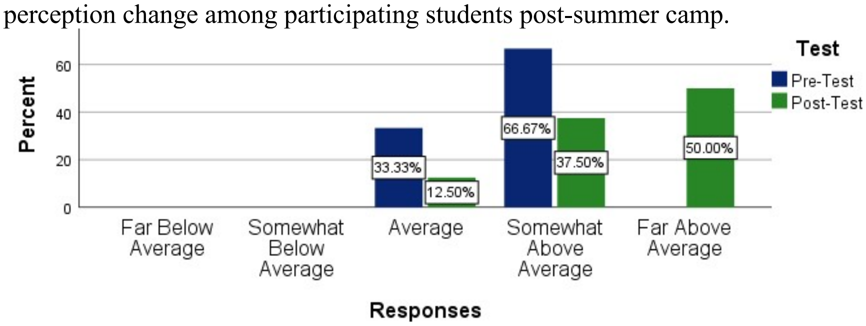

Figure 4. Physics Law/ Forces (STEM TEKS 112.39) - Pre and Post-Test

Table 2. Mean responses for Physics Law/ Forces (STEM TEKS 112.39)

Test	N	Mean	Std. Deviation	Std. Error Mean
Pre-Test	9	3.67	.500	.167
Post-Test	8	4.38	.744	.263

Additionally, 62.5% of the participants indicated that the summer experience impact on their knowledge of Newton's Law was "A great deal" (Figure 5).

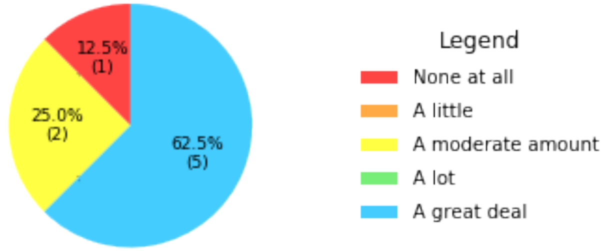

Figure 5. Impact of the Summer Experience on Physics Law (Forces) Knowledge (STEM TEKS 112.39)

Technology - 3D Modeling - TEKS 112.46

The students' responses regarding knowledge in developing 3-D Models after the summer experience were higher than those before the summer (Figure 6). 3-D modeling mean value before the summer experience was 3.44 (between "Average" and "Somewhat Above Average"), and the mean value after the summer experience was 4.63 (between "Somewhat Above Average" and "Far Above Average) - Table 3. This improvement is very encouraging, especially compared to the science component, among the participating students post-summer camp.

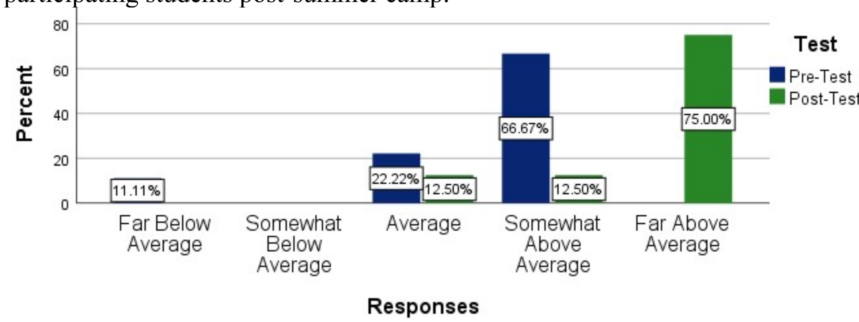

Figure 6. 3D Modeling (STEM TEKS 112.46) - Pre and Post-Test

Table 3. Mean responses for 3D Modeling (STEM TEKS 112.46)

Test	N	Mean	Std. Deviation	Std. Error Mean
Pre-Test	9	3.44	1.014	.338
Post-Test	8	4.63	.744	.263

Additionally, 75% of the participants indicated that the summer experience impacts their knowledge of 3-D modeling as "A lot" or "A great deal" (Figure 7).

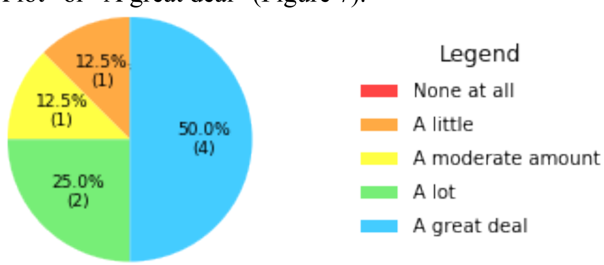

Figure 7. Impact of the Summer Experience on 3D Modeling Knowledge (STEM TEKS 112.46)

Math - Geometry - TEKS 111.41

The students' responses regarding knowledge in geometry after the summer experience were higher than those before the summer experience (**Error! Reference source not found.**Figure 8). The geometry knowledge mean value before the summer experience was 3.00 (around "Average"), and the mean value after the summer experience was 4.38 (between "Somewhat Above Average" and "Far Above Average) - Table 4. This improvement is encouraging, but it should be noted that the perception change was similar to that for the science component but lesser than the technology component among the participating students post-summer camp.

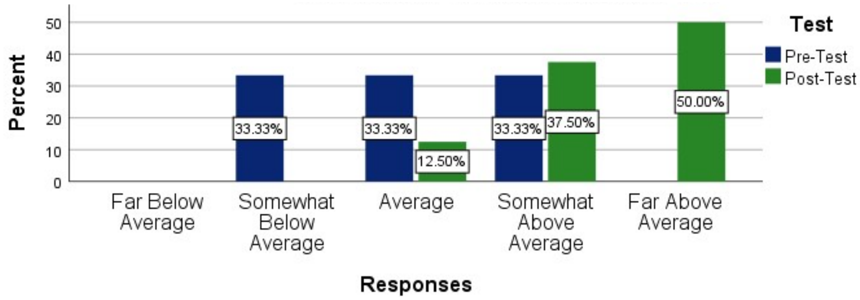

Figure 8. Geometry (STEM TEKS 111.41) - Pre and Post-Test

Table 4. Mean responses for Geometry Knowledge (STEM TEKS 111.41)

Test	N	Mean	Std. Deviation	Std. Error Mean
Pre-Test	9	3.00	.866	.289
Post-Test	8	4.38	.744	.263

Additionally, 75% of the participants indicated that the summer experience impacted their knowledge of geometry as "A lot" or "A great deal" (Figure 9).

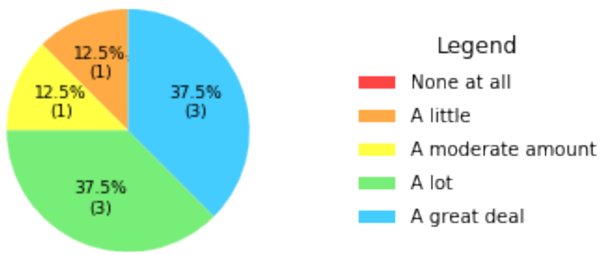

Figure 9. Impact of the Summer Experience on STEM TEKS 111.41 - Geometry Knowledge

Summary, Limitations, and Future Work

This one-week hands-on pilot summer experience implementation on a construction transportation infrastructure was very informative and encouraging. The mean score in all of the STEM topical areas increased (scale of 1 to 5): science from 3.67 to 4.38, technology from 3.44 to 4.63, and math from 3.00 to 4.38. The students also indicated that the summer experience's impact was "A lot" or "A great deal" on all STEM topics: 62.5% on science, 75% on technology, and math. Although the study was pilot in nature and had a limited number of participants, these positive results are significant as they support further research on this topic. Therefore, it is anticipated another summer experience cycle will be executed (Figure 3**Error! Reference source not found.**).

Lessons learned are that (1) grounding summer experiences in a theoretical framework is possible, (2) further deployments of the summer experience are needed to extrapolate results, (3) minority and economically disadvantaged high school students fully engaged in the experience, (4) explicitly linking construction with STEM is beneficial, and (5) exploring another construction context will enrich research process.

References

American Society of Civil Engineers (ASCE). (2017). America's Infrastructure Grade. ASCE's 2017 Infrastructure Report Card. American Society of Civil Engineers. Retrieved from: https://www.infrastructurereportcard.org/americas-grades/, Last Retrieved: July 2020.

Azevedo, F. S. (2011). Lines of practice: A practice-centered theory of interest relationships. Cognition and Instruction, 29(2), 147–184. DOI:10.1080/07370008.2011.556834.

Bada, D., & Olusegun, S. (2015). Constructivism Learning Theory: A Paradigm for Teaching and Learning. Journal of Research & Method in Education, 5(6), 66–70.

Balwant, P. T. (2016). Transformational Instructor-Leadership in Higher Education Teaching: A Meta-Analytic Review and Research Agenda. Journal of Leadership Studies 9(4), 20–42.

Bass, B. M. (1999). Two Decades of Research and Development in Transformational Leadership. Eur. J. Work Organ. Psychol. 8, 9–32.

Bhattacharyya, S., Mead, T. P., & Nathaniel, R. (2011). The Influence of Science Summer Camp on African-American High School Students' Career Choices. School Science and Mathematics, 111(7), 345–353.

Carr, J. H., & Kutty, N. K. (2008). Segregation: The Rising Costs for America. Routledge, Taylor & Francis Group.

Carrasquillo, A., Pradhananga N., & Eraso., M. (2017). A University-Based Summer Camp to Promote Construction Technology Career for High School Students. Associated Schools of Construction, 143-150.

DeWitt, J., & Storksdieck, M. (2008). A short review of school field trips: Key findings from the past and implications for the future. Visitor Studies, 11(2), 181–197.

Duncan, G. J., Brooks-Gunn, J., & Aber, J. L. (1997), Neighborhood Poverty, 1, Russell Sage Foundation Publications.

Ellen, I. G. (2001). Sharing America's Neighborhoods: The Prospects for Stable Racial Integration. Harvard University Press.

Escamilla, E., & Mohammadreza, O. M. (2017). Construction Management Academy Career Exploration Program: Strategy for Recruitment of Under-Represented Minority Groups. Associated Schools of Construction, 261-269.

Gaedicke, C., Shahbodaghlou, F., & Guiney D. (2016). Promoting Construction in K-12 STEM Education Through an Innovative University-based Summer Camp. Associated Schools of Construction.

Garst, B. A., Browne, L. P., & Bialeschki, M. D. (2011). Youth development and the camp experience. New Directions for Youth Development, (130), 73–87.

George, R. (2006). A Cross-domain Analysis of Change in Students' Attitudes toward Science and Attitudes about the Utility of Science. International Journal of Educational Administration, 41(3), 571–589.

Hammack, R., Ivey, T. A., Utley, J., & High, K. A. (2015). Effect of an Engineering Camp on Students' Perceptions of Engineering and Technology. Journal of Pre-College Engineering Education Research, 5(2), 10-21.

Harasim, L. M. (2017). Learning theory and online technologies. Routledge, Taylor & Francis Group.

Knapp, D., & Barrie, E. (2001). Content evaluation of an environmental science field trip. Journal of Science Education and Technology, 10(4), 351–357. DOI:10.1023/A:1012247203157.

Kong, X., Dabney, K. P., & Tai, R. H. (2014). The Association Between Science Summer Camps and Career Interest in Science and Engineering. International Journal of Science Education 4(1), 54–65.

Kramer, T. J. (2007). Transformational Leadership (2nd ed.) by M. B. Bass & E. G. Riggio. *Psychol.-Manag. J.* 10, 152–155.

Langar, S., & Sulbaran, T. (2021). Framework for a Summer Experience based on Transformational Leadership and Constructivism (SumEx-TLC). EPiC Series in Built Environment, 2, 514–523.

Loughmiller, K. (2018). City of Minecraft: Introducing middle school students to the construction industry through gaming. Associated Schools of Construction, 159-168.

Mehany, M., Fontana, A., & Valdes-Vasquez, R. (2019). The Development of a Construction Management Summer Program for Young Females – A Case Study, ASC, 205-212.

Newman, S. J. (2008). Does housing matter for poor families? A critical summary of research and issues still to be resolved. Journal of Policy Analysis and Management, 27(4), 895–925.

Online Learning Insights (OLI). (2013). "How Course Design Puts the Focus on Learning Not Teaching," Online Learning Insights, Retrieved from: https://onlinelearninginsights.wordpress.com/tag/constructivism/, Last Retrieved: July 2020.

Phillips, D. C. (1995). The Good, the Bad, and the Ugly: The Many Faces of Constructivism.

Prokop, P., Tuncer, G., & Kvasničák, R. (2007). Short-Term effects of field programme on students' knowledge and attitude toward biology: A Slovak experience. Journal of Science Education and Technology, 16(3), 247–255. DOI:10.1007/s10956-007-9044-8.

Sampson, R. J. (2012). Great American City: Chicago and the Enduring Neighborhood Effect. University of Chicago Press.

Sampson, R. J., Morenoff, J. D. & Gannon-Rowley, T. (2002). Assessing "Neighborhood Effects": Social Processes and New Directions in Research. Annual Review of Sociology, 28, 443–478.

Sharkey, P. (2013). Stuck in Place: Urban Neighborhoods and the End of Progress toward Racial Equality, The University of Chicago Press, Chicago, US.

Ratcliffe, C. (2015). Child Poverty and Adult Success. 15. Urban Institute. Retrieved from: https://www.urban.org/sites/default/files/publication/65766/2000369-Child-Poverty-and-Adult-Success.pdf, Last Retrieved: July 2020.

Redden, L., & Simons A. (2018), Summer Camp's Impact on High School Students' Perceptions of Construction Management: A Case Study, Associated Schools of Construction, 289-296.

Tam, M. (2000). Constructivism, Instructional Design, and Technology: Implications for Transforming Distance Learning. Educational Technology & Society, 3(2), 50-60.

Wilson, W. J. (2012), The Truly Disadvantaged: The Inner City, the Underclass, and Public Policy, Second Edition. University of Chicago Press, Chicago, US.

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Integrated Project Delivery for Mechanical Contractors

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Funded by the Sheet Metal & Air Conditioning Contractors' National Association (SMACNA), this paper discusses Integrated Project Delivery (IPD) from the perspective of mechanical trade contractors that have been part of IPD projects and serves as a guide for those mechanical contractors interested in expanding their market share into IPD market sectors. Based on in-depth interviews and 'lessons learned' from six SMACNA-member contractors who have been trade partners on IPD projects, this paper guides mechanical contractors joining an IPD team and the mechanical trade contractor's role during design and preconstruction phases and factors for successful construction and project close-out. This paper intends not to provide an overview of the IPD process, as this has been covered in detail with previous research. This paper provides feedback and shares the opinion of mechanical contractors that have previously participated in the IPD process to benefit mechanical contractors not yet familiar with the IPD delivery method.

Keywords: mechanical trade contractor, integrated project delivery, interview.

Introduction

Traditionally, three major constraints within a construction project have been: cost, schedule, and quality. Owners have come to realize that they can typically choose any two at the expense of the third. Integrated Project Delivery (IPD) strives to change this mentality by optimizing all three to increase value and Owner satisfaction.

So why IPD? The 'checks and balances' of traditional delivery methods have created an inefficient, even adversarial relationship between designers, contractors, and subcontractors where each attempt to further its interests ahead of the interests of the project. 'Silos' often emerge, restricting collaboration, transparency, and information flow. The IPD process helps break down these 'silos' by creating a more collaborative process.

The purpose of this paper is to help mechanical contractors better understand and respond to IPD opportunities to improve their productivity and competitiveness while expanding and diversifying their market share. Based on in-depth interviews and 'lessons learned' from six SMACNA-member contractors having been trade partners on IPD projects, this paper provides contractor insights by compiling the mechanical contractors' responses to the following topics:

- What is IPD, and how does it differ from other project delivery methods?
- Is IPD a good fit for my company, and how do I get involved with an IPD project?
- What is my role in an IPD project during preconstruction, construction, and closeout?
- What challenges, lessons learned, or other experiences can be expected with IPD?

Background

What is IPD?

According to the American Institute of Architects (AIA), IPD is a project delivery method that integrates people, systems, and practices into a process that collaboratively harnesses the talents of all participants to reduce waste and optimize efficiency. Simply defined, IPD is a project delivery method that attempts to align many of the key project participants as trade partners (owner, architect, engineers, general contractor, and main subcontractors) both ideologically and contractually to deliver a project as a unified team. IPD differs from traditional project delivery methods by creating groups of trade partners aligned to achieve the same goal and make decisions that are best for the owner and the overall project, not just the individual firms. Prime contractors and key trade contractors are involved far earlier in the IPD process, and their input in the design phase is valued. IPD also differs from traditional projects in that there is shared risk and reward between the trade partners. The defining element of a true IPD project is when multiple project participants (trade partners) enter into a multi-party agreement (MPA) or integrated form of agreement (IFOA) that has a risk/reward sharing structure where all parties win or lose together. The risk/reward structure is shown in Figure 1. Please refer to the reference section to obtain additional sources of information to more fully explain the IPD process.

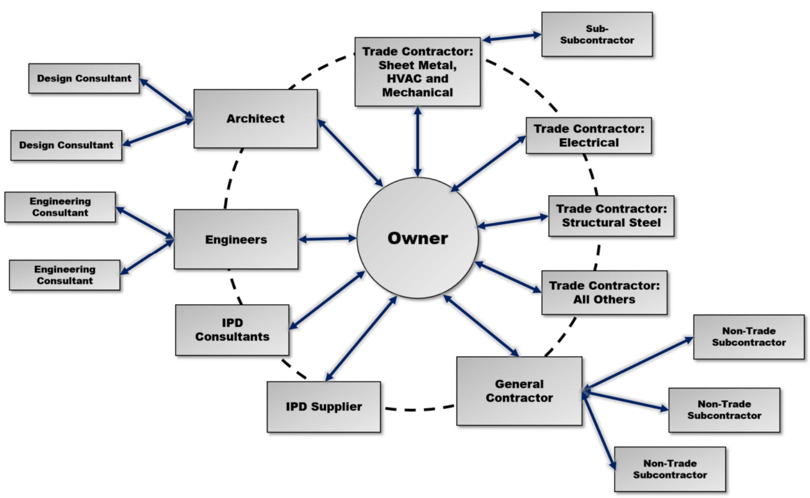

Figure 1. Risk-reward division of typical IPD MPA contracts (Ashcroft, 2012).

Methods

The purpose of this paper is to provide guidance to mechanical contractors that are not familiar with the IPD process. Since IPD is a project delivery method that many mechanical contractors have not participated in, the authors choose to conduct interviews with mechanical contractors that have previously participated in IPD projects. Interviews were conducted with six (6) SMACNA-member contractors having experience on IPD projects. Only six mechanical contractors were selected due to the limited time available to complete the interviews and concerns with COVID-19. Participants were solicited by the authors and SMACNA staff, and their participation was voluntary. Each 60-minute interview was conducted by telephone or Zoom, and responses were kept confidential.

As part of the interview, each respondent was asked the following five (5) open-ended questions:

- Why does IPD work?
- What does a mechanical contractor need to know before joining an IPD team?
- What does a mechanical contractor need to know during design and preconstruction to make the IPD process more effective?
- What does a mechanical contractor need to know during construction to make the IPD process more effective?
- What challenges or lessons learned have you had with IPD?

Table 1. Interview participant profiles.

Contractor	1	2	3	4	5	6
Region	Great Lakes	Midwest	Rocky Mtn.	Great Lakes	Great Lakes	National
Offices	1	13	3	1	1	8
Revenue ('19)	$82M	$400M	$157M	$45M	$50M	$1B
Trade	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical
Markets	Commercial Education Government Healthcare Hospitality Industrial Pharmaceutical	Commercial, Education, Entertainment Government Healthcare Hospitality Industrial	Commercial, Education Entertainment Government Healthcare Hospitality Industrial	Commercial, Education Entertainment Government Healthcare Industrial	Commercial, Education Entertainment, Healthcare Industrial Mixed-use	Commercial, Education Entertainment Government Healthcare, Hospitality Mixed-use
IPD projects	>50	1	1	1	8	>55
Trade partner	Yes	Yes	Yes	No	Yes	Yes

Interview Findings – Summary of Mechanical Contractors' Responses

Question #1: Why does IPD work?

The overall success of a project is measured by Owner satisfaction with the end product. The mechanical contractors noted that IPD is the delivery method that provides the greatest level of Owner satisfaction given their involvement in the process. The results of the interviews also point to the fact that if all project team members are aligned with the same end goal, the process and the end product will benefit.

"We are in the business to make Owners happy, and IPD is the best way to increase Owner satisfaction through the construction process. It's probably the delivery method that is the most fair to all players and aligns the team with the Owner's goals."

The overall attitude of mechanical contractors on an IPD project must be one of collaboration. IPD works because trade partners truly win as a team or lose as a team. In the IPD process, a single trade partner will not make a profit unless all trade partners make a profit. Mechanical contractors are used to having their profit at risk, but they are not used to having their profit depend on the performance of other trade contractors. When an issue arises on an IPD project, the problem is addressed immediately. The team focuses on the best solution for the project, not the best solution for an individual trade partner. In an IPD project, trade partners lookout equally for themselves, the Owner, and the other trade partners.

"Conversations are way more positive. Everybody is truly pulling in the same direction and trying to get the best end results."

"The reality is that when we are on an IPD job, we are all pulling on the same end of the rope. My foremen are looking out for the other foremen and aren't looking to (take advantage of) the other guy because we are all in this together."

The mechanical contractors also felt it was a significant advantage to have a direct line of access to the Owner, architects, and engineers during the project. Instead of resolving issues through a time-intensive request for information (RFI) process, trade contractors can go directly to the design staff in the 'big room' and collaboratively find a solution. The mechanical contractors also noted that the earlier they were involved with the design and preconstruction phase of the project, the better. While there were mentions of "spinning some wheels" and attending too many meetings, every mechanical contractor interviewed felt that they could not get involved in the IPD process too soon.

Question #2: What does a mechanical contractor need to know before joining an IPD team?

The mechanical contractors noted it is essential to understand their role in the IPD process fully. Different IPD jobs have different trades as trade partners. It is important to know which trades will be trade partners and which trades will be subcontractors to trade partners. It is essential to understand if and how non-trade partner subcontractors are tied to the MPA/IFOA and if there are clauses in the subcontract agreement that tie profit to the risk pool and require open book accounting procedures. It is imperative that the designers be part of the MPA/IFOA to ensure the integrity of the IPD process. If the architect and engineer are not contractually tied to the IPD process, the Owner and other trade partners will not get the full advantage of the IPD process.

"If you don't contract as an IFOA, you don't get the right behavior, period. You have to have risk and reward. It's just a different kind of game. You've got to get the right kind of people and the right kind of culture."

The mechanical contractors noted it is important to understand what project costs are at risk. The IPD contract structure will typically reimburse the trade partners for all direct project costs and all project-specific overhead costs, no matter if the project comes in over the target value or not. The mechanical contractors' standard profit and any shared savings at the end of the projects are always at risk. A mechanical contractor's general and administrative overhead can either be at risk or fully reimbursed, depending on the structure of the MPA.

An IPD team is only as strong as the weakest member. It is in the project team's best interest to select team members who exhibit traits conducive to the IPD process. Such traits include financial stability, trustworthiness, team-oriented employees, and the ability to forecast cost without complete design documents, self-perform most of their work, and provide in-house design support. The owner, design team, and general contractor need to assemble a group of trade partners that is a cultural fit.

"The culture is most important. The culture is built by understanding how you make money on an IPD project and how what you do affects other people."

IPD projects allow mechanical contractors to work on some of the highest-profile projects with some of the industry's most sophisticated owners. As a result, an IPD project will require the highest caliber designers, project managers, superintendents, foremen, and tradesmen. Typically, on a mechanical contractor's first IPD project, senior-level staff are very involved in the process and often will fill the project manager role. However, as the team gains experience on IPD projects, management tasks are delegated to project management level staff.

"The IPD process will require your highest performing team members."

"You have to use high-performance human capital on the IPD projects, and you have profit they could be making on other projects locked up in the IPD process. If you put those people on other jobs, they might be able to outperform the estimate and make you more profit at the end of the day. You have to balance repeat IPD work with the potential loss of additional profit on other projects."

IPD is a new delivery method that many mechanical contractors haven't used. One of the challenges mechanical contractors face is changing the mindset of their current employees to align with the IPD process. If mechanical contractors approach IPD projects with the same mindset as "plan and spec work," they will not be a valued trade partner. Changing the company mentality is something that is required from the top down.

"This was the first IPD project for all of the trade partners, and everybody came in with the traditional mindset, so we had to break free of that and reframe how we think about an IPD project."

"I will say that not every one of my foremen is good at IPD jobs. There are foremen that I won't put on an IPD job. They are good foremen, but they might not be able to grasp the big picture."

IPD projects can require greater cash flow since profit is distributed at pre-determined milestones or, in some cases, at the end of the project. Another item that affects cash flow is retention. If the Owner is only paying for the direct cost of the work but withholding profit, administrative overhead, and retention, the mechanical contractor is financing the project. Mechanical contractors must understand how retention will be handled to evaluate their cash flow requirements before executing the MPA/IFOA. Mechanical contractors noted that IPD projects often require access to cash or lines of credit. If financing is needed, it should be considered a cost of the work and billed to the job accordingly. For IPD jobs with interim profit distributions, these distributions are not guaranteed unless certain conditions have been met and all trade partners vote to release the profit.

To minimize cash flow, it is imperative that mechanical contractors accurately bill to ensure all costs are being recaptured and no reimbursable items go unaccounted for. To accomplish this, however, mechanical contractors noted that monthly progress billings for cost-reimbursable IPD projects require more time than with traditional projects. A few of the mechanical contractors interviewed had MPAs/IFOAs requiring detailed backup for general conditions and project overheads. At the same time, some MPAs/IFOAs allowed these to be billed as a percentage of markups. Mechanical contractors required to provide backup found that the pay application process took approximately twice the time compared to billing a design-bid-build (DBB) job. However, the mechanical contractors felt it was far easier to justify their costs by showing the other trade partners their actual backup than trying to explain how they arrived at a percentage markup without backup. Many MPAs/IFOAs will also require general and administrative costs to have complete supporting documentation. This typically requires access to years of sensitive company financial information. The mechanical contractors interviewed acknowledged that the open-book billing process exposed their financial information, but they did not feel it was a deterrent to working on an IPD project.

Question #3: What does a mechanical contractor need to know during the design and preconstruction phases?

"There is an IPD saying, go slow to go fast. Spend the time upfront in planning to ensure that everything can be built efficiently when you are in the field. That is where the benefit and cost savings come in."

One of the reoccurring themes in interviews with the mechanical contractors was the increased time that the preconstruction process required. Many mechanical contractors anticipated this but didn't fully understand the increased personnel commitments that IPD collaborations require until they were part of the process. Many of the mechanical contractors noted that full-time co-location in the big room was crucial to the success of the construction. Still, opinions varied on whether full-time co-location was needed during the preconstruction phase. Project size and complexity seemed to drive the degree of co-location required for preconstruction. It is interesting to note that one project was being designed during the quarantine restrictions of COVID-19 and that the mechanical contactor felt they were able to achieve the benefits of co-location while working entirely online. The contractor felt remote online collaborations could change the big rooms look for future preconstruction efforts. None of the mechanical contractors interviewed suggested that time was wasted during the preconstruction phase. While some mechanical contractors noted that it was not always the most efficient process, all indicated the effort paid off when the construction started.

"One thing about the big room environment is that you are available to people 100% of the time. So, the benefit is you are always available - and the downside is you are always available."

"It took me a while to get my people to dedicate the right amount of time to these jobs. When you land them, that is when the work starts. It is much different than in the DBB arena where my 'get work team' will land a job, and then we will hand it off to operations. Not with the IPD jobs."
"There's a lot of time in the pre-con side of things that you might not normally do. It's different, and it is frustrating at times because sometimes you feel like you're meeting to death."

"The biggest thing they need to understand is pre-con doesn't mean pre-con in the traditional sense. You're going to spend a lot of time talking about the project before you're ever going to be able to bill for much of anything other than your office overhead. If you've got project managers that you're used to being a profit center, you're not getting to their profit center for months or even a year."

"The preconstruction phase of the IPD project requires much more manpower be expended upfront than traditional project delivery methods."

Question #4: What does a mechanical contractor need to know during construction?

As an IPD project moves into the construction phase, many of the mechanical contractors interviewed again mentioned the importance of team alignment and team culture as one of the critical elements to the success of the IPD process. Many noted the effectiveness of using IPD coaches to help onboard new teams and felt coaching was essential for team members participating in an IPD project for the first time. Having trade partners and team members that help everyone keep the end goal in mind is vital in keeping people from reverting to their old ways.

"Team alignment and team culture are important. You need people that are open to new ideas. If they're stuck in their ways, they're going to fail, and they are going to drag you down with them. The jobs are all about teamwork, and it's everybody succeeding or failing together, and it can take some time for people to change their mindset because that's not necessarily the way construction has traditionally been."

'Understand that promises made are promises kept. Never ever make a commitment to schedule or material procurement that you can't meet. Other trades rely on these promises to develop the pull plan. Do not be afraid to say NO if something seems unrealistic. This is why you're part of the project. Claim your time and space as needed but never break a promise or make a false statement."

Many of the mechanical contractors interviewed reported success in changing the mindset of their employees. Issues did arise when employees couldn't get out of the traditional "plan and spec" mentality, but there were plenty of traditional projects these employees could be assigned to. While most foremen and superintendents truly enjoyed working on an IPD project, interview findings suggest that many mechanical contractors found it was easier to get the management team aligned with the IPD process than at the craft level. All agreed that the IPD mindset could not be left in the office; it must be passed down to the field.

"It was our job from the management side to educate our field superintendents and foremen on the IPD process and how the risk pool and incentive contracts work. This mentality then needs to be pushed down to the craftsmen in the field so they understand why we are doing things a certain way. It is important to involve them early in the education process. I can tell you that our field supervision down to our foremen and sub-foremen level are fully bought in. It is just continuing the education with workers below that level."

"The entire team needs to be on board. Since this was my first full project, it was easy for me to get into the IPD mindset. It is more difficult to get the field workers on board, and our foremen and superintendents needed to have the right personality and mindset for it. If a conflict did arise in the field between the trade partners, it was typically handled at the foreman or superintendent level, and they were able to mediate it."

One of the individuals interviewed was new to the industry and was asked, "As someone new to the industry do you feel that being on an IPD project helped accelerate your professional development?"

"Being a fly on the wall and hearing people's issues, opinions, comments, and concerns was very informative, even though I wasn't directly a part of the conversation. I learned so much being

immersed in the IPD environment. My challenge has been going back to a traditional project delivery method. It has been an adjustment and certainly a struggle. The mindset is certainly different and very self-oriented."

Question #5: What challenges or lessons learned have you had with IPD?

All the mechanical contractors interviewed felt that the IPD delivery method was an effective delivery method that they would all participate in again. However, most mechanical contractors pointed out that for an IPD project to be successful, all trade partners must be 100% bought into the IPD process. All the trade partners need to be contractually tied to the project's outcome via the risk pool. Projects where trade partners are not contractually tied to the project or risk pool often referred to as 'IPD-lite,' don't obtain the same results. The key players must have their profit at risk. In addition, nearly all mechanical contractors noted the importance of a fully committed, involved, and knowledgeable Owner to the overall success of an IPD project.

"There are times when a general contractor wants to get into the IPD process and talks their client into trying it. Those don't always work quite as well because the Owner doesn't always know what they are getting into. If the Owner and the general contractor aren't setting the right expectations, it is hard for the other trade partners to pull everybody along."

"One of the challenges early on is the Owner had project representation but didn't have a full-time decision maker onboard very early."

"Your Owner's representative needs to be very well versed in IPD and able to make the hard decisions quickly to keep the team moving forward. I felt like we needed an Owner's rep that was more decisive as there were times we spent weeks spinning our wheels waiting for a decision. We didn't really have the leader that could move the team forward so we spent a lot of time just talking about things and being at a loss for what to do."

"One of the biggest hurdles for getting Owners involved is having them determine who from their company is going to manage this process. You have to have an active and involved Owner in IPD. In the absence of an active and involved Owner in IPD, it's not true IPD. You need one person that can pull the appropriate people into meetings and make decisions when appropriate."

"The trade contractor should be aware of the arrangement between the Architect and Engineer with the Owner. Without a similar an agreement tying the A/E fees and reimbursables to the project profits, it becomes difficult for the trade partners to get cost savings options approved. As a team partner with fees tied to the profit pool, the designer is more apt to allow revisions as their profit will increase along with the trade partners."

The IPD process sets the target value of the project early in the design process. Two mechanical contractors had issues when they weren't involved with developing the initial target price.

"Having us be part of setting the initial target cost is really important. This job had some challenges on target cost due to the fact the initial project cost was set by the Owner, architect, and GC taking a larger previous project and scaling it down to meet the size of this project."

"All of the trade partners were brought on board after the price had been given to the Owner. When the trade partners became involved, the target price was immediately $20M over the initial budget. This created a lot of contention between the Owner, the GC, and the other trade partners. We should have been part of the original pricing and brought on board to help with that process."

Limitations

The main limitation of this study is the small sample size of six mechanical contractors. Future research could include a larger sample size and include the other trade contractors beyond the mechanical scope of work.

Summary and Conclusions

According to the mechanical contractors interviewed, IPD is the delivery method that provides the most significant level of Owner satisfaction. The mechanical contractors felt the overall risk on an IPD project tends to be less than traditional project delivery methods. Perhaps most important was the mechanical contractors' requirement to have direct access to a fully committed, involved, and knowledgeable Owner. Many mechanical contractors do not have familiarity with IPD. Those that do have found difficulties adjusting to the upfront time commitments, 'open-book' accounting, transparent communications, and overall culture of IPD projects. The interviews also found other challenges for mechanical contractors. Responding to an RFP for an IPD project is often much more time-consuming than bidding on a DBB project. Early involvement in preconstruction and the retention of profit and overhead can require greater cash flow. Monthly progress billings often require more time and documentation than traditional projects. The open-book billing process has the potential to expose sensitive financial information. However, the mechanical contractors interviewed understood these risks and did not consider them to be a deterrent for pursuing future IPD projects.

References

1. AIA California Council. (2014). Integrated Project Delivery: An Updated Working Definition. *American Institute of Architects*, 1–18.
2. American Institute of Architect California Council. (2007). Integrated Project Delivery: A Guide. *American Institute of Architects*, 1–62.
3. Ashcraft, H. W. (2012). The IPD framework. *Hanson Bridgett LLP*, 1–25.
4. Ashcraft, H. W. (2014). Integrated Project Delivery: Optimizing Project Performance. *Howard Bridgett LLP, from OwnersPerspective.Org, 16–21.*
5. Ashcraft, H. W. (2016). Targets of Opportunity: The Art of IPD Target Setting. *Hanson Bridgett IPD/BIM Practice Group,* 1-4
6. Cheng, R., & Johnson, A. J. (2016). Motivation and Means: How and Why IPD and Lean Lead to Success, *Integrated Project Delivery Alliance & Lean Construction Institute*, 1–255.
7. Allison, M., Ashcraft, H. W., Cheng, R., Klawans, S., Pease, J, (2018). Integrated Project Delivery An Action Guide for Leaders. *Charles Pankow Foundation, Center for Innovation in the Design and Construction Industry, & Integrated Project Delivery Alliance,* 1-79
8. McLin, M. (2018). Construction Contracts - Alternate Delivery Methods. *Sheet Metal and Air Conditioning Contractors' National Association,* 1-20
9. Thomsen, C., Darrington, J. W., Dunne, D., & Lichtig, W. A. (2009). Managing Integrated Project Delivery. *Construction Management Association of America*, 1-105.

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Project Delivery Method for Facility Condition Assessments – A Study of Industry Practices by AEC Service Providers

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Abstract
The practice of Facility Condition Assessments (FCA's) in the built environment can be the first step in development of new business opportunities for architecture, engineering, construction and asset management firms. In the United States, more than $279 billion in building retrofit investment opportunities exist across all market segments, which could yield more than $1 trillion in owner savings over the next 10 years. (Rockefeller Foundation 2012). AEC providers have risen to the need by providing FCA services, however, little is understood of which AEC providers are providing FCA services and project delivery approaches of FCA services. This study identified key inputs and outputs of FCA project delivery, resulting in an FCA project delivery method. Additionally, this study took the first step towards evaluating how FCA results are integrated with technology. This is the first global study of its kind and sets in motion a call for AEC stakeholders to provide FCA interoperability with asset management, facility management and capital planning.

Key Words: Facility condition assessment, AEC service providers, engineering management, architectural engineering

Introduction

In the United States, more than $279 billion in building retrofit investment opportunities exist across all market segments, which could yield more than $1 trillion in owner savings over the next 10 years. (Rockefeller Foundation 2012). A byproduct of Facility Condition Assessments (FCA's) is savings through the replacement of inefficient systems and or assets. Upgrading and replacing energy-consuming equipment in buildings offers an important capital investment opportunity and owners can utilize an FCA to develop and defend capital funding allocations. AEC providers have risen to the need by providing FCA services, however, little is understood of which AEC providers are providing FCA services and project delivery approaches of FCA services.

The practice of Facility Condition Assessments (FCA's) in the built environment can be the first step in development of new business opportunities for architecture, engineering, construction and asset management firms. Federal assistance programs may present additional opportunities for AEC industry, specifically in government and K-12 AEC sectors (AGC, 2021). Arguably, the first step in capital project work is to measure existing conditions to determine a course of action for which to take and which capital projects should be pursued. In addition, there appears to be a need for post-pandemic design and retrofit of existing buildings, which will benefit the AEC profession (AIA, 2021). Further, there is uncertainty of new commercial construction trends due to shifts in space utilization, identifying potential for existing buildings renovations to be an opportunity for AEC service providers.

The purpose of this study was to identify a review of literature on who is providing FCA services in the built environment and which inputs and outputs are included in the practice of FCA's. An additional research objective for this study was to investigate FCA results integration with technology.

Literature Review

Purpose and Value of FCA's

Previous research reviewed facility condition assessment literature and 94 various sources of literature were mapped to various purpose themes based upon content presented (Hillestad, et. al 2021). Results indicated that FCA's are used to increase knowledge of assets within an organization, with special emphasis related to strategic capital renewal or budget planning. Hillestad (2021) also found the practice of FCA's assists in determining capital funding allocations within organizations.

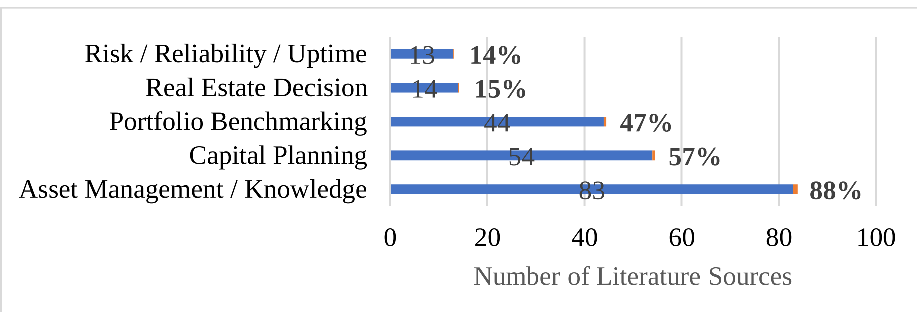


Figure 1. Purpose of a Facility Condition Assessment (Hillestad, et al. 2021)

FCA Project Delivery

Facility Condition Assessments contain information that is collected and filtered from multiple sources. The provider must figure out historical information such as when the building was originally constructed, any renovations or upgrades that have been performed over the lifespan of the building and an estimate of probable costs associated with potential capital projects (Ezovksi, 2009). If an FCA provider is stating that there are only 1 or 2 professionals that will participate in their services, a red flag should be raised by the facility manager as an FCA is recommended to be administered by a multi-disciplinary team of AEC professionals (IFMA, 2018; Bartels, 2014; RICS, 2020).

Key FCA Inputs

In this section, key inputs and outputs of FCA project delivery methods are explored with the assistance of industry standards. ASTM (2015) identifies key inputs as interviews with stakeholders, building walk-throughs and a review of provided facility information. Key outputs or deliverables of FCA projects may include a condition report, opinions of probable cost for projects or capital equipment replacements and additional considerations.

Review of Existing Facility Information Provided by Owner

Another method to discover information is to administer a survey to chief engineers, facility managers, administrators and facility occupants. This feedback can be helpful in determining space utilization trends and potential areas for further investigation. ASTM (2015) recommends owner provided documentation and information to assist with assessment development:

- Warranty information, safety inspection records, previous FCA reports
- Records indicating age of material building systems (roof, chillers, boilers, electrical, etc.)
- Pending proposals or contracts for capital equipment replacement
- Description of future improvements planned
- ADA survey and status of any improvements
- Drawings and specifications (as-built or construction)

Interviews to Discover Facility Information

Sullivan (2010) states the interview is the most dominant transfer of information in the selection process of a design services for a project. Comparatively, an informational interview with the facility manager or chief engineer can increase knowledge of existing systems and assets, thereby allowing for a more comprehensive review of existing conditions. While it is important to conduct an interview with a C-suite or executive level position responsible for identifying the purpose of the FCA for the organization, information obtained from executive level interviews may not reveal enough detailed information on building assets and systems for the assessor. Another challenge in this arena is executive turnover whereas newer employees may not have the necessary experience or knowledge with the organization’s decision-making history relative to FCA’s, building systems, assets and overall condition.

Building Walk-Throughs

ASTM (2015) suggests the objective of the FCA walk-through survey is to visually observe the property so as to obtain information on material systems and components. Learning a building through drawings can be a good starting point for developing knowledge, but a physical site walk-through allows confirmation of as-built conditions, identifies additions or renovations that have occurred since the date stamp on drawings and creates a more realistic snapshot of the current conditions. It is common for equipment to be replaced without documentation and by visiting each asset, an assessor can create increased accuracy with results.

The use of photogrammetry to visualize findings obtained from the building walk-through can be valuable for owner or client reporting. ASTM (2015) recommends that capture technology should be used to include typical elevations of exteriors, site work, parking area, roofing, structural systems, plumbing, HVAC, electrical systems, conveyance systems, life safety systems, representative interiors and or special or unusual conditions present. Before the building walk-through, there should be an agreement between the owner and contractor on components and or building systems to be included in scope of the report. For example, if the owner is in the public assembly facility sector, inclusion of videoboards may be a core assessment component, whereas in other sectors of facility management videoboards may not even be an asset for the owner.

Key FCA Outputs

Condition Report

A key output or deliverable of a facility condition assessment project is a condition report. This report includes a representative description of observed conditions (ASTM, 2015). Documentation includes photographic evidence of findings. Report content varies by facility type, size, use, location, construction type and design style (ASTM, 2015).

Opinions of Probable Costs

Winters (2003) notes facility managers should embrace the concept of requiring opinions of probable construction cost, which ordinarily occurs at the end of each design phase. FCA's are typically a reporting of a snapshot in time, and cost projections can fluctuate based upon economic and or market conditions. Winters (2003) advocates for cost consultants to be used for large or complex project types, like an FCA for institutional owners of a large facilities portfolio. Winters also notes that a reputable construction manager can also provide this function.

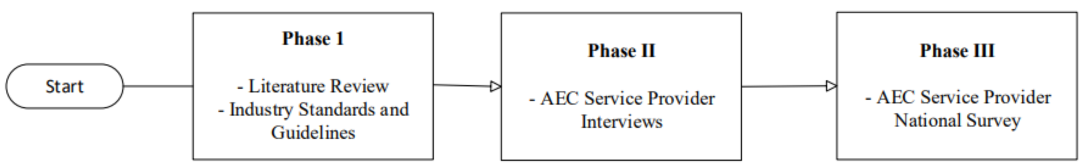
Additional Considerations

The final report can take varying directions based upon owner focus areas. Considerations typically out of scope may include engineering calculations to determine assets or systems compliance with design requirements, pest management observations, destructive testing, opinions on security posture of the facility and environmental assessments such as asbestos, potable water quality and hazardous wastes (ASTM, 2015).

Research Method

This research examines the current state of FCA practice by AEC providers through three phases:

- Phase I – Literature Review
- Phase II – Interviews with AEC FCA Service Providers (N=7)
- Phase III – National survey sent to 228 AEC firms advertising FCA services (N=30)



Phase 1

A limited presence of academic research on the practice of facility condition assessments exists. Therefore, a review of applicable industry standards and guidelines helped form a basis of themes to conduct an FCA.

Phase II

Seven interviews were conducted with AEC service providers of FCA's. The interview questions and answers were recorded via Zoom and then documented for further data analysis. The interview included demographic questions that asked position title and how many years of experience in the built environment interviewees possessed. Open ended questions were asked to further data collection. The participants were asked to identify the primary purpose of their firm (architecture, engineering, asset management, specialty FCA service). Additional questions asked participants to list key inputs and outputs of an FCA project, what industry standards or guidelines are used and valuation opinions of an FCA. For the sake of convenience, delimitations included geographic representation. Interviews were limited to FCA service providers working in Minnesota, Georgia, Arizona and California.

Phase III

A list of FCA service providers throughout the United States was assembled through using internet searches using the term "facility condition assessment", "building condition assessment" with the added State. This process was repeated for all 50 states. This resulted in a distribution list of 228 email addresses associated with organizations that are advertising on their respective websites that facility condition assessment services are offered as part of their professional services. Qualtrics was used to distribute the survey via a direct email to the distribution list. The survey was sent to 4 FCA service providers within the author's network to pilot the survey and obtain feedback on ease of navigating the survey and flow of questions and answers. Then, the survey was sent on July 27, 2021 to the assembled email addresses. 21 responses were recorded from this method. 19 responses were 100% complete and 2 responses were partial. On August 14, 2021, an anonymous survey link with survey purpose narrative was posted by the author on the social media platform LinkedIn to further data collection within the built environment. This added 9 responses to the survey for a total of 30 responses for data analysis.

Survey questions focused on answering questions linked to research objectives, specifically which inputs and outputs are included in the practice of FCA's. An additional research objective for this study was to investigate FCA results integration with technology.

Results and Findings

Results indicate diversity in who is conducting FCA's. There is not a dominant AEC stakeholder that performs FCA's, rather the data shows a multi-disciplinary approach with a collaborative team of AEC professionals in the delivery of FCA services. In this study, 81% of respondents indicated their organization has the ability to integrate FCA results into a capital planning software tool or Computerized Maintenance Management Systems (CMMS) program that their organization owns. This signals strength of interconnected facility and asset information across varying facility management functions. To that end, it appears the firms that offer a fully integrated architecture, engineering, construction, and capital/asset management consulting with software solutions are best positioned in the FCA market.

Table 1.1	Research Phase	
AEC Stakeholder Study Participant	Phase 2	Phase 3
Multi-discipline engineering firm	X	X
Multi-discipline architecture and engineering firm	X	X
Asset management firm	X	X
Architecture firm		X
Engineering firm		X
Construction General Contractor		X
Specialty consultant for facility condition assessments	X	X
Owners' representative / facility management consultant		X
Outreach institute of an educational institute		X
Mechanical contracting firm that offers engineering consulting services		X

The practice of FCA's in the AEC profession may be an emerging trend, but results of this survey indicate organizations have been offering FCA services for decades. This study found that 48% of organizations have been performing FCA's for 20 years or more and 74% of respondents indicated their organization has been performing FCA's for 10 years or more.

FCA Inputs

This study aimed to analyze which inputs are offered at a base level and if other inputs are used, would result in increased costs for the client requesting the FCA. Findings from the national survey are organized in Table 1.2 by percentage of respondents to each question as yes, offered as a base service or yes, offered as an additional cost to the client. This study confirmed the top inputs for conducting an FCA are interviews with chief engineer or lead maintenance personnel and a walk-through survey of building, spaces and equipment. Other key inputs included an interview with chief executive and use of information from previous FCA reports or client owned asset information systems, such as a CMMS.

Table 1.2		
Base Inputs vs. Added Cost Inputs	Yes, offered as a base service	Yes, offered as an additional cost to client
Interviews with chief engineer or lead maintenance personnel	100%	0%
Walk-through of building, spaces and equipment	100%	0%
Interview with chief executive (CFO, COO, etc.)	85%	15%
Occupant survey	61%	39%
Use of information from previous FCA reports or client owned asset information systems such as CMMS	57%	43%
Historical review of code permits associated with properties assessed	29%	71%
Energy management analysis	26%	74%
Drone inspections of roof or envelope	22%	78%

FCA Outputs

Similar to measurement of FCA inputs, questions were developed to better understand which FCA outputs are provided as a base FCA service and which outputs are offered at an increased cost to the client. Results from the national survey indicate the presentation of visual evidence, identification and or prioritization of capital projects and opinions of probable costs associated with capital projects as leading outputs of an FCA. Please refer to Table 1.3 for further analysis.

Table 1.3		
Base Outputs vs. Added Cost Outputs	Yes, offered as a base service	Yes, offered as an additional cost to client
Visual evidence (photos, videos, digital tours) of walk-through survey	95%	5%
Identification and prioritization of capital projects	95%	5%
Opinions of probable costs for capital projects	95%	5%
Asset useful life analysis	90%	10%
Calculation of FCI as portfolio measurement of building conditions	74%	26%
FCA results export to existing CMMS or enterprise asset management system used by client	39%	61%
FCA results upkeep services	21%	79%

Integration of FCA Results with Technology

Data from the national survey indicated a strong presence of software integration with FCA results. There appears to be robust adaptability by industry practitioners of FCA services to integrate results into a software that the client requesting the FCA owns or operates. Results also confirm a trend by FCA providers to offer a capital planning software that integrates FCA results.

Table 1.4		
FCA Results Integration Capabilities with Technology	% of Respondents	Rank
Ability to integrate FCA results into capital planning software or CMMS program the client owns	81%	1
Respondents' organization integrates FCA results into an existing CMMS software tool their client owns	66%	2
Respondents' organization integrates FCA results into a capital planning software tool they own	52%	3

Discussion

A proposed methodology to conduct an FCA includes purpose or project drivers, inputs and outputs. Figure 2 illustrates a conceptual method to conduct an FCA.

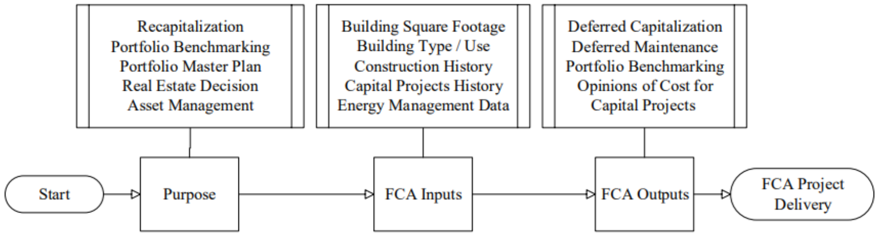


Figure 2. Facility Condition Assessment Project Delivery Method

Multi-Disciplinary Team

A key finding from this study was feedback that identified concern of hiring an FCA provider based upon business development objectives of the company. For example, if a construction general contractor is performing FCA's, FM's should carefully evaluate and structure FCA requirements to not encourage solicitation of new construction work, even though FCA results oftentimes end in capital projects. Likewise, a participant shared they would never award work to an FCA that has "skin in the game" for new work. Respondents with this view identified asset management or FCA specialty consultants as their FCA service provider. Thus, an inter-disciplinary team must be assembled to represent all phases of the facility lifecycle.

Interoperability of Asset Management, Facility Management and Capital Planning

An emerging practice of interdisciplinary FCA service providers answers the call of facility managers that are looking to integrate FCA results within a broader asset management and capital planning strategy for the organization. These companies offer FCA services as part of a combined analysis of asset data, leading to lifecycle and continuous management of facility engineering and operations. This approach typically would combine enterprise asset management (EAM) or computerized maintenance management (CMMS) platforms with customized FCA and capital planning capabilities. Further, possibilities exist with integrations of building automation systems (BAS) and energy consumption data to provide a comprehensive tool for facility managers to optimize their portfolio. Limited research has been performed connecting FCA proposed solutions to energy management practices over the lifecycle of a building. Significant opportunity exists to align FCA proposed solutions to energy efficiency (Lewis & Payant, 2000).

Conclusion

This study aimed to take the first step in identifying who is practicing FCA's in the built environment. 30 participants identified key inputs and outputs of an FCA project delivery method, resulting in a proposed project delivery method for the practice of FCA's by AEC service providers. Globally, this is the first study of its kind and serves as a call to research for further investigations into the practice of FCA's. Further research opportunities include analysis of energy management, interconnectedness of facility management practices with FCA results and how technology can be utilized with FCA results for improved owner decision making.

References

American Institute of Architects (AIA). (2021) Retrieved on October 26, 2021 from https://www.aia.org/articles/6312502-nonresidential-building-spending-projected

American Society of Civil Engineers, ASCE/SEI 30-14 Guideline for condition assessment of the building envelope, 2014.

Associated General Contractors. (2021, May 13). U.S. Treasury outlines how states can spend $350 billion state and local government COVID relied. Retrieved online at https://www.agc.org/news/2021/05/13/us-treasury-outlines-how-states-can-spend-350-billion-state-local-government-covid

ASTM International, E2018-15 – Standard guide for property condition assessment: baseline property condition assessment process, 2015.

Bartels, L. (2014). Alternate Methods to Obtain Facility Condition Assessment Data Using Non-Engineering Resources. International Journal of Information and Electronics Engineering, 4(4), 326.

Burr, K., & Jones, C. (2010). History, Current Practices, and Implications for the Future: The Role of an Architect. Associated Schools of Construction Proceedings of the 46th Annual International Conference. April 7-10, Boston, Massachusetts

Ezovski, D. (2009). The Value of Property Condition Assessments in Commercial Real Estate Lending-A property condition assessment can tell lenders if a property is being maintained and has defects or flaws that make it hard to maintain, manage, or sell. RMA Journal, 91(7), 46.

Hillestad, D., Sullivan, K., Hurtado, K., Ayer, S., Smithwick, J. (2021). Condition Assessments in the Facility Management Profession – A Literature Review. Journal of Facility Management Education and Research.

International Facility Management Association, IFMA. (2008). Asset lifecycle model for total cost of ownership management. A framework for facilities lifecycle cost management. Retrieved from http://www.ifma.org/docs/knowledgebase/asset_lifecyle_model.pdf?sfvrsn=2

Mayo, G., & Karanja, P. (2018). Building Condition Assessments–Methods and Metrics. Journal of Facility Management Education and Research. Vol. 2, No. 1, pgs. 1-11

RICS (2020). Technical due diligence of commercial property. Retrieved online at https://www.rics.org/globalassets/rics-website/media/upholding-professional-standards/sector-standards/building-surveying/technical-due-diligence-of-commercial-property.pdf

Rockefeller Foundation (2012). United States Building Energy Efficiency Retrofits. Retrieved September 26, 2021 online at https://www.rockefellerfoundation.org/report/united-states-building-energy-efficiency-retrofits/

Sullivan, K., Kashiwagi, J., & Kashiwagi, D. (2010). The optimizing of design delivery services for facility owners. Journal of Facilities Management. Vol. 8, No. 1, pgs. 26-40.

Winters, P. (2003). What owners want from architects – and how to ensure that expectations are met. Journal of Facilities Management. Vol. 2, No. 3, pgs. 276-284.

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A Comparison of Contract Requirements for Design Professional Liability Insurance in Design-build Highway Projects

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In the transportation design-build (DB) industry, the responsibility of the design is transferred to the design-build team from the owner. One of the critical issues for state departments of transportation (DOTs) is design professional liability. To cover designers' professional negligence, design professional liability insurance (DPLI) should ensure satisfactory coverages in DB projects for state DOTs. The objective of this study is to identify the variability of the DPLI policy requirements that are found in DOT DB projects. This study conducts content analysis and comparative analysis of 15 DOT archival data that consist of design-build agreements and requests for proposals. This study determines six common elements of DPLI requirements: (1) types of DPLI, (2) indemnifying party, (3) coverage amount, (4) extended reporting period, (5) retroactive date, and (6) supplemental policies. The results show that these DPLI policy elements depend on the available customizable options and requirements. Some DOTs tend to explicitly state all six elements, while other DOTs require a few of these six elements. The findings also explain the significant characteristics and implementation of each policy element. Its findings contribute to a better understanding of DPLI requirements and provide opportunities for decision-makers to reduce issues related to insurance coverage gaps.

Key Words: Design professional liability insurance, errors and omissions insurance, design-build, transportation infrastructure

Introduction

Design-build (DB) is no longer considered an experimental project delivery method. The number of projects in the transportation infrastructure industry procured with DB in the United States increased 600 percent from 2002 to 2016 (DBIA, 2016). In 2018, the FMI Corporation reported that DB spending was anticipated to increase by 18 percent in the nonresidential construction market between 2018 and 2021. As of August 2021, DB had been fully authorized in 30 states and the District of Columbia, widely permitted in another 5 states, and authorized with certain limitations in 11 additional states, while only four states do not have the authority to use DB in highway programs (DBIA, 2021). In the DB environment, a single entity, a design-builder, can overlap design and

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construction activities and even initiate its construction work before the design phase is complete to save cost and time (Ashuri et al., 2013). However, in this alternative method, more roles and responsibilities have shifted from state departments of transportation (DOTs) to design-builders, and this change can create problems in determining liability when a dispute arises between the owner and design-builder and between the design-builder and design professional (Loulakis et al., 2015).

One critical risk factor in the delivery of highway projects is design liability (Ashuri et al., 2018; Gad et al., 2015; Kraft & Molenaar, 2015; Lee et al., 2020). State DOTs require a design professional liability insurance (DPLI) policy to cover designers' professional negligence, commonly known as an errors and omissions (E&O) policy. A few of the literature has identified several elements in DPLI policies in DB. Rowings, Federle, & Rusk (2000) asserted the importance of reviewing contractual responsibilities, insurance, and obligations because most of the liability is passed through to the designer in the DB team. They found two very common practices in DB electrical projects: using project-specific professional liability insurance and modifying the corporate design professional liability insurance to allow participation in DB projects. They found that 69 percent of electrical contractors obtained additional professional liability insurance for individual projects, while 49 percent of them stated their firm had modified the policy to allow DB projects (Rowings et al., 2000). Stephen Wichern (2004) studied three approaches for protecting the owner in DB projects against the design liability risk by providing comprehensive insurance coverage. The first approach is to demand the minimum standards in the designer's E&O insurance coverage, including appropriate insurance minimums, long-term protection, retroactive coverage, and even excess E&O coverage. The second approach is to require the contractor to purchase a standalone professional liability policy to cover the design liability exposure of the project. The third suggested approach is owner-controlled insurance programs (OCIPs), a type of project-specific DPLI purchased by the owners. This policy is typically employed on large and complex construction projects involving numerous parties.

Mayssa, Abdul-Malak, & Srour (2018) provided comprehensive research on multi-tiered professional liability coverage in DB. The research identified different insurance policies for construction projects, including designers' practice professional liability indemnity, contractors' professional liability, owners' protective professional indemnity, contractors' protective professional indemnity, project-specific professional liability insurance, and mitigation of loss/damages. The researchers proposed a process model that illustrates the considerable insurance-coverage claim path and explains how various coverages can be triggered. They concluded that the increasing complexity of projects and integration between design and construction in design-build make professional liability risk the most challenging issue to ensure (Kalach et al., 2018).

The literature has identified several elements in DPLI policies in DB. However, previous research on the practice of design professional liability insurance in design-build has been scarce, and only a few previous studies have been found in the area. A gap remains regarding the state of practice of DPLI across the U.S., and the underlying thought process for selecting the E&O policy requirements has not been fully identified. Therefore, this study aims to identify the fundamental elements of DPLI policies commonly required by state DOTs for transportation DB projects and characterize each policy element and implementation.

Research Methodology

This study conducted a comparative content analysis of DOT procedures using a mix of qualitative archival data to develop a systematic understanding of contract requirements for DPLI in design-build highway projects. We sampled public archival data that consisted of design-build agreements (DBAs) and requests for proposals (RFPs) that specify the insurance requirements for specific projects. Based on the availability of public information in the documents, we sampled from three DBAs and 14 RFPs from 15 DOT documents. DPLI requirements show great variations in policy elements depending on the available customizable options. This study provides the foundation on the variability of contractual policy requirements and the emerging trend of state DOTs' practice of DPLI.

Results

Key Elements of DPLI Policy Requirements

This study found that state DOTs require design-builders to meet the minimum requirements for the DPLI policy, and the language of DPLI requirements varies from state to state. The insurance section from state DOT RFPs and DBAs shows several elements of DPLI policy requirements that are commonly used under the DPLI policy language. Table 1 shows the six elements in DPLI policies: (1) types of DPLI, (2) indemnifying party, (3) coverage amount, (4) extended reporting period, (5) retroactive date, and (6) supplemental policies. Some DOTs tend to explicitly state all six elements in their RFPs or/and DBAs, while other DOTs require some of these elements. This research also found the similarities and differences in describing each element among state DOTs. This study attempts to present the state-of-the-art practices in fundamental elements of DPLI requirement from state DOTs that are actively using DB programs and determine significant characteristics of each policy element.

Table 1

Fundamental elements in state DOT's DPLI requirement section

	DPLI type	Indemnifying parties	Coverage amount	Extended reporting period	Retroactive date	Supplemental policies
Arkansas DOT	X	X	X	X	X	X
Caltrans	X		X	X	X	
Colorado DOT			X	X	X	
Connecticut DOT	X		X	X		
Florida DOT	X		X			
Georgia DOT	X		X	X	X	
Idaho DOT			X	X		
Maine DOT			X			
Massachusetts DOT		X	X	X	X	
Mississippi DOT			X	X		
Missouri DOT	X		X		X	
Montana DOT			X			
Ohio DOT	X		X	X	X	
South Carolina DOT			X	X	X	
Texas DOT	X	X	X	X		X

Types of DPLI

Engineering firms can purchase a DPLI policy either on an annual basis or for specific projects. The most common policy that covers all ongoing projects of the firms if the policy is renewed every year is annual-based DPLI, also known as "practice policy" or "corporate policy."

Annual-based DPLI is for the named insured—the engineering firm only—and the coverage amount is shared by all the projects performed by the engineering firm during the coverage period. In contrast to the annual-based policy, project-specific DPLI is purchased to cover design liability for a specific project. The rationale for purchasing this type of policy for a specific project is whether or not the coverage has already been exhausted by other projects under the same annual-based policy of the engineering firm (Hickman, 2013).

Based on content analysis of requests for proposal and design-build agreements from 15 DOTs, the study found that the requirements regarding types of DPLI show variations in three ways, shown in Figure 1. First, some DOTs do not specify the types of DPLI in their insurance requirements, as no such language is found in their insurance requirement sections of the DB contract documents. Example language from Massachusetts DOT is "[t]he DB Entity shall provide professional liability coverage with limits not less than $1,000,000 per claim and aggregate, protecting against any negligent act, error or omission arising out of design or engineering activities with respect to the Project […]." In such a paragraph of insurance requirements, required design professional liability insurance types are not mentioned. Idaho, Colorado, Maine, Massachusetts, Mississippi, Montana, and South Carolina DOTs are under this category.

Second, some DOTs require DPLI for a design-build project to be a project-specific policy. Per the project requirements, the project-specific policy must be purchased; providing annual-based practice design professional liability insurance will not be acceptable for these state DOTs' design-build projects. Example language from Georgia DOT is that "[s]uch policy is to be project-specific." Four out of fifteen DOTs show such requirements in their design-build documents: Connecticut, Florida, Georgia, and Missouri DOTs.

Lastly, state DOTs are open for either annual-based or project-specific policies. Design-build contract documents specifically indicate that design-builders can choose either annual-based or project-specific policies, showing that DOTs have been aware of the two types of policies used in current practice. They indicate their openness regarding the use of the two types of policies. Arkansas DOT, Caltrans, Ohio DOT, and Texas DOT use this type of requirement. Example language from Texas DOT is "DB Contractor may satisfy such insurance requirement via either a series of annual practice policies or a project-specific policy covering the period of design and construction." Ohio DOT is a bit different from the other DOTs mentioned above. They differentiate the design professional liability insurance requirement based on the size and complexity of the project. The Ohio DOT representative mentioned that, for large/complex projects, Ohio DOT requires project-specific DPLI for the design-build team and annual-based practice DPLI for a contractor's in-house design service. For other projects, Ohio DOT mentions annual-based practice DPLI only.

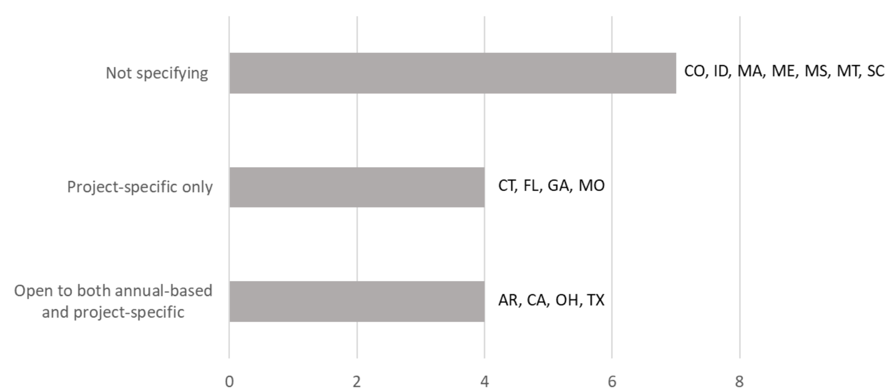

Figure 1. State DOTs' practices in the requirement for DPLI types

Coverage Amount

The coverage amount is the maximum amount of money that the insurance company provides the insured for coverage under DPLI. It is a typical term in all DPLI policies. State DOTs set the minimum amount of coverage the design-builder needs to provide or change minimum coverage requirements depending on project size based on their criteria size and cost.

For the first case, the coverage limit term usually is specified by a certain amount per claim and in aggregate in the policy. The coverage amount of DPLI shows wide variation depending on the requirement from the insured and the available options from the insurance company. A certain amount per claim and/or aggregate is always found as one of the DPLI requirements in their contracts. The results show that eleven DOTs usually specify a certain amount for the policy coverage. Table 2 shows the coverage variations among DOTs, ranging from $1M to $25M. Georgia DOT requires a coverage limit per claim only, and Idaho DOT requires only a coverage limit in aggregate. Aside from Georgia and Idaho DOTs, the other nine DOTs set the policy thresholds for each claim and aggregate amount.

Table 2

Typical minimum coverage requirements

State DOT	Limit per claim ($)	Limit in aggregate ($)
Arkansas	10M	10M
California	2M	2M
Colorado	1M	1M
Georgia	1M	-
Idaho	N/A	1
Maine	1M	1M
Massachusetts	1M	1M
Mississippi	3M	5M
Montana	1M	1M
South Carolina	10M	10M
Texas	5M	25M

On the other hand, four DOTs—Connecticut, Florida, Missouri, and Ohio—tend to change minimum coverage requirements depending on project size based on their criteria, such as project size and cost (see Table 3). Ohio DOT classifies DB projects based on their sizes (small or large) and specifies different minimum limits for DPLI coverage (per claim or in aggregate) for the project types. For small projects, Ohio DOT does not require the design-builder to purchase a project-specific policy, as mentioned in the previous section, and the minimum coverage requirements are $1M for each claim and in aggregate. Ohio DOT increases the minimum requirements for large projects and requires the design-builder to hold a project-specific policy. Ohio DOT requires increased liability requirements if the project has high-risk items, and large projects typically have higher risk items, so that the requirements need to be increased. The Ohio DOT representative explained that any project over $100M is typically considered a large project. For large projects, the minimum requirement for coverage is $10M per claim and in aggregate. Three other DOTs—Connecticut, Florida, and Missouri—require a project-specific policy only, and they classify the minimum requirements based on project cost. The study found that the main reasons to classify projects based on their size to specify DPLI depend on owner risk and project risk.

Table 3

Coverage requirements variation

	Project Size	Minimum Per Claim ($)	Minimum Aggregate Limit ($)
Connecticut DOT	- Under $25M	N/A	2M
	- Under $50M	N/A	3M
	- Under $100M	N/A	4M
	- Over $100M	N/A	5M
Florida DOT	- Under $30M	N/A	1M
	- Under $75M	N/A	2M
	- Over $75M	N/A	5M
Missouri DOT	- Under $50M	1M	1M
	- Over $50M	10M	10M
Ohio DOT	- Small projects	1M	1M
	- Large projects	10M	10M

Indemnifying Party

Indemnity endorsement is a term that specifies another party as the indemnifying party under the policy so that it holds the party harmless from any claims brought by a third party due to professional negligence. The annual-based policy does not allow the prime insured to indemnify any other parties. At the same time, indemnity endorsement can be added under a project-specific policy regardless of the purchaser of the project-specific DPLI.

The study found that the Texas, Massachusetts, and Arkansas DOTs include indemnity endorsement in their DBA. Texas DOT stated that “[s]uch insurance shall provide an indemnified party endorsement for the benefit of TxDOT.” Massachusetts DOT stated, “[t]he policy must also indemnify MassDOT for any liabilities, damages or judgments, and reasonable attorneys’ fees and related costs due to a Breach of Professional Duty of the Named Insured(s) and/or their subconsultants.” Finally, Arkansas DOT stated that “[…] the Department and the parties listed in Section 9.2.6 as indemnified parties on such policies.”

Extended reporting period

DPLI policy is written on a “claims-made” basis so that the coverage triggers when an actual claim is filed during the policy period (Hickman, 2013). Extended reporting period (ERP) provisions are commonly used on claims-made policies. ERP provisions do not mean the extension of the policy, but this allows the insured have additional time to file or present claims based on acts, errors, or omissions to the insurer after the policy period has ended (Hickman, 2013).

According to the content analysis of RFPs and DBAs, this research found that most DOTs have ERP provision in their DPLI section, as shown in Figure 2. Four DOTs—Florida, Maine, Mississippi, and Montana—do not require ERP in their documents. Three to five years of ERP were required by eight DOTs. Ohio DOT has different ERPs based on the complexity of the projects. It requires 3-year ERP for small projects and 5 years for large/complex projects.

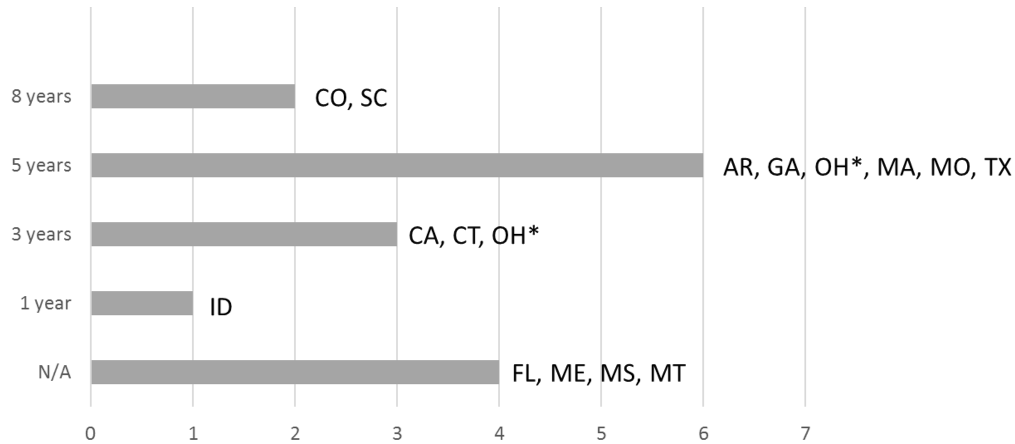

Figure 2. Requirements for the extended reporting period

Retroactive date

Similar to ERP, retroactive date provisions are standard in DPLI policies because of the nature of claims-made policies that limit coverage triggers during the policy period (Hickman, 2013). The policy can be covered after a designated date, called a retroactive date. Claims that arise out of acts, errors, or omissions could be covered under the policy if the claims occurred after the policy's retroactive date and before the policy's expiration date (Hickman, 2013).

Based on the content analysis of RFPs and DBAs from 15 DOTs, 8 out of 15 DOTs include retroactive date provisions, and the other seven DOTs do not include the provisions. These eight DOTs use different languages for the retroactive date since the retroactive date is a designated date that the policy coverage can be in effect. This date can vary depending on the choice of DOTs. The study found four types of example languages that are required under DPLI sections: (1) design work commencement, (2) contract execution, (3) exact date, and (4) final RFP issue. Their example languages regarding the retroactive date are shown below.

1. Design Work Commencement
   - Colorado DOT: "a retroactive date which covers the period in which the design work began"
   - Georgia DOT: "a retroactive date no later than the date that design services commenced"
   - Missouri DOT: "[t]he policy shall have a retroactive date of no later than the date the first design or engineering Activities have been conducted by the Designer"
2. Contract Execution
   - Arkansas DOT: "a retroactive date of no later than the date of execution of this Design–Build Agreement"
   - California DOT: "a retroactive date no later than the date of this contract execution"
   - South Carolina DOT: "any retroactive date under the policy shall precede the effective date of this Contract"
3. Exact Date
   - Massachusetts DOT: "[t]he policy shall have a retroactive date no later than the date hereof"
4. Final RFP Issue

- Ohio DOT: “the policy shall have a retroactive date no later than the date on which the final Request for Proposal documents are issued”

Supplemental policies

Some additional policies supplemental DPLI and provide extra protection regarding losses due to professional negligence. These policies aim to fill the potential gaps of the prime DPLI policy and provide the team with extra coverage. The contractor’s protective professional indemnity (CPPI) is a policy that supplements the prime DPLI policy and provides additional protection for the design-builder. The policy provides the design-builder with excess coverage over the DPLI policy of design sub-consultants if the design-builder suffers losses due to professional negligence by its design sub-consultants. It also provides coverage for losses from professional negligence by the design–builder’s self-performed design work. The owner’s protective professional indemnity (OPPI) is another supplemental policy that provides additional protection for the owner. OPPI covers the professional negligence damages that exceed the DPLI policy coverage provided by the design-build team. It also protects the owner by indemnifying the owner against third-party claims arising from professional negligence, which can be an alternative to indemnity endorsement under the main DPLI policy.

The researchers found state DOTs’ practices in these supplemental policies. Two DOTs out of the eleven DOTs being examined—Arkansas and Texas—specifically require CPPI as supplemental policies under the DPLI requirement section. None of the DOTs studied in this research has used OPPI. This may lack familiarity with this policy since only limited underwriters offer this coverage (Taylor, 2012).

Conclusions

In the current insurance market, various DPLI products are available following the growing number of DB projects and the increasing demand for customizable policy options. The study determines the fundamental elements in DPLI policies commonly required by DOTs. The study examined the DPLI requirement section from state DOTs’ RFPs and DBAs and found six common elements: (1) types of DPLI, (2) indemnifying party, (3) coverage amount, (4) extended reporting period, (5) retroactive date, and (6) supplemental policies.

The authors found that the annual-based practice DPLI by the engineering firm is favorable as it has been in the industry for the most prolonged period. The engineering firms are typically required to hold the annual-based practice policy to perform design service in the highway industry. However, the annual-based practice policy has less flexibility of modifying specifically for one project because this policy is to cover all other projects in the engineering firm during the policy period, while the project-specific policy is designed for a specific project only. Inclusion of indemnifying parties, ERP, or retroactive date might be a hassle when using an annual-based practice DPLI because of its lack of policy flexibility, while it is common when a project-specific DPLI is used. Regarding the coverage amount, the authors found that the main reasons to classify projects based on their size so as to specify DPLI depend on owner risk and project risk.

The ways to elaborate DPLI requirements vary from state to state and project by project. Some DOTs tend to explicitly state all six elements in their RFPs or/and DBA, while other DOTs require some of these seven elements. This study also found the similarities and differences in describing each element among state DOTs. This study contributes to identifying the contractual requirements for design professional liability insurance, commonly required by state DOTs. It is anticipated that transportation professionals would benefit from the findings of this study through a better understanding of DPLI requirements. Its findings contribute to a better understanding of professional liability insurance as a risk management tool and provide opportunities for decision-makers to reduce issues related to insurance coverage gaps.

References

Ashuri, B., Jallan, Y., & Lee, J. H. (2018). *Materials Quality Management for Alternative Project Delivery*.

Ashuri, B., Mostaan, K., & Hannon, D. (2013). *How Can Innovative Project Delivery Systems Improve the Overall Efficiency of GDOT in Transportation Project Delivery?*

Design-Build Institute of America (DBIA). (2016). *Design-build done right: Transportation sector* (Issue April).

Design-Build Institute of America (DBIA). (2021). *DBIA State Maps*. Design-Build Institute of America. https://dbia.org/advocacy/state/

Gad, G. M., Adamtey, S. A., & Gransberg, D. D. (2015). Trends in quality management approaches to design-build transportation projects. *Transportation Research Record: Journal of the Transportation Research Board*, 87–92. https://doi.org/10.3141/2504-11

Hickman, A. (2013). *Design-Build Risk and Insurance*. International Risk Management Institute, Inc.

Kalach, M., Abdul-Malak, M.-A., & Srour, I. (2018). Multi-Tiered Professional Liability Coverage for Designers and Contractors under Design-Build Project Delivery. *Construction Research Congress (CRC)*, 723–732. https://ascelibrary.org/doi/pdf/10.1061/9780784481301

Kraft, E., & Molenaar, K. R. (2015). Quality assurance organization selection factors for highway design and construction projects. *Journal of Management in Engineering*, *31*(5). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000289.

Lee, J. H., Jallan, Y., & Ashuri, B. (2020). Key Issues and Differences in Practical Components of Quality Management in Design-Build Highway Projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *12*(1), 04519029. https://doi.org/10.1061/(asce)la.1943-4170.0000334

Loulakis, M. C., Smith, N. C., Brady, D. L., Rayl, R. E., & Gransberg, D. D. (2015). *Liability of Design-Builders for Design, Construction, and Acquisition Claims*. National Academies Press. https://doi.org/10.17226/22074

Rowings, J. E., Federle, M. O., & Rusk, J. (2000). Design/build methods for electrical contracting industry. *Journal of Construction Engineering and Management*, *126*(1), 15–21. https://doi.org/10.1061/(ASCE)0733-9364(2000)126:1(15)

Taylor, R. J. (2012). *Professional liability insurance for construction projects*. International Risk Management Institute. https://www.irmi.com/articles/expert-commentary/professional-liability-insurance-for-construction-projects

Wichern, S. (2004). Protecting Design-Build Owners through Design Liability Coverage, Independent Construction Managers, and Quality Control Procedures. *Transportation Law Journal*, *35*, 1–106.

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Time, Cost, and Construction Intensity Comparison between Design-Manufacture-Construct and Traditional Design-Bid-Build Delivery Methods

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The Design-Manufacture-Construct (DMC) technique is a novel delivery method that decreases construction time and cost while increasing construction intensity compared to a traditional delivery method. The purpose of this study was to understand the time, cost, and construction intensity differences between DMC and the conventional Design-Bid-Build (DBB) delivery method. The study utilized semi-structured interviews (SSI) and quantitative data analysis for investigation. The study included interviews with employees from BLOX LLC (a firm specializing in the DMC delivery method) and includes an analysis of data collected on multiple free-standing emergency department (FSED) projects constructed using both the DMC and DBB delivery methods. Descriptive and inferential statistics were used to test hypotheses based on the two delivery methods' time, cost, and construction intensity performance factors to analyze the project data. The results suggested that DMC outperforms DBB in cost performance, supported by inferential statistics data ($p \approx 0.00$). Moreover, although inferential statistics do not show any significant difference between DMC and DBB ($p > 0.05$) concerning time and construction intensity performance, descriptive studies indicated that DMC still performs better than DBB in both these factors.

Key Words: Modular Construction, Design-Manufacture-Construct (DMC), Delivery Method, Business Model, Performance

Introduction

At present, the traditional construction industry's performance remains low, and productivity improvement is slight compared to other sectors such as the manufacturing industry (Mao et al., 2017). Unlike traditional construction, most studies suggest that modular construction reduces project duration and cost (Azhar et al., 2013; Blismas & Wakefield, 2009; Wuni & Shen, 2019; Jaillon & Poon, 2009) moving the productions to offsite factories. On the contrary, some studies argue that modular construction exhibits little difference in time and cost performance than conventional construction (Mao et al., 2016). Zhai et al. (2014) concluded their research by suggesting a thorough time and cost comparison between traditional and modular construction methods. The architecture, engineering, and construction (AEC) industry has been reluctant to drastically alter its business model of in-situ construction. It is suggested that the modular construction industry could learn from the manufacturing industry's more efficient production methods (Luo et al., 2017).

In contrast with manufacturing, construction is a project-oriented business producing a unique product, where more resources are involved and more stakeholder relationships exist between activities. The establishment of an innovative delivery method is essential to increase productivity. Architects need to learn from the manufacturing industry and view buildings as manufacturing products (Wuni & Shen, 2019; Hu et al., 2019) to consider the assembly process thoroughly. Some industry practitioners have taken the challenge to initiate a novel modular construction business model. One such company, BLOX LLC, proposes a Design-Manufacture-Construct (DMC) delivery method that oversees the means and methods from design to construction by intentionally leveraging manufacturing. A recent article in the *Engineering News Record* suggests that the DMC delivery method could provide a new platform for the AEC industry (Judy, 2020).

Research Rationale

While there are other studies that compare cost and time in favor of modular construction, none have been specifically focused on the design-manufacture-construct process that seems to be disrupting the conventional means of building the freestanding-emergency-department building classification type. Therefore, this study addresses this gap by conducting a time, cost, and construction intensity comparison between the DMC modular construction method and the traditional construction method of DBB. This research is unique in that it provides an analytical approach toward understanding the effectiveness of the DMC method used for the FSED building type through both a descriptive and inferential lens.

Methodology

A quantitative analysis was conducted using data collected from BLOX LLC for projects using the DMC method and similar projects using a traditional DBB method. These quantitative data and qualitative data via informal interviews were also collected to enrich the comparisons between the two delivery methods. The following sections describe the equations used to analyze the data.

Analysis of Time

The design and construction duration measures the time between the start of the design phase to the certificate of occupancy. This time analysis compares the projects' duration from design to construction between DMC and DBB. The format of the time analysis is displayed in EQ. (1):

$$Time = Final\ certificate\ of\ occupation\ date - Final\ design\ start\ date \tag{1}$$

Analysis of Cost

The cost comparison is calculated by dividing the final project cost, which includes transportation costs (the original contract amount plus all changes orders for the project) by the overall area in terms of square feet. The general format of cost analysis is presented in EQ. (2):

$$Cost = \frac{Final\ design\ and\ construction\ cost}{Total\ project\ square\ feet} \tag{2}$$

Analysis of Construction Intensity

The construction intensity compares the construction square footage installed over time as shown in the following equation EQ. (3):

$$Costruction\ intensity = \frac{Total\ project\ square\ feet}{Final\ design\ and\ construction\ duration} \tag{3}$$

Furthermore, these metrics were then analyzed using an inferential two paired-sample t-test to determine a significant difference between the DMC and DBB delivery methods on time, cost, and construction intensity performances. These data are then used to decide the following hypotheses and associated null hypotheses.

1. $H1_A$: $Cost_{DMC} < Cost_{DBB}$ ($H1_0$: $Cost_{DMC} \geq Cost_{DBB}$)
2. $H2_A$: $Time_{DMC} < Time_{DBB}$ ($H2_0$: $Time_{DMC} \geq Time_{DBB}$)
3. $H3_A$: $Construction\ Intensity_{DMC} > Construction\ Intensity_{DBB}$ ($H3_0$: $Construction\ Intensity_{DMC} \leq Construction\ Intensity_{DBB}$)

The questions were asked to elicit views from participants in the design, manufacture, and construction process and obtain opinions on critical factors influencing time and cost using DMC. A series of data was then processed through equations to determine DMC's performance in terms of time and cost.

Semi-Structured Interviews

Data were also collected by conducting semi-face-to-face (Zoom) interviews with three team members who worked on the case study projects, they were the Design operations manager, the Superintendent, and the Lead- MEP vertical. The questions were asked to elicit views from participants in the design, manufacture, and construction process and obtain opinions on critical factors influencing time and cost using DMC.

Results

Samples

The researcher collected 21 DMC and 34 DBB project data sets. Of these projects, the 21 DMC projects were collected from BLOX LLC (modular building method). The 34 DBB data sets were collected from competitors to BLOX LCC that built FSED projects using the DBB delivery method. Out of these 21 DMC projects, 7 were health clinics that significantly differed in size and programs than the rest of the data and were therefore excluded from the analysis. Thus, for this research n_{DMC} = 14 and n_{DBB} = 34.

Time Results

Figure 1 illustrates the 14 DMC and 34 DBB projects' time in a boxplot. This figure shows DBB has a more concentrated distribution between 213 to 241 days with a median of 235 days. By comparison, DMC has a broader distribution range between 190 to 240 days with a median of 220 days. Both DBB and DMC have a significant duration gap between the shortest and longest project completion times.

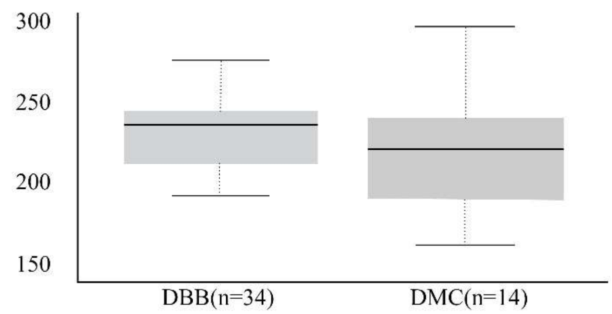

Figure 1. *DMC vs. DBB Design & Construction Duration (Calendar Days) Scatter Plot Comparison*

Figure 2 compares duration of the 14 DMC projects and 34 DBB projects in the same plot. This scattered plot illustrates that while the DMC projects and DBB projects have a relatively similar performance duration, DMC's duration decreases higher than DBB projects. The DBB trend line is unchanged over time. In other words, DMC has a better continuous improvement opportunity in design and construction duration, and over time, DMC tends to outperform DBB.

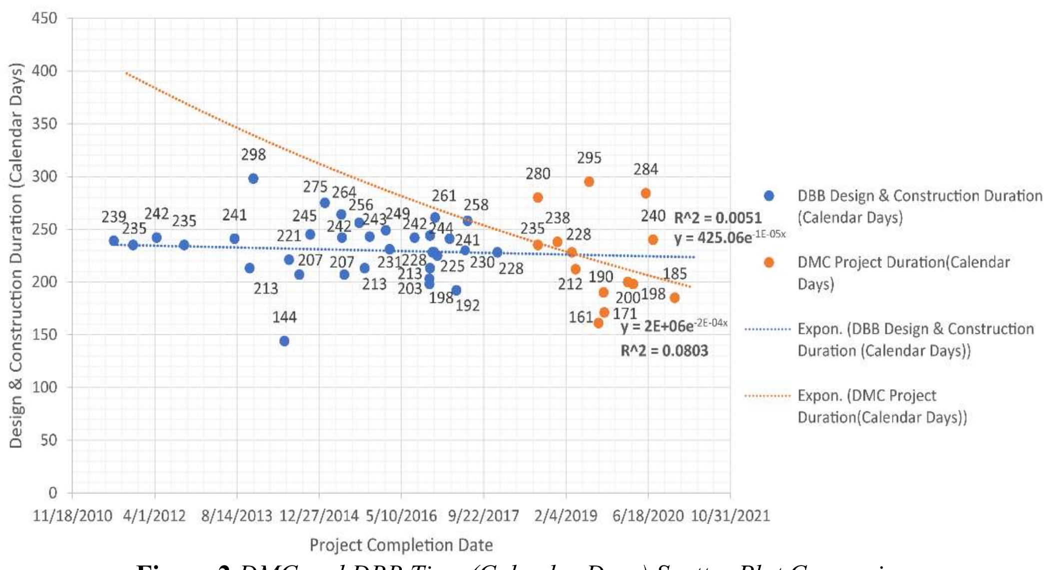

Figure 2 *DMC and DBB Time (Calendar Days) Scatter Plot Comparison*

Design and Construction Cost Results

The distributions of the 34 DBB projects are from the year 2011 to 2017, and the 14 DMC projects are from 2018 to 2019. The DMC cost data includes all change order costs. Due to lack of specification, the researcher assumed that all DBB cost data included change order costs as well. The researcher realized the inflation and material prices could significantly vary due to the different time periods of the DMC and DBB projects. To make the cost data more comparable, the researcher uniformly adjusted all values to a future value in 2021 with a 2% annual inflation rate using the equation:

$$Future\ Value = Present\ Value \times (1 + i)^n$$

Figure 3 illustrates the 14 DMC and 34 DBB projects cost in the boxplot. This figure shows DBB has a broader distribution between \$801/SF to \$992/SF with a median of \$895.5/SF cost. By comparison, DMC has a tighter distribution range between \$560/SF to \$664/SF with a median of \$621/SF cost. The figure clearly shows DMC outperforms DBB in the design and construction cost metrics by a significant amount.

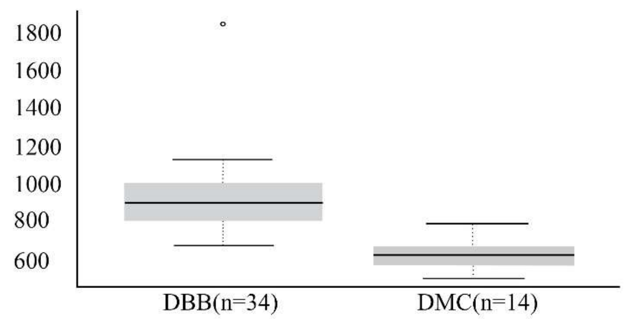

Figure 3 *DMC vs. DBB Design & Construction Cost (\$/SF) Boxplot Comparison*

Figure 4 compares the cost tendency of the 14 DMC projects and 34 DBB projects in the same plot and indicates that the DMC cost is significantly lower than that of DBB projects. The cost is steadily increasing for both DBB and DMC-delivered projects. However, the DMC projects are growing at a slightly higher rate when compared to DBB projects.

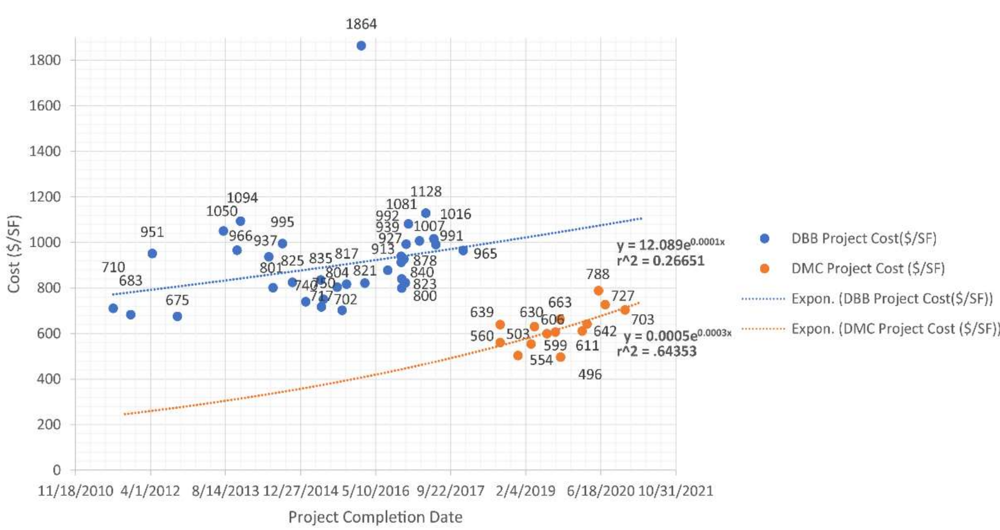

Figure 4 *DMC and DBB cost per square foot scatter plot*

Construction Intensity Results

The final design and construction intensity is calculated by the completion date less the final start date. The DMC data specified that the start date is when the team first started the project's design stage. Due to lack of information, it was assumed that the DBB start date was when the project team first started the project design stage. Figure 5 illustrates the intensity of the 14 DMC and 34 DBB projects in the boxplot. This figure shows that DBB has a more concentrated distribution between 41.9 to 49.1 SF per day with a median of 46.9 SF per day. In comparison, DMC has a broader distribution range between 42.6 to 58.8 SF per day with a median of 56.4 SF per.

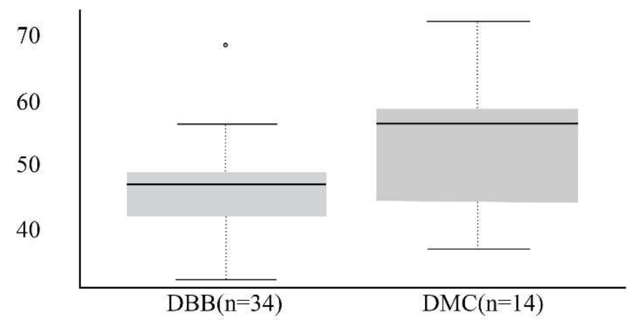

Figure 5 *DMC vs. DBB Design & Construction Intensity (SF/Calendar Days) Boxplot Comparison*

Figure 6 illustrates the construction intensity tendency data of DMC and DBB delivered projects. This figure shows that the DMC delivered projects seem to have a little bit higher construction intensity. The slope suggests that DMC's construction intensity increases at a much higher rate than DBB showed projects. In other words, DMC is improving construction intensity at a much higher rate while DBB remains stable.

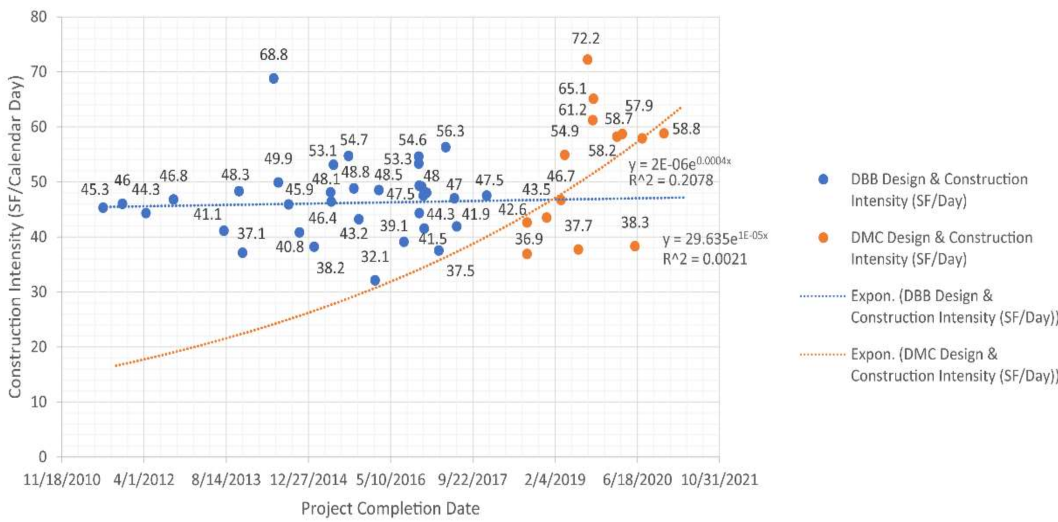

Figure 6 *DMC and DBB construction intensity scatter plot*

Inferential Two-Samples t-Test Results

Two samples t-test performed to test the alternate hypothesis for H1, H2, and H3 mentioned earlier in the paper. Outliers were not omitted. The performance metrics calculated according to the equations (1), (2), and (3). Mean ratings were used to compute the three determining performance metrics for each delivery method. Table 1 organizes the mean and standard deviations for each performance factors of the delivery methods were as follows: $Time_{DBB}$ (M=232.9, SD=27.2), $Time_{DMC}$ (M=222.6, SD=42.2), $Cost_{DBB}$ (M=912.9, SD=81.8), $Cost_{DMC}$ (M=622.9, SD=209.7), Construction $Intensity_{DBB}$ (M=46.6, SD=6.7), Construction $Intensity_{DMC}$ = (M=52.3, SD=11.3). There was a significant difference between the $Cost_{DBB}$ mean of 912.9 (SD=81.8) and $Cost_{DMC}$ mean of 622.9 (SD=209.7), t=6.89, p=0.00, in favor of the $Cost_{DMC}$. The null hypothesis **$H1_0$**: X_{DBB} (cost) = X_{DMC} (cost), rejected. Therefore, the alternate hypothesis, **$H1_A$**: X_{DMC} (cost) < X_{DBB} (cost), was correct, which the cost to DMC is significantly better than the cost of DBB delivered projects. However, the time hypothesis (p=0.77) and intensity hypothesis (p=0.09) are larger than 0.05. Therefore, the null hypothesis was not rejected, and there were no significant differences between DBB and DMC in time and intensity performance factors.

Table 1
Inferential study results on cost, time, and construction intensity performance factors

	H1-Cost Hypothesis		**H2-Time Hypothesis**		**H3-Intensity Hypothesis**	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
	($/SF)		(Calendar days)		(SF/Calendar Day)	
DBB (n=34)	912.9	81.8	232.9	27.2	46.6	6.7
DMC (n=14)	622.9	209.7	222.6	42.2	52.3	11.3
p	1.3 ^-08 (≈ 0.00)		0.41		0.09	
t	6.89		0.77		1.78	
Hypothesis Determination	$H1_0$: XDBB (cost) = XDMC (cost) REJECTED		$H2_0$: XDBB (time) = XDMC (time) ACCEPTED		$H3_0$: XDBB (intensity) = XDMC (intensity) ACCEPTED	

Discussion

Reduction in time and cost is argued to be the significant advantage of modular construction systems compared to conventional construction methods. (Azhar et al., 2013; Blimas & Wakefield, 2009; Jang et al., 2020). This study analyzed 14 DMC and 34 DBB project data using both descriptive and inferential two-tailed samples t-test. Respectively, both descriptive and inferential two-samples t-test confirmed DMC outperforms DBB in terms of cost. Figure 3 and 4 shows the DMC cost result (M=622.9, Median=621), and DBB cost result (M=912.9, Median=895.5). There is a mean difference of $290/ SF, and a median difference of $274/ SF. Descriptively, DMC performs better in terms of cost. Moreover, Table 1 indicates the inferential p-value for cost 0.00 is less than 0.05 ($p \leq 0.05$), which rejects the H_0, and concludes that the cost when using DBB is higher than using DMC. However, for time ($p= 0.41$) and construction intensity ($p= 0.09$) performances, the two-tailed p test accepted the null hypothesis ($p > 0.05$) that DMC shows no significant differences when compared to DBB at a 95% confidence level (Table 1). The conservative assumption on the DBB data could have influenced this result since the study conservatively included the design stage in DBB's time data. Nonetheless, the descriptive scatter plots and boxplot still showed advantages (Figure 1, 2, 5, and 6). With the DMC time result (M=222.6, Median=220), DBB time result (M=232.9, Median=235), DMC construction intensity result (M=52.3, Median=56.4), and DBB construction intensity data (M=46.6, Median=46.9). It still showed a time mean difference of 10.3 calendar days, time median difference of 15 calendar days, construction intensity mean difference of 5.7, and construction intensity median difference of 9.5. Descriptively, DMC performs better. In addition, the descriptive studies showed tremendous continuous improvement opportunities in DMC, which was illustrated in the plotted trend lines.

Based on the interview with BLOX, the researcher concluded that DMC has three major advantages: (1) DMC allows efficient communication between all stakeholders, (2) DMC cuts redundant work such as acquiring building permits by working on repeated well-established projects, and (3) DMC utilizes concurrent engineering to innovatively design standard parts that could improve efficiency.

Limitation

There were several limitations to the study. The first limitation was related to the sample and sample size. The sample size was small, with only 14 DMC, 34 DBB and 3 interviewees included in the study. A second limitation was that the quantitative data was solely collected from BLOX LLC. The researcher made assumptions about the data due to the lack of information provided with each data set. For example, the researcher assumed that the DBB duration included the design and construction phases, but this is unknown if true. Therefore, both limitations impact external validity and make the results challenging to generate the most accurate sample conclusions. The third limitation was related to project types. FSED projects are the only type included in this study and are typically conservative to explore DMC's full potential since they have a complex program. The fourth limitation was the lack of considerations of location. For example, the operation manager mentioned the cost differential to build an FSED project in Texas vs. Florida vs. Nevada could be millions of dollars based on site-specific conditions alone.

Conclusion

DMC demonstrated advantage compared to DBB in terms of cost, time, and construction intensity performance factors for the large-scale expansion of well-established projects. The continuous improvement opportunities simultaneously advance design simplification, process optimization, and product innovation, ultimately improving time, cost, and construction intensity performances. Future research should consider investigating other building types. Moreover, future studies should conduct in-depth qualitative research to measure the practitioners' opinions involved in the modular building process. Furthermore, future studies should specifically investigate potential opportunities available when the DMC process is used.

Reference

Arashpour, M., Wakefield, R., Blismas, N., & Minas, J. (2015). Optimization of process integration and multi-skilled resource utilization in offsite construction. *Automation in Construction*, *50*, 72–80. https://doi.org/10.1016/j.autcon.2014.12.002

Azhar, S., Lukkad, M., & Ahmad, I. (2013). An investigation of critical factors and constraints for selecting modular construction over conventional stick-built technique. *International Journal of Construction Education and Research*, *9*, 203–225. https://doi.org/10.1080/15578771.2012.723115

Blismas, N., & Wakefield, R. (2009). Drivers, constraints and the future of offsite manufacture in australia. *Construction Innovation: Information, Process, Management*, *9*, 72–83. https://doi.org/10.1108/14714170910931552

Goulding, J. S., Rahimian, F. P., Arif, M., & Sharp, M. D. (2015). New offsite production and business models in construction: Priorities for the future research agenda. *Architectural Engineering and Design Management*, *11*(3), 163–184.

Hu, X., Chong, H.-Y., Wang, X., & London, K. (2019). Understanding Stakeholders in Offsite Manufacturing: A Literature Review. *Journal of Construction Engineering and Management*, *145*(8), 03119003.

Jang, J., Ahn, S., Cha, S. H., Cho, K., Koo, C., & Kim, T. W. (2020). *Toward productivity in future construction: Mapping knowledge and finding insights for achieving successful offsite construction projects*. 14.

Judy, S. (2020). Blox looks for a better way to build projects. *ENR: Engineering News-Record*, *284*(12), 24–25.

Luo, J., Zhang, H., & Sher, W. (2017). Insights into Architects' Future Roles in Offsite Construction. *Construction Economics and Building*, *17*, 107. https://doi.org/10.5130/AJCEB.v17i1.5252

Mao, C., Xie, F., Hou, L., Wu, P., Wang, J., & Wang, X. (2016). Cost analysis for sustainable offsite construction based on a multiple-case study in china. *Habitat International*, *57*, 215–222. https://doi.org/10.1016/j.habitatint.2016.08.002

Wuni, I., & Shen, G. (2020). Stakeholder management in prefabricated prefinished volumetric construction projects: Benchmarking the key result areas. *Built Environment Project and Asset Management*, *10*, 407–421. https://doi.org/10.1108/BEPAM-02-2020-0025

Wuni, I. Y., & Shen, G. Q. (2020a). Critical success factors for management of the early stages of prefabricated prefinished volumetric construction project life cycle. *Engineering, Construction and Architectural Management*, *27*(9), 2315–2333. https://doi.org/10.1108/ECAM-10-2019-0534

Wuni, I. Y., & Shen, G. Q. (2020b). Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. *Journal of Cleaner Production*, *249*, N.PAG-N.PAG. https://doi.org/10.1016/j.jclepro.2019.119347

Zhai, X., Reed, R., & Mills, A. (2014). Factors impeding the offsite production of housing construction in china: An investigation of current practice. *Construction Management and Economics*, *32*(1–2), 40–52. https://doi.org/10.1080/01446193.2013.787491

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Delivery Method for Rapid Bridge Construction

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A growing body of previous studies suggested that Alternative Contracting Methods (ACM) could foster constructability, increase innovation, reduce schedules, decrease risks, have a higher project intensity, and eventually save on project costs. The objective of this study was to compare Design-Build procurement and delivery of Bridges in Georgia with Design-Bid-Build in terms of cost, schedule, and intensity. The study used factual data from all Bridges completed using Design-Build and Design-Bid-Build delivery methods between 2008 and 2018. Data points were collected through personal interviews and survey questionnaires with Georgia Department of Transportation (GDOT) personnel. The intended audiences for the study were State DOT officials engaged in the bridge procurement process. The findings from this study would benefit State DOTs by improving their understanding of the advantages of the Design-Build delivery method, most importantly expediting bridge construction projects in metropolitan areas where each day delay could impact millions of users adversely. The study also provided quantitative evidence in support of advantages achieved from the Design-Build delivery method in terms of cost growth, schedule reduction, and project intensity as compared to the Design-Bid-Build delivery method.

Keywords: -Alternative Contracting Method (ACM), Design-Build (DB), Schedule Growth, Cost Growth, Project Intensity, Design-Bid-Build (DBB).

Introduction

‘‘In the DB project delivery method, the state executes a single contract for both the design and construction, awarded on either a Low-Bid or Best-Value basis. This project delivery method is sometimes pursued to reduce project duration and cost over more traditional approaches. Under the traditional transportation project delivery method, known as DBB, a project owner contracts with separate entities to design and construct a transportation project’’ (Borowiec, et al.,2016). ‘‘The shift to DB from DBB allots responsibility and risk to the parties who can best manage the processes and outcomes. It allows for innovation in design, construction techniques, construction phasing, sequencing, risk management, traffic management, Public Information, and cooperative communication’’ (CDOT 2016).

The primary objective of this paper was to offer empirical evidence for the project performance criteria by comparing DB, and the traditional DBB project delivery techniques for Bridge Projects. The focus was to verify that DB was the fastest and effective project delivery method for Bridge Construction in the Georgia Department of Transportation (GDOT). The main question of this research analyzes ‘‘how do schedule growth, cost growth, and project intensity’’ impact the delivery system of DB and DBB on bridge projects completed between 2008 to 2018.

This paper aimed to improve business and management practices with bridge construction. It also contributed to the construction body of knowledge by presenting one of the first research efforts in the State of Georgia that compared bridge project performances between DBB, and DB projects based on empirical data analysis. The intended audience of this study would be State DOT offices involved in the bridge procurement business. It is also the right moment to evaluate the performance of DB bridge projects in the State of Georgia, which has an aggressive plan to replace more than 377 bridges with the DB delivery method across the State over the next five years.

The State of Georgia’s Bridge Construction

‘‘Georgia’s transportation infrastructure ranks second-best in the nation among the U.S. states’’, according to a report published by MSN Money. According to GDOT’S website and internal publications, the State of Georgia has a total of around 14,750 Bridges. The Department record shows 6,600+ structures (4,500 bridges and 2,100 culverts) with an estimated average age of 43 years. Since the 2014 ASCE Report Card, ‘‘GDOT has reduced the number of posted bridges from 2% to 1.5% of all bridges on the state system’’. Currently, GDOT is scheduled to restore or replace bridges, which are load restricted or closed for traffic on the State bridge system.

Out of 4,300, all National Highway System Bridges found in Georgia, 1997 bridges are in good condition,2,285 in fair condition and 18 are in poor condition’’ (DuVall, B. 2018). ‘‘The Transportation Funding Act of 2015 (TFA) provided nearly $1 billion in additional revenue for Georgia’s transportation system each year, including for the 14,863 bridges and culverts across the state. As a result, Georgia has decreased the percentage of structurally deficient bridges, from 8.6% in 2014 to 4.6% in 2017’’ (ASCE 2019). The American Society of Civil Engineers (ASCE) Infrastructure report card in 2019 rated the Georgia roads and bridges a C+.

According to GDOT’s internal report, ‘‘GDOT has created the Local Bridge Replacement Program (LOCBR) to reduce this number. The Low Impact Bridge Program (LIBP) was introduced in 2014 and replaced and reopened 14 bridges with 3 under construction and 33 more programmed for replacement within the next two to three years. The Local Bridge Replacement Program (LOCBR) was initiated in 2017 with 52 bridges solicited for replacement throughout the state and 25 bridges entering Preliminary Engineering activities to date. In the past three years, there has been a growing inventory of 86 Bridges since 2015, excluding the 38 newly built bridges on the Northwest Corridor (NWC)''. Following the GDOT Design-Build Bridge replacement program, ''Georgia's Transportation Funding Act of 2015 resulted in an additional $757 million in 2016 and an estimated $824 million in 2017 for GDOT''. With that, the GDOT bridge program increased from $155 million in 2015 to nearly $168 million in 2016, $279 million in 2017, $301 million in 2018, and $369 in 2019.

GDOT's program goal was to conduct projects most efficiently to rapidly reduce the number of locally owned bridges in poor condition. For this reason, GDOT decided to use the DB project delivery method combined with low-bid procurement for selecting DB contractors. ''GDOT utilizes resolute ACM staff, a Program Management Consultant (PMC), and General Engineering Consultants (GECs) throughout the ACM pre-award and post-award stages'' (Gransberg 2018).

Table 1-Summary of Georgia Bridges Condition

State-owned Bridges	Locally owned Bridges	Load restricted Bridges-State owned	Load restricted Bridges-Locally owned	Good condition Bridges	Fair condition Bridges	Poor condition Bridges
6,736	8,014	656	1,451	6,250	8,103	374
14,750		2,107		14,727		

Source: -GDOT Department Record.

Point of Departure

A lot of previous studies have mainly focused on highway road projects at the national level however this research was one of the first research efforts in the State of Georgia and compared the performance of Design-Build delivery method to Design-Bid-Build projects on bridge projects about schedule growth, cost growth, and project intensity. Specific questions that drove the research were:

I. How does the DB delivery method affect cost growth?
II. How does the DB delivery method affect project speed and schedule growth?
III. How does the DB delivery method affect the production rate or project intensity?

Research Methodology

This study collected cost, schedule, and intensity data for DB projects completed by GDOT from 2008 to 2018, analyzed and compared the same with DBB (Antoine et al., 2019), (Douglas et al.,2016), and a technical summary of the Federal Highway Administration Report Alternative Contracting Method Performance in U.S. Highway Construction (DTFH61-13-C-00024). The authors carried out three basic steps: Collecting data, categorizing, and performing statistical analysis.

Data Collection

The questionnaire, which was prepared using MS Excel format, was divided into two sections: General & Procurement Data, and Performance Data. The first section asked for general information about a project, such as a project name and contract description. The additional section asked for data that were available during the procurement phase of the projects, which were the contracting methods, procurement methods, project size, award basis, and Design-Bid Team. The second section asked for data that were available for duration and cost performance metrics such as the contract awarded amount, the final paid amount, awarded days, days used, and job letting date.

Data Analysis

After the data was collected and statistically analyzed, this study calculated the performance metrics, which include cost growth, schedule growth, and Project Intensity, quantitatively defined as follows:

- Cost growth is calculated as the difference between the final project cost and the initial contract award and expressed as:

$$\textit{Cost Growth (\%)} = \frac{\text{Final actual Cost} - \text{Initial planned Cost}}{\text{Initial Planned Cost}} \times 100$$

- Schedule Growth is calculated as the difference between the actual time taken to complete the project and the planned project duration signed at the contract expressed as:

$$\textit{Schedule Growth (\%)} = \frac{\text{Actual Completion Time} - \text{Planned Schedule Time}}{\text{Actual Completion Time}} \times 100$$

- ‘‘Project intensity is a hybrid measure of the rate that resources are put into a project and a solid indicator of a highway construction project’s delivery speed’’ (Konchar and Sanvido 1998). It is a measure of how much money is spent per day during project delivery. ‘‘Intensity is, therefore, an excellent measure of how agencies are minimizing the impact of Highway construction on the traveling public by completing projects at a faster pace’’ (Alleman and Antoine 2019).

$$\textit{Project Intensity} = \frac{\text{Final Contract Cost}}{\text{Actual Construction Duration}}$$

Result and Discussions

Project Duration

Table 2 reveals that the mean procurement duration from the ‘‘date project advertised’’ to the ‘‘date project awarded’’ was higher for Georgia DB and Bridge projects compared to DBB for other states. This was because procurement efforts in the Design-Build category have required additional time needed to prepare explicitly defined contract documents. On the other hand, Projects executed by the Design-Build delivery method attained substantial schedule acceleration when compared to the traditional Design-Bid-Build system on both cost categories, which eventually construction duration.

For projects in a cost category of $2M to $10M in Table 2 showed that the mean project duration for DB Projects in Georgia was found to be 49% shorter than DBB for all states. In the same cost category, DB Georgia Bridge projects were 57% shorter than DBB for all states. For projects in a cost category of $10M to $50M in Table 3, the mean project duration for DB Projects in Georgia was found to be 54% shorter than DBB for all states while DB Georgia Bridge projects were 56% shorter than DBB for all states.

In GDOT bridge construction history, the following bridge projects could be taken as a success story for expedited bridge construction. In March of 2017, the Interstate 85 bridge collapsed because of a fire incident under the bridge. Despite the incident, GDOT reopened the bridge several weeks ahead of schedule by formulating a more advanced plan to rebuild the bridge using contractor incentives in addition to DB to expedite the project. Moreover, the bridge carrying State Route 299 over I-24 in Northwest Georgia was fully replaced using an Accelerated Bridge Construction (ABC) method in 56 hours. GDOT also demolished and reconstructed the 110-year-old Courtland Street Bridge by using the Design-Build procurement method as well as (ABC) technology. This bridge connects Martin Luther King Jr. Drive to Gilmer Street in Downtown Atlanta close to the Georgia State Capitol and serves as a major link to the Georgia State University campus. The road closed for approximately six months and interrupted traffic for many commuters as well as for 32,000 GSU students. MARTA

(Metropolitan Atlanta Rapid Transit Authority) rerouted bus service and other transits were also impacted by the bridge construction. If the bridge was constructed by the traditional DBB delivery system, it could have been worse and taken up to two years. Thanks to the ABC and DB Alternative Contracting Method that reduced the scheduled growth up to 41% as shown in Table 4 and made it possible in less than six months. Generally, GDOT bridge construction reduced the scheduled growth by 12% as shown in Table 4 and this number will be higher as the department gain more experience on bridge construction projects through the DB delivery system in the future.

Table 2. The Average duration for DBB and DB projects between $2 million and 10 million

Delivery Method	Sample Size	Mean Project duration(days)	Mean Design duration (days)	Mean Procurement duration(days)	Mean Construction duration(days)
DBB for All states	19	1,506*	795*	51*	508*
DB for All States	10	773*	181*	116*	380*
DB Georgia	7	771	217	216	507
DB Bridge Georgia	2	651	179	197	342

Note. * from " Technical summary of the Federal Highway Administration Report Alternative Contracting Method Performance in U.S. Highway Construction (DTFH61-13-C-00024)'', 2018.

Table 3. The Average duration for DBB and DB projects between $10 million and 50 million

Delivery Method	Sample Size	Mean Project duration(days)	Mean Agency Design duration (days)	Mean Procurement duration(days)	Mean Construction duration(days)
DBB for All states	34	2,130*	1,139*	67*	818*
DB for All States	10	1,420*	638*	127*	639*
DB Georgia	7	973	300	351	752
DB Bridge Georgia	3	948	309	251	710

Note. *from " Technical summary of the Federal Highway Administration Report Alternative Contracting Method Performance in U.S. Highway Construction (DTFH61-13-C-00024)'', 2018.

Project Cost

One of the advantages of the Design-Build delivery system is minimizing the potential for design errors and omissions. It is also permitting simultaneous activities of design and construction for distinct sections of the same project. DB provided flexibility during construction that allowed for changes to be made on the fly without requiring a supplemental agreement, which ultimately save money and benefit the owner by transferring the risk to the DB contractor. On the contrary, the Design-Bid-Build contracting method, design modifications, and unforeseeable issues would result in a supplemental agreement or a change order which increases the cost to the owner.

Table 4. Georgia Design-Build Projects Schedule Growth by Award Value

Project Award Value	Sample Size	Schedule Growth (%)
All Project	18	-3.49%
Over $ 20M	7	-3.87%
Under $20M	11	-3.24%
Under $ 10M	9	-3.40%
Under $ 5M	5	4.22%
All Bridge	5	-11.93%
Courtland Street ABC Project	1	-41.09%
SR 299 at I-24 Bridge Replacement ABC Project	1	-35.57%

The cost growth for DB Georgia bridge project at each cost category showed no increase except over $ 20 million with a 1.43% upsurge. This fact demonstrated that the DB delivery method saved cost over the traditional approach. In the same token, the cost growth for DB Georgia projects at each cost category showed an insignificant increase except over $20 million cost category with a 5.41% rise but it is still better compared to the DBB delivery system. According to the Federal Highway Administration study, ''the mean cost growth for DBB projects in the US was 4.1 percent''. The data analysis for Design-Build projects completed as of 2018 in GDOT showed that there was a 1.94% cost growth with an average of nearly three change orders per project as well as a budget increase of $971,284.03 per project. Many of the change orders could have added value to the project but further study will require whether these change orders were agency directed, plan errors and omissions, plan quantity changes, unforeseen conditions, or others.

Table 5 showed DB Georgia and DB Georgia bridge projects almost did not show any cost growth except the DB project over $20M cost category. These two projects were the I-85 Express Lane extension and SR-400 widening that showed 7.65% and 22.48% cost growth, respectively. Many of the supplemental agreement on the I-85 express lane project was for additional scope due to coordination with other corridor projects. In the same manner, the cost growth on the SR-400 widening project was due to the full depth slab and outside shoulder replacement.

Project Intensity

The project intensity for DB for Georgia and DB Georgia Bridge projects was found to be higher when compared with DBB or DB for all states. Table 6 showed that DB for Georgia projects spent an average of $16,216 per day while DB Bridge projects for Georgia spent $26,652 per day on average for a cost category between 2 and 10 million. For the cost category between 10 and 50 million on Table 7 exhibited that the mean amount spent daily were $35,158 and $40,167, respectively. Table 8 also disclosed higher construction intensity for DB bridge projects under the 10 and 20 million award categories. From the result, we concluded that the higher the money spent each day indicated projects completed at a faster pace and reduced construction impact on the end-users.

Table 5. Average Cost growth by Delivery Type and Award Value

Delivery Method	Over $20M		Under $20M		Under $10M		Under $ 5M	
	Sample Size	Cost Growth	Sample Size	Cost Growth	Sample Size	Cost Growth	Sample Size	Cost Growth
DBB for All States	47*	6.2%*	83*	3.4%*	52*	2.3%*	36*	1.00%*
DB for All States-LB	6*	3.40%*	31*	3.2%*	26*	3.8%*	20*	3.80%*
DB for All states -BV	42*	4.40%*	35*	3.30%*	19*	2.2%*	9*	3.80%*
DB Georgia	7	5.41%	11	0.24%	9	0.04%	5	-0.47%
DB Bridge Georgia	3	1.43%	2	0.00%	2	0.00%	1	0.00%

Note. * from ‘‘The Use and Performance of Alternative Contracting Methods on Small Highway Construction Projects,’’ by Douglas et al, 2016.

Table 6. Project Intensity for DBB and DB projects between $2 million and $10 million

Delivery Method	Sample Size	Mean ($/day)	Standard Deviation($/day)	Minimum ($/day)	Median ($/day)	Maximum ($/day)
DBB for all states	10	$4,431*	3,129*	$838*	$3,710*	$11,101*
DB for All States	10	$8,040*	6,004*	$2,728*	$5,864*	$23,509*
DB Georgia	7	$16,216	13,291	$6,705	$12,639	$44,905
DB Bridges Georgia	2	$26,652	25,814	$8,398	$26,652	$44,905

Note. * from "Examination of project duration, Project Intensity, and Timing of Cost certainty in Highway Project Delivery Methods," Antoine et al,2019

Table 7. Project Intensity for DBB and DB projects between $10 million and $50 million

Delivery Method	Sample Size	Mean ($/day)	Standard Deviation($/day)	Minimum ($/day)	Median ($/day)	Maximum ($/day)
DBB for all states	10	$17,201*	16,985*	$4,723*	$13,021*	$63,397*
DB for All projects	10	$18,679*	11,412*	$3,846*	$31,718*	$159,031*
DB for Georgia	7	$35,158	18,668	$18,023	$26,565	$67,374
DB Bridge Georgia	3	$40,167	24,304	$20,705	$32,272	$67,374

Note. * from "Examination of project duration, Project Intensity, and Timing of Cost certainty in Highway Project Delivery Methods," Antoine et al,2019.

Table 8. Project Average Construction Intensity by Delivery Type and Award Level

Delivery Method	**Over $20M**		**Under $20M**		**Under $10M**		**Under $ 5M**	
	Sample Size	Construction Intensity	Sample Size	Construction Intensity	Sample Size	Construction Intensity	Sample Size	Construction Intensity
DBB for All States	-	-	81	$14,151*	50*	$9,881*	34*	$5,869*
DB for All States-LB	-	-	30	$13,018*	25*	$10,975*	19*	$9,464*
DB for All states -BV	-	-	34	$17,862*	19*	$11,119*	9*	$6,495*
DB Georgia	7	$67,431	11	$16,090	9	$13,795	5	$8,722
DB Georgia	3	$40,117	2	$26,652	2	$26,652	1	$8,398

Note. * from "The Use and Performance of Alternative Contracting Methods on Small Highway Construction Projects, " Douglas et al,2016.

Conclusions

According to the post-Design-Build evaluation report of GDOT, ‘‘Design-Build projects’ goal was to expedite delivery and to make use of the available fund’’**.** GDOT benefited from the Design-Build delivery method by integrating the design and construction stages into a single contract, which accelerate project delivery. One of the most significant findings that emerged from this study was that GDOT Design-Build projects were found to have substantial time saving with 50-60 percent over DBB projects. It also accelerated the schedule with the overall project duration from award to completion when they compared to the traditional delivery technique in all cost categories. The FHWA's January 2006 Report to Congress, titled: Design-Build, Effective Study documented that ‘‘the greatest motivation and realized benefit to a project contracting agency of using DB instead of DBB contracting is the ability to reduce the duration of the project development process by eliminating a second procurement process for the construction contract, reducing the potential for design errors and omissions, and allowing for more concurrent processing of design and construction activities for different portions of the same project ’’. However, how DB benefits were not yet fully understood throughout the State and favorable legislation would be formulated to allow local agencies to procure with DB delivery method.

The prominent aspect of the Design-Build delivery system is encouraging innovation and collaboration, which ultimately saved time and money. This integrated and highly collaborative process encourages teamwork, creativity, and problem-solving skills in the DB team. One of its manifestations has been shown on facilitating a faster and inexpensive utility relocation process by avoiding conflict. During the Design-Build contract, many projects achieved efficiencies in delivery time because of the high degree of Contractor/Designer collaborative interaction. The construction work could partially start concurrently while another part of the project was under design by the Design-Build team. The early start of the design and construction phase simultaneously shortens the schedule and accelerated the project delivery time by overlapping activities.

The other major finding was that Georgia DB projects had lower average cost growth of 1.94% when compared to DBB with 4.1%. In addition, the project intensity results for DB Georgia projects were found to be higher when compared with DBB or DB for all states. The Design-Build method was facilitating project delivery at a rapid pace, where the rate of resources expended in the project per day with relatively insignificant cost growth. Generally, Design-Build is the best-suited delivery method for projects that require acceleration as well as projects that need a proper transfer of risk to the Design-Build Team. What is more, the Design-build contracting method is a viable delivery option for projects with opportunities to innovate and significantly decrease contract time, reduce costs, improve the safety and quality of the project. The findings from this study would benefit State DOTs by improving their understanding of the advantages of the Design-Build delivery method, most importantly expediting bridge construction projects in metropolitan areas where each day delay could impact millions of users adversely.

GDOT needs to keep using the DB delivery method, especially when projects are in Urbanized or Central Business districts and when projects need innovative design solutions that best manage the processes and outcomes. A Similar study will be conducted in the future after all ongoing DB projects have been completed to effectively measure the performance metric findings. GDOT also will need to keep post-Design-Build evaluation report and advance record-keeping for adequate and quality data related to change order, Design cost, Engineering estimate, Project size (Bridge width, length), and the role of Disadvantaged Business Enterprises participation on each project.

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References

1. Alleman, D., Antoine, A. and Molenaar, K. 2016. "The Use and Performance of Alternative Contracting Methods on Small Highway Construction Projects.'' Procedia Engineering.
2. American Society of Civil Engineers, 2019. ''Report Card for Georgia's Infrastructure''.
3. Antoine, A. and Alleman, D. 2019. ''Examination of Project Duration, Project Intensity, and Timing of cost Certainty in Highway Project Delivery Methods.'' Journal of Management in Engineer.
4. Borowiec, J., Norboge, N., Huntsman, B., Schrank, C. and Beckerman, W. 2016.''Design-Build Highway Projects: A Review of Practices and Experiences Final Report." Transportation Policy Research Center. Texas A&M Transportation Institute.
5. CDOT (Colorado Dept. of Transportation). 2016. ''Design-Build Manual".
6. Douglas D. Gransberg, (2018). ''NCHRP Synthesis 518: Staffing for Alternative Contracting Methods." Transportation Research Board of the National Academies, Washington, D.C.
7. Duvall, B. 2018. ''State of Georgia Bridges'' GDOT Georgia Department of Transportation.
8. Federal Highway Administration, (2006a). "Design-Build Effectiveness Study - As Required by TEA-21 Section 1307 (f)." Final Report to Congress, Prepared by: SAIC, AECOM Consultant, and the University of Colorado at Boulder. Washington, D.C.
9. Federal Highway Administration, (2018). "Alternative Contracting Method Performance in U.S Highway Construction." FHWA publication No: FHWA-HRT-17-100.
10. Konchar, M., and V. Sanvido. 1998. ''Comparison of U.S. Project delivery systems.''
11. Molenaar, K. and Franz, B. 2019." Revisiting Project Delivery Performance 1998-2018".

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Evaluating Viable Additive Manufacturing Alternatives In Comparison to Traditional Construction Methods

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Additive manufacturing, also known as three-dimensional printing (3DP), is a technique of producing desired objects from feedstock, typically filament, input. This process currently has several applications in construction, some with potential for large-scale implementation in industry. Five applications, or alternatives, were considered and compared based on their equipment costs, unit production savings, scalability, output time, and operational crew size. Three alternatives showed the most potential value for implementation into industry. Viable alternatives include 3DP walls, 3DP small offices, and 3DP concrete roof tiles. These viable alternatives were further explained with benefits and impediments that could affect real-world production. Entities that would consider implementing 3DP as a construction method would join other innovative companies at the forefront of utilizing new construction techniques.

Key Words: Additive Manufacturing, Concrete Homes, Concrete Roof Tiles, Three-Dimensional Printing, 3DP

Introduction to Three-Dimensional Printing

Three-dimensional printing (3DP) ranges from common tabletop (thirteen inches wide by thirteen inches deep by fifteen inches tall) machines that extrude thousands of layers of plastic filament into replicas of engineered assemblies to 10 feet tall machines that use a six-axis arm and metal alloy filament to produce unbroken cross-braced designs with an emphasis on structural integrity (Relativity, 2021). The construction industry uses 3DP as an automated way to develop architectural models, replacing hand-made methods. Research into development of physical 3D models, using 3D computer modeling programs such as Revit, shows that clients prefer to see a rendering rather than a set of plans (Wu, Wang, & Wang, 2016). However, the application of 3DP can also be used for producing structural components. While there were many startups in this area, one firm has shown the most successful to date, ICON.

ICON is a residential and space entrepreneur company based in Texas that has been using the emerging technology to produce the first 3D printed homes for sale in the United States (Nellemann, 2018). A goal of Icon was to develop a large-scale 3D printer capable of using concrete-like filament to create family sized long term livable homes (Projects, 2021). To achieve this goal, ICON has developed a proprietary concrete-like filament called “Lavacrete”. This material is used on exterior walls and some interior walls, providing load bearing structural support, as well as achieving desired R-values by being used in conjunction with a batt insulation system (Projects, 2021). The use of the Lavacrete walls allows for less traditional wood framing to be used, reducing outsourced materials used in the construction of the structure. Traditional activity lead times are reduced by printing the walls on site, allowing for a shorter delivery time of the overall project.

International companies such as Winsun, use 3DP for a variety of purposes related to the construction industry. They make 3D printed structural precast beams, 3D printed precast panels, and 3D printed portable multi-use spaces to name a few. They produce 3D printed construction materials that are used globally, with customers in countries such as Nigeria, China, and France (3D Construction, 2019).

Relevance to Construction

The purpose of this paper is to highlight capabilities of 3DP currently used in construction and evaluate emerging construction methods. The importance of 3DP in residential construction is due to the production of the wall system in one to three days, instead of one to three weeks using wood light framing. Also, homes can be designed to custom specs including curved walls, and traditional framing techniques are no longer the limiting factor in designs regarding load capacity. As the recent trend of working from home continues, Mighty Buildings has the advantage of using 3DP to produce “tiny houses”, that can function as small modular offices, at a faster rate than traditional methods (Pricing, 2021). Icon claims that a 500 square-foot home can be printed in 24 hours (Projects, 2021). Winsun claims an 1100 square-meter, or 11,840 square-foot, house can be printed in three days (3D Construction, 2019). As supply chain issues are prevalent to the steel industry, the commercial construction industry receives delays. 3DP technology can be used to manufacture lightweight beams to replace traditional precast or wide-flange members. Implementation of printed beams in commercial construction could reduce reliance on lead times from steel suppliers experiencing delays. Lead times for projects could be reduced with the development of printed roof tiles. Oshkosh Public Museum used 3DP to repair a section of terra cotta roof tiles in 2020 (Oshkosh, 2020). The execution of this repair was completed with clay filament, but cementitious material works in the same manner with the same machinery.

Methodology

Data used to calculate traditional framing output was collected from a report generated by the National Association of Homebuilders for the U.S. Department of Housing and Urban Development (NAHB, 1994). Current framing cost data was collected from estimate suggestions available on Home Advisor (O’Keefe, 2021). Beams were chosen to be wide-flange “W” steel beams and multiple sources were considered. A sample of beam prices gathered from MK Metal (Wide, 2021) was compared with prices listed in Texas (2020) and Indiana (2011). The average cost was $1.05 per pound of steel for all comparison calculations. Prefabricated small office data was considered from Home Guide, included in a report for square-foot estimates for modular homes and home additions (2021 modular, 2021). Bus stop manufacturing cost was gathered from Twin Modular Services at a price of $7800 for a size of 8’ x 15’ footprint unit (8 x 15, 2021). Manufacturing time was considered to be one day, since the factory can produce several units during a workday. Factory produced concrete roof tiles were considered from Boral Roofing (Boral, 2012). Tile dimensions and weights used for calculation were gathered from the Boral Villa product information (Boral, n.d.). Production cost data was collected from “Concrete Tile Roof Cost in 2021: Boral & Eagle Roofing Tiles” available on the Roofing Calculator website (Boesky, 2021).

Alternatives and Requirements

The modes of application, also known as alternatives, of additive manufacturing to the North American construction industry reviewed are walls, beams, small office buildings, bus shelters, and roof tiles. These alternatives were subjected to requirements outlined in Table 1. These requirements were used to determine the five alternatives to be evaluated from a number of other processes performed with 3DP. The first requirement was that the alternative had to have a comparable traditional construction method. The purpose of this review is to determine the best application of 3DP, not to propose new construction techniques. The alternatives had to be applicable to many construction types, meaning that proprietary processes were not included. The third requirement was that they have to use materials that are readily available. Machines requiring alloy forging processes to generate filament were not considered. Filaments used by printers in this review are Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), and cementitious material known as *Sikacrete*. Each alternative had to show potential for the ability to be an improvement over a comparable traditional construction method. Alternatives that could not beat standard production cost, weight, output, or time were not considered. The last requirement is that alternatives had to meet minimum strength requirements commonly used in North America, such as IBC regulations for homes and offices, ASTM A36 for steel, ASTM C109 for hydrolyzed cement, and ASTM C1492 for concrete roof tiles.

Table 1

Requirements Used to Choose Alternatives

Requirement	Name
1	Current comparable method in industry (Innovative approach vs. existing approach)
2	Generalizable to multiple construction types
3	Uses readily available materials (filament)
4	Shows a level of improvement/benefit over traditional method
5	Passes ASTM strength standards/codes

Measures of Merit

Five measures of merit were used to rank the mode alternatives, shown in Table 2. The cost of machinery measure consists of the total cost of purchasing one printing process machine, without shipping. The cost of machinery will be higher as the size of the machine needed increases. The percent savings measure relates the cost of production per unit compared to traditional construction methods, without overhead and indirect costs. The feasibility of scalability is a subjective measure based on current levels of use and potential for further development, with a score of 1 being low and 3 being high. The percent output measure compares the time of production per unit with traditional construction methods. Operational crew size is the amount of people needed to operate and monitor the equipment.

Table 2

Measures Of Merit

Measure of Merit	**Name**	**Is a high value good or bad?**
1	Cost of Machinery	bad
2	Percent Savings vs Traditional (product)	good
3	Feasibility of scalability (subjective)	good
4	Percent Output vs Traditional	good
5	Operational Crew Size	bad

Calculations

Printer cost data was collected using the Aniwaa website (3D Printer, 2021). This site lists printer capabilities, specifications, and prices, separated into categories based on uses such as industrial, commercial, and desktop. Concrete printer data was considered from the guide for construction printers also published on the Aniwaa website (Ultimate, 2021). Output for 3DP walls was based on Icon’s statement that a 1,000 square foot home could have walls printed in two days (Nelleman, 2018). Traditional wood framing production of one week was derived from two weeks to complete framing for a 2000 square foot home (NAHB, 1994). Printed walls are used currently by several companies in the United States and internationally, so Feasibility was scored as 3. Printed beams are being researched, but not used in industry yet, so they were scored 1. Printed small offices are being used in the United States, but are currently made by one company, Mighty Buildings. Winsun produces printed modular offices overseas, so a score of 2 was given.. Printed bus shelters were developed by Winsun to achieve a sustainable design goal but are not being produced by another company. This lack of interest earns the score of 1. Printed roof tiles were used by a museum in the United States and proven to be successful. Similar success has been achieved with researchers printing cementitious materials for coral reef repairs (3D Printed, 2021). The scalability of printed roof tiles scored 2 because it shows potential for more utilization. A printed beam would take one day to print. A rolled beam would take one day to produce, with steel material lead time and transportation not considered. A modular office would take one day to print. Framing would take two days. A bus stop would take one day to print, (as low as two hours), as claimed by Winsun (Global, 2021). A manufactured bus stop could be assembled in one day at a factory. Both options could produce several bus stops in one day. Several hundred roof tiles could be printed in one day, while allowing another day to dry (3D Printing, 2021). Concrete roof tiles from a factory would take three days to manufacture. Considering time to print roof tiles assumes dry mix is available on site and time to hydrate, mix, and feed the printer is optimal. Manufacturing time used for roof tiles only considers the process time at the production site, not ordering time. Crew size was determined based on data from direct knowledge of using printers and information available on the Aniwaa Additive Manufacturing website (3D Printer, 2021). Table 3 shows data calculated for each alternative and measures of merit.

Table 3

Alternatives and Data Calculated

Alternative	Name	Cost of Machinery	% Savings vs Traditional	Feasibility of Scalability	% Output vs Traditional	Crew Size
1	3DP Walls vs WLF	100000	0.64	3	250	2
2	3DP Beam vs Rolled Wide Flange	40000	0	1	100	1
3	3DP Small Office vs Spec	35000	0.7	2	200	2
4	3DP Bus Shelter vs Covered Bus Stops	30000	0	1	100	2
5	3DP Roof Tiles vs Concrete S Tiles	10000	0.32	2	150	1
Best Value Presented		10000	0.7	3	2.5	1

Weighting and Scoring

The weight of categories was selected to emphasize start-up cost to purchase a printer and savings that printing offers compared to traditional construction, shown in Table 4. Feasibility of scalability was considered to be more valuable than output to allow for future implementation of large-scale production to be considered more than direct output of one machine. Output and operational crew sizes were considered as low weighted factors due to high importance when starting a business to develop techniques mentioned, but importance dropping towards negligible once a company grows and is capable of mass-production and operating with a staff of employees. Normalized score standardizes the best value in each measure of merit as 1 and relates the value from other alternatives as a percentage of the best value. Weighted score multiples the normalized score of each alternative in each measure of merit category by the assigned weight of the category. Total weighted score sums the five weighted scores for each alternative and produces a decimal number that allows the alternatives to be compared.

The total weighted scores of 3DP Beams and 3DP bus shelters are less than half the value of the other three alternatives due to them both having no perceivable cost savings compared to current methods. Beams made from PLA or ABS would be up to 80% lighter than traditional steel W Sections, as mentioned in Noe (2021), but material cost could not outweigh using steel. As steel W section was considered to be $1.05 per pound, a beam of 100 pounds would cost $105. A factor of 75% weight reduction was considered for PLA and ABS filament material, meaning that 25 pounds of filament would be considered. A bulk-sized, 25-kilogram spool of ABS was $490, meaning that 25 pounds of material would cost $222 (Push Plastics, 2021). A 25-kilogram spool of PLA was $450, calculating to $204 for 25 pounds of material (Push Plastic, 2021). Both of these costs are greater than the list price for a steel beam, not considering shipping and transportation factors. A cost of filament material under $4.00 per pound would have shown cost savings compared to steel. The 3DP walls, 3DP small office, and 3DP roof tiles have similar values, all over 0.6 total weighted score. This means that all three alternatives have potential to be implemented into industry, with production scale not considered.

Table 4

Decision Matrix

			3DP Walls vs WLF	**3DP Beam vs Rolled Wide Flange**	**3DP Small Office vs Spec**	**3DP Bus Shelter vs Covered Bus Stops**	**3DP Roof Tiles vs Concrete 'S' Tiles**
	Weight:	**Score:**					
Cost of Machinery	0.3	Normalized	0.10	0.25	0.29	0.33	1.00
		Weighted	0.03	0.08	0.09	0.10	0.30
Percent Savings vs Traditional (product)	0.3	Normalized	0.91	0.00	1.00	0.00	0.46
		Weighted	0.27	0.00	0.30	0.00	0.14
Feasibility of Scalability	0.2	Normalized	1.00	0.33	0.67	0.33	0.67
		Weighted	0.20	0.07	0.13	0.07	0.13
Percent Output vs Traditional	0.1	Normalized	1.00	0.40	0.80	0.40	0.60
		Weighted	0.10	0.04	0.08	0.04	0.06

Operational Crew Size	0.1	Normalized Weighted	0.50 0.05	1.00 0.10	0.50 0.05	0.50 0.05	1.00 0.10
Sum (Weights)	1	Total Weighted Score	0.65	0.28	0.65	0.26	0.73

Results and Interpretations

The results of the decision matrix can be interpreted to show which application of additive manufacturing has the most potential for future use in industry. The highest rated alternative was 3DP roof tiles, with 3DP walls and 3DP small offices tied for second. The alternatives at the bottom of the ranking are 3DP beams and 3DP bus shelters. The option for lightweight beams to replace standard wide flange beams does not show potential based on the current prices of bulk printer filament compared to steel. Modular bus shelters are not a viable option either because they use too much filament, which current prices cannot overcome traditional costs to order from a supplier. The alternatives that show potential for use are 3DP walls, 3DP small offices, and 3DP roof tiles. The option for 3DP walls is not the highest rated option because of the barrier to entry. The machinery for this option is the most expensive, over double the price to purchase compared to the next highest option in the list. Based on the weight of the measures of merit, 3DP walls would be the best option to pursue if machinery costs were lower. The option for 3DP small offices has merit for potential industry use. The equipment cost is relatively low, matched with high savings compared to wood framing, and quick build time. The highest rated choice from the DMM is to print concrete roof tiles to replace ordering from local suppliers. This alternative has the lowest price of machinery and provides benefits in production cost savings and in output time when compared to ordering tiles from a factory through a supplier. The interpretations of results of the decision matrix regarding viable alternatives are included in Table 5.

Table 5

Interpretation of Results from the Decision Matrix

	Benefits of Development:	**Obstacles to Development:**
3DP Walls	• High production cost savings • High production output • High scalability potential	• High cost of entry • Meeting local building codes
3DP Small Offices	• Low cost of entry • Highest production cost savings • Modular design • High production output	• Low current scalability • Unknown market bubble
3DP Roof Tiles	• Lowest cost of entry • Easiest production	• Low current scalability • Meeting testing standards

Conclusion

Viable additive manufacturing methods include 3DP walls, 3DP small offices, and 3DP concrete roof tiles. Pursuit of each of these alternatives has its own benefits and obstacles that should be considered. Implementing any of these viable techniques has potential to be more efficient than traditional construction methods. As additive manufacturing research grows in popularity within the construction industry, further improvements to the technology will take place.

References

2021 modular home prices: Cost to build Prefab House. (2021). Retrieved November 11, 2021, from https://homeguide.com/costs/modular-home-prices

3D Construction Printing (Director). (2019, August 13). Exclusive Winsun 3D Concrete Printing Factory Tour, Suzhou China [Video file]. Retrieved November 11, 2021, from https://www.youtube.com/watch?v=ZUdrorzKrrc

3D printed terra cotta tiles create artificial reefs in the Red Sea. (2021, April 28). Retrieved November 11, 2021, from https://scubadiverlife.com/3d-printed-terra-cotta-tiles-create-artificial-reefs-red-sea/

3D printer comparison: Over 2,300 3d printers to choose from. (2021). Retrieved November 11, 2021, from https://www.aniwaa.com/comparison/3d-printers/?filter_topics%5B%5D=40848

3D printing cement - 3D potter real clay 3D ceramic printers. (2021, September). Retrieved November 11, 2021, from https://3dpotter.com/3d-printing-cement

8 x 15 bus stop shelter 2 opening. (2021, October 20). Retrieved November 11, 2021, from https://www.guardboothonline.com/product/8-x-15-bus-stop-shelter-2-opening/?gclid=CjwKCAjwiY6MBhBqEiwARFSCPqYMmbWtwJKDiIh3tTIB0f7GCIig-uHZYGuktPQKvsTt7RRlMGHugRoCIOsQAvD_BwE

Boesky, A. M. (2021, January 11). Concrete tile roof cost in 2021: Boral & Eagle Roofing Tiles. Retrieved November 11, 2021, from https://www.roofingcalc.com/concrete-tile-roof-cost/

Boral Roofing. (2012). Texas Concrete Roof Tiles. Retrieved November 11, 2021, from http://www.wrs.us.com/product-info/Boral/TX%20Brochure-low%20res.pdf

Boral Roofing. (n.d.). Product information - Villa Concrete Tile. Retrieved November 11, 2021, from https://boralroof.com/wp-content/uploads/boral-pdfs/boral-11732.pdf

Global first 3D printing bus stop appeared in Jinshan Garden, Zhangjiang. (2021). Retrieved November 11, 2021, from http://www.winsun3d.com/En/News/news_inner/id/269

Indiana Department of Transportation. (2011). Prestressed concrete member type linear foot aashto type I ... Retrieved November 11, 2021, from https://www.in.gov/dot/div/contracts/standards/dm/2011/Part6/Ch59/figures/Fig59-5A.pdf

NAHB Research Center. (1994, July). Alternative framing materials in residential construction: Three case studies. Retrieved November 11, 2021, from https://www.huduser.gov/portal/Publications/PDF/altframe.pdf

Nellemann, C. (2018, March 19). 3D printer creates $10,000 tiny house in 24 Hours - Tiny House blog. Retrieved November 11, 2021, from https://tinyhouseblog.com/humanitarian/print-your-own-10000-3d-tiny-house/

Noe, R. (2021, March 10). A lightweight, 3D-printed alternative to reinforced concrete beams. Retrieved November 11, 2021, from https://www.core77.com/posts/106803/A-Lightweight-3D-Printed-Alternative-to-Reinforced-Concrete-Beams

O'Keefe, C. (2021, August 24). House Framing Costs. Retrieved November 11, 2021, from https://www.homeadvisor.com/cost/walls-and-ceilings/install-carpentry-framing/

Oshkosh Media (Director). (2020, February 10). 3D Printed Roof Tile for the Oshkosh Public Museum Carriage House [Video file]. Retrieved November 11, 2021, from https://www.youtube.com/watch?v=GmA2hJI_tMk

Pricing. (2021). Retrieved November 11, 2021, from https://mightybuildings.com/pricing#mods

Projects. (2021). Retrieved November 11, 2021, from https://www.iconbuild.com/projects

Push plastic - bulk PLA (3KG/10kg/25kg)black / 1.75mm / 25kg. (2021). Retrieved November 11, 2021, from https://project3dprinters.com/products/push-plastic-bulk-pla-3kg-10kg-25kg?variant=31117586464842

Push plastics bulk premium ABS filament. (2021). Retrieved November 11, 2021, from https://ultimate3dprintingstore.com/products/push-plastics-bulk-premium-abs?currency=USD&variant=31322039877735&utm_medium=cpc&utm_source=google&utm_campaign=Google+Shopping

Relativity Space. (2021). World's Largest 3D Metal Printers. Retrieved November 11, 2021, from https://www.relativityspace.com/stargate

Texas Department of Transportation. (2020). 1 of 3 table 1. FY 20 average unit cost - ftp.dot.state.tx.us. Retrieved November 11, 2021, from https://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/bridge/unit-costs-2020.pdf

Ultimate Guide to Construction 3D printers in 2021. (2021). Retrieved November 11, 2021, from https://www.aniwaa.com/buyers-guide/3d-printers/house-3d-printer-construction/

Wide Flange Steel Beam. (2021). Retrieved November 11, 2021, from https://www.mkmetal.net/wide-flange-steel-beam#2

Wu, P., Wang, J., & Wang, X. (2016). A critical review of the use of 3-D printing in the construction industry. Automation in Construction, 68, 21-31. doi:10.1016/j.autcon.2016.04.005

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A Taxonomy-based Approach to Analyze the impacts of Automation on Human Workers' Qualifications

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The 4th industrial revolution is changing every aspect of the construction industry. However, recent studies indicated that, at least for the foreseeable future, most of the new automated technologies will have a complementary role that requires interaction and collaboration with human workers. Therefore, it is critical to prepare and train human workers to work with and alongside robots. Middle-skill workers must gain new skills, knowledge, and abilities to contribute to the industry effectively and stay employed during this technological revolution. To prepare, educate, and train middle-skill workers to embrace the unprecedented changes and get ready for their parts in the automation era, it is critical to, first, analyze and understand how new automated technologies change the work and required qualifications for human workers. This study aims to address this need by proposing a systematic approach based on three types of taxonomies: (1) taxonomy of the work and its tasks, (2) taxonomy of the robot and its functionalities, and (3) taxonomy of the human worker's qualifications. Using these taxonomies, the interactions between the functionalities of a robot, the work, and human workers' requirements are mapped to systematically identify the potential impacts of new technologies on middle-skill workers. The proposed approach is implemented for Hilti's Jaibot, a semi-automated robot for overhead drilling. The outcomes of this study will help experts systematically design strategic plans to prepare and train middle-skill construction workers to efficiently and successfully work in the digital era.

Key Words: Automation, Taxonomy, Middle-Skill Workers, Qualifications

Introduction

The 4th industrial revolution is changing the construction industry through a wide range of technological advancements, including artificial intelligence (AI), automation, robotics, and 3D printing, making construction works easier, faster, and safer (Leopold et al., 2016). These revolutionary advancements change the nature of work and the required qualifications for human workers. Recent studies indicate that most automated solutions will not substitute for human workers, at least for the foreseeable future (MIT 2019). Manyika et al. (2017a) argued that advanced technologies could entirely displace only 5 percent of tasks. The new automated technologies mostly have a complementary role that requires interaction and collaboration with human workers (Sachs et al., 2015). In this new environment, tasks that once only needed human workers now require interaction and collaboration between automated technologies such as robots and human workers. This complementary role changes human workers' qualifications. Human workers must gain new skills, knowledge, and abilities to contribute to the industry effectively and stay employed during this technological revolution. McKinsey Global Institute (2017) estimates that more than 2,000 work activities across 800 jobs are affected by automation. Leopold et al. (2016) point out that on average more than one-third of the skill sets that are currently required in many innovative industries including construction will change due to automation.

The MIT task force on the work of the future (2019) reports that middle-skill workers are the majority of the class of workers affected by the 4th industrial revolution. Recent studies (Aladbulkareem et al., 2018) point out that AI and automation drive labor employment disproportionately and increase middle-skill workers' exposure to skill shortages and job displacement. Thus, the middle-skill workers whose work and tasks have the highest potential for automation face a more complicated transition. The MIT report (2019) addresses that training and lifelong learning are effective ways to update the middle-skill workers' qualifications for the labor market challenges caused by ongoing technological change. As construction is continually evolving towards automation, it is essential to provide workers with training in technological innovation and prepare and retrain them to interact and collaborate with robots (Stern, 2019). To prepare, educate, and train middle-skill workers to embrace the unprecedented changes and get ready for their parts in the automation era, it is critical to, first, analyze and understand how new automated technologies change the work and required qualifications for human workers.

This study aims to address this need by proposing a systematic approach to identify the potential impacts of new technologies on human workers' required qualifications. The proposed approach is based on three types of taxonomies: (1) taxonomy of the work and its tasks, (2) taxonomy of the robot and its functionalities, and (3) taxonomy of the human worker's qualifications (i.e., abilities, skills, and knowledge). To better present the proposed approach and its implementation, we considered Hilti's Jaibot for overhead drilling and examined how it changes the work tasks and required qualifications for plumber helpers whose tasks involve a lot of overhead drilling. Jaibot is a great example of a semi-automated robot that directly interacts with a human operator.

The primary contribution of this study to the body of knowledge is to create a systematic method to analyze the impacts of automation on middle-skill workers' required qualifications and work tasks. The outcomes of this study will help experts systematically design strategic plans to prepare and train middle-skill construction workers accordingly.

In the remainder of this paper, after a brief overview of Jaibot's functionalities, we introduce the proposed framework. Next, we discuss the outcomes. Finally, we present the conclusion and potential future works.

Jaibot: A Semi-automated Robot for Overhead Drilling

Jaibot is a semi-autonomous construction robot designed for mechanical, electrical, and plumbing installation to support overhead drilling in concrete ceilings with a dust control system based on building information modeling data (BIM) or AutoCAD layout. Jaibot is able to locate itself on the jobsite with human's control. Its navigation capability allows it to position and orientate where needed to drill holes based on digital plans. The level of robot autonomy is shared control as the human worker monitors the robot's process and carries out this task together (Endsley & Kaber, 1999). Jaibot has a safety capability as it helps remove potential risks associated with overhead drilling for users and is environmentally friendly with a dust shroud. Since Jaibot acts as a complementary role that requires interaction and collaboration with the worker, the human role is categorized as an operator who directly controls and works alongside the robot. Therefore, the team is composed of a human operator and the robot. The form of input for communication channels is electronic, which indicates that Jaibot receives information through a control device from the operator and passes information back to the worker by visual communication (Hilti 2020). Physical proximity is classified as approaching, and temporal proximity is synchronous for the operator and the robot to share the same space and work closely together without physical contact (Huttenrauch & Eklundh, 2004; Yanco & Drury, 2004). Jaibot can work up to eight hours with full charge to drill numerous holes overhead for many physical, repetitive installation tasks. Figure 1 shows a Jaibot performing overhead drilling.

Figure 1. Jaibot performing the overhead drilling task (source from Hilti Corporation)

Methodology

To systematically understand the impacts of automation on middle-skill workers' required qualifications and work activities, our study develops a framework consisting of three types of taxonomies: (1) taxonomy of the work and its tasks, (2) taxonomy of the robot and its functionalities, and (3) taxonomy of the human worker's qualifications. The design of the robot's taxonomy and its functionalities is inspired by previous works that aimed to classify robots characterized from different perspectives including Yanco and Drury (2002), Yanco and Drury (2004), Beer et al. (2014), Onnasch and Roesler (2020), and Jahn et al. (2020). We created the other two taxonomies (i.e., human workers' qualifications and work tasks) based on the Occupational Information Network (O*NET) data developed by the U.S. Department of Labor (2021). The dataset consists of a comprehensive directory of occupations in different industries and their required qualifications, including skills, abilities, and knowledge. O*NET collects this information through continual surveys from subject-matter experts. The latest version of the dataset was published in August 2021. For each job, the database provided a list of work activities and required qualifications. The required qualifications include 35 types of skills, 52 types of abilities, and 33 types of knowledge.

The latest version of the O*NET database contains 93 construction occupations. 84 out of the 93 occupations are considered middle-skill jobs. Among these occupations, a job entitled "Helpers of Pipelayers, Plumbers, Pipfitters, and Steamfitters" (HPPPS) is one of the jobs that involve tasks that require overhead drilling. To present the proposed method in this study, we focus on this job.

After creating the taxonomies, we use them for mapping the interactions among the elements of the taxonomies and identifying the impacts of automation on the human worker's qualifications.

Analysis

Taxonomy of the Robot and its Functionalities

Taxonomy, initially invented in biology, is the science of classifying the characteristics of an entity through a hierarchical structure (Ohl, 2015). As robotics has become a popular research field in recent decades, the application of taxonomy is extended to sorting robots based on types, applications, capabilities, and implementations (Jahn et al., 2020). Previous studies have proposed different taxonomies from various perspectives. Yanco (2002) created a Human-Robot Interaction (HRI) taxonomy that includes team composition, required interaction, and space-time location. In another study, Yanco (2004) updated the proposed taxonomy by adding human interaction roles, task types, and human-robot physical proximity to reflect the changes in HRI and its tasks. Beer et al. (2014) proposed a taxonomy framework to draw a relationship between human-robot interaction (HRI) and human-automation interaction to understand human-related variables. Onnasch (2020) developed a new HRI taxonomy that adds the context of the HRI and its application to various HRI scenarios. Inspired by the existing taxonomies for robots, our study proposes a new and comprehensive robot taxonomy. In this study, we calibrated the taxonomy to Jaibot, its characteristics, and functionalities.

The proposed taxonomy of the Jaibot consists of two main parts: capabilities and tasks. The capability part consists of six subcategories: (1) navigation; (2) autonomy; (3) safety; (4) human-robot interaction; (5) energy efficiency; and (6) usability. The task part consists of four subcategories: (1) information exchange, (2) physical load reduction, (3) manipulation, and (4) cognitive stimulation. Jaibot takes over most of the strenuous and exhausting tasks based on digitization, reducing the human's physical workload (i.e., lifting, climbing, and walking). The manipulation task is drilling holes overhead and then marking them automatically. Jaibot can memorize the process and upload it to the Hilti Cloud for tracking purposes, defined as a cognitive task. The information exchange describes the robot's acquisition of information from the environment and transfers it to the human (Onnasch, 2020). Therefore, Jaibot's information exchange task is a visual display because the robot receives the information through digital plans and transfers this information to the human through implementing the drilling task.

Each one of the subcategories is divided into more detailed elements. For example, the HRI subcategory is further subdivided into the human role, communication channel, proximity, and team composition. These elements are also divided into further detailed subcategories. Next, the characteristics are nested directly under their related subcategories. For example, under the human role element, we put "operator." Figure 2 shows the complete taxonomy.

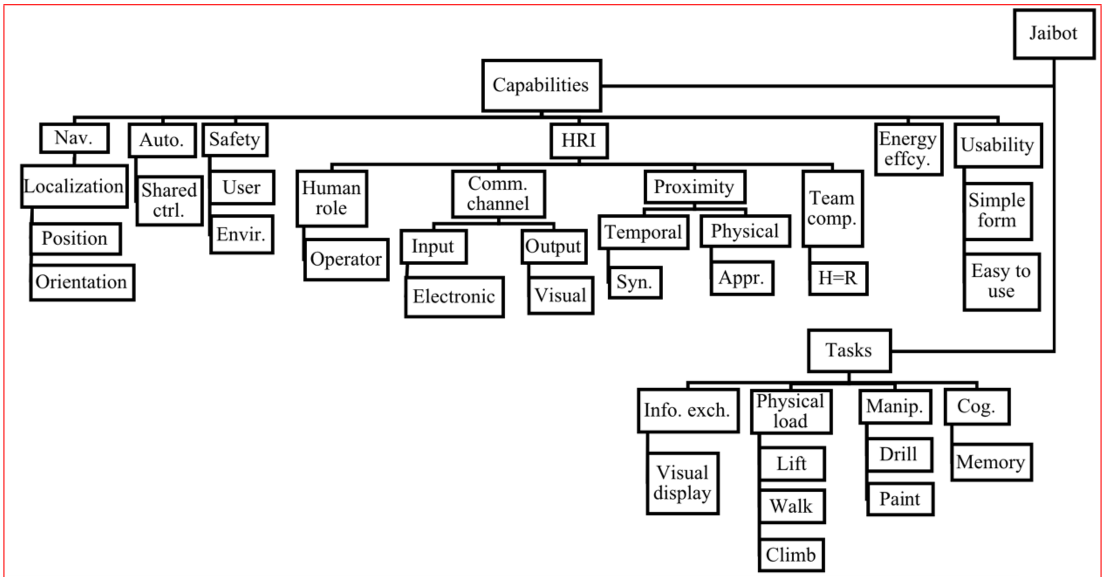

Figure 2. The proposed hierarchical taxonomy of Jaibot

Taxonomy of the Human Workers' Qualifications

As noted before, the taxonomy of human workers' qualifications is designed based on the O*NET database. Among the required qualifications for an HPPPS, we identified 15 skills, 9 knowledge areas, and 26 types of abilities linked to overhead drilling. Using these qualifications, we created the taxonomy that is shown in Figure 3. The required skills are classified into four categories: (1) basic skills; (2) social; (3) resource management; and (4) technical. The knowledge area does not have subcategories, but it contains the nine elements directly. The required abilities are also subdivided into four categories: (1) physical, (2) psychomotor, (3) cognitive, and (4) sensory.

After developing the taxonomy, the robot's capabilities should be mapped with the human worker's qualifications to identify the potential impacts of the new technology on the human worker's requirements. The human qualifications can be categorized into three groups: (1) those that are needed more when the worker uses the robot; (2) those that are needed less when the worker uses the robot; and (3) those that do not change. This process can be done by subject-matter experts. In this study, we did this based on inputs received from experts who have used the robot. We showed these groups in Figure 3.

Figure 3 shows that many human worker's qualifications that are linked to their physical characteristics will have a lower level of importance when Jaibot is used. For example, arm and hand steadiness under psychomotor abilities will not be that critical when a construction worker uses Jaibot for overhead drilling. Another example of qualifications that are needed less when workers use Jaibot would be near vision under the sensory abilities. Overall, most items under the ability category will have a lower level of importance when Jaibot is involved. On the other hand, some other qualifications, such as those under the technical skills category, will play a more critical role when workers interact with Jaibot. Examples include troubleshooting, operation and control, and equipment maintenance.

The importance level of a few qualifications may not change significantly when we use Jaibot. One example would be the management of material resources under resource management skills. In both cases of using and not using Jaibot, the user needs to make sure materials and equipment are ready for the job.

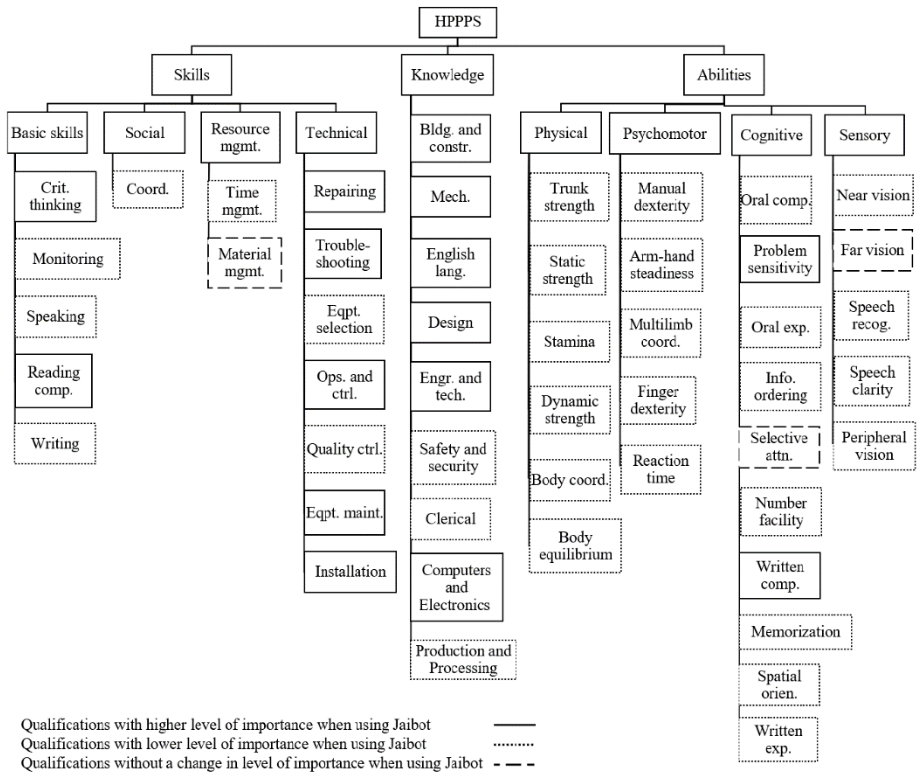

Figure 3. The taxonomy of the worker's qualifications

Taxonomy of the Work and Its Tasks

Not only do new technologies change the human worker's required qualifications, but they also may change the nature of the work and its tasks. The taxonomy of the work and its tasks help us systematically identify the changes. As noted before, this taxonomy is also designed using the O*NET dataset. The O*NET dataset lists 41 tasks for an HPPPS. Eighteen tasks, out of the 41, are related to overhead drilling. According to the O*NET classifications, we grouped those 18 tasks into four categories: (1) information input, (2) interacting with others, (3) mental processes, and (4) work outputs.

The information input category includes tasks related to inspection, getting information, quantifying, and process monitoring. The second category, interacting with others, involves communication with others and coordinating the work activities. The category of mental processes covers 7 tasks, including analyzing data and information. Finally, the fourth task, work output, includes tasks such as handling and moving objects.

Figure 4 shows the taxonomy of the work and its tasks. Similar to the taxonomy of human workers' qualifications presented in the previous section, we identified the tasks that change when Jaibot is used. The outcomes indicate that tasks that are linked to physical activities such as handling and moving objects and documenting will contribute less to what human workers do when Jaibot works. On the other hand, activities that need human judgments, such as repairing and maintenance of equipment, updating and using relevant knowledge, will play a more important role on the human side of the work when the robot is used.

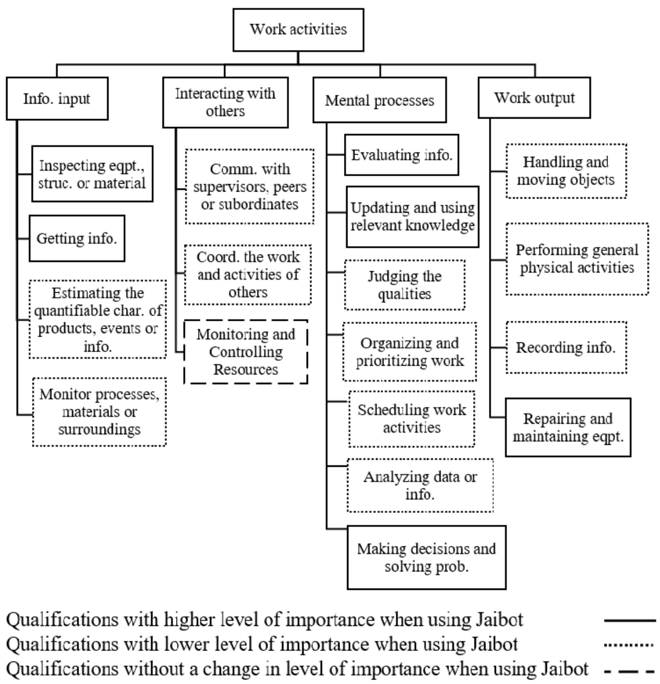

Figure 4. The taxonomy of the work and its tasks

Conclusion and Future Work

This study developed a systematic approach to analyzing how automation affects middle-skill workers' required qualifications and the work based on three types of taxonomies, namely the taxonomy of the work and its tasks, the taxonomy of the robot and its functionalities, and the taxonomy of the human worker's qualifications. To present and implement the proposed approach, we analyzed the impacts of the Jaibot robot by Hilti on the required qualifications that a plumber helper needs to have for overhead drilling.

We created the taxonomy of the Jaibot and its functionalities using a wide range of previous studies that designed robot taxonomies from different perspectives. To create the taxonomy of human workers' qualifications and the taxonomy of the work and its tasks, we used the O*NET database. We systematically mapped the robots' characteristics with human qualifications and the work tasks using the three taxonomies. The outcomes helped us systematically identify the changes that Jaibot creates in the human's required qualifications and work tasks.

Through the proposed framework, we identified the human worker's qualifications that may have a lower level of importance when Jaibot is part of the project team. Most of these qualifications are linked to the human worker's physical characteristics since the robot will take care of many physical aspects of the job. Examples include physical abilities such as strength and body equilibrium, psychomotor abilities such as manual dexterity, arm-hand steadiness, and multilimb coordination, and sensory abilities such as near vision and speech clarity. In addition, some cognitive abilities such as memorization may be less critical too, as the robot can record and keep all the data.

The required human qualifications that will be less critical is the positive side of employing new technologies. The challenge is the qualifications that are needed more when a human interacts with a robot. Using the proposed framework, we aimed to identify those factors too. Examples include repairing, troubleshooting, reading comprehension, and critical thinking.

In addition to the impacts of the new technology on human workers' qualifications, we also analyzed the impacts of the robot on work tasks. Using the proposed framework, we identified the tasks that will take a lower amount of time from the human when Jaibot is involved in the project and also those that will need more attention from the human side when they use the robot. For example, when workers use Jaibot, they may not need to perform general physical activities, move objects, and manually record data. However, they may need to do more equipment inspection, decision-making, and problem-solving tasks.

The primary contribution of this study to the body of knowledge is to create a systematic method to analyze the impacts of automation on middle-skill workers' required qualifications and their tasks. Although we focused on Jaibot to implement the proposed method in this study, the introduced method based on the taxonomy analysis can be applied to any other robot as well. The outcomes of this study will help experts systematically design strategic plans to prepare and train middle-skill construction workers accordingly. To the best of our knowledge, this study is the first effort to analyze potential changes of automated technologies on the qualifications of middle-skill workers and their work activities based on various taxonomies.

One of the limitations of this study is its dependency on the recency and accuracy of the O*NET database. The construction industry is a rapidly changing environment in which new tasks and qualifications are created, and it is critical that O*NET continuously captures these changes in its databases. Another limitation is that our study only considers skills, abilities, and knowledge as the worker's qualifications as we defined. However, other factors (i.e., personal interests and values) are not taken into account in this study. Addressing these limitations can be a basis for future studies. This study can set the stage for future research focusing on analyzing the impacts of automation on the middle-skill workers' qualifications and the work tasks during this technological revolution.

References

Alabdulkareem, A., Frank, M., Sun, L., Alshebli, B., Hidalgo, C. & Rahwan, I. (2018). Unpacking the polarization of workplace skills. *Science Advances*.

Beer, J.M., Fisk, A. D., & Rogers, W. A. (2014). Toward a framework for levels of robot autonomy in human-robot interaction. *Journal of Human-Robot Interaction*. *3* (2), 74-99.

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics*. *42*(3), 462-492.

Hilti Corporation. (2020). Hilti unveils BIM-enabled construction jobsite robot. Retrieved from https://www.hilti.group/

Huttenrauch, H., & Eklundh, K. (2004). Investigating socially interactive robots that give the right cues and make their presence felt. *The CHI 2004 workshop on shaping human-robot interaction.* 17–20.

Jahn, U., Heß, D., Stampa, M., Sutorma, A., Röhrig, C., Schulz, P., & Wolff, C. (2020). A taxonomy for mobile robots: types, applications, capabilities, implementations, requirements, and challenges. *Robotics. 9.* 109.

Leopold, T. A., Vesselina, R., & Zahidi, S. (2016). The future of jobs report in world economic forum. *Global Challenge Insight Report.*

Manyika, J., Chui, M., Miremadi, M., Bughin, J., George, K., Willmott, P., & Dewhurst, M. (2017a). Harnessing automation for a future that works. *McKinsey Global Institute.*

Massachusetts Institute of Technology. (2019). The work of the future: shaping technology and institutions. *MIT Task Force for Work of the future*.

McKinsey Global Institute. (2017). A future that works: automation, employment, and productivity. *MGI A future that works.*

Occupational Information Network. (2021). O*NET OnLine, https://www.onetonline.org/ (August, 2021)

Ohl, M. (2007). 4 Principles of taxonomy and classification: current procedures for naming and classifying organisms. *ResearchGate.*

Onnasch, L., & Roesler, E. (2020). A taxonomy to structure and analyze human-robot interaction. *International Journal of Social Robotics. 13*, 833-849.

Sachs, J., Benzell, S., & LaGarda, G. (2015). Robots: curse or blessing? A basic framework. *National Bureau of Economic Research.*

Stern, B. E. (2019). Addressing the workforce skills gap in construction and CRE-related trades. *NAIOP Research Foundation.*

Yanco, H. A., & Drury, J. L. (2002). A taxonomy for human-robot interaction. *AAAI Fall Symposium on Human-Robot Interaction.* 111-119.

Yanco, H. A., & Drury, J. L. (2004). Classifying human-robot interaction: an updated taxonomy. *IEEE International Conference on Systems, Man and Cybernetics. 3.* 2841-2846.

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Single Image based Volume Estimation for Dump Trucks in Earthmoving using Machine Learning Approach

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Earthmoving is one of the key activities in most heavy civil construction projects. The dump truck is one primary construction vehicle for earthmoving. Two popular approaches are currently used to estimate earthmoving volume by trucks, i.e., manually counting the number of loaded trucks and weighing loaded trucks on a scale station. Considering both methods are either error-prone, time-consuming, or costly, this study aims to estimate different earth volumes in dump trucks from a single image using the machine learning approach. By establishing a pre-trained deep learning neural network from 3663 images with sixteen different volumes of the earth using a scaled dump truck model, the proposed approach is tested to estimate the truckload in a quantitative manner in real-time. Another 1221 images are used for verification in six case combinations out of the sixteen different volumes. The preliminary results show that the classification accuracy by using the pre-trained network is 100% if the volume gap between adjacent classes is more than 5%, while 76.67% if the volume gap is 1%. The preliminary test results show a great potential that the proposed methods could be applied to the field and provide a fast and accurate estimate of truckload with minimal cost.

Key Words: Machine learning, Image-based volume estimation, Earthmoving, Productivity

Introduction

Earthmoving is a base operation in field construction. Dump trucks are a major means used for earthmoving operations (Jabri & Zayed, 2017). Determining the amount of load moved by dump trucks is required to track the earthmoving operations' productivity and is used for financial settlements within the earthmoving contractors. There are currently two types of earthmoving quantity statistics methods, i.e., manually counting the overall number of truckloads moved (i.e., Overall Truck Number Counting (OTC)) or weighing trucks at load weigh stations (Single Truck Load Weighing Stations (STW)). OTC can be used for scenarios like airport constructions which have a large quantity of overall transportation that is made with low unit load price and uniform trucks (Moselhi &

Alshibani, 2009). It is based on only checking by humans whether the truck is full or empty and the number of trucks. Since full load is determined by the human eye, there can be minor errors in this method which can lead to a major loss for contractors because the method does not provide a realistic quantity. Different quantities (usually from 100% to 60% loaded trucks) are counted as fully loaded trucks. This method comes with inevitable human error and high labor cost. Overall Truck Number Counting is limited under conditions like unfamiliar altitude and extreme weather, which are threatened labor safety (Guo et al., 2016; Yi & Chan, 2017). On the other hand, STW can provide more accurate statistics about the amount of truckload (Lin et al., 2017). However, it is applicable for cases with a small amount of total transportation in general (Lee & Chow, 2011). It can also be useful for cases that have multi-party contracting, a small amount of earthmoving, and/or expensive highway transportation charges (Fekpe et al., 1993). This method, however, has disadvantages. In addition to the land and facility necessary for STW, a single truck scale costs between $35,000 to $100,000 along with a maintenance cost in the following period (Carlton Scale, 2021). It needs to be replaced after fulfilling its lifetime which is not so long to compensate for the cost. Scales are placed in stations on highways which require trucks to get in line first to be weighted and then stop on the scale. Therefore, these stations can cause a bottleneck which ends up with traffic jams on busy highways, especially during peak times (Lee & Chow, 2011). These bottlenecks in stations also cause delays in the truck flow in each project and affect the cost efficiency of all projects which use these stations for weighing their trucks (Samandar et al., 2018). Therefore, the current implementations have their limitations, such as high labor and economic costs, limited application environment, continuous maintenance requirement, and transportation interruption (Liu et al., 2019).

A comparison study by Liu et al. (2019) proposes the framework of the novel, automated earthmoving quantity statistics that mainly applies vision-based deep learning for full/empty-loaded truck classification as the core work and counts full-load trucks. It utilizes the field-equipped surveillance video system and deep learning convolutional neural network (CNN) related image recognition models to achieve unmanned and non-contact truckload condition judgment. The study compares 12 deep learning models constructed by four classical CNNs and two transfer learning methods to classify empty and fully loaded trucks. Isolated projects in an open construction site with uniform and uncovered trucks are required for the vision-based earthmoving quantity statistics method proposed in their study. Although this study successfully validated the feasibility in use of deep learning approach for vision-based full/empty-loaded truck classification, it is still a binary classification problem, which solves the problem of Yes and No question. This study steps further to evaluate the possibility in use of the deep learning approach for quantitatively estimating the earth volume in uniform and uncovered dump trucks. By addressing this research question, the associated cost or error in earthmoving volume can be reduced and the total number of trucks used in earthmoving projects can be optimized, especially for large construction areas. Besides, if the use of the deep learning approach in earthmoving operations can be validated to a quantitative level, the value of this research can be extended to various relevant application scenarios, which includes but not limited to roads, airports, ports, buildings, utilities, etc.

Methodology and Experiments

This study aims to estimate different earth volumes in dump trucks from a single image using the machine learning approach. By establishing a pre-trained deep learning neural network from images with different volumes of the earth in the dump trucks, the proposed approach is designed to estimate the truckload in a quantitative manner. Deep learning is a subfield of machine learning. It is based on artificial or convolutional neural networks, inspired by the human brain. It allows computers and/or machines to solve problems by learning large data sets. These data sets can contain images, text, or sound (LeCun et al., 2015). The proposed methodology consists of four main parts as shown in the Figure below: data collection, code preparation, training process (including pre-processing, training, and testing), and comparison (see Figure 1). The details will be explained in the following of this section.

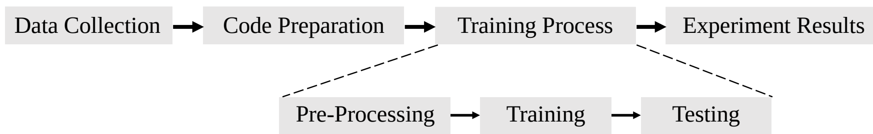

Figure 1. The overall workflow

Data Collection

The data collection was obtained from a toy truck which has the identical features as a real scaled dump truck. To make the experiment more realistic, photos were taken at different places and different times of the day, so the different lights and backgrounds would be used within the data set. Two types of fill materials were used: play sand from Home Depot and the soil from the backyard. The light was set to the natural sunlight, and the background and fill material colors were set to the same tone. For twelve different load ranges, photo images were collected, which includes the empty load case (441 photos), 200ml load case (437 photos), 400ml case (478 photos), 600ml load case (395 photos), 610ml load case (184 photos), 620ml load case (207 photos), 630ml load case (200 photos), 640ml load case (231 photos), 650ml load case (225 photos), 700ml load case (200 photos), 750ml load case (276 photos), 800 ml load case (373 photos), 850 ml load case (276 photos), 900 ml load case (303 photos), 950 ml load case (265 photos) and 1000 ml load case (393 photos). With the camera held in the landscape orientation for each image taken, the angle and the height were not fixed but all borders of the dump truck were required to be visible in the photo images. The original image is 3456x2304. Figure 2 shows sample images with different earth volumes.

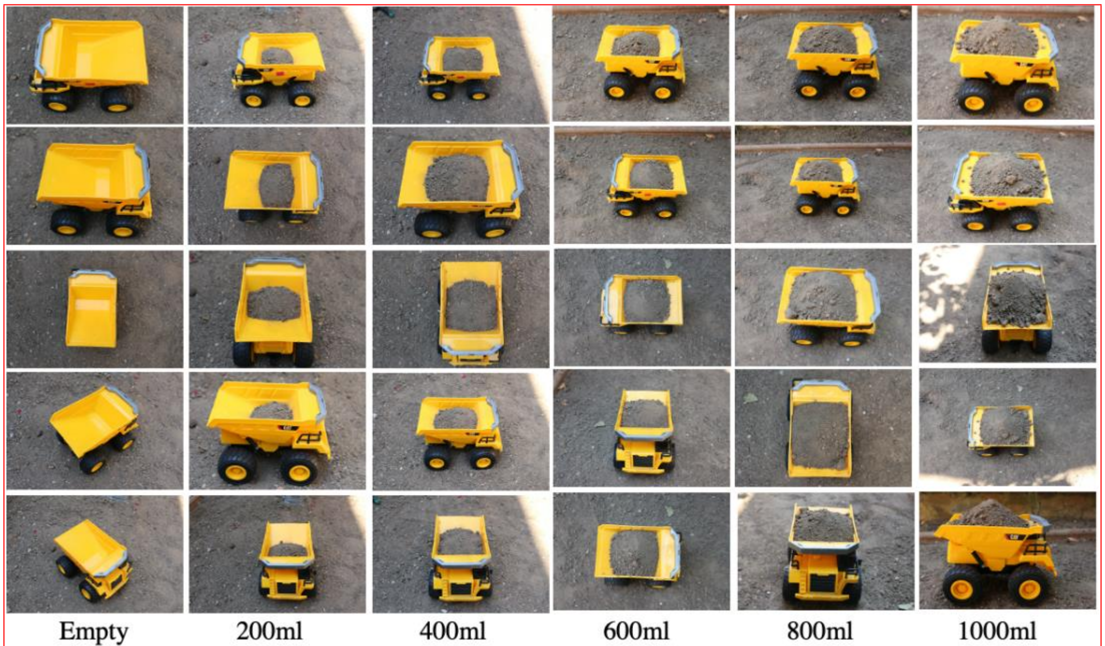

Figure 1. Sample images with different earth volumes

Code Creation in Matlab

In the code creation process in Matlab (MathWorks, 2021), a pre-trained network architecture with layer replacement is used to conduct a convolutional deep learning process, which is divided into the following six main parts: load and explore image data, define network architecture, specify training options, train network, and classify validation images and compute the accuracy (see Figure 3).

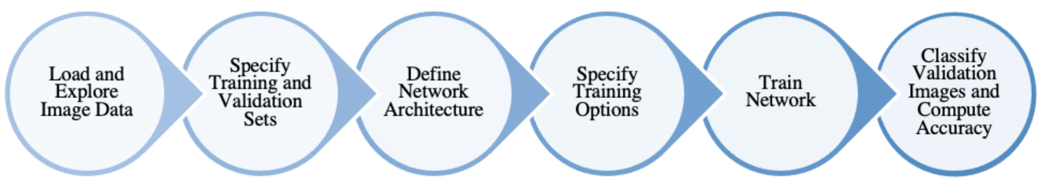

Figure 2: The general structure of network models

Loading and exploring the image data

The sample data are loaded as an image data store by specifying the data set path and using the "*imageDatastore" Matlab* command. The image datastore enables the network to store large image data and efficiently read batches of images from folders during the training of the convolutional neural network.

Specifying training and validation sets

The data are divided into two different sets, i.e., a training set and a validation set. While 75% of the total number of images are used as a training set, the remaining 25% are used as a validation set.

Defining the network architecture

Liu et al. (2019) found that the pre-trained network named VGG16 is working fast in terms of training and testing/validation time while it also has a high testing/validation accuracy to determine if a truck is either empty loaded or fully loaded. Since the results of the paper are promising VGG16 is selected to be used in this experiment. VGG16 is a convolutional neural network model proposed by Simonyan and Zisserman (2014), which has 16 layers. For this experiment, only the architecture of the network model is used, which has 41 layers (see Figure 4). The layers are started with the image input layer and followed by five convolutional groups, three fully connected layer groups, ending with the classification layer as the output (MathWorks, 2021). The details of each layer group are as follows.

Image Input Layer is where the image size is specified. The image size in this study is specified as 224 x 224. The first two convolutional group includes two convolutional 2D layers, and each is followed by a relu layer. The following three convolutional groups include three convolutional 2D layers and each is followed by a relu layer. Convolutional groups are divided from each other by max-pooling layers. Convolutional 2D Layer is where the filter size and number of filters are specified. In this study, the filter size is specified as 3 x 3 with the number of filters as 64, 128, 256, 512, and 512 respectively (see Figure 4). For max-pooling 2D layer, the size of the rectangular region is [2, 2], while the name-value pair argument is specified as “Stride”. The first two fully-connected layer groups include one fully connected layer each followed by a relu layer and a drop out layer, while the last fully connected group includes one fully connected layer followed by a softmax layer. The dropout layer randomly sets input elements to zero with a given probability. In this approach, both dropout layers have a probability of “0.5”. For each experiment case, the number of output classes of the network is changed based on the experiment requirement.

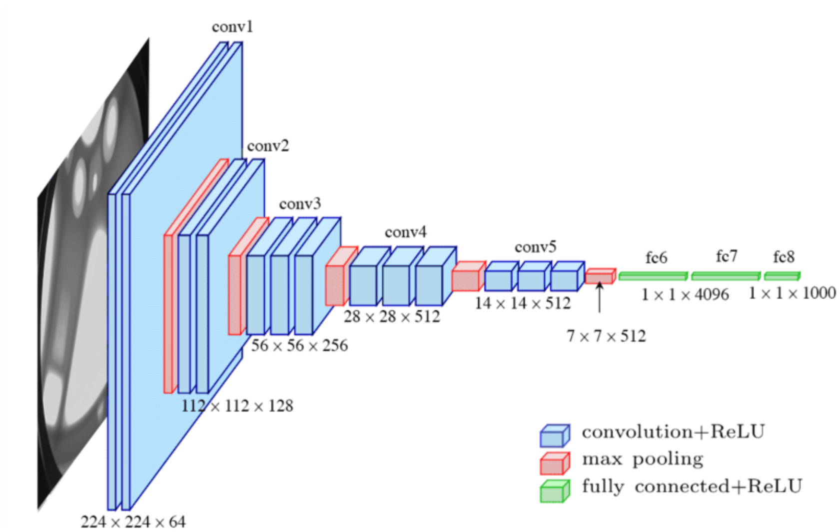

Figure 3: Pretrained network architecture

The training options that have been used in this approach are listed as followed. The training options “Solver Name”, “Plots”, “Max Epochs”, “Mini Batch Size”, “Shuffle”, “Validation Data”, "Validation Frequency", and "Initial Learning Rate" are specified as "sgdm" (stochastic gradient descent with momentum), "training-progress", "100", "every-epoch", "imds" (image data store), "5", and "0.0001" respectively. The rest of the training options are set as default values.

Specifying the training options

All options have been specified except the preferred default settings. Training options include "Solver Name", "Plots and Display", "Mini-Batch Options", "Validation", "Solver Options", "Gradient Clipping", "Sequence Options", "Hardware Options", and "Check Points". The specified options are discussed in the following subsections.

Training the network

Specified training data set, network architecture layers and training options are used to train the network.

Classifying the validation images and computing the accuracy

The validation data set is classified by using the trained network. Accuracy is the percentage of labels that the network correctly predicts.

An example of the Matlab code can be found from the shared link below:
https://www.dropbox.com/sh/jfoit87ahjju068/AAA8TiBLI1GQVePT6lMQNHrCa?dl=0

Training Process

Pre-processing

In this process, there are three main steps which are pre-processing, training, and validation. While the pre-processing step is done by the XnView App, training and validation steps are performed in MatLab. The collected image data are resized according to the requirements of the pre-trained network model. The original size of all images is 3456 x 2304. For the VGG16 convolutional neural network model, the input required is the size of 224 x 224 so all the images are resized to 224 x 224 for this study.

Training and Testing

The training command is given as "net= trainNetwork (imds, layers, options)" in the network. The command means that the network is using 75% of the "imds" data store with the specified layers to train the network with specified training options. During the training process, a plot is progressing along with the training.

For testing, the network is using the remaining 25% of the "imds" data store with the "YPred = classify (net, imdsTest)" command. The accuracy of the network is also calculated by the validation results. The accuracy calculation is made by the comparison between the network's predicted label and the original label of the image. The validation is also made with a stand-alone function (pre-trained network) that is created with the training network. In this process, labeled images are randomly given to the function. The system predicts the labels, and the results are compared for the accuracy calculation. The original volume and predicted volume comparison can be seen in the experiment results section.

Experimental Results

The proposed Deep Learning method is applied to six different case combinations. The accuracy of the stand-alone (pre-trained) function is 100% with the usage of the network model which was created for nine cases (50 ml apart) and 76.67% for 10 ml apart cases. For the 50 ml apart cases test, 18 random and new (non-added in the training process) images are given to the system to predict the classes. For the 10 ml apart cases test, 30 random and new (non-added in the training process) images are given to the system to predict the classes. The pre-trained network model can detect every random image with a 5% difference of the total volume correctly but not the 1% difference of the total volume. The detailed information and the validation accuracy results of each case are shown in Table 1 below. The training progress plots can be found in Figure 5.

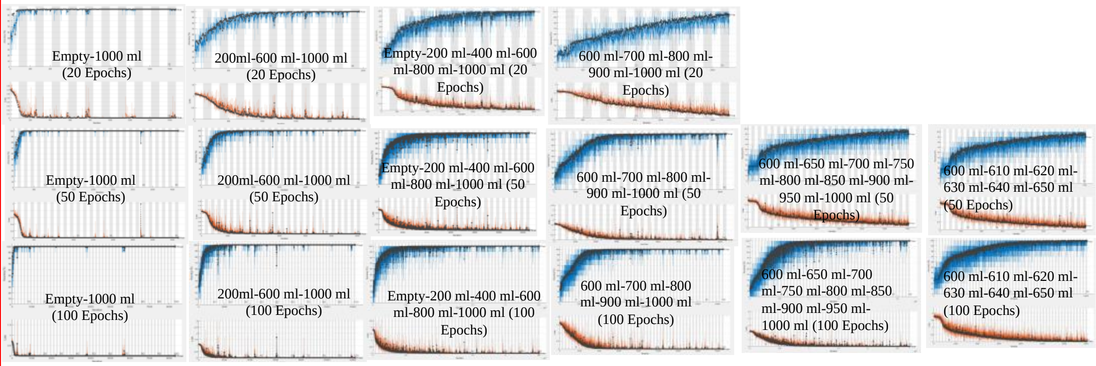

Figure 4. The training progress plots

In Table 1, it can also be observed that the number of epochs is in direct proportion to the accuracy. The results show that the number of images and number of epochs is in direct proportion to the number of iterations. As much as the number of iterations increased the time that the system needs to complete the training is also increasing, while the accuracy is improved. In consideration of 100 epochs runs, the training progress plots in Figure 5 show that as much as the volume difference decreases the network needs more time to improve the validation accuracy. While the 20 epoch runs gave an acceptable accuracy with a meaningful time consumption for a large difference of volume between classes, the 50 epoch runs gave a higher accuracy with an acceptable time consumption for each case. Thus, the suggested maximum epoch for the training is 50 epochs due to the possible overfitting issue in 100 epochs.

Table 1.

Experiment results

Case combinations	Max Epoch	Iteration	Time	Accuracy
Empty-1000ml	20	1660	30 min 16 sec	99.40%
	50	4150	68 min 28 sec	100%
	100	8300	133 min 40 sec	100%
200ml-600ml-1000ml	20	2440	56 mins 3 sec	100%
	50	6100	141 min 18 sec	100%
	100	12200	283 min 40 sec	100%
600ml-700ml-800ml-900ml-1000ml	20	3320	96 min 20 sec	94.30%
	50	8300	246 min 11 sec	100%
	100	16600	484 min 34 sec	100%
Empty-200ml-400ml-600ml-800ml-1000ml	10	2510	101 min 46 sec	93.17%
	20	5020	205 min 53 sec	98.53%
	50	12550	523 min 32 sec	100%
	100	25100	1053 min 39 sec	100%
600ml-650ml-700ml-750ml-800ml-850ml-900ml-950ml-1000ml	50	13500	574 min 34 sec	99.70%
	100	27100	1202 min 35 sec	100%
600ml-610ml-620ml-630ml-640ml-650ml	50	7050	174 min 28 sec	89.72%
	100	14100	362 min 21 sec	98.01%

Discussions and Future Works

In this study, the authors investigated the feasibility in the use of the deep learning approach for quantitatively estimating the earth volume in uniform and uncovered dump trucks. The toy truck was used to validate the concept. Total 4884 images were collected, with 3663 images used for training and the remaining 1221 images for validation. The preliminary results show that the pre-trained network architecture model is sensitive to the 5% difference in total volume but not the 1% difference in the total volume. 100% accuracy is achieved for all cases when volume difference in different classification is 5%, i.e., 50ml out of max load 1000mL or larger. Even for the last case where the volume difference is 1%, i.e, 10ml apart from 600 to 650, the pre-trained network still gives 98.01% accuracy with 100 epochs and 89.72% accuracy with 50 epochs. The results of 10 ml apart cases' validation test show that the network cannot classify the middle class correctly.

Meanwhile, to avoid the overfitting issues using a larger number of epochs, authors are implementing a few experiments using Transfer Learning with a smaller number of epochs, i.e., 30 versus 50. It is found that for cases that have no more than 3 classes, the accuracy is quite close to the results in Table 1, plus the training efficiency is improved obviously. As the classes increase to 4~5, the accuracy drops by 5~10%. Besides, the accuracy becomes very sensitive to the images if more irrelevant background features are included. Therefore, authors need to design a comprehensive testing plan, to investigate the possible major factors that will affect the training performance and volume estimation accuracy, such as image size, image quality, the suggested number of images as the training dataset, the optimal maximum epochs in the training model, the validation frequency, minimal batch size, etc. Since the ultimate goal for the research team is to automate this volume estimate process for real-time applications in the earthwork field application, the future study will investigate the challenges and performance if the proposed approach is applied to the field setting of the earthmoving operations, which might include but not limited to the light conditions under different weather or from different shooting angles, different size/colors of trucks in the images, varied shade effects due to the earthwork.

References

Carlton Scale. (2021). How Much Does A Truck Scale Cost. Retrieved from https://www.carltonscale.com/much-truck-scale-cost/

Fekpe, E. S., Clayton, A. M., & Alfa, A. S. (1993). Aspects of performance of truck weigh stations. *Canadian Journal of Civil Engineering*, *20*(3), 380-385.

Guo, C., Xu, J., Wang, M., Yan, T., Yang, L., & Sun, Z. (2016). Study on oxygen supply standard for physical health of construction personnel of high-altitude tunnels. *International journal of environmental research and public health*, *13*(1), 64.

Jabri, A., & Zayed, T. (2017). Agent-based modeling and simulation of earthmoving operations. *Automation in Construction*, *81*, 210-223.

Lee, J., & Chow, G. (2011). Operation analysis of the electronic screening system at a commercial vehicle weigh station. *Journal of Intelligent Transportation Systems*, *15*(2), 91-103.

Lin, H., Xiang, H., Wang, L., & Yang, J. (2017). Weighing method for truck scale based on neural network with weight-smoothing constraint. *Measurement*, *106*, 128-136.

Liu, Q., Feng, C., Song, Z., Louis, J., & Zhou, J. (2019). Deep learning model comparison for vision-based classification of full/empty-load trucks in earthmoving operations. *Applied Sciences*, *9*(22), 4871.

MathWorks. (2021). Deep Learning with Images. Retrieved from https://www.mathworks.com/help/deeplearning/deep-learning-with-images.html?s_tid=CRUX_lftnav

Moselhi, O., & Alshibani, A. (2009). Optimization of earthmoving operations in heavy civil engineering projects. *Journal of Construction Engineering and Management*, *135*(10), 948-954.

Samandar, M. S., Williams, B. M., & Ahmed, I. (2018). Weigh Station Impact on Truck Travel Time Reliability: Results and Findings from a Field Study and a Simulation Experiment. *Transportation research record*, *2672*(9), 120-129.

Simonyan, K., & Zisserman, A. (2014). Very deep convolutional networks for large-scale image recognition. *arXiv preprint arXiv:1409.1556*.

Yi, W., & Chan, A. P. (2017). Effects of heat stress on construction labor productivity in Hong Kong: a case study of rebar workers. *International journal of environmental research and public health*, *14*(9), 1055.

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Real-time Construction Inspection in an Immersive Environment with an Inspector Assistant Robot

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Construction project management requires frequent inspections to ensure the quality and progress of the construction work. Multiple stakeholders are involved in the inspection process during the project lifecycle. Some project stakeholders, such as architects, owners, structural engineers are involved with multiple construction projects at a time and are responsible to conduct timely inspection and monitoring tasks. This paper studies the potential of Virtual Reality (VR) and robotics for real-time remote inspection. The benefits and challenges of using VR for construction inspection and monitoring were identified and ranked through a systematic literature review. The top 5 benefits were found to be enhanced collaboration, realistic and immersive visualization, remote presence, reduction in inspection time, and support for decision-making. The top 5 challenges identified in this study include low-resolution displays, limited integration with existing technologies (such as BIM), causing disorientation and dizziness for the user, cost of adoption, and job site internet access limitations. Finally, a new approach was investigated for using VR to enable an immersive experience in remote inspection with an inspector assistant robot for real-time remote construction inspection. The experimental investigation verified the identified benefits and challenges.

Key Words: construction inspection, legged robots, virtual reality, Spot, quadruped robots

Introduction

Continuous inspection and monitoring provide timely and accurate information about the project, which is essential for successful project completion (Lee et al., 2018). Conventional methods of inspection are time-consuming and require physical presence at the job site (Rahimian et al., 2020). Jaselskis et al., (2015) explored the concept of "telepresence" for real-time monitoring of projects without being present at the site. This remote inspection aims to bring the site to the inspector through various mediums. Studies (Du et al., 2018; Follini et al., 2021; Khan et al., 2021) have used robotics, augmented reality (AR), and virtual reality (VR) for remote inspection. Robotics supports automated data collection from the site that enables remote inspection (K. Asadi et al., 2020). AR and VR provide an intuitive visualization of the collected data (Khan et al., 2021).

This study explores the use of two of these technologies for construction inspection - robot assistants and virtual reality. The main contributions of the study are the identification of the major benefits of

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using VR for construction inspection, identification of challenges that prohibit the use of VR for inspection, and a novel approach of using VR for real-time remote inspection of projects with the help of assistant robots.

In the following sections, the assistant robots are explained briefly. Following that, prior uses of robotics for inspection in the literature are discussed. Later, findings of a systematic literature review on the use of VR for construction inspection and monitoring are presented. The goal of the literature review was to identify the benefits and challenges of using VR for construction inspection. Then, a new approach to integrating VR with robotics is discussed. The proposed approach is further evaluated in an experimental investigation through prototype development and testing. Finally, potential directions for future research are discussed.

Assistant Robots

Assistant robots or mainly collaborative robots work side-by-side with humans and are also referred to as "cobots" (Vysocky & Novak, 2016). Collaborative robots have additional safety requirements (Gambao et al., 2012) that needs to be integrated into their design because they share the workspace with humans. The workspace in which the robot operates is also known as the work envelope (Dritsas et al., 2019). Methods of task execution by assistant robots can be categorized into three categories – a) teleoperated, b) preprogrammed, and c) intelligent systems (Afsari et al., 2018).

Assistant robots, if mobile, use different types of locomotion for navigation through the space (Lattanzi & Miller, 2017). The choice of locomotion depends on the target area of work. For façade inspection, a cable-suspended robot can carry more payload and are safer compared to other types of robots (Barry et al., 2016). For bridge deck inspection, flying robots, also known as, drones or Unmanned Aerial Vehicles (UAV) are more suited (J. et al., 2021). An indoor inspection might be more suited for ground-based robots as UAVs may create additional safety hazards and distractions on the construction site (Khalid et al., 2020). UAVs also have less payload capacity than ground robots (Lattanzi & Miller, 2017). Ground robots may use wheels or crawlers (Lattanzi & Miller, 2017). Wheeled or crawler robots have the inherent limitations of being unable to climb stairs (Afsari et al., 2021). For this, legged robots prove to be advantageous. Legged robots can also walk on rough terrains and unfinished surfaces and over small obstacles which are prevalent on construction sites (Halder et al., 2021).

In an industrial setup, assistant robots support human workers for improving product quality and economic efficiency (Afsari et al., 2018; Vysocky & Novak, 2016). They help isolate workers from unhealthy and hazardous work environments (Vysocky & Novak, 2016).

Robot-enabled Construction Inspection

In construction, assistant robots can be used for inspection (K. Asadi et al., 2018), material handling (Gambao et al., 2012), painting (E. Asadi et al., 2018), etc. Customized robots were designed for research purposes that can augment human capabilities. For example, a cable-crawling robot was used for cable inspection (Sawada et al., 1991). Small micro-bots provide required support for the inspection of small pipes and ducts (Krishna Lakshmanan et al., 2020).

The benefits of using robots for construction inspection are manifold. Purpose-built robots can enable inspection of hard-to-reach places (Katrasnik et al., 2010). They can also isolate human inspectors from hazardous workspaces (Mita & Shinagawa, 2014). Autonomous and intelligent systems can be used to collect information without human intervention and improve productivity (Prieto et al., 2020). Assistant robots can also facilitate remote inspection. Remote inspections are useful for project stakeholders who are located far from the project site and require frequent travel to visit the site (Halder et al., 2021; Jaselskis et al., 2015). Assistant robots on the site can provide updated information to project stakeholders without additional human support (Follini et al., 2021).

Virtual Reality for Construction Inspection

With increasingly affordable pricing and computational power, Virtual Reality Head-Mounted Displays (HMDs) have become much more accessible to the general public (Sidani et al., 2021). Modern VR HMDs, like Oculus Quest 2 used in this study, use Inertial Measurement Unit (IMU) sensors and cameras to track the position of the user in the given space. In the Architecture, Engineering, Construction, and Operations (AECO) industry, VR has shown many advantages in design reviews, collaboration, and decision making (Sidani et al., 2021). A VR scene can be created from virtual models (Khan et al., 2021) or spherical images (Napolitano et al., 2017). Building Information Modeling (BIM) is often used to create VR scenes (Khan et al., 2021). On the other hand, unlike model-generated scenes which present artificial content, spherical 360° images show the realistic view of the physical site which opens more possibilities for construction inspection as shown in this study.

Methodology

This study used a mixed-methods methodology to study VR and robotics together. First, a systematic literature review was conducted to identify the benefits and challenges of using VR specifically for construction inspection and monitoring. Second, a new approach is proposed to integrate VR with robotics to facilitate a remote immersive inspection by making use of both technologies. The proposed approach was tested qualitatively through experimental investigation to confirm the benefits and challenges identified from the literature review.

The Preferred Reporting of Items for Systematic Reviews and Meta-Analyses (PRISMA) approach used by Sidani et al. (2021) was used for conducting the literature review. Three databases were used to download research papers on the topic of VR for construction inspection. These were a) Web of Science, b) Scopus, and c) Proquest. The search phrase used was: (VR or "Virtual Reality") and construction and (inspection or monitoring). The search fields were the abstract, title, and author's keywords. No filter was applied on the subject or type of source. Figure 1 shows the review process based on the PRISMA approach.

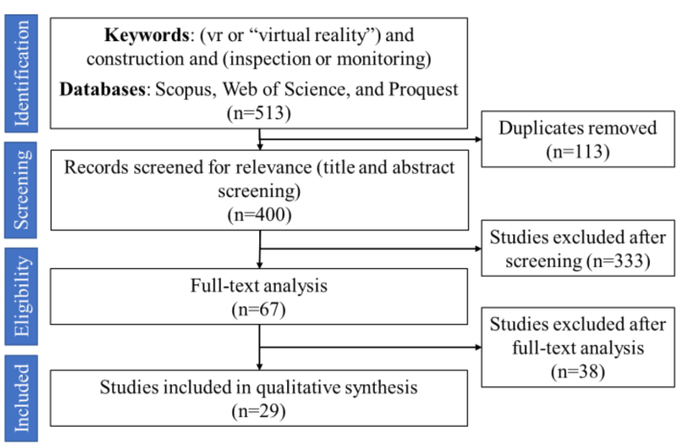

Figure 1. Systematic review process

Total 513 papers were identified from the three sources. After the duplicates were removed, 384 papers remained. Then, the papers were excluded through the review of the title and abstract. Here the papers which were clearly out of the scope of the review were excluded in this step. These were the papers that either used the keywords in the meaning unintended in this review (e.g., VR = Video Recorder) or were from other domains such as medical, mining, or power systems. Papers that used VR for tasks other than inspection or monitoring of construction were also excluded. After this step, 67 papers were remaining on which a full-text analysis was performed. Finally, 29 papers were included in the final qualitative analysis that discussed the benefits and challenges of VR specifically for construction inspection and monitoring. The qualitative content analysis was performed to answer the following research questions:

1. What are the benefits of VR in construction inspection and monitoring?
2. What are the limitations and challenges of VR in construction inspection and monitoring?

Systematic Literature Review Findings

The literature review revealed that VR has been used sparingly for construction inspection and monitoring. Cloud-based VR was found to enhance communication and collaboration by creating a common understanding of a project between remote stakeholders (Du et al., 2018). The immersive visual experience in VR provides a user more realistic experience similar to being present at the site as compared to 2D or 3D models (Attard et al., 2018). Faster navigation in VR than in real-life reduces total inspection time and thereby cost (Omer et al., 2019). Ali et al., (2020) argue that the use of an immersive VR environment for progress monitoring supports decision-making and improves the construction product quality. Figure 2 lists and ranks all the benefits identified from the literature review.

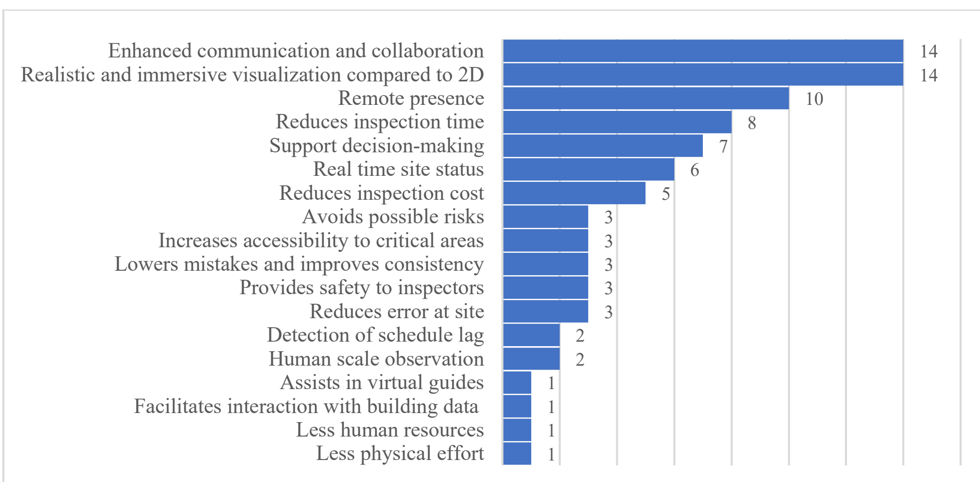

Figure 2. Benefits of VR for construction inspection identified from the literature

Some of the reasons still inhibiting the use of VR for remote construction inspection were identified from the literature. They are listed and ranked in Figure 3. The major limitations identified are the technological limitations. The low resolution of the displays of the existing VR headsets is a limiting factor for inspection because it prevents the user to observe the finer details. Another technical limitation is the juddering effect due to the low refresh rate (Wen & Gheisari, 2020), which is tiring on the eyes of the user. There is also only limited integration with the existing technologies (Sidani et al., 2021). There is a lack of work on creating a real-time data transfer between BIM and VR (Wen &

Gheisari, 2020). The VR development process is also very complex and time-consuming (Wen & Gheisari, 2020).

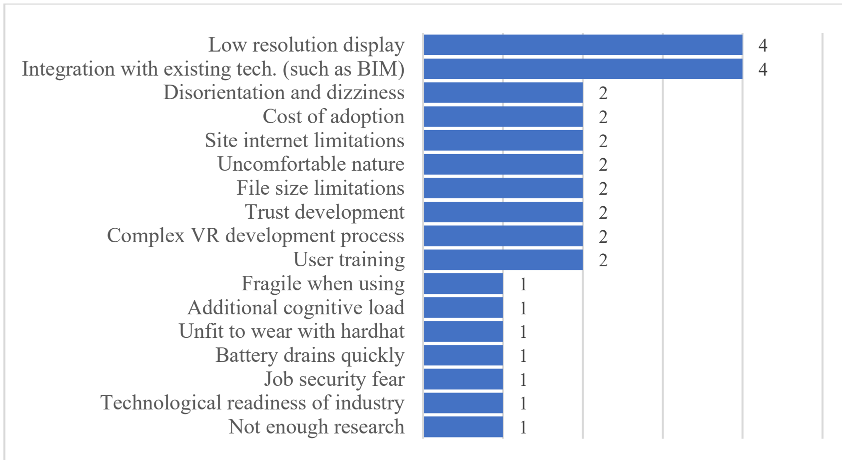

Figure 3. Challenges in using VR for construction inspection identified from the literature

From the literature review, it was found that the content for VR has been predominantly generated from virtual models or prerecorded images and videos. Existing studies have not explored VR with robotics for real-time remote inspection. Robots allow more frequent data capture for construction inspection (Halder et al., 2021). In this research, we conducted an experimental investigation through prototype development and testing to investigate the feasibility of integrating VR with robotics.

Robot-assisted VR for Real-time Remote Inspection

In this section, we propose a new approach to use VR with an inspector assistant robot for real-time remote inspection. The inspector assistant robot is performing remotely on the site to provide real-time remote reality capture while its human operator is located off-site. The approach is based on creating an immersive 3D virtual environment in Virtual Reality where a remote inspector can perform a walkthrough of the building in both reality (through 360° live video feed) and virtuality (through the BIM model). The Unity Engine was used for VR development. The virtual environment was created in Unity by exporting the BIM model from Revit as an FBX file. The hardware included a quadruped robot called Spot by Boston Dynamics with a mounted Ricoh Theta V 360° camera, an Oculus Quest 2 VR headset with its 2 accompanying handheld controllers, and a laptop running a server to interface between devices. All the hardware is connected to the Wi-Fi hotspot hosted from the laptop. Figure 4 shows the schematic diagram of the proposed approach.

The quadruped robot used in this study was the base model of Spot. For more information regarding the fundamentals of quadruped robots, Spot features, standard operating procedure of Spot on construction sites, the accuracy of Spot in construction inspection and monitoring, and BIM-enabled robotic construction inspection and monitoring with Spot, readers are encouraged to review the authors' previous research (Afsari et al., 2021; Halder et al., 2021).

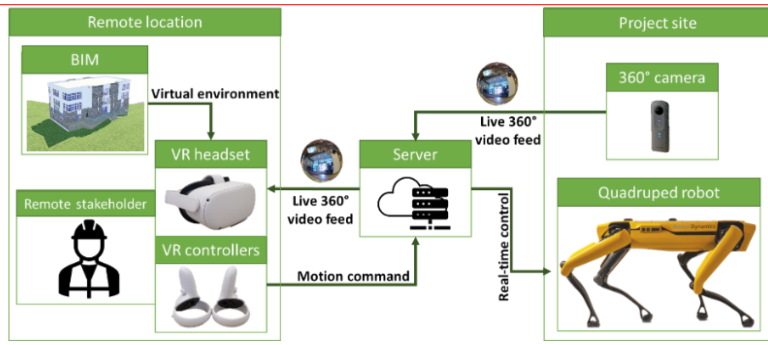

Figure 4. Proposed approach

The live video feed from the 360° camera was applied as texture to a sphere surrounding the virtual camera in the Unity scene at a refresh rate of 20Hz. The VR environment is composed of two components: a virtual environment created from BIM and a 360° live video feed of the remote site from the 360° camera mounted on top of the robot. The user can toggle between the video feed and the BIM model by using one of the hardware buttons in the Oculus controller. The user can also control the robot and navigate it through the space using the joysticks on the controllers of the VR headset (Figure 5).

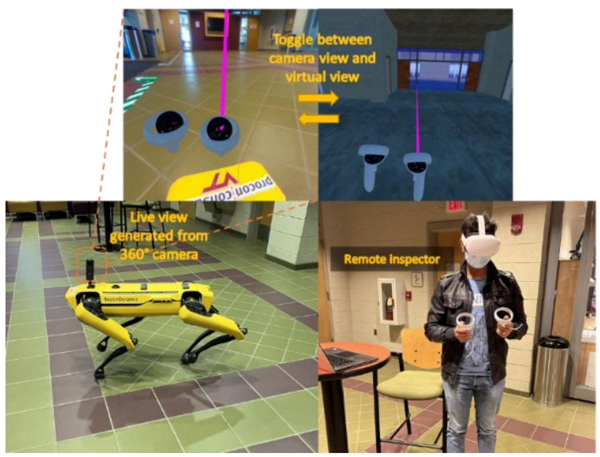

Figure 5. Prototype testing

The proposed approach was validated through experimental testing. The validation focused on the feasibility of the idea and identifying challenges for further improvement of the proposed approach. The main criteria for evaluation were real-time control and the ability to perform the inspection satisfactorily. The research team used the HMD and controlled the robot with the handheld controllers. The robot was walked around in a controlled environment and the area was visually inspected. The observational findings from the experiments are presented below in the next section.

Results and Discussions

The experimental investigation through the developed prototype testing showed the potential of using an inspector assistant robot with Virtual Reality for remote construction inspection and progress monitoring. During the investigation, the robot was directly controlled from the VR environment while the user was looking at the live video feed from the 360° camera on top of the robot. The prototype provided a real-time and immersive view of the site. Due to the immersive viewing, a closer inspection was possible from the environment. The preliminary testing of the proposed approach of integrating VR with robotics indicated potential benefits from real-time remote inspection of construction, such as remote sense of presence in the space as well as immersive and realistic visualization.

Following technical challenges were faced during the testing:

- Network lag – There were about 1-2 seconds of lag between issuing a motion command and seeing the robot move through the VR headset. This lag can cause potential safety risks in robot navigation.
- Dizziness and discomfort – The VR HMD was found to create discomfort after long use. This can prevent remote inspectors from using the device for longer inspections. However, future improvements in the headsets may partially make them more comfortable.

The experimental testing only focused on identifying the technical challenges and limitations. There can be many managerial challenges as identified from the literature review and presented in Figure 3, such as trust development, training requirements. Future research needs to solve the challenges identified in this study before the benefits of the robot-enabled Virtual Reality inspection can be realized.

Future Directions for Research

VR is an emerging technology and currently available VR headsets have many inherent challenges, such as low-resolution displays. Future studies can investigate the design of lighter and clearer VR headsets for remote inspection. The live VR scene generated from the 360° camera lacked depth information. Stereo cameras or cameras with depth sensors can be used to create 3-dimensional views for VR. Also, in this study, the proposed approach of integrating VR with inspector assistant robots was not investigated with experienced human inspectors. Future studies can conduct human-factors research to study the experience of the inspectors with the proposed immersive environment and to assess the usability and effectiveness of the proposed system. A comprehensive cost analysis is also required to investigate the return on investment (ROI) from the proposed system. Although the robot used in this study was an advanced quadruped robot with relatively high cost, other mobile robots (e.g. legged robots, wheeled robots, or hybrid robots,) might provide more cost-effective solutions.

Conclusion

This study explored robotics and VR for remote construction inspection. Inspection and monitoring is important aspect of construction management. Regular and consistent inspections ensure better project control. Remote inspection capabilities provide a method for remote stakeholders to stay updated about the project's progress and access the project status at any given time. Assistant robots have been used in construction and other industries while these robots work side-by-side with humans and provide support for repetitive and mundane tasks. Assistant robots have the potentials to be used remotely by their human operators to provide remote assistance. VR is another technology that provides immersive visualization of a digitally generated reality known as virtual reality. This virtual reality can be model-generated or can be created from real-life visual data and this study uses a virtual environment that combined the two. In this study, a systematic literature review was conducted on virtual reality for construction inspection and monitoring. After identifying key studies from three databases (Scopus, Web of Science, and ProQuest) using the PRISMA approach, a qualitative analysis was performed on 29 shortlisted papers. The papers were analyzed to identify and rank several benefits and challenges of VR for construction inspection and monitoring. Some of the benefits of using VR are that it provides an immersive and realistic experience as compared to 2D drawings and reports, the intuitive visualization of information enhances communication, and it provides a remote inspector virtual experience close to being physically present at the site, which in turn supports decision-making. There are many challenges for VR to become the primary inspection tool. Some of those challenges are low-resolution displays of the HMDs, lack of strong integration with existing technologies like BIM, the discomfort from long-use of the HMDs, cost of adoption, and site internet limitations. The study also proposed a novel approach to integrating VR with robotics through an experimental investigation using a VR prototype integrated with remote robot control and the identified benefits and challenges were discussed to guide future research.

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References

Afsari, K., Gupta, S., Afkhamiaghda, M., & Lu, Z. (2018). Applications of Collaborative Industrial Robots in Building Construction. *54th ASC Annual International Conference Proceedings*, 472–479.

Afsari, K., Halder, S., Ensafi, M., DeVito, S., & Serdakowski, J. (2021). Fundamentals and Prospects of Four-Legged Robot Application in Construction Progress Monitoring. *ASC International Proceedings of the Annual Conference*, 271–278.

Ali, A. K., Lee, O. J., & Park, C. (2020). Near Real-Time Monitoring of Construction Progress: Integration of Extended Reality and Kinect V2. *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, *37*, 24–31.

Asadi, E., Li, B., & Chen, I.-M. (2018). Pictobot: A Cooperative Painting Robot for Interior Finishing of Industrial Developments. *IEEE Robotics & Automation Magazine*, *25*(2), 82–94.

Asadi, K., Kalkunte Suresh, A., Ender, A., Gotad, S., Maniyar, S., Anand, S., Noghabaei, M., Han, K., Lobaton, E., & Wu, T. (2020). An integrated UGV-UAV system for construction site data collection. *Automation in Construction*, *112*(4), 103068.

Asadi, K., Ramshankar, H., Pullagurla, H., Bhandare, A., Shanbhag, S., Mehta, P., Kundu, S., Han, K., Lobaton, E., & Wu, T. (2018). Vision-based integrated mobile robotic system for real-time applications in construction. *Automation in Construction*, *96*, 470–482.

Attard, L., Debono, C. J., Valentino, G., Di Castro, M., Osborne, J. A., Scibile, L., & Ferre, M. (2018). A comprehensive virtual reality system for tunnel surface documentation and structural health monitoring. *2018 IEEE International Conference on Imaging Systems and Techniques (IST)*, 1–6.

Barry, N., Fisher, E., & Vaughan, J. (2016). Modeling and control of a cable-suspended robot for inspection of vertical structures. *Journal of Physics: Conference Series*, *744*, 12071.

Dritsas, S., Gim, ·, & Soh, S. (2019). Building robotics design for construction Design considerations and principles for mobile systems. *Construction Robotics*, *3*, 1–10. https://doi.org/10.1007/s41693-018-0010-1

Du, J., Shi, Y., Zou, Z., & Zhao, D. (2018). CoVR: Cloud-based multiuser virtual reality headset system for project communication of remote users. *Journal of Construction Engineering and Management*, *144*(2), 4017109.

Follini, C., Magnago, V., Freitag, K., Terzer, M., Marcher, C., Riedl, M., Giusti, A., & Matt, D. T. (2021). BIM-Integrated Collaborative Robotics for Application in Building Construction and Maintenance. *Robotics*, *10*(1), 2.

Gambao, E., Hernando, M., & Surdilovic, D. (2012). A new generation of collaborative robots for material handling. *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, *29*, 1.

Halder, S., Afsari, K., Serdakowski, J., & DeVito, S. (2021). A Methodology for BIM-enabled Automated Reality Capture in Construction Inspection with Quadruped Robots. *Proceedings of the 38th International Symposium on Automation and Robotics in Construction (ISARC)*, 17–24.

J., L. J., Amir, I., Shubham, S., & Mani, G.-F. (2021). Bridge Inspection with Aerial Robots: Automating the Entire Pipeline of Visual Data Capture, 3D Mapping, Defect Detection, Analysis, and Reporting. *Journal of Computing in Civil Engineering*, *35*(2), 4020064.

Jaselskis, E., Sankar, A., Yousif, A., Clark, B., & Chinta, V. (2015). Using telepresence for real-time monitoring of construction operations. *Journal of Management in Engineering*, *31*(1), A4014011.

Katrasnik, J., Pernus, F., & Likar, B. (2010). A Climbing-Flying Robot for Power Line Inspection. In B. Miripour (Ed.), *Climbing and Walking Robots* (pp. 95–110).

Khalid, M., Namian, M., & Massarra, C. (2020). The Dark Side of the Drones: A Review of Emerging Safety Implications in Construction. In T. Leathem, Perrenoud A., & W. Collins (Eds.), *57th Annual Associated Schools of Construction International Conference* (pp. 18–27).

Khan, A., Sepasgozar, S., Liu, T., & Yu, R. (2021). Integration of BIM and immersive technologies for AEC: a scientometric-SWOT analysis and critical content review. *Buildings*, *11*(3), 126.

Krishna Lakshmanan, A., Elara Mohan, R., Ramalingam, B., Vu Le, A., Veerajagadeshwar, P., Tiwari, K., & Ilyas, M. (2020). Complete coverage path planning using reinforcement learning for Tetromino based cleaning and maintenance robot. *Automation in Construction*, *112*, 103078.

Lattanzi, D., & Miller, G. (2017). Review of robotic infrastructure inspection systems. *Journal of Infrastructure Systems*, *23*(3), 1–16. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000353

Lee, J. H., Park, J., & Jang, B. (2018). Design of Robot based Work Progress Monitoring System for the Building Construction Site. *2018 International Conference on Information and Communication Technology Convergence (ICTC)*, 1420–1422.

Mita, A., & Shinagawa, Y. (2014). Response estimation of a building subject to a large earthquake using acceleration data of a single floor recorded by a sensor agent robot. *Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2014*, *9061*, 90611G.

Napolitano, R., Blyth, A., & Glisic, B. (2017). Spherical imaging and virtual environments for structural health monitoring. *SHMII 2017 - 8th International Conference on Structural Health Monitoring of Intelligent Infrastructure, Proceedings*, 398–404.

Omer, M., Margetts, L., Hadi Mosleh, M., Hewitt, S., & Parwaiz, M. (2019). Use of gaming technology to bring bridge inspection to the office. *Structure and Infrastructure Engineering*, *15*(10), 1292–1307.

Prieto, S. A., de Soto, B., & Adan, A. (2020). A Methodology to Monitor Construction Progress Using Autonomous Robots. *Proceedings of the 37th International Symposium on Automation and Robotics in Construction (ISARC)*, 1515–1522.

Rahimian, F. P., Seyedzadeh, S., Oliver, S., Rodriguez, S., & Dawood, N. (2020). On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning. *Automation in Construction*, *110*, 103012.

Sawada, J., Kusumoto, K., Maikawa, Y., Munakata, T., & Ishikawa, Y. (1991). A mobile robot for inspection of power transmission lines. *IEEE Transactions on Power Delivery*, *6*(1), 309–315.

Sidani, A., Dinis, F. M., Sanhudo, L., Duarte, J., Baptista, J. S., Martins, J. P., & Soeiro, A. (2021). Recent tools and techniques of BIM-based virtual reality: A systematic review. *Archives of Computational Methods in Engineering*, *28*(2), 449–462.

Vysocky, A., & Novak, P. (2016). Human-Robot collaboration in industry. *MM Science Journal*, *9*(2), 903–906.

Wen, J., & Gheisari, M. (2020). Using virtual reality to facilitate communication in the AEC domain: A systematic review. *Construction Innovation*.

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Feature Engineering for development of a Machine Learning Model for Clash Resolution

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To automate clash resolution tasks, it is important to capture domain knowledge for the Machine Learning (ML). One way to add domain knowledge is by training data that divides tasks into input and output variables. The selection of input variables that are most relevant to a task is an important step towards automation. In this paper, the authors detail framework that uses literature review, industry interviews, and Modified Delphi to capture domain knowledge for clash resolution. The features identified through this paper can in future be processed through Feature Selection, that can provide empirical evidence of why the selected features or set of features are important to ML algorithm. Data collection processes discussed in this paper is not finalized and is discussed to help provide readers with framework of the proposed systematic method. Factors considered when resolving clashes were identified through literature review (22 factors) and industry interviews (16 factors). 14 factors identified from the interviews had a similar matching factor in the literature reviewed, the other 2 factors were not mentioned in any publications found during the initial literature review. After comparing results from literature review and interviews, 13 factors were considered critical for automating clash resolution.

Key Words: Feature Engineering, Clash Coordination, Machine Learning, Clash Resolution, Dimensionality Reduction, Features and Labels.

Introduction and Objective

Design coordination, including clash identification and resolution, is a construction task that can benefit from automation through ML. Hsu, Chang, Chen, and Wu (2020) have explored the use of supervised learning to automate the resolution of clashes occurring between mechanical components with considerable accuracy. However, due to the limited availability of a training data set, the model developed could be subject to over-fitting reducing the accuracy of the model for new clashes. This limitation can be overcome by providing a larger training dataset. However, labeling the training dataset highly relies on human experts and labor work (Huang & Lin, 2019).

To overcome this limitation, Harode and Thabet (2021) proposed a combined supervised-reinforcement ML approach to develop an automation model with high accuracy using a limited training dataset. The proposed model uses supervised learning with a limited labeled training dataset as pre-training for a reinforcement learning component. Reinforcement learning would use the supervised learning model to interact with clashes in a BIM model and improve on the automation model with each iterative interaction. The supervised learning component of the proposed model requires domain knowledge in the form of training dataset as input. Supervised learning algorithms develop new knowledge and make decisions by relying on accurate and complete labeled training datasets related to the business problem at hand. A labeled dataset contains both the input variables and corresponding output variables. In supervised learning, the input variables are referred to as features and the output variables are referred to as labels. Selecting features that appropriately depict the ML task is an important step towards adding domain knowledge to ML algorithms (Sutton & Barto, 2018). To generate optimal results from the model, it is important that training data used as input must contain features that are most relevant to the task (Theobald, 2017).

The objective of this paper is to present a framework that can be used to identify and capture decision-making data used by industry experts during their clash resolution process to extract the required features for the proposed combined supervised reinforcement learning model. Literature review and partial industry interviews are conducted in this paper to identify and capture data on factors used by industry experts' to resolve clashes as part of domain knowledge collection step of Feature Engineering. In future, Feature Engineering techniques like Feature Selection, can be applied to selected features to provide evidence supporting better efficacy of ML algorithm. Along with manipulation and transformation of selected features to facilitate development of ML model using selected features. As this paper discusses topics and keywords related to the field of ML, to facilitate the reading if the article by a larger audience Table 1 has defined these keywords.

Table 1

Keywords related to ML

Keywords	**Definition**
ML	A subfield of computer science that provides computers with the ability to learn without explicit programming (Theobald, 2017)
Supervised Learning	A ML technique that analyzes combination of known inputs and outputs to predict output to future inputs (Theobald, 2017).
Reinforcement Learning	A ML technique that develops automation knowledge by randomly interacting with the tasks to achieve desired output (Theobald, 2017).
Training Dataset	Known combination of input and output variable that can be used to develop automation model through supervised learning
Labeled Dataset	A dataset that contains both the inputs and their corresponding outputs.
Automation Model	An algorithmic equation developed through the ML process that facilitates in the automation of task.
Features	Inputs that are used to describe the data points.
Labels	Desired outputs corresponding to the given features (inputs).
Feature Engineering	"Act of extracting features from raw data and transforming them into format suitable for ML" (Zheng & Casari, 2018).
Feature Selection	Statistics-intensive process that provides empirical evidence on why certain features or set of features are important for automation (Ramasubramanian & Singh, 2019).

Domain Knowledge	Knowledge specific to the specialized discipline.
Over-fitting	Statistical error in ML where the developed model closely aligns with the limited data points.

The following sections will discuss the importance of Feature Engineering for automation of clash resolution, the methodology adopted to identify factors considered by industry experts for clash resolution, and the final set of 13 factors selected to automate clash resolution using the proposed ML model. The paper concludes with a discussion on the results of data collection and analysis and proposed future research work.

Literature Review

In ML, a feature is used to describe a data point (Dong & Liu, 2018). When performing clash resolution, for example, the system type of the clashing elements can be considered features of the clash. For effective ML, features that help in accurately describing/defining the task that needs to be automated should be identified and selected. For a given task, the process of selecting, formulating, and transforming the most appropriate features is called Feature Engineering (Zheng & Casari, 2018). A robust Feature Engineering process can provide ML algorithms with the following benefits: (1) improved predictive performance of the ML model, (2) faster and computationally less heavy ML process, (3) develop a better understanding of data relationships, and (4) create an explainable and implementable ML model (Ramasubramanian & Singh, 2019).

The concept of Feature Engineering can be divided into two supporting processes: (1) Business/domain knowledge, and (2) Feature Selection (Ramasubramanian & Singh, 2019). The domain knowledge process focuses on making sure that the features selected make sense and accurately reflect the domain knowledge. While Feature Selection is a more statistical-intensive process focused on providing empirical evidence to support the selection of a feature or set of features for a ML algorithm. In this paper, the authors focus on using Feature Engineering to collect and analyze domain knowledge for the automation of clash resolution.

Korman, Fischer, and Tatum (2003) captured knowledge related to the design, construction, operations, and maintenance of MEP systems using a research project to create a computer tool that can assist in resolving MEP coordination problems. Radke, Wallmark, and Tseng (2009) investigated an alternate approach for clash detection and resolution based on the parametric description of design elements. Wang and Leite (2016) proposed a systematic way to capture clash features and associated solutions for MEP coordination to support clash documentation. Results from their research assisted in the management of clash coordination and allowed the capture of existing domain knowledge to support future decision-making. Several research efforts are being expended to use ML for the automation of clash coordination. Hsu et al. (2020) used six features to define a clash and develop a supervised learning model to automate clash resolution of a student residence basement. Huang and Lin (2019) also performed a Feature Selection study to select six features to automate the classification of clashes using supervised learning. Hu, Castro-Lacouture, and Eastman (2019) analyzed six kinds of spatial relationships between clashing elements to develop a spatial network to eliminate irrelevant clashes, select clashes without enough room, and select clashes where the movement of one object can resolve multiple clashes. Hu, Castro-Lacouture, Eastman, and Navathe (2020) also designed an optimization algorithm to determine the optimal sequence for clash correction. This algorithm was based on clashing volume, the impact of moving one clashing element on the other MEP element in its proximity, the relationship between the clashing elements, and logical connection relations between building components.

Based on the review of the literature, the authors have identified two major research gaps. The research focused on formalizing knowledge for clash coordination focused only on documenting clash cases and knowledge associated with clash resolution but did not address the use and formatting of the knowledge collected as input to ML models. Literature focused on automating clash coordination did not address the methodology of identifying the features used in their automation models or why these features were selected. To overcome these knowledge gaps, the authors in this paper propose a systematic methodology using Feature Engineering to extract domain knowledge for automation of clash resolution. Using this methodology, the authors define a list of factors that should be considered as features for the proposed combined ML algorithm.

Research Approach

The process of Feature Engineering includes selecting, transforming, and formulating features that are most appropriate for the automation of a given task. In this paper the authors focus on the selection of features that most accurately reflects industry professionals' decision making for clash resolution, i.e., domain knowledge for clash resolution. Figure 1 details the entire proposed Feature Engineering step for the development of a strong ML model for the automation of clash resolution. In this paper, the authors have focused only on the domain knowledge collection process of Feature Engineering.

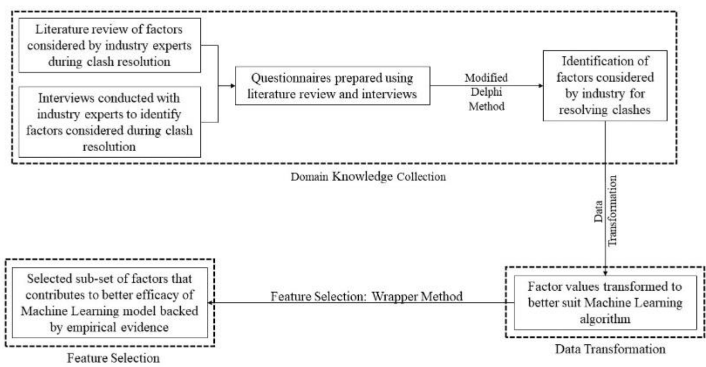

Figure 1. Complete process of Feature Engineering proposed to develop a ML model.

A Feature Engineering process to collect domain knowledge will comprise three main steps:

1. **Literature Review:** The first step involved the review of literature focused on clash resolution automation and industry best practices for clash coordination, summarized in Table 2. Based on the literature reviewed, 22 factors that should be considered in resolving clashes were identified. These factors were grouped into 4 categories: (1) Geometric Characteristic: Properties of the clashing element describing their geometry, (2) Functional Characteristic: Properties of the clashing elements related to their function, installation, operation, and maintenance,(3) Topological Relation: How the elements clash and how they intersect (Hu et al., 2019), and (4) Spatial Relation: Spatial relationship of the clashing elements relative to the surrounding elements.

Table 2
Factors identified through literature review

Factor Category	Factor	Factor Description	Literature
1. Geometric/Physical Characteristic	Start and End Point (X, Y, Z)	The 3D coordinates of the endpoints of the clashing elements	(Korman et al., 2003; Radke et al., 2009)
	Clash Component Dimensions	The height, width, length, and radius of the clashing elements.	(Korman et al., 2003; Radke et al., 2009; Wang & Leite, 2016)
	Baseline direction of the clashing elements	The geometric baseline direction of clashing elements (e.g., Horizontal and Vertical)	(Hsu et al., 2020)
	Element Slope	The existing slope of the clashing elements.	(Wang & Leite, 2016)
2. Functional/Operational Characteristic	Clashing element's type	The type of each clashing element (e.g., pipes, duct, structural framing)	(Huang & Lin, 2019; Wang & Leite, 2016)
	Clashing element's system type	The building system each clashing element belongs to	(Hsu et al., 2020; Hu et al., 2020; Korman et al., 2003; Wang & Leite, 2016)
	Constrained Slope	The required slope that needs to be maintained for the clashing elements	(Wang & Leite, 2016)
	Insulation	The size of insulation present around the clashing elements	(Wang & Leite, 2016)
	Clashing Element's Material	The material of clashing elements	(Wang & Leite, 2016)
	Rigidity of the clashing elements	Clashing element rigid or flexible?	(Wang & Leite, 2016)
	Critical Element in the clash	The presence of a critical element in the clash	(Wang & Leite, 2016)
3. Topological Relation	Hard or Soft Clash	Is the clash hard or soft?	(Hu et al., 2019; Radke et al., 2009; Wang & Leite, 2016)
	Clash Distance	The relative distance of the clashing elements	(Huang & Lin, 2019)
	Clash Type	Clashing elements oriented parallel or perpendicular to each other	(Hsu et al., 2020; Hu et al., 2019)
	Intersection Type	Intersection of the clashing elements is penetrating or puncturing	(Hsu et al., 2020; Hu et al., 2019)
	Clashing Volume	The overlapping volume of the clashing elements	(Hu et al., 2020; Wang & Leite, 2016)
	Clash Group	Group of clashes involving a common clashing element	(Wang & Leite, 2016)
4. Spatial Relation	Moveable Area	Area where the element with low priority can move without violating any space constraints	(Hu et al., 2019; Radke et al., 2009; Wang & Leite, 2016)
	Location of the clash	The floor/room where the clash is located (e.g., Mechanical Room)	(Huang & Lin, 2019; Korman et al., 2003; Wang & Leite, 2016)
	Clash Point	3D coordinates of the clash location	(Huang & Lin, 2019)
	Impacted Object	Object not part of the clash but is present within proximity of the clash	(Hu et al., 2019; Korman et al., 2003)
	Connections	Number of vertical and horizontal connections/fittings per length of the clashing element	(Korman et al., 2003)

2. **Industry Interviews:** Unstructured/structured interviews with industry experts from various disciplines (GC and mechanical) were conducted to augment the findings of the literature review and fill any gaps. Additionally, these interviews helped the authors to reduce redundancy and eliminate any overlaps between the factors that were identified during the literature review (Gunduz & Elsherbeny, 2020). The interviews focused on discovering answers to several questions, including: (1) What factors does the project coordination team consider while resolving a clash?, (2) What considerations do industry professionals make when resolving a clash?, (3) How does the orientation of clashing elements affect the clash resolution?, and (4) How are priorities between clashing elements established? Interviewees were also asked to discuss specific examples of clashes from BIM models provided and analyzed by the authors prior to the interviews The interviews were video recorded to facilitate further analysis of the discussion following the meetings. All interviews were transcribed and coded by the authors to identify specific clash resolution factors discussed during each interview.

3. **Industry Survey using Modified Delphi:** Through the interviews and literature review process, a substantial list of factors considered by design coordination teams while resolving a clash will be generated. This third step will focus on developing a common consensus on the identified factors by the industry experts. To achieve this objective, a Modified Delphi Method will be used. The intended purpose of the Delphi methodology is to obtain a common consensus of qualified industry experts on a particular subject (factors considered for clash resolution) by allowing them to look at a set of updated questionnaires along with feedback provided. If the questionnaire is developed through literature review and interviews, this process is called modified Delphi (Gunduz & Elsherbeny, 2020). A survey will be sent to industry experts listing the identified clash resolution factors. Each individual receiving the survey results will be asked to select all the factors that they believe affect clash resolution decisions. Once the response for the first round of the questionnaires has been received, the result of the first round will be analyzed. This analysis will be sent back to industry experts along with the first-round of questionnaire. In the second round, industry experts will be given the opportunity to change their answers based on the analysis summary. They can choose to keep their original answer or modify it. Individuals who decide to keep their original answer will be asked to provide an explanation. Industry experts will be allowed to add any factors they think are important for clash resolution but are missing from the given list. Multiple rounds of modified Delphi will be conducted until a common consensus is reached.

Results

Table 3a shows a comparison between factors identified from literature review and interviews, factors that were not discussed are omitted from the table. Using this comparison, a final preliminary list of 13factors considered by the authors for automation of clash resolution was prepared and shown in Table 3b.

Table 3a
Comparison between literature reviews and interviews

Factors identified through Literature Review	Factors discussed in Interview 1	Factors discussed in Interview 2	Factors discussed in Interview 3
Clash Component Dimensions.	X	X	X
Baseline Direction of the Clashing Elements.		X	
Element Slope.	X	X	X

Clashing Element's Type.	X	X	X
Clashing Element's System Type.	X	X	X
Constrained Slope.		X	X
Insulation.	X		
Clashing Element's Material.			X
Rigidity of the Clashing Elements.			X
Critical Element in the Clash.		X	X
Clash Group.		X	
Moveable Area.	X	X	X
Location of the Clash.	X	X	X
Connections.	X	X	X
Additional Factors discussed during Interview 1 and 3: Cost of resolving a clash			
Additional Factors discussed during Interview 3: Construction stage the clashing elements is in			

Table 3b

List of factors considered while resolving the clashes

S. No.	Factors	S. No.	Factors
1.	Start and End Point (X, Y, Z)	8.	Rigidity of the Clashing Elements
2.	Clash Component Dimensions	9.	Critical Element in the Clash
3.	Clashing Element's Type	10.	Clash Group
4.	Clashing Element's System Type	11.	Moveable Area
5.	Constrained Slope	12.	Location of the Clash
6.	Insulation	13.	Connections
7.	Clashing Element's Material		

Three rounds of initial interviews were conducted with industry experts experienced in clash coordination. These interviews were coded, and factors considered while resolving clashes were identified by the authors. Out of the 22 factors identified in the literature reviewed, only 14 matching factors were identified from the interviews. Factors related to topological relation between the clashing element were not discussed during the interview, except for the 'Clash Group' factor. Other factors that were not discussed during the interview were 'Start and End Point (X, Y, Z)', 'Clash Point', and 'Impacted Object'. The 'Start and End Point (X, Y, Z)' factor, although not discussed during the interviews, was still included in the final list of factors in place of the 'Baseline Direction' factor. The authors argue that the baseline direction of clashing elements is a function of the coordinates of the endpoints of the elements which can be easily obtained using Navisworks or Revit Application Programming Interface. Another reason for selecting the 'Start and End Point (X, Y, Z)' factor over element baseline direction is endpoint coordinates can also help represent the current location and orientation of the clashing element in the ML algorithm, hence providing more useful and necessary information. Using the 'Start and End Point (X, Y, Z)' as a factor can also eliminate the use of the 'Element Slope' factor in the ML algorithm. As the existing slope of the element is also going to be the function of its endpoint coordinates. Using 'Start and End Point (X, Y, Z)' allows for removing the 'Element Slope' as a feature, making the ML algorithm computationally less heavy without removing the influence of the 'Element Slope' factor from the overall decision making.

Discussion

All clash resolution strategies discussed during the industry interviews focused on looking at the clash and its surrounding, and other connected model elements. Topological relations describing a single clash were not discussed so far. Factors such as 'Clash Point' and 'Impacted Object' were not discussed in the interviews conducted but can be considered as a part of the factor 'Moveable Area' which relates to the area and elements surrounding the clash. Another factor that was not discussed during the interviews was the 'Start and End Point (X, Y, Z)', Industry experts did not see the need to understand the orientation and baseline direction of the clashing element to keep the updated elements as close to the original design as possible while resolving the clash. The authors concluded that orientation and baseline direction of the clashing elements can become the function of their start and endpoint coordinates in ML algorithm, 'Start and End Point (X, Y, Z)' can be used to replace baseline direction and orientation of elements as factors for the ML algorithm. Another aspect of Feature Engineering that was discussed in this paper was reducing the dimensionality of the ML problem to make it computationally less heavy without eliminating the influence of necessary factors. As the existing slope of the clashing element can also be expressed using the endpoint coordinates of the clashing element. Using 'Start and End Point (X, Y, Z)' as one of the factors in our ML algorithm will eliminate the necessity of using 2 additional factors ('Element Slope' and 'Baseline Direction') without compromising their influence on the algorithm. During the interviews, two other factors that influence the clash resolution but were not found in the literature were also identified. Industry experts during the interviews discussed the consideration of the cost of resolving clashes. For example, in a clash scenario discussed related to a conflict between a duct and a pipe, an argument for modifying the duct location (usually given a higher priority) was made instead of the pipe (usually with lower priority). The reason for this exception was attributed to the pipe's copper material that requires more labor cost to modify and more costly to add additional copper fittings to resolve the clash. Making changes to the copper pipe, in this case, would have increased project cost. The authors suggest that the cost of clashing elements while resolving the clash should be considered as one of the factors and will be added as a feature in the proposed ML automation model. Another factor discussed during the interviews was the stage at which the clashing BIM element is, in the construction process. If a pipe has already been prefabricated for installation and a clash is identified that includes the pipe, it would be more cost and time-effective to move the other clashing elements. Through these interviews, it was realized that initial hierarchy of priority defined for different elements should sometimes be modified, when situations involving elements of lower priority may have a higher cost impact over elements of higher priority.

Concluding Remarks

The authors through the literature review and interviews have identified 13 critical factors that the industry experts consider while resolving clashes. These factors represent the domain knowledge utilized by industry professionals to make decision on clash resolution. As the next step within Feature Engineering, in future the authors would like to focus on data transformation to match a format suitable for ML algorithm. For example, text-based value of clashing element's system type can be converted to their numeric OmniClass values, "HVAC Ducts and Casings" to "22233100". Another step within Feature Engineering is Feature Selection, the authors plan to use wrapper methods for Feature Selection to evaluate the performance of the predictive algorithm for different subset of the factors and select the subset of factors that generates the most accurate predictive performance (Chandrashekar & Sahin, 2014). Once the Feature Engineering step is completed the selected factors will be utilized in future research to input domain knowledge to a proposed combined supervised-reinforcement ML algorithm that can more efficiently automate clash resolution based on industry standards. The goal of this research was to provide a framework to identify factors considered by industry experts while resolving clashes as part of domain knowledge collection process of Feature Engineering for the automation of clash resolution. The Feature Engineering process proposed in this paper focused on selections of factors that served two purposes, (1) accurate transfer of domain knowledge to the ML algorithm, (2) assist in making ML algorithm computationally less heavy without compromising its efficiency. In this paper, the authors have only completed the literature review step of the proposed Feature Engineering methodology. The initial interviews conducted in this research utilized two construction industry experts. As part of future work, the authors plan to conduct more interviews using a bigger pool of experts from different companies. Once the interviews are completed, the authors plan to update the list of factors. Following additional interviews, a Modified Delphi Process is planned to determine consensus among industry experts, hence concluding the domain knowledge collection process of Feature Engineering.

Reference

Chandrashekar, G., & Sahin, F. (2014). A survey on feature selection methods. Computers & Electrical Engineering, 40(1), 16-28. doi:https://doi.org/10.1016/j.compeleceng.2013.11.024

Dong, G., & Liu, H. (2018). Feature engineering for machine learning and data analytics: CRC Press.

Gunduz, M., & Elsherbeny, H. A. (2020). Operational framework for managing construction-contract administration practitioners' perspective through modified Delphi method. JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT, 146(3), 04019110.

Harode, A., & Thabet, W. (2021). Investigation of Machine Learning for Clash Resolution Automation. EPiC Series in Built Environment, 2, 228-236.

Hsu, H.-C., Chang, S., Chen, C.-C., & Wu, I. C. (2020). Knowledge-based system for resolving design clashes in building information models. Automation in Construction, 110, 103001. doi:https://doi.org/10.1016/j.autcon.2019.103001

Hu, Y., Castro-Lacouture, D., & Eastman, C. M. (2019). Holistic Clash Resolution Improvement Using Spatial Networks. In Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation (pp. 473-481): American Society of Civil Engineers Reston, VA.

Hu, Y., Castro-Lacouture, D., Eastman, C. M., & Navathe, S. B. (2020). Automatic clash correction sequence optimization using a clash dependency network. Automation in Construction, 115, 103205.

Huang, Y., & Lin, W. Y. (2019, 2019). Automatic Classification of Design Conflicts Using Rulebased Reasoning and Machine Learning-An Example of Structural Clashes Against the MEP Model.

Korman, T. M., Fischer, M. A., & Tatum, C. B. (2003). Knowledge and Reasoning for MEP Coordination. JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT, 129(Part 6), 627-634.

Radke, A., Wallmark, T., & Tseng, M. (2009). An automated approach for identification and resolution of spatial clashes in building design. Paper presented at the 2009 IEEE International Conference on Industrial Engineering and Engineering Management.

Ramasubramanian, K., & Singh, A. (2019). Machine learning using R : with time series and industry-based uses in R [1 online resource (712 pages)](Second edition. ed.). Retrieved from https://doi.org/10.1007/978-1-4842-4215-5

Sutton, R. S., & Barto, A. G. (2018). Reinforcement learning: An introduction: MIT press.

Theobald, O. (2017). Machine learning for absolute beginners: a plain English introduction: Scatterplot press.

Wang, L., & Leite, F. (2016). Formalized knowledge representation for spatial conflict coordination of mechanical, electrical and plumbing (MEP) systems in new building projects. Automation in Construction, 64, 20-26.

Zheng, A., & Casari, A. (2018). Feature engineering for machine learning: principles and techniques for data scientists: " O'Reilly Media, Inc.".

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Implementation of Laser Scanning and Photogrammetry in the US Commercial Building Sector

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Studies investigating the construction project stakeholders experience with implementing laser scanning and photogrammetry as Reality Capture Technologies (RCT) in the US commercial building sector are limited. Therefore, this study explored the status of construction project stakeholders experience with the use of RCT. The research aimed to answer questions regarding stakeholder's personal experience with RCT and their companies' use of RCT on commercial projects, RCT use on the specific commercial building project types, and use of RCT on both new construction and renovation projects in the commercial sector. A survey was distributed to owners/developers, designers, contractors, and Construction Managers (CMs)/owner representatives in the US. Survey findings indicated that the majority of the respondents had heard of RCT, used RCT personally, and worked for the companies that used RCT on their projects. Core and shell buildings, healthcare, and education projects were the major commercial project types on which participants reported using RCT. Additionally, participants reported implementing RCT on both new construction and renovation projects. The research contributes to the body of knowledge by providing the current status of RCT use on commercial building projects by US construction project stakeholders.

Key Words: Laser scanning, Photogrammetry, Reality Capture, Commercial Buildings, Construction project stakeholders

Introduction and Purpose

The construction industry has traditionally been slow in adopting new technologies and, as a result, has been suffering from low productivity (McCoy & Yeganeh, 2021). However, there has been a significant surge of using Building Information Modeling (BIM) by the AEC industry (Boton & Forgues, 2018; McGraw-Hill Construction, 2014; Smith, 2014). In addition, research about creating as-built BIMs (i.e., BIM models generated in the construction phase) and as-is BIMs (i.e., BIM models generated when the project is in the operation and maintenance phase) has been increasing in the last decade. Data acquisition is considered the first and one of the most challenging steps of creating both as-is BIMs of existing buildings and as-built BIMs of new construction projects.

The emergence of advanced data capturing technologies, also known as Reality Capture Technologies (RCT), indicates the importance of developing efficient ways for collecting accurate geometric data on both new construction and renovation projects (Lu & Lee, 2017; Volk et al., 2014). Reality Capture is a process that uses hardware such as laser scanners, cameras mounted on Unmanned Aerial Vehicles (UAVs) or high definition 360-degree photography to collect spatially accurate surface points of an existing object, building, or site and generate a three-dimensional (3D) representation of real-world conditions in the form of textured, high-resolution, geometrically precise 3D point cloud data or meshes (Autodesk, 2021; Skanska, 2021; Almukhtar et al., 2021). In addition, project site webcams, ground penetrating radar, robotic total stations, and GPS rover are also considered reality capture hardware (Dodge Data & Analytics, 2021). In this study, RCT denotes laser scanning, photogrammetry, and the integration of these two technologies.

Despite the numerous research studies on laser scanning, photogrammetry, and UAVs in the construction industry, there is limited research exploring AEC professionals' perspectives about RCT use. Therefore, the goal of the study was to investigate the perceptions of the US construction project stakeholders about using RCT in the commercial building sector. Specifically, this research investigated perceptions of owners/developers, designers, contractors, construction managers (CMs) and owner representatives.

Literature Review

In recent years, technological advancement has provided the opportunity to collect accurate and comprehensive data representing real-world conditions (Almukhtar et al., 2021). Traditional surveying techniques, such as measuring tapes, optical theodolites, and calipers, were time-consuming manual processes that resulted in incomplete and inaccurate documentation of existing field conditions (Klein et al., 2011). RCT have been developed to overcome the limitations of traditional surveying methods and enhance construction productivity. Research on advanced data capturing techniques has been rapidly growing in the last two decades (Wang & Kim, 2019). Recent technological advancements have provided new opportunities for RCT implementation on construction projects. For example, the point cloud data generated by reality capture can be used for 3D model creation, construction progress tracking, construction Quality Assurance and Quality Control (QA/QC), construction safety management, restoration of historical heritage, building performance analysis, and renovation purposes (U.S. General Services Administration (GSA), 2009; Wang & Kim, 2019). With recent advancements, reality capture using photogrammetry and remote sensing technologies such as laser scanning has become a superior approach that provides accurate, fast, and reliable information about construction sites, work, and equipment (Wang & Kim, 2019; Wang et al., 2020).

With the expansion of BIM use, the need for accurate and up-to-date information about the project has increased (Lu & Lee, 2017). The use of RCT on a project can help AEC professionals in decision-making by providing a full understanding of the project. Using laser scanners or photogrammetry, AEC professionals can collect accurate 3D-datasets of a building, structure, or environment and compare what exists in reality with 3D design models. Using RCT throughout different phases of a project enables construction tasks to conform to the drawings and specifications and helps the project team avoid deviations and identify problems early to avoid additional costs downstream. RCT can be utilized on new construction projects as well as renovation, addition, and interior fit-out projects. However, literature indicates that less than 9% of the research on RCT focuses on renovation projects (Almukhtar et al., 2021; Wang & Kim, 2019).

Inaccurate assumptions about the existing conditions of a building resulting from a lack of as-built documents can lead to unintended errors and even accidents (Lu & Lee, 2017). And, design teams may benefit from complete as-built documents as a starting point to develop their design in renovation, addition, and interior fit-out projects. Having accurate geometric data of an existing environment reduces uncertainties during the design phase, assists designers to obtain accurate dimensions where there may be a lack of as-built plans, enables the visualization of the design model in the existing context, reduces the number of visits to the job site, and enables effective collaboration among the stakeholders throughout a project (Autodesk, 2021; Leica Geosystems AG, 2017, Rubenstone, 2020). Data visualization helps owners in decision-making, and increasing the owners' awareness regarding the benefits of using RCT throughout the project lifecycle could increase the demand for RCT services on construction projects (Deutsch, 2015; Gerges et al., 2017).

Modern RCTs devices are less expensive, lighter weight, easier to operate, and are able to collect data at a higher level of accuracy than in the recent past. The point cloud data can be registered in real-time in the field using a handheld mobile device. In addition, new RCT software solutions have provided a smoother Scan-to-BIM workflow (Autodesk, 2021). Although the reduced barriers to the use of RCT in the last decade have led to wider adoption of these technologies in the AEC industry, at the time of conducting this study, no research was found investigating the status of RCT implementation by different construction project stakeholders. Therefore, given the potential advantages of RCT implementation and limited research on different construction project stakeholders' experience with using RCT, this research investigates the prevalence of RCT use on commercial construction projects in the US through the exploration of the following research questions (RQ):

RQ 1: Have US construction project stakeholders heard of RCT?
RQ 2: Do US construction project stakeholders have personal experience with RCT?
RQ 3: Do US construction project stakeholders' companies have experience with RCT?
RQ 4: On what commercial project types do US construction project stakeholders use RCT?
RQ 5: Do US construction project stakeholders use RCT on new construction projects and renovation projects?

Methodology

In order to address the research questions, the authors developed a quantitative, cross-sectional survey that was distributed among various stakeholders in the commercial construction industry. The research questions aimed to investigate the perceptions of different construction industry project stakeholders about RCT use. Descriptive statistics were conducted to analyze the survey results. The statistical analysis in this study was conducted using IBM SPSS statistical software. Specifically, frequency distribution and cross-tabulations were used to address the RQs.

Survey and Distribution

The survey comprised two sections: 1) Demographics and questions regarding respondents' awareness and general knowledge of RCT, and 2) Questions related to stakeholder experience with RCT use on construction projects. The online survey defined RCT for participants as the process of collecting surface data points to produce a digital 3D depiction of an existing object, building, structure or site using static, mobile or aerial laser scanning (LiDAR) and/or photogrammetry equipment (Autodesk, 2021). The survey responses were collected for four weeks. The potential participants were identified in two different ways. First, the survey link was distributed to the US-based membership of the Construction Management Association of America (CMAA) and a selection of members of the International Facility Management Association (IFMA) working in the US. Second, a survey link was shared with the authors' LinkedIn connections that work in the US AEC industry.

Results and Discussion

Sample and Data Screening

The survey was distributed widely and among numerous segments of the construction industry. However, given the commercial focus of the current manuscript, the sample was delimited to respondents who indicated that their primary construction industry sector was 'commercial' (n = 187). Of the 187 participants that worked primarily in the commercial building sector, 11 did not respond to the question about their role on a typical construction project, yielding 172 responses for analysis. The participants were coded into four groups based on their role on a typical construction project, including 1) owner/developer, 2) designer (including architects and engineers), 3) contractor (including general contractors and subcontractors), and 4) Construction Managers (CM) and owner representatives. Since the variables were independent, pairwise deletion was employed in this study, resulting in a different number of responses (n) for each analysis. Table 1 shows the demographic data of the cleaned and screened sample. Forty percent (68) of the 172 respondents were contractors, while 17% (30) were designers. The same number of respondents were owners/developers (37, 21.5%), and CMs and owner representatives (37, 21.5%). The average industry experience was over 20 years for all groupings except contractors, who reported an average of 15 years of industry experience.

Table 1. Description of commercial building sector participants by their role (n=172)

Stakeholder	*n*	*%*	*Average industry experience (years)*
Owner/Developer	37	21.5	23.9
Designer	30	17.4	21.3
Contractor	68	39.5	15.4
CM and Owner Representative	37	21.5	25.9

Addressing the Research Questions (RQs)

Research Question 1 explored if the stakeholders had heard of RCT. A majority of the 160 participants who responded to this survey item, (128, 80%) indicated they had heard of RCT (see Figure 1). Approximately 83% of the contractors, 81% of the designers, 77% of the CMs & owner representatives, and 76% of the owners/developers who responded to the survey had heard of RCT. The survey findings indicated that most construction project stakeholders, regardless of their role, reported hearing about RCT.

Research Question 2 investigated if construction project stakeholders had personal experience using RCT. The results revealed that 68 (53%) of the 128 respondents indicated personal experience using RCT on their projects (see Figure 2). Almost 70% of contractors and approximately half of owners/developers (52%) had personal experience with RCT compared to one-third of designers (33%) and 37% of CMs and Owner Representatives. It should be noted that of all the 68 respondents who had experience with RCT, over half (56%) were contractors, while 19% were owners/developers, 15% were CMs and owner representatives, and 10% were designers. The literature confirmed that adopting RCT on a project requires using both physical equipment (i.e., laser scanners, cameras, etc.) for capturing geometric data and software applications for data processing. The results indicating that a larger portion of contractors, who are more involved in the day-to-day field activities, had personal experience with RCT than other stakeholders is congruent with recent literature.

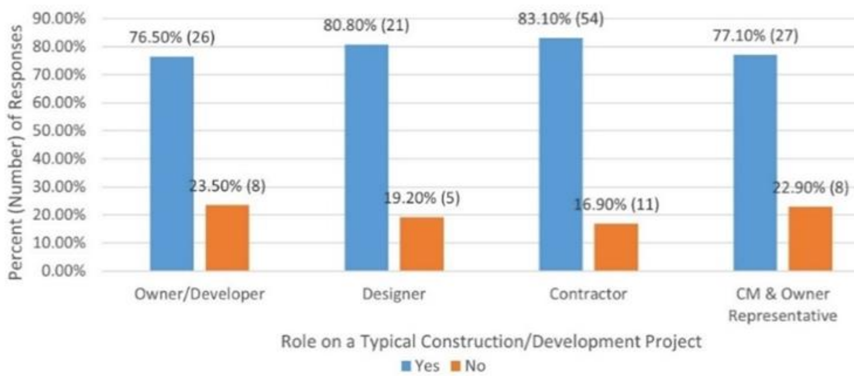

Figure 1. Stakeholders' Familiarity with RCT (n=160)

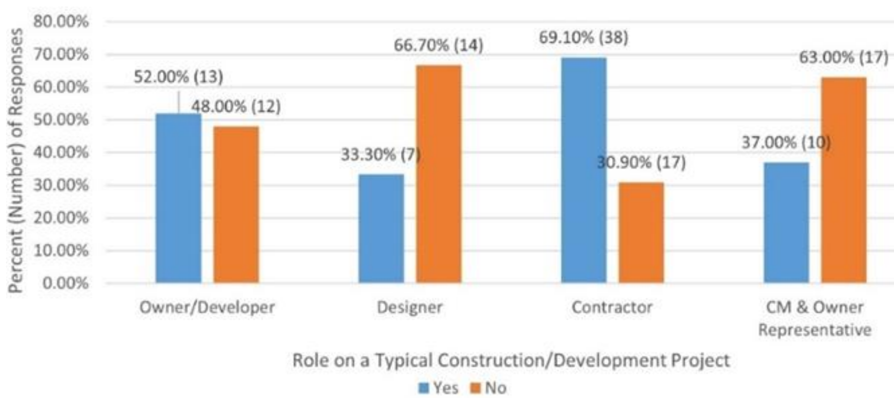

Figure 2. Stakeholders' Personal Experience with RCT (n=128)

Research Question 3 explored the experience of participant's companies with RCT. Of 128 participants who responded to this question, more than half (79, 62%) reported that their company had experience with using RCT on their projects, approximately one-fourth (29, 23%) indicated their company had no experience with RCT, and approximately 16% were not sure about their company's experience with RCT. As shown in Figure 3, a majority of the contractors (43, 78%), more than one third (8, 38%) of the designers, about half of the owners/developers (13, 52%) and more than half of the CM and owner representatives (15, 56%) stated that their company had experience with RCT. This is an important finding since it suggests that using RCT is more common among contracting firms than among other stakeholders. These findings correspond to the results of the recent studies, in which contractors surpassed designers in implementing BIM on their projects (McGraw Hill, 2014).

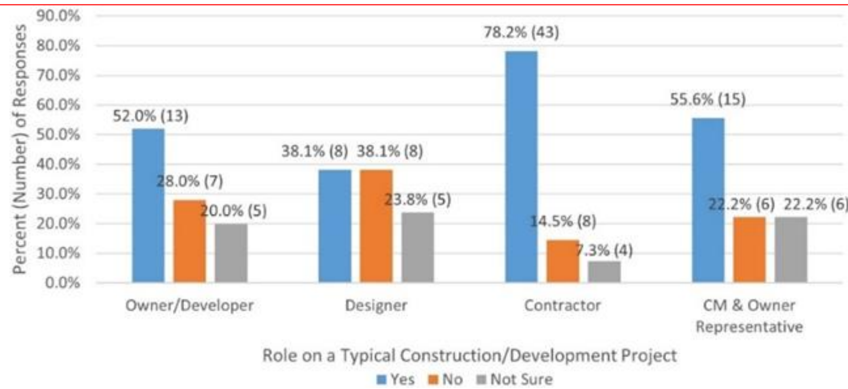

Figure 3. Stakeholders' Company's Experience with RCT (n=128)

Research Question 4 investigated participants' experience with using RCT on specific commercial project types, including core and shell buildings, multi-family residential, retail, mixed-use, education, healthcare, interior/tenant fit-out, and other types of projects. The participants were asked to select the commercial project types in which they used RCT. It should be noted that participants were asked to "select all that apply" when answering this question. Figure 4 shows the use of RCT on different commercial project types regardless of a participant's role on a typical construction/ development project. Almost half (78, 49%) of the 158 participants who responded to the question stated they used RCT on core and shell projects. Approximately 45% of 151 respondents reported they used RCT on healthcare projects. Interestingly, less than one-fourth of 146 respondents (33, 23%) reported using RCT on multi-family residential projects. This is an important finding that may suggest that construction project stakeholders tended to use RCT more on complex projects (e.g., healthcare projects and core and shell buildings) than simple projects (e.g., multi-family residential and retail). This finding corresponds to the results of previous studies about emerging construction technologies in which construction project stakeholders were more willing to use technologies on complex structures (Dodge Data & Analytics, 2015; McGraw Hill Construction, 2014).

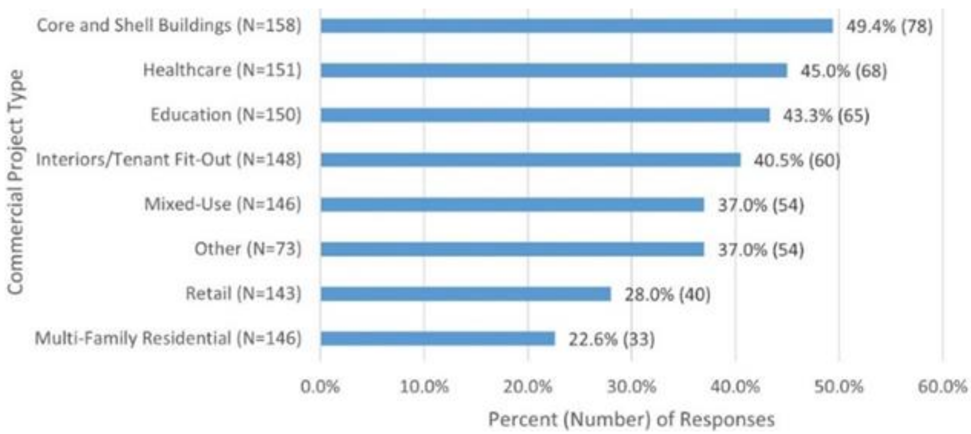

Figure 4. RCT Use on Specific Commercial Project Types: All Respondents

Research Question 5 explored the use of RCT on new construction projects and renovation projects by stakeholder. A majority (51, 65%) of 78 respondents who had experience with using RCT reported using the technology on new construction projects (see Figure 5). Approximately three-fourths (31, 76%) of the contractors, 57% of CM and owner representatives, 56% of designers, and half of the owners/developers indicated that they had experience with RCT on new construction projects. It should be noted that, except for contractors, the number of participants responding to this question was relatively low. For addition, renovation, and/or interior fit-out projects, 49 (68%) of 72 respondents indicated using RCT on addition, renovation, and/or interior fit-out projects (see Figure 6). Almost three-fourths (74%) of the contractors, 64% CM and owner representatives, 64% of owners/developers, and approximately half of the designers (56%) reported that they used RCT on addition, renovation, and/or interior fit-out projects.

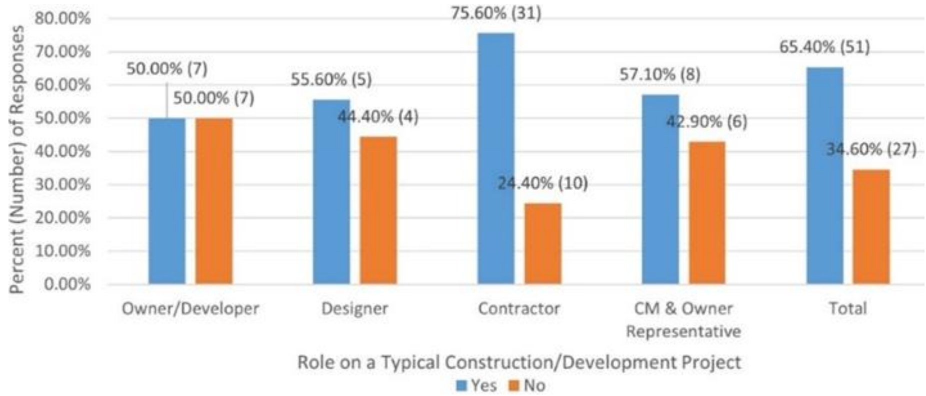

Figure 5. Stakeholders' Experience with RCT Use on New Construction Projects (n=78)

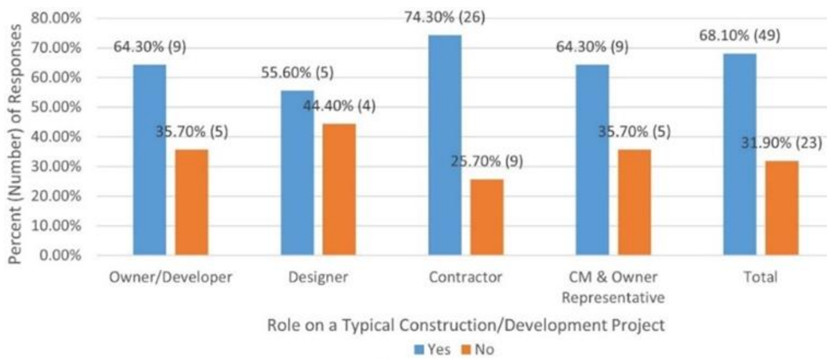

Figure 6. Stakeholders' Experience with RCT Use on Addition, Renovation, and/or Interior Fit-Out Projects (n=72)

Discussion and Conclusions

This study represents an initial attempt to better understand the current status and extent of RCT use among US construction stakeholders in the commercial building sector. This study adds to the body of knowledge by shedding light on the perceptions and experiences of US construction project stakeholders with RCT. Incomplete survey responses were culled, and the complete responses were classified based on the respondent's primary market sector. The collected responses from the designers, contractors, owners/developers, and CMs/owner representatives who reported commercial buildings as their primary market sector were further analyzed in this paper.

The study finding indicated that the majority of all four groups of stakeholders had heard of RCT. The results revealed that over half of the respondents had used RCT personally, or their company had implemented RCT on their projects. This finding reinforces the hypothesis of the general acceptance of RCT use within the commercial building sector. Additionally, and as expected, a larger number of contractors reported having experience with RCT as compared to other stakeholders. Research findings showed that core and shell buildings, healthcare, and education projects are the major commercial project types on which participants used RCT. On the other hand, fewer respondents stated that they had experience with using RCT on multi-family residential and retail projects. This was an important finding indicating that survey participants tended to use RCT more on complex projects.

Finally, the research findings revealed that those stakeholders with RCT experience implemented RCT on both new construction projects and renovation projects, suggesting that using RCT may benefit all projects, regardless of project type. The literature review revealed few studies exploring or reporting the use of RCT on renovation projects. However, respondents reported similar frequencies of using RCT on both new construction projects and renovation projects. These findings may suggest that once a company implements RCT, they may utilize the technology on all their projects, regardless of the project type.

Limitations and Future Research

The following limitations should be considered when interpreting the results of this study. The collected data from different construction professionals were sub-aggregated before conducting the statistical analysis. Responses from architects and engineers were aggregated into the designer group, and responses from the general contractors and subcontractors were combined in the contractor stakeholder group. Also, those participants who chose “other” as their role, but their text entry indicated they were CMs or owner representatives, were aggregated in the fourth group of stakeholders (i.e., CM and owner representatives). Additionally, the results of this study may not be generalizable to the whole US construction industry due to the relatively small sample compared to the population. Thus, findings herein should be interpreted given these limitations, and readers should be cautious regarding generalization of the results beyond the study sample.

Literature review revealed the need for further exploratory studies on RCT use during the project lifecycle. Determining the benefits and obstacles of using RCT during different phases of the project could be the next step. Future studies are needed to investigate RCT use within different construction sectors, including heavy civil, facilities management, and single-family residential. Additionally, exploring the use of RCT in existing buildings would be a potential area for future studies due to the increasing trend to incorporate circular economy and sustainability across the project lifecycle.

References

Almukhtar, A., Saeed, Z. O., Abanda, H., & Tah, J. H. (2021). Reality capture of buildings using 3D laser scanners. *CivilEng, 2*(1), 214-235.

Autodesk, Inc. (2021), How Reality Capture is Changing the Design and Construction Industry. Retrieved November 13, 2021, from https://www.autodesk.com/campaigns/reality-capture.

Boton, C., & Forgues, D. (2018). Practices and processes in BIM projects: An exploratory case study. *Advances in Civil Engineering, 2018.*

Dodge Data & Analytics (2021). Civil Quarterly, Issue 4. Retrieved December 22, 2012, from https://www.construction.com/toolkit/reports/the-civil-quarterly-2021-Issue-4

Deutsch, R. (2015). *Data-driven design and construction: 25 strategies for capturing, analyzing and applying building data.* John Wiley & Sons.

Gerges, M., Austin, S., Mayouf, M., Ahiakwo, O., Jaeger, M., Saad, A., & El Gohary, T. (2017). An investigation into the implementation of Building Information Modeling in the Middle East. *Journal of Information Technology in Construction*, *22*, 1-15.

Klein, L., Li, N., & Becerik-Gerber, B. (2011). Comparison of image-based and manual field survey methods for indoor as-built documentation assessment. In *Computing in Civil Engineering (2011)* (pp. 59-66).

Leica Geosystems AG. (2017). Reality Capture for Construction and Engineering Projects. Retrieved November 13, 2021, from https://blog.hexagongeosystems.com/wp-content/uploads/2019/09/Reality-Capture-for-Construction-and-Engineering.pdf.

Lu, Q., & Lee, S. (2017). Image-based technologies for constructing as-is building information models for existing buildings. *Journal of Computing in Civil Engineering*, *31*(4), 04017005.

McCoy, A., & Yeganeh, A. (2021). An Overview of Emerging Construction Technologies. *NAIOP Research Foundation.*

McGraw-Hill Construction. (2014). *The business value of BIM for construction in major global markets: How contractors around the world are driving innovation with building information modeling* (Smart Market Report).

Rubenstone, J. (2020, July 15). 5D scheduling and reality capture may speed payments. *Engineering News-Record.* Retrieved November 13, 2021, from, https://www.enr.com/articles/49710-d-scheduling-and-reality-capture-may-speed-payments.

Skanska (2021). What We Deliver; Reality Capture. Retrieved December 22, 2021, from: https://www.usa.skanska.com/what-we-deliver/services/innovation/reality-capture/

Smith, P. (2014). BIM implementation–global strategies. *Procedia Engineering, 85, 482-492.*

U.S. General Services Administration (GSA). (2009). *GSA building information modeling guide series: 03 – GSA BIM guide for 3D imaging*, Washington, DC.

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction*, *38*, 109-127.

Wang, Q., & Kim, M.K. (2019). Applications of 3D point cloud data in the construction industry: A fifteen-year review from 2004 to 2018. *Advanced Engineering Informatics, 39*, 306-319.

Wang, Q., Tan, Y., & Mei, Z. (2020). Computational methods of acquisition and processing of 3D point cloud data for construction applications. *Archives of Computational Methods in Engineering, 27*(2), 479-499.

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The Impact of Virtual Construction Field Trips on Students' Perceptions in Commercial Construction

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Field trips are an integral part of students' education, especially for those pursuing a degree in construction or engineering where practical experience is needed to understand the complexities of the profession. University programs struggle to provide adequate field trip experiences due to several reasons, including limited project availability, travel costs, and safety concerns. One option that has become increasingly prevalent, is the implementation of virtual field trips (VFTs). VFTs provide educators and students a flexible option to view and experience various projects from their personal computer or mobile device. This paper provides an exploratory overview of students' perspectives of real field trips (RFTs) in comparison to VFTs. A VFT was created using StructionSite, Inc. and a 360-degree camera, and compared to the same project that was visited in person, as a RFT by a different group of students. Pre and post surveys were used to sample construction management students studying commercial construction at a major university. The main findings were VFTs and RFTs both contributed to students' interest in commercial construction. Students perceived VFTs as a valuable resource that can be used to contribute to knowledge and skill attainment. In addition, VFTs were viewed as a valuable aspect in a students' education that can supplement certain types of RFTs, but students agreed VFTs should not replace RFTs completely.

Key Words: virtual field trip, experiential learning, student perceptions, construction management

Introduction

Construction management and engineering are practical professions that require pragmatic and innovative experiences to successfully prepare students for their future careers. As students are introduced to large amounts of knowledge in the classroom, with no previous knowledge on the subject, it is increasingly important to relate this new knowledge to practical experience (Paez & Rubio, 2015). Universities are tasked to provide students an opportunity to make connections between theoretical concepts taught in the classroom and real-world applications (Seifan et al., 2020). In order to provide construction and engineering students with practical knowledge, educators rely heavily on field trips, specifically jobsite visits, also referred to as a real field trip (RFT). These jobsite visits allow students to visualize and identify construction components, means and methods, durations, and safety elements which they are currently learning in the classroom.

As researched in a number of previous studies, field trips are an important element of students learning as they are exposed to different activities that increase cognition, confidence, and enjoyment of a specific subject (Seifan et al., 2020). A critical goal of field trips is to provide students with experiential learning. Kolegraff et al. (2019), determined that experiential learning is not only a preferred method for learning but is also perceived by students to be one of the most effective methods in construction education. Experiential learning provides students an avenue to "learn-by-doing" and gives them an opportunity to observe and further understand the dynamic construction processes onsite (Murray & Tennant, 2016). Adding field trips to a course can increase overall learning by providing students an opportunity for exploration of original experiences. A field trip enables students to visualize the theoretical concepts covered in a course and students are able to relate their experiences to the classroom content (Seifan et al., 2020).

However, implementing RFTs into a course can be time consuming and costly. RFTs are also becoming more difficult to implement due to concerns about safety, reduced university budgets, and increased class sizes (Leydon & Turner, 2013). Specifically, it can be difficult for universities in rural areas with limited local jobsites to visit. University courses typically cover specific topics, such as pavement design, commercial construction, or heavy timber framing. In addition, many courses cover specific phases of construction, such as underground utilities, foundations, structure, exteriors, and interiors. Finding a project relating to a specific phase or topic can be challenging in certain geographical areas. To adapt to these restrictions, a potential option is virtual field trips (VFTs). It has been reported that VFTs can be a successful alternative to RFTs to simulate the realities of the outside world in the classroom (Spicer & Stratford, 2001). Researchers have explored how to effectively implement VFTs to provide easier access to a construction jobsite compared to traditional trips (Stoddard, 2009).

The use of VFTs has increased in recent years as the technology has improved, giving students and faculty the ability to create an immersive experience. VFTs are described as the ability to provide an experiential learning environment that observes the physical elements, and has the ability to be assessed using a virtual tool, such as a mobile or desktop device (Eiris et al., 2019; Jaselskis et al., 2010). They are also able to be viewed at anytime and anywhere by a student. Pham et al. (2018) successfully applied a 360-degree panoramic virtual reality to assist in construction safety education. Eiris et al. (2021) created virtual 360-degree panoramic site visit experiences enhanced with virtual humans (avatars) to produce realistic site visits for students to practice collaborative problem-solving skills. Eiris et al. (2020) successfully used immersive storytelling with digital 360-degree panoramas to improve hazard recognition and risk perception.

A recent study conducted by Seifan et al. (2020) examined student perceptions on the use of VFTs as part of their university experience and the extent to which it could replace the traditional RFTs. The study concluded that students consider VFTs an enjoyable way to learn but it is not a suitable replacement for RFTs. It is unclear if general videos were used for this study, rather than a similar experience to those that evaluated the RFT. To determine the direct value of VFTs it is important to provide students a similar experience to those evaluating the RFT to clearly understand the value of substituting VFTs for RFTs. The research to date, examines the different tools and methods to implement VFTs but does not provide specific findings comparing one specific jobsite utilizing an RFT and compare it to the same jobsite using VFT. In addition, there is limited research evaluating the current virtual walkthrough software systems utilized in construction and whether these can be used in higher education to enhance student learning.

The objective of this paper is to study initial findings of a specific type of VFT, StructionSite, Inc., which is a software system used in the architecture, engineering, and construction (AEC) industry that utilizes 360-degree panoramas and virtual site walks. This paper will examine construction management students' perspectives after experiencing a VFT utilizing StructionSite, Inc. and compare these results to students who experienced a traditional RFT of the same project. Specifically, the study sought to assess: (1) do VFTs or RFTs contribute to students' interest in commercial construction, (2) do students perceive VFTs or RFTs to contribute to knowledge and skills attainment in a commercial construction course, and (3) can VFTs be successfully utilized in construction management. This work contributes to the body of knowledge related to construction and engineering education by documenting the specific learning preferences voiced by students related to VFTs and the overall implementation of immersive learning.

Research Methodology

Participants

This study aims to provide an exploratory overview of students' perspectives of RFTs in comparison to their perspectives of VFTs. The target population was undergraduate students studying construction management at a major university. One specific course was selected for the study, and two sections were surveyed. Both sections were asked to complete the same pre-field trip survey. After the field trip, students were asked to complete a post-field trip survey. There were two different post-field trip surveys, one for the RFT student population and one for the VFT group. The responses were analyzed using a qualitative and quantitative research methodology to produce conclusions to inform future field trip teaching strategies.

Field Trip Project and Location

The project selected was a multi-family and mixed-use development. It consisted of 78 units, Type VA construction on top of a 1.36 acre Type IA parking garage, also referred to as a podium parking structure. Within the podium there are five retail spaces totaling 6,800 square feet. Atop the podium, the residential portion included eight 3-story buildings connected by a network of breezeways and

Figure 1 and 2. 790 Foothill in San Luis Obispo, CA

courtyards. Building amenities included a rooftop deck and multiple amenity spaces. As shown in Figure 1, the project was 80% complete with the podium deck concrete and mechanical, electrical, and plumbing (MEP) trades and the framing was 35% complete which started at the first phase of the building. During the field trips, both RFT and VFT, students were exposed to concrete shoring, rebar installation, MEP deck rough-in, framing, MEP unit rough-in, safety protocols, and storm water pollution prevention plans, and others.

Pre-Field Trip Survey

To investigate the objectives of this study two anonymous surveys, pre and post-field trip, were designed using a similar methodology for VFTs assessment from a study conducted by Siefan et al. (2020), with pre and post survey questions modified to reflect the course and circumstances. The pre-field trip survey was distributed to all students prior to their RFT or VFT. In addition to the demographic information of academic level, major of study, and gender, the students were asked to indicate their level of agreement with the 14 statements presented in Table 1. The statements were scored based on a 5-point Likert scale. The students were also asked for free response answers about their experience in statements 13 and 14. Table 1 shows the pre field trip survey that every student completed, and two versions of the post-field trip. Students either completed the post RFT survey (wording where different, in bold) or the post VFT survey (wording where different, underlined).

Table 1

Pre and Post Survey Statements

#	Pre Field Trip Statements	#	Post **Real** or <u>Virtual</u> Field Trip Statements
1	A field trip (real site visit) can increase my interest in Commercial construction.	1	A field trip (**real** or <u>virtual</u> site visit) increased my interest in Commercial construction
2	Taking the Commercial construction course WITHOUT a jobsite visit enables me to think creatively and innovatively.	2	Taking the Commercial construction course WITH a (**real** or <u>virtual)</u> jobsite visit enabled me to think creatively and innovatively.
3	Taking the Commercial construction course WITHOUT a jobsite visit enables me to identify and solve practical problems.	3	Taking the Commercial construction course WITH a (**real** or <u>virtual</u>) jobsite visit enabled me to identify and solve practical problems.
4	Taking the Commercial construction course WITHOUT a jobsite visit enables me to work as a part of a team.	4	Taking the Commercial construction course WITH a (**real** or <u>virtual</u>) jobsite visit enabled me to work as a part of a team.
5	I prefer taking the Commercial construction course WITHOUT a jobsite visit.	5	I prefer taking the Commercial construction course WITH a (**real** or <u>virtual</u>) jobsite visit.
6	I can understand most aspects of Commercial construction WITHOUT a jobsite visit.	6	I can understand most aspects of Commercial construction WITH a (**real** or <u>virtual</u>) jobsite visit.
7	In class materials (lectures, activities, group work) are sufficient to understand different scopes of work in Commercial construction.	7	Attending a commercial (**real** or <u>virtual</u>) jobsite visit is essential in supplementing (adding to) lecture material.

8	In class materials (lectures, activities, group work) enhances my learning and gives me insight on implementing theory (ie: understanding) Commercial construction.	8	The (**real** or <u>virtual</u>) jobsite visit enhanced my learning and gave me insight on implementing theory (ie: understanding) of Commercial construction.
9	In class materials (lectures, activities, group work) are sufficient to help me understand different aspects of Commercial construction.	9	The (**real** or <u>virtual</u>) jobsite visit was a sufficient activity to help me understand different aspects of Commercial construction.
10	In class materials (lectures, activities, group work) increase my overall confidence that I can be successful working in the Commercial construction industry.	10	The (**real** or <u>virtual</u>) jobsite visit increased my overall confidence that I can be successful working in the Commercial construction industry.
11	In class materials (lectures, activities, group work) have had a positive impact on my interest in Commercial Construction.	11	The (**real** or <u>virtual</u>) jobsite visit had a positive impact on my interest in Commercial Construction.
12	Do you think you can be motivated to choose a career in Commercial construction based of In class materials (lectures, activities, group work).	12	Do you think you can be motivated to choose a career in Commercial construction based off of the (**real** or <u>virtual</u>) jobsite visit.
13	Do you think you can be motivated to choose a career in Commercial construction based of In class materials (lectures, activities, group work). (short answer)	13	Do you think you can be motivated to choose a career in Commercial construction based off of the (**real** or <u>virtual</u>) jobsite visit? (short answer)
14	In the Commercial construction industry, I prefer to work in the following discipline? And the following building type? (short answer)	14	In the Commercial construction industry, I prefer to work in the following discipline? And the following building type? (short answer)
15	I prefer to watch a virtual site tour (e.g., video) rather than visiting a jobsite in person.	15	I prefer to watch a virtual site tour (e.g., video) rather than visiting a jobsite in person.
16	Watching videos provides the same sort of information as visiting a jobsite in person.	16	Watching videos provides the same sort of information as visiting a jobsite in person.

Creating the Virtual Field Trip

To provide students a similar experience as the students who completed the RFT, the instructor created a VFT of the same construction project, and on the same day the RFT was completed. The instructor used an Insta360 ONE X2 360-degree camera and processed the photos and videos using StructionSite, Inc. As shown in Figure 3, this created a visual walkthrough of the project. The instructor used 360-degree videos and photos to document the different locations and uploaded all of the information on StructionSite, Inc. After the data was uploaded, the instructor created an 11-minute video utilizing a video software tool. The instructor narrated the video as he walked through the virtual jobsite using StructionSite, Inc. In addition, to deliver the same amount of information as the RFT, the instructor documented all of the talking points, and certain areas of focus, and provided this same amount of information during the VFT.

Figure 3. StructionSite, Inc. VFT Walkthrough Visual Example

Course Format

The curriculum of the construction management program at [University] is integrated. The program defines this integrated curriculum as a method of combining all the core academic subjects such as scheduling, estimating, materials and methods into a single course under an overarching theme, such as residential construction, commercial construction, or civil construction. Construction management majors must take seven practice-specific integrated lab courses. These labs cover fundamentals, residential, commercial, specialties, heavy civil, jobsite, and program management. Each of the integrated labs includes technical foundational information, estimating, scheduling, methods, material and a project based learning (PBL) component. Taken in sequence, these courses form a spiral learning (SL) framework.

Two sections of the commercial course met during the fall quarter 2021 with 21 and 23 students. Students were divided into teams of five or six students for group assignments and building activities. The sections met in-person, with the course content delivered in a range of instructional methods including reading assignments, lectures, video content, discussions, activities, quizzes and exams, assignments, working with a team, hands-on building, and VFTs or RFTs.

The commercial course concerns all aspects associated with large commercial and institutional construction operations and include topics such as building system analysis of foundations, waterproofing, structural framing, exterior cladding, and finishes. Students received safety and shop training for the hands-on activities where each group builds a ten-foot long, ten-foot tall commercial exterior wall system. Students alternated building activities with classroom instruction, requiring students to apply what they had learned through various learning methods with hands-on building activities including forming and pouring concrete, installing CMU, metal studs, exterior sheathing, siding, stucco, and finishing. These learning activities culminate in a construction project proposal for a commercial project based on the full set of plans and specifications.

Results & Discussion

A side-by-side comparison of the aggregate response of the pre-trip survey and post RFT and VFT surveys is provided for statements 1, 5, and 10-12 in Figure 4, for statements 2, 3, and 6-9 in Figure 5. Students scored the statements based on a 5-point Likert scale where 1 = strongly disagree, 2 = disagree, 3 = unsure, 4 = agree, 5 = strongly agree. The responses were compiled to establish the aggregate response for each statement.

The study sought to assess:

(1) do VFTs or RFTs contribute to students' interest in commercial construction,
(2) do students perceive VFTs or RFTs to contribute to knowledge and skills attainment in a commercial construction course,
(3) can VFTs be successfully utilized in a construction management curriculum.

The online anonymous surveys were conducted over one quarter in a commercial construction management integrated lab course with one separate instructor providing course instruction for each section. The 21 and 23 students enrolled in the course sections all completed the pre field trip survey. In one section, 18 of 23 students completed the post trip survey, for the RFT, for a response rate of 78%. All 21 students completed the post field trip survey for the VFT for a response rate of 100%.

There were five questions intended to assess students' interest in the commercial construction industry prior to the field trip and following a VFT or RFT, in addition two opportunities for free responses were provided: statements 1, 5, and 10-14 (13 and 14 free response) as shown in Figure 4. These questions indicate that most students perceive course materials, RFTs, and VFTs can all contribute to and have a positive impact on their interest in commercial construction. Further, the majority of students prefer RFTs at a higher rate than VFTs, and both significantly more than no field trip. In addition, 18 students indicated in the free responses that they were interested in the commercial construction industry from course materials, as well as 6 from the RFT, and 6 from the VFT. Of interest, four additional students attending the VFT noted that a VFT alone was not enough to interest them in commercial construction but that it could contribute to their overall interest. These responses clearly indicate the value of a VFT in a commercial construction management course, but not as a replacement for RFT.

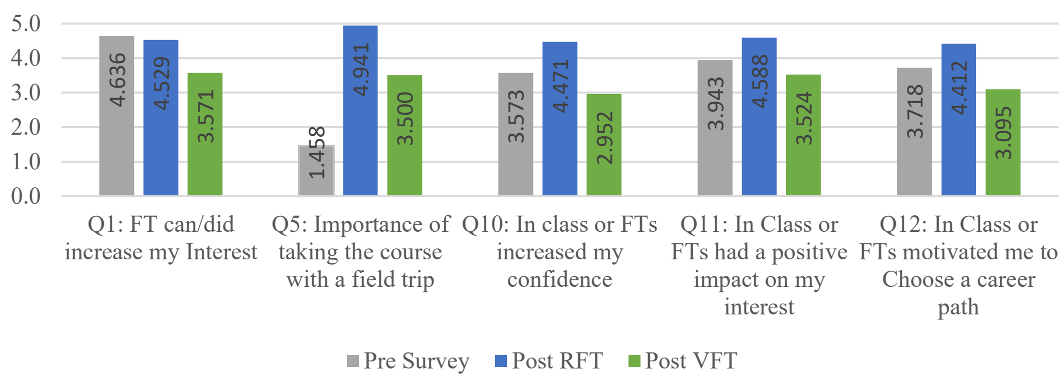

Figure 4. Interest in commercial construction

There were six questions intended to assess students' perception on the effectiveness of a VFT or RFT and the skills associated with the construction management course: creative and innovative thinking, problem solving, and understanding the material; statements 2, 3, and 6-9 as shown in Figure 5. The responses to these questions indicate that the majority of students perceive a VFT or RFT as more effective to gaining skills than without. In addition, as indicated in the responses to question 9, a majority of students positively indicated that class materials, RFT and VFT were sufficient to help in understanding different aspects of commercial construction.

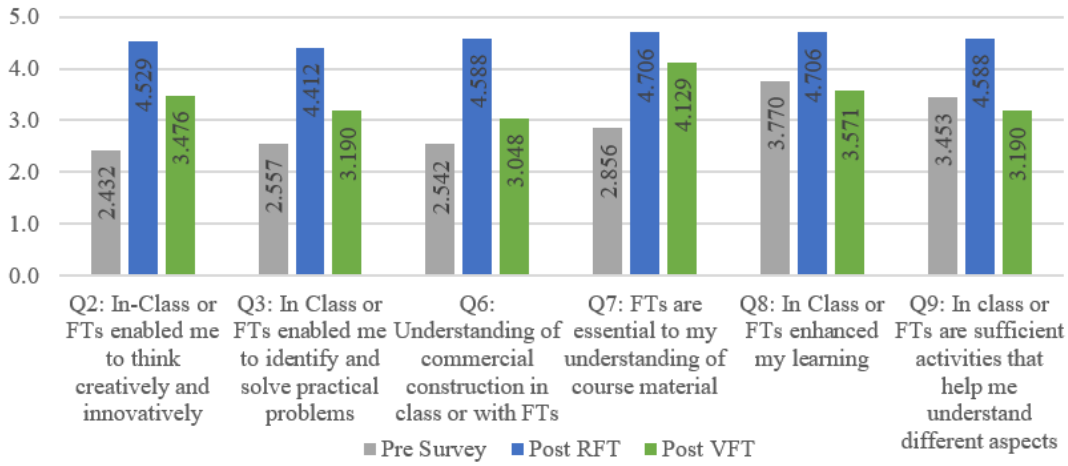

Figure 5. Perceived effect on knowledge and skills

There were two questions intended to assess students' perception of VFTs in a commercial construction management course: statements 15 and 16. Student aggregate responses to question 15 which asked if they prefer to watch a virtual tour rather than visiting in person, and responses to question 16 which asked if watching videos provides the same information as visiting a jobsite in person strongly indicate that students do not perceive VFTs or videos as providing the same information as visiting a jobsite in person. The aggregate mean rating for question 15 was 1.42 in the pre survey and 1.48 in the post VFT survey. The aggregate mean rating for question 16 was 1.71 in the pre survey and 1.62 in the post VFT survey. These were the lowest mean ratings for both the pre and post surveys and these responses are consistent with findings of Kolegraff et al. (2019) and Seifan et al. (2020) which indicated students preferred hands-on learning and RFTs.

Conclusion

Three conclusions are evident from this study. First, in a commercial construction management integrated lab course VFTs and RFTs can contribute to students' interest in commercial construction. Although students indicated that VFTs may contribute to their interest, they preferred in person experiences to virtual ones. Second, students perceive VFTs and RFTs along with course content to contribute to knowledge and skills attainment in a commercial construction course. The students surveyed clearly value VFTs but do not find them as a replacement for an RFT. Finally, VFTs can be successfully utilized in a construction management curriculum, but these responses indicate that VFTs alone are not enough for a successful commercial construction management course.

A recommendation for future study would be to investigate the aspects of VFTs that students perceive as effective to integrate with course materials. This could allow the introduction of VFTs into course work to highlight certain aspects of construction or to demonstrate sequencing or site logistic plans using StructionSite, Inc. where a RFT is not possible due to proximity to the location, access to the site or the schedule of the activities.

References

Eiris, R., Wen, J., & Gheisari, M. (2021). iVisit-Collaborate: Collaborative problem-solving in multiuser 360-degree panoramic site visits. *Computers & Education*, 104365.

Eiris-Pereira, R., & Gheisari, M. (2019). Site visit application in construction education: A descriptive study of faculty members. *International Journal of Construction Education and Research*, *15*(2), 83–99.

Eiris, R., Jain, A., Gheisari, M., & Wehle, A. (2020). Safety immersive storytelling using narrated 360-degree panoramas: A fall hazard training within the electrical trade context. *Safety Science*, *127*, 104703.

Jaselskis, E. J., Jahren, C. T., Jewell, P. G., Floyd, E., & Becker, T. C. (2010). Virtual construction project field trips using remote classroom technology. *Construction Research Congress 2010: Innovation for Reshaping Construction Practice*, 236–245.

Kolegraff, S. A., Kline, A., & Kelting, S. (2019). Hands-On Building as an Instructional Delivery Method in an Integrated Lab Curriculum. *55th ASC Annual International Conference Proceedings*, 33–40.

Leydon, J., & Turner, S. (2013). The challenges and rewards of introducing field trips into a large introductory geography class. *Journal of Geography*, *112*(6), 248–261.

Murray, M., & Tennant, S. (2016). " Off-piste pedagogy": Construction site visits for undergraduate civil engineers. *Sixth International Symposium of Engineering Education*, 165–172.

Paez, D., & Rubio, L. A. (2015). The Use of Field Trips in the Context of Engineering Collaborative Teaching: Experiences of Hands-On Geomatics Activities in Colombia. *Wisdom of the Ages to the Challenges of the Modern World Sofia, Bulgaria*, 17–21.

Pham, H. C., Dao, N., Pedro, A., Le, Q. T., Hussain, R., Cho, S., & Park, C. (2018). Virtual field trip for mobile construction safety education using 360-degree panoramic virtual reality. *International Journal of Engineering Education*, *34*(4), 1174–1191.

Seifan, M., Dada, O. D., & Berenjian, A. (2020). The Effect of Real and Virtual Construction Field Trips on Students' Perception and Career Aspiration. Sustainability, 12(3), 1200. https://doi.org/10.3390/su12031200

Spicer, J. I., & Stratford, J. (2001). Student perceptions of a virtual field trip to replace a real field trip. *Journal of Computer Assisted Learning*, *17*(4), 345–354.

Stoddard, J. (2009). Toward a virtual field trip model for the social studies. *Contemporary Issues in Technology and Teacher Education*, *9*(4), 412–438.

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Adaptation of Autonomous Vehicles into Highways and Roads

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Autonomous vehicles (AVs) are considered as the one of main components of the future transportation system. By 2040, over 90% of the vehicles are expected to be autonomous vehicles in the U.S. Therefore, it is imperative that the infrastructure systems, including highways and roads, need to be updated accommodate AVs before they become prominent in the transportation system. The main benefits of AVs are easing congestion, shortening commutes, reducing fuel consumption and global warming, enhancing accessibility, the liberation of parking spaces for better uses, and improving public health and social equity. To provide the current state of adaptation of AVs into highways and roads, the objectives of this paper are to investigate the current legislation and to explore impacts from the implementation of AVs and consequence considerations. Since Michigan is the home to one permanent testing site for autonomous vehicles, Michigan was selected as a case study in this paper. By providing an overview of the current implementation of AVs in the U.S., this paper will bring a comprehensive understanding of the adaptation of AVs so far and provide insights into future directions for a better implementation.

Key Words: Adaptation of autonomous vehicles, Highway and Road Update and Rehabilitation, Implementation of Legislative Regulations

Introduction

Autonomous Vehicles (AV) are cars that guide themselves without human control. In other words, it is a computer, GPS, sensor, and augmented reality-based vehicle that is made to move and function on its own. This type of vehicle is being said to be our future of transportation systems (Nikitas et.al. 2017). Bullis (2014) has mentioned, “self-driving will add benefits to our whole society, such as providing transportation for people who are otherwise not able to drive because of age or physical impairment, that is both exciting and meaningful”. There are six levels of autonomy as follow: level 0: all major systems are controlled by humans; level 1: certain systems, such as cruise control or automatic braking, may be controlled by the car, one at a time; level 2: the car offers at least two simultaneous automated functions, like acceleration and steering, but requires humans for safe operation; level 3; the car can manage all safety-critical functions under certain conditions, but the driver is expected to take over when alerted; level 4; the car is fully-autonomous in some driving scenarios, though not all; and level 5; the car is completely capable of self-driving in every situation

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(Cooke 2018). Among six levels of autonomy, AVs with levels two and three runs in our current community, and they could be reached to levels four and five in the coming years.

The technology used in AVs is similar yet different from conventional cars. The types of technology used for AVs are sensors, connectivity, and software/control algorithms. Mattern (2017) mentioned that "Some of them have redundant front cameras that cover different visual depths and angles so that they can simultaneously detect nearby lane markers, construction signs on the side of the road, and streetlights in the distance. Radar sensors, unimpeded by weather, track the distance, size, speed, and trajectory of objects that may intersect the vehicle's path, and ultrasonic sensors offer close-range detection, which is particularly useful when parking" (Mattern 2017). To implement AVs into our current transportation system, it is imperative to plan to update existing transportation systems in the U.S. This will in turn help the adaptation in a smoother transition period. However, as of today, it is not understood well how this transition will be because the needs have not fully been defined. With the growth of AVs in the U.S., there were a lot of attempts across the states to implement AV and amend legislation related to AV. This paper focused on identifying the legislation status in the U.S with a comparison of different states and exploring impacts and considerations for AV adaption in Michigan as a case study.

Literature Review

Since AV technology has been considered an emerging trend in the transportation area, many researchers have been studying the adoption of AVs in terms of their mobility, environmental impacts, and possible concerns. By conducting a literature review, Golbabei et al (2020) examined and classified individual predictors of public acceptance and intention of AVs. Then, they developed a conceptual framework based on these individual factors to illustrate public attitudes towards AVs. From this study, they have identified that the key individual factors are demographic, psychological, and mobility behavior characteristics and the finding reveal those public perceptions and intentions are varied among different socio-demographic cohorts (Golbabei et al. 2020). Similarly, another research studied the individual level AV adoption and timing process by considering the psycho-social factors of driving control, mobility control, safety concerns, and tech-savviness (Asmussent et al. 2020). The conclusion of the study emphasizes that the adoption of AVs should be examined from a psychosocial perspective (Asmussent et al. 2020). By conducting a survey of 391 participants and analyzing the data using structural equation modeling (SEM), Dirsehan and Can (2020) examined the adoption attitudes of individuals toward AVs in terms of trust and sustainability concerns, and they confirmed that the participants' intention to use the AVs depends on how useful it is rather than how easy it is to use. Moreover, this study showed that sustainability concerns and trust have a significant effect on the behavior intention of AVs (Birsehen and Can 2020). There are some studies focused on the impacts of AVs. Greenblatt and Shaheen (2015) reviewed the history, current developments, and projected future trends and environmental impacts of AVs as well as its on-demand mobility and potential synergies. It was mentioned that shared AVs could become a major public transportation facilitating accessibility among a wide range of sociodemographic groups, high efficiency, small size, affordability, and very low GHG emissions, a wide range of land uses (Greenblatt and Shaheen 2015). In Litman's study, the result of the analysis shows that Level 5 AVs may be commercially available and legal to use in some jurisdictions by the late 2020s, but this will require high initial costs and limit performance (Litman 2020).

AV Legislations in the U.S.

Many researchers forecast that there will be approximately 8 million autonomous or semi-autonomous vehicles on the road by 2025. Each year, the number of states considering legislation related to AVs has gradually increased. This warns the government of the potential impacts of AV technology socially and environmentally across the U.S. Before AVs become widespread, it is essential to analyze the policy implications and legislation of AVs with proper and thorough planning, especially with in-depth analysis of conflicts and disruptive impacts. Especially, regulating vehicle capabilities, human factors, and insurance requirements are factors that should be considered by policymakers (Anderson et al. 2014). These include examining liability changes for insurance in the manufacturer versus personal level and understanding the impacts of inconsistent state regulations related to AVs. Additionally, it is also important to examine the overlaps in legislation between federal, state, and even local laws.

Currently, 15 states enacted 18 AV bills, and 33 and 20 states introduced legislation in 2017 and 2016, respectively. Twenty-nine states (i.e., Alabama, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Maine, Michigan, Mississippi, Nebraska, New York, Nevada, North Carolina, North Dakota, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Vermont, Washington, and Wisconsin) and Washington D.C. have enacted legislation related to AVs. Governors in Arizona, Delaware, Hawaii, Idaho, Illinois, Maine, Massachusetts, Minnesota, Ohio, Washington, and Wisconsin have issued executive orders related to AVs.

Since 2016, the U.S. Department of Transportation (DOT) has published three reports regarding federal AV policies. These reports include best practices of vehicle regulation including a set of voluntary, publicly available self-assessments by automakers representing how they are building safety into their vehicles, and a proposal to modify the current system of granting exemptions from federal safety standards (Canis 2019). However, most importantly, level 4 and 5 AVs are not aligned with the existing regulations. Therefore, the implementation of local and federal guidelines and regulatory standards, as well as a legal framework for AVs is challenging (Nyashin 2018). Even though there has been recent keen interest in AV legislation, as part of the Endless Frontier Act, Congress has not passed AV legislation thus far. The legislation did not pass the 115th Congress due to disagreements on several key issues (Canis 2019). As a result, now the nation is under an uncertain regulatory environment and lacks a clear path to AV deployment.

Figure 1 presents the states in the U.S. with their legislation status. As shown here, 30 states have enacted the legislation, 5 states have executive orders, and five states both enacted legislation and had executive orders. The current legislation status of the five states given in Figure 1 (i.e., California, Arizona, Florida, Washington D.C., and Michigan) was examined in this research. Among these states, Michigan permitted the testing of AVs in 2013, while the other states, Nevada, Florida, and Arizona permitted 2011, 2012, and 2015 respectively. Also, Michigan allowed the operation of AVs without a person in a vehicle in 2016, and Nevada was allowed this in 2017. Florida also allowed driverless AVs on the public road in 2019. Furthermore, Michigan is a state that addresses the liability of the vehicle manufacturer in 2013 and limited the liability of damages resulting from modifications made to an AV in 2014. Table 1 shows the chronologic orders in legislations for selected four states, Nevada, California, DC, and Florida, and Table 2 provides the legislative orders for Michigan.

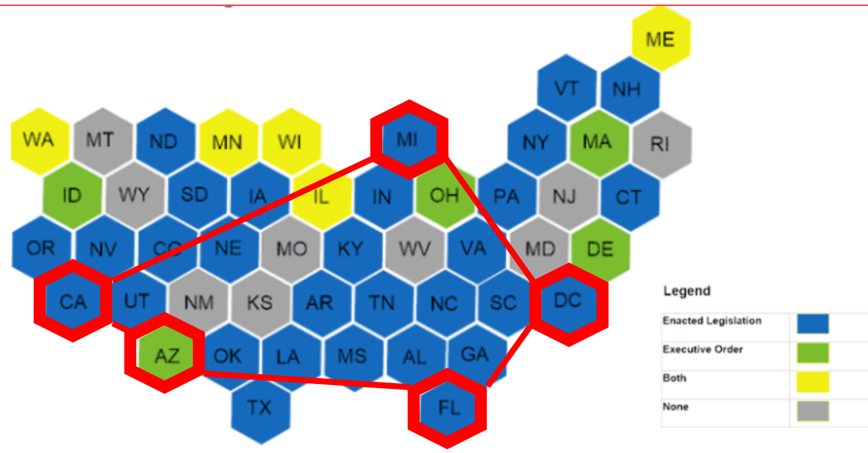

Figure 1. States with AV Enacted Legislation and Executive Orders (NCSL, 2021)

Table 1

Chronologic Orders in Legislations for the Selected States

Nevada	
2011	The first state to authorize the operation of AVs.
	Directed DMV to adopt rules for license endorsement, operation, and safety.
2013	Required proof of insurance from AV operators and that the vehicle meets state standards.
2016	Issued nation's first av-restricted driver license.
2017	The first fully autonomous shuttle operating on public streets in the US.
	Allowed use of autonomous platooning on highways. Required crashes be reported to the DMV within 10 days of resulting in damages over $750.
	Allowed a fine of up to $2,500 for violations of AV regulations.
	Allowed fully autonomous vehicles without a human operator.
	Specified that the following distance rule does not apply to vehicles in a platoon.
	Imposed an excise tax on autonomous vehicles used for transportation services.
	Permitted AV use by carriers and taxi companies under conditions.
2021	Fully autonomous vehicle – Enacted.
Florida	
2012	Declared legislative intent to encourage the development, testing, and operation AVs. - Determined that the state would not prohibit/regulate the testing/operation of AVs. - Directed for additional legislation for the safe testing and operation of AVs.
2016	Permitted operation of AVs on roads by individuals with a valid driver's license.
	Required a study on the use and operation of autonomous truck platooning technology and allowed a pilot project once completed

2019	Driverless AVs allowed on public roads
2021	Autonomous vehicles operation on public - Enacted
District of Columbia	
2013	Required a human driver to be prepared to take control, restricted conversion to recent vehicles, and addressed the liability of the original manufacturer.
2018	Gave its Department of Transportation one year to have a study publicly available that evaluates and makes recommendations regarding AVs
California	
2012	Required the Department of Highway Patrol to establish safety standards and performance requirements to ensure the safe operation and testing of AVs.
2014	DMV autonomous vehicle tester program was established.
2016	Allowed to test autonomous vehicles that did not have steering wheels, brake pedals, gas pedals, or an operator inside the vehicle.
2017	Requested that its DOT use funds from its Road Maintenance and Rehabilitation Program advance technologies accommodate advanced automotive technologies.
	Three bills regarding autonomous vehicles: -Extended the date that autonomous test vehicles could travel with a limit. -Authorized to test AVs without a driver in the driver's seat, steering wheel, etc. -Repealed the requirement to operate an AV without a driver and etc.
2018:	-AV tester driverless program is established Vehicle testing, enacted -Authorized to impose a tax on each ride originating in the City or County. -Authorizes the City and County to set a lower tax rate for net rider fares for a ride
2019	Vehicle testing is enacted

Table 2

Chronologic Orders in Legislations for Michigan

Michigan	
2013	Permitted testing of automated vehicles under conditions and addressed the liability of the vehicle manufacturer.
2014	Limited liability of the manufacturer for damages resulting from modifications made to an automated vehicle.
2016	Open operation of CAVs testing. On-demand AV networks link passengers to transportation options
	-Allowed autonomous vehicles under certain conditions. Allowed operation without a person in the autonomous vehicle. -Specified that the requirement that vehicles maintain a minimum 500 feet following distance doesn't apply to vehicles in a platoon. - Allowed mobility research centers for automated technology testing. Provided immunity for automated technology manufacturers when modifications are made without consent.
2018	Established state infrastructure council to collect data on infrastructure system
2020	Created Michigan office of future mobility

The Impacts of Autonomous Vehicles Implementations in Michigan

With the downfall in the automobile industry, Michigan had experienced a huge economic crisis through the twentieth century. Now, by implementing upcoming technology and AVs, it is hoping that Michigan comes back to its glory days. For such a turn, it is needed to improve and modernize the infrastructure in Michigan. Indeed, it has prospected that Michigan's infrastructural system will be improved and ready for the next generation transportation formation with the new coming infrastructure bill. While rehabilitating the roads, highways, and bridges, technology implementation should also be taken as a part of the process as well as connections and access to charger stations. In other words, the transportation landscape in cities in Michigan should be redesigned with the consideration of new technology.

The current main roads in Michigan's cities, especially in Detroit, are usually multilane in each direction with a turn lane in the center. At each intersection, there is a traffic signal that directs right turns, left turns, straight through traffic, and pedestrians, and the average traffic signal cycle is 120 seconds long. The main road usually gets 60 seconds or more, then, the minor street and pedestrians split the remaining time. Modern traffic signals use loop detectors or video detection to keep the traffic on the main roads flowing until one or two cars are waiting on the minor cross street. The introduction of high automated or fully automated vehicles will make these traffic signals obsolete. It will take forty years that traffic signals to be phased out, but the operation will change to meet the demand for autonomous vehicles. Autonomous vehicles will need to communicate with traffic signals to let groups or platoons of cars through. Presently traffic signal timings are determined by computer modeling programs. In the future, these programs will need to be adapted to communicate and coordinate with autonomous vehicles to keep traffic flowing.

In addition, roadways will be reconfigured for pickup and drop-off zones. It could be either one continuous lane or a block of on-street parking converted into a pickup area like a bus stop. Therefore, these bus stops will become multi-uses as autonomous vehicles are introduced. With increased uses of AVs, the bus stops will be improved, from a sign next to the road or a small shelter to larger stations or waiting areas. This will make businesses want to be located near transit stops due to the volume of people passing by. Approximately 100 years ago, road signs started to become standardized. As autonomous vehicles become predominant, these signs should be restructured and implemented with the needs. However, it is difficult to predict all needs before autonomous vehicles are fully implemented (Shladover, 2018).

Furthermore, one of the important areas is the implementation of legislative regulations. As autonomous vehicles are introduced, new laws and customs will also be introduced to operate the system smoothly and efficiently. However, there are many uncertainties regarding what should be revised such as open container laws, or over the .08 limit still getting a DUI. For now, these laws are still in place because a driver may need to take control of the vehicles (Shladover, 2018). When cars are fully automated and there is no need for driver interaction, then, the judicial system should determine whether this law still applies to the circumstances. Autonomous vehicles may have dedicated lanes, but this will be problematic when drivers need to utilize the lane for passing or traveling if there is no traffic in the AV's lanes. For this situation, police cameras could be installed to enforce lane laws, but pushback is also be expected. Moreover, the lane width for AVs can be reduced, since they are more capable of staying in the center of the lane than human drivers. Narrower lanes will leave more room for sidewalks, trees, bike lanes, light rail trains, and restaurant patios.

The effort of Michigan on AV implementation

As Michigan was hit by an economic crisis about a decade ago, there are still traces of the collapse in various areas. Historically, Michigan has been the leader of the automotive industry till the crisis. With the new vehicles and transportation technologies, now, Michigan is trying to be a part of the new generation automotive industry. However, there are still existing problems that may take a long period to address. Roads and highways in Michigan have been in poor conditions for a long time. Since the transportation system plays an important role in economic growth, such badly shaped roads disadvantage MI's economic growth. People working in Detroit are commonly living in the outside circle of the city due to various reasons such as safety and educational preferences for kids, so commuting routes and transportation grid are critical in the state re-development. Traffic congestion can be tracked by the level of service during peak hours (Highway Capacity Manual 2000). Also, parking has become an issue in the city. However, there is much uncertainty if the need for parking will increase, decrease, or be shifted to the outer ring around downtown Detroit with AV technology. Therefore, it is needed to see which theory is appropriate for a parking spot inventory as a baseline.

Michigan is already home to one of the permanent testing sites for AVs, with another slate to be open in the near future. In Figure 2, some samples are given. The first facility given in Figure 2.a, opened in 2015 by the University of Michigan, is called Mcity. This is a 32-acre site in Ann Arbor, Michigan that claims to be the world's first controlled environment to specifically test the potential of connected and automated vehicle technologies that will bring driverless cars to the mass market. University of Michigan Transportation Research Institute broke ground in early 2014 on the U.S. DOT funded Michigan Mobility Transformation Center at Ann Arbor, Michigan: "The $30 million simulated city, built like a movie set on 32 acres, will test connected vehicle and infrastructure technology to simulate crash scenarios in a realistic environment." Michigan has strongly tackled that perception, with new initiatives like Planet M, a state-run organization, investors, and research pilots by connecting them to the state's existing automotive environment. Then, the state launched the way of establishing the leading test facilities for AV in Ypsilanti such as the American Center for Mobility as seen in Figure 2.b. There's another rising mobility research facility between Ann Arbor and Detroit, that has the future headquarters of Ford's AVs department in Dearborn, Detroit, given in Figure 3. In this complex, AV research and implementation have been carried. In addition, Michigan State University (MSU) is testing these vehicles, patrolled within 80 miles roads. Many research activities and proposals are being considered and carried out by supporting groups and businesses.

a. Mcity is a 32-acre simulated urban and suburban environment

b. American Center for Mobility

Figure 2. Sample Developments in Michigan: MCity and American Center for Mobility


Figure 3. Ford World Headquarters in Dearborn MI

Conclusion

There is a big expectation from AVs that will greatly improve our daily lives, environment, and productivity. AVs will bring positive benefits such as fewer vehicle crashes due to the decrease in driver faults, increase in mobility for young, elderly, and disabled, the ease of congestion, reduced the costs of travel time, and more time doing other activities than driving, alternate energy sources, and less parking structures and lots. However, it is important to consider various aspects carefully including planning and implementations before the world is ready to see AVs on the roadways, highways, and infrastructures. To cope with upcoming AV technology, this paper provides detailed information and background of legislation aspects of AVs and investigates the implementation of AV in the transportation system Also, Michigan was selected as a case study to explore the impacts of AVs and their effort to implement AVs so far in the state. Since AVs will be the most common transportation tool in the future, the transportation system should be adjusted according to this new technology with all components and implementations.

The legislation is an important part of AVs adaptation. In this research, five different states California, Arizona, Florida, Washington D.C., and Michigan were investigated and compared with each other's status. Important dates were tabulated for these states which provide an easy comparison in different states. Providing specific dates regarding legislation of AVs in five states gives an insight into the future of the AVs in these states. In addition, Michigan was investigated as a case study that has lots of opportunities with coming AV technology. Detroit's economic status is expected to recover more quickly in the next couple of years because of the high shift of technology coming with autonomous vehicles. The unemployment rate in Detroit will come down since many initiatives by auto companies located in Michigan, and other companies are in developing the neighborhoods of Detroit for coping with the next generation of technology. Ford Motor Company is working in renovating their development and research Center in Dearborn at an estimated cost of $1.2 Billion with 48,000 employees. One of the main components of this investment is to enhance AV research and implementation. It also includes building new parking lots and transits. As autonomous vehicles are introduced to the community, new laws and customs should be introduced. Consequently, the technical phase should go with the legislation hand to hand. It is expected that these efforts will lead to a successful implementation of AVs in the state.

References

Anderson, J.M., Nidhi, K., Stanley, K.D., Sorensen, P., Samaras, C., & Oluwatola, O.A. (2014). Autonomous Vehicle Technology: A Guide for Policymakers. *Rand Corporation*.

Asmussen, K.E., Mondal, A., & Bhat, C.R. (2020). A Socio-Technical Model of Autonomous Vehicle Adoption Using Ranked-Choice Stated Preference Data. *Transportation Research Part C: Emerging Technologies*, *121*, 102835.

Bullis, K. (2014). SelfDriving Car Tech Could Help Make Solar Powered EVs Practical, *MIT Tech Rev*

Cooke, D. (2018). Self-Driving Cars Explained, How Do Self-Driving Cars Work and What Do They Mean for The Future? https://www.ucsusa.org/resources/self-driving-cars-101

Canis, B. (2019). Issues in Autonomous Vehicle Testing and Deployment (No. R45985). *Congressional Research Service*.

Dirsehan, T., & Can, C. (2020). Examination of Trust and Sustainability Concerns in Autonomous Vehicle Adoption. *Technology in Society*, *63*, 101361.

Golbabaei, F., Yigitcanlar, T., Paz, A., & Bunker, J. (2020). Individual Predictors of Autonomous Vehicle Public Acceptance and Intention to Use: A Systematic Review of The Literature. *Journal of Open Innovation: Technology, Market, and Complexity*, *6*(4), 106.

Greenblatt, J.B., & Shaheen, S. (2015). Automated Vehicles, On-Demand Mobility, And Environmental Impacts. *Current Sustainable/Renewable Energy Reports*, *2*(3), 74-81.

Highway Capacity Manual, (2000). Transportation Research Board, National Research Council https://trid.trb.org/view/475202

Litman, T. (2020). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning.

Mattern, S. (2018). Mapping's Intelligent Agents 1. In *Mapping and Politics in The Digital Age* (Pp. 208-224). Routledge.

NCSL, (2021). Autonomous Vehicles: Self-Driving Vehicles Enacted Legislation https://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx

Nikitas A, Kougias I, Alyavina E, Tchouamou E, (2017). How Can Autonomous and Connected Vehicles, Electromobility, BRT, Hyperloop.

Nyashin, N. (2018). The State and Future of Autonomous Vehicle Regulation in the United States.

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Distance Discrepancies in T-LiDAR, Point-Cloud Models Georeferenced via RTK and Static GNSS

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This article analyzes two virtual 3D point-cloud models, generated via terrestrial light detection and ranging (T-LiDAR), to compare the relative inaccuracies in distances introduced by two different georeferencing approaches. One is rapid (~30 seconds per ground point) and commonly used in practice, the Real-Time, Kinematic (RTK) Global Navigation Satellite System (GNSS) approach, and the other is a more accurate, but time consuming (4 hours per ground point), Static GNSS scheme. The goal is to determine statistical length discrepancies in the same distances extracted from two differently georeferenced 3D models of the same spatial geometry. Currently, this type of comparison is not readily available to practitioners and could assist in selecting the type of GNSS-based georeferencing procedure. The modeled area encompasses ~30,000 ft^2 of a university campus and includes the exterior portion of a building. To determine the discrepancy in measured distances from the two differently georeferenced models, the same one hundred points were identified simultaneously in each of them, and the same 600+ distances were virtually extracted from each model. Then, the discrepancy of each pair of corresponding distances was calculated and its statistics were determined. A full analysis of those discrepancies is presented in this article.

Key Words: Georeferencing, GNSS, LiDAR, Distance Discrepancy

Introduction

Laser-based terrestrial scanners become commercially available in the mid-1990s and evolved significantly in the last 25 years (Gaurav, 2018). Today, the latest devices and their associated software packages are faster, more powerful, and more affordable. This has contributed to their current ubiquity in the Architecture, Engineering and Construction (AEC) industry. The resulting models capture existing spatial conditions (i.e., topography and/or built environments) and are employed for various purposes, including virtual surveying, predesign/design processes, monitoring of construction progress, determination of pay quantities, capture of as-built conditions, etc. Even though manufacturers disclose the accuracies of their respective laser scanning devices, it is still necessary to study the resulting accuracies under real field conditions and after implementing certain postprocessing tasks that may affect those accuracies, such as the georeferencing of the final point-cloud models. According to Boehler et al (2003), "The accuracy specifications given by laser scanner producers in their publications and pamphlets should always be doubted." Several studies have analyzed those accuracies, including the work of Maldonado et al. (2020) where the discrepancy between georeferenced and non-georeferenced models were investigated. Additionally, Maldonado et al. (2021) estimated the error introduced by georeferencing a point-cloud model via an accurate closed-traverse survey. These two articles include more extensive literature reviews on this topic.

The goal of this study is to determine statistical length discrepancies in pairs of same distances extracted from two T-LiDAR, point-cloud models of the same spatial geometry, shown in Figure 1 (a). Each model is georeferenced by a different GNSS-based technique: (i) A rapid RTK GNSS approach and (ii) a more accurate, but slower, Static GNSS approach. The objective is to quantify statistical differences in lengths caused by the rapid georeferencing approach with respect to the more accurate, but slower static, alternative technique.

Instruments and Methodology

This study employed two instruments from Leica Geosystems. They are the ScanStation C10 and the Viva GS14 GNSS Smart Antenna device, with its CS10 handheld controller, as shown in Figure 2. The scanner was used to generate a non-georeferenced point-cloud model of a selected area (~3330 yd^2 ≈ 30,000 ft^2). The manufacturer (Leica 2021a) indicates that the C10 scanner has position accuracy of 6 mm (0.24 in) and measurement accuracy of 4 mm (0.16 in), both are 1σ at 1m-50m range. This scanner contains a dual-axis compensator with horizontal and vertical angular accuracies of 12 seconds. Its scanning range is 300 m (328 yd) at 90% albedo and 134 m (146.5 yd) at 18% albedo. The maximum scanning rate is 50,000 points per second. The Viva GS14 GNSS antenna has a maximum position update rate of 20 Hz and can track various constellations of satellites (GPS, GLONASS, BeiDou, Galileo and SBAS). However, this study only employed the GPS and GLONASS constellations. According to Leica Geosystems (Leica 2021b), the GS14 device has different horizontal (Hz) and vertical (V) position accuracies, depending on the employed technique. For a network-based, rapid RTK approach, the position accuracies are Hz 8mm+0.5ppm and V 15mm+0.5ppm (Hz 0.31in+0.5ppm and V 0.59in+0.5ppm). For long static individual observations, requiring post-processing, the indicated accuracies are Hz 3mm+0.1ppm and V 3.5mm+0.4ppm (Hz 0.13in+0.1ppm and V 0.14in+0.4ppm). Additionally, for this GNSS device, Leica indicates "Measurement precision, accuracy, reliability and time for initialization are dependent upon various factors including number of satellites, observation time, atmospheric conditions, multipath, etc. Figures quoted assume normal to favorable conditions."

The modeled area includes the West exterior portion of the Engineering Building and its surrounding garden, at the Statesboro Campus of Georgia Southern University (see Figure 1). Approximately, it encompasses an open space of 30,000 ft^2. The completion of this project involved four main tasks: (i) Data collection in the field, via the C10 and GS14 instruments. (ii) Postprocessing of the scanned data in the BEaM laboratory using the Leica Cyclone software. It consisted in the removal of noise (i.e., pedestrian traffic) and in the registration (stitching) of all scans. (iii) Postprocessing of georeferencing position data via the Online Positioning User Service (OPUS) of the National Geodetic Survey (NGS). (iv) Statistical analysis of the discrepancies in the same distances extracted from each of the two models, RTK-Georef and Static-Georef, which were georeferenced using different approaches.

(a) (b)

Figure 1. (a) Plan view of modeled area, marked in red, of Engineering Bldg. Picture from Google Maps, 2021. (b). Resulting Virtual, 3D, Point-Cloud Model (perspective view)

Before scanning, 100+ black-and-white, stickers (~10cm×10cm each) were attached at different locations on the walls, columns, window frames, and other features within the modeled area. This was done to properly capture and identify the same100 points in the two distinctly georeferenced models.

(a) (b) (c) (d) (e)

Figure 2. Employed devices and targets. (a) Leica's ScanStation C10, (b) & (c) Leica's GS14 GNSS Smart Antenna. (d) White, Six-Inch, Spherical Target. (e) Captured B&W Sticker Target

During field operations, a total of thirteen (13) exterior scans were completed to cover the selected area. This took approximately 35-45 minutes per scanning station. In this study, we adopted the target-based registration (stitching) process to build the initial, non-georeferenced model. Therefore, various white, spherical, six-inch diameter targets (see Figure 2 d) were employed to serve as connecting points while registering (stitching) the different scans into a common system of reference. Before georeferencing the model, the selected system of reference is arbitrary. This system coincides with the reference frame of the first scan listed in the stitching group. To properly register two neighboring scans, it is necessary that they both contain at least 3 common targets. This target-based registration was adopted since it is more accurate than the other two available techniques in Leica's Cyclone software, the cloud-to-cloud, and the visual-alignment registrations. However, the adopted target-to-target approach required additional time in the field for target acquisition. One-foot-long steel nails were employed to materialize the ground points where the spherical targets were placed, on top of aluminum poles. Four of those ground points (TP1, TP3, TP5, and TP8) were selected as ground control points for georeferencing purposes. The spherical targets were preferred because, unlike plane-circular targets, they can be acquired from different angles without the need of human intervention to rotate them toward the different scanning stations. This minimizes potential errors introduced during that reorientation process.

The coordinates of four fixed ground control points were acquired in the Georgia-East State Plane Coordinate System (GA-E SPCS), to georeference the resulting point-cloud model. First, those coordinates were obtained via a rapid RTK GNSS approach. For this, the GS14 antenna served as a rover connected via Wi-Fi (provided by an Android-based cellular phone) to the Internet to access the privately owned eGPS Network of fixed bases, in Georgia and Alabama. It took approximately 20-30 seconds to obtain these RTK coordinates for each of the 4 ground control points. Then, these coordinates were employed to georeference the previously generated, fully stitched, 3D point-cloud model. The resulting georeferenced model is herein referred to as the *RTK-Georef* model. Second, the coordinates of the same four ground control points were acquired via a slower, but more accurate, long Static GNSS approach. For this, 4 hours of continuous position data acquisition was completed at each of the 4 ground control points. This data was submitted to OPUS for processing and correction. The 4 hours of continuous data acquisition was selected to assure close approximation to the most accurate position values attainable with the GS14 GNSS device via OPUS processing. In this regard, information available at OPUS' website (OPUS, 2021) shows two convergence graphs, one for horizontal and one for vertical positioning coordinates, extracted from Gillis et al (2019). Those graphs show that 4 hours of continuous data acquisition almost attain convergence in the horizontal and vertical positions (with a root mean square error of ~10 mm ≈ 0.4 in). The georeferenced model resulting from these, more accurate, coordinates is herein referred to as the *Static-Georef* model. Table 1 shows the GA-E SPCS coordinates of the four ground control points acquired by these two GNSS approaches.

Table 1

Coordinates of Ground Control Points and their Discrepancies

Fixed Ground Control Points	RTK-GNSS COORDINATES (GA E SPCS)			STATIC-GNSS COORDINATES (GA E SPCS)			DISCREPANCY in COORDINATES			MAGNITUDE of DISCREPANCY VECTOR	
	North (US foot)	East (US foot)	Elev. (US foot)	North (US foot)	East (US foot)	Elev. (US foot)	North (inch)	East (inch)	Elev. (inch)	(inch)	(mm)
TP1	881054.443	773544.654	211.652	881054.567	773544.627	211.532	-1.49	0.32	1.44	2.10	53
TP3	881057.605	773510.552	210.672	881057.736	773510.507	210.387	-1.57	0.54	3.42	3.80	97
TP5	880931.134	773662.035	211.321	880931.243	773662.019	211.276	-1.31	0.19	0.54	1.43	36
TP8	880940.019	773553.334	207.201	880940.089	773553.309	207.142	-0.84	0.30	0.71	1.14	29
					Magnitude of Averaged Discrepancy Vector				→	**2.12**	**54**

After the two distinct RTK-Georef and Static-Georef models were generated, 100 virtual pairs of points were identified in them. Each pair contained the coordinates of the same point but extracted from different georef models. That is, each point in each pair presented slightly different coordinate values. Additionally, 7 points were randomly selected from the original 100 to server as center points (CPs) in each georef model. Virtual distances were measured from each of these CPs to the remaining 99 points in each model. This resulted in numerous pairs of 2 corresponding virtual distances, each from a different georef model. Repeated distances were removed, so they did not weigh more than once in the calculated statistics. The total number of non-repeated distances in each model was 672. They ranged from near 0 to about 180 ft. However, it was inferred that a few of these distances involved points that contained erroneously acquired coordinates. These errors could have occurred when participating assistants manually extracted 600 numbers (3 coordinate components per point per model). That is, either the actual coordinates were wrongly recorded, or different, nearby points were wrongly considered as the same point in both point-cloud models. Those erroneous points and their defined distances are referred to as outliers. All local statistics (for distances from each center point) and global statistics (for all distances involved in this study) were calculated with and without outliers. The final statistics of all distance discrepancies are presented in the following section of this article.

Results

The GNSS coordinates acquired for the 4 ground control points are presented in table 1. They are in US-Foot units, as customarily used in the GA-E SPCS. This table indicates that the magnitude of the discrepancy vectors, between the RTK and the Static coordinates, range from 1.14 in to 3.8 in, with an average of 2.12 in. These initial discrepancies in the coordinates of the control points are expected as the RTK-GNSS approach is less accurate than the long Static-GNSS one. This difference prompted the completion of this study to observe how it affects the lengths of virtual distances measured within models georeferenced with each distinct set of control coordinates.

The discrepancies in all non-repeated 672 distances, from all 7 CPs, are graphically depicted in Figure 3. They involve distances defined by all 100 virtual points, in the RTK-Georef and Static-Georef models, including the outlying points.

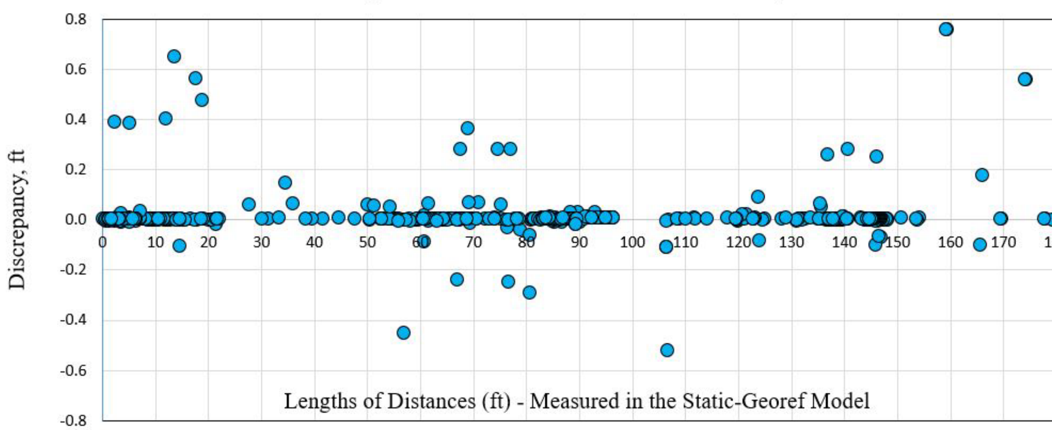

Figure 3. Discrepancies in 672 Measured Distances (**including outliers**)
RTK-Georef Model – Static-Georef Model

If the same set of control-point coordinates were employed to georeference both models, the extracted virtual distances, from each of them, would be the same, and their discrepancies would all be zero. Since the 4 control points were well distributed in the study area, and the largest position discrepancy between all 4 of them is 2.1 in + 3.8 in = 5.9 in ~ 0.49 ft (See TP1 and TP3 in table 1), it is inferred that 6 in = 0.5 ft is an appropriate estimate of the maximum discrepancy to be expected in all measured virtual distances in this study. However, Figure 3 shows a few discrepancy magnitudes (5 or 6) larger than 0.5 ft. This suggested that those distances were defined by outlying points, i.e., by points erroneously identified as the same one in the point clouds of both georef models, or by points with erroneously acquired/recorded coordinates from any of those models. This prompted the need to design and implement a two-component criterium to identify potential outliers:

{1} Individual Component: |Distance Discrepancy| must be ≥ 0.1 ft in 3 or more distances to CPs.
{2} Averaged Component: The averaged |Distance Discrepancy| to all 7 CPs must be ≥ 0.2 ft.

Criterion component {1} uses a relatively low 0.1-ft (i.e., 1.2-in) |Distance Discrepancy| threshold to assure that all potential outliers are considered. The selected 1.2-in level is just above the minimum discrepancy magnitude (1.14 in) shown by all 4 control points (see point TP8 in table 1). This criterion is satisfied only when that threshold is exceeded by the potential outlier in at least 3 distances to CPs, out of all 7 ones. Criterion component {2} uses a 0.2-ft (i.e., 2.4-in) threshold for the averaged discrepancy magnitudes of all 7 distances, from the potential outlier to the respective CPs. The 0.2-ft threshold was selected because it is just above the magnitude of the averaged discrepancy vector for all 4 ground control points, 2.12 in ≈ 0.177 ft ≈ 0.2 ft (see table 1). The application of these criteria is summarized in table 2 and resulted in the identification of only six outliers: Points: 3, 5, 6, 15, 31, & 62, out of the initially selected 100 points.

Table 2

Coordinates of Ground Control Points and their Discrepancies

Potential Outlier Point →	Points with |Discrepancy| ≥ 0.1 ft in Distance to Center Point							
	# 3	**# 5**	**# 6**	**# 15**	**# 20**	**# 31**	**# 62**	**# 65**
Center Points (CPs)	|Discrepancy| in Distance to Center Point (foot)							
1st (# 11)						0.363	0.522	
2nd (# 21)		0.279		0.561		0.383	0.454	
3rd (# 35)		0.281	0.249	0.473		0.389		
4th (# 50)		0.280	0.243	0.649		0.401		
5th (# 70)	0.249	0.278	0.259			0.291	0.146	0.107
6th (# 85)	0.558	0.176	0.755					0.110
7th (# 100)	0.559	0.101	0.755		0.101			0.109
# of Instances →	3	6	5	3	1	5	3	3
Magnitude range of each potential outlier (foot)	From 0.249 to 0.559	From 0.101 to 0.281	From 0.243 to 0.755	From 0.473 to 0.649	From 0.101 to 0.101	From 0.291 to 0.401	From 0.146 to 0.522	From 0.107 to 0.110
Averaged Discr. (ft) →	0.455	0.233	0.452	0.561	0.101	0.365	0.374	0.109
Identification Criteria:	# of Instances ≥ 3 AND Averaged Discr. ≥ 0.2 ft							
Identified Outliers →	**# 3**	**# 5**	**# 6**	**# 15**		**# 31**	**# 62**	

After removing the indicated 6 outliers, and their associated 42 distances, the remaining 94 points defined 630 non-repeated distances. The discrepancies of this reduced set are presented in Figure 4.

Discrepancies statistics were calculated for both groups, with and without outliers. They include Standard Deviations of the Population (STD P), Standard Deviations of the Sample (STD S), and Root Mean Square Values (RMSVs). These statistics were determined in a local sense, for each local set (considering only the radial distances to each CP), and in a global sense, for all involved distances in this study. Their summary is presented in table 3, where it is observed that all RMSVs approach the STDs. This is so because the mean values of the discrepancies in distances is almost equal to zero.

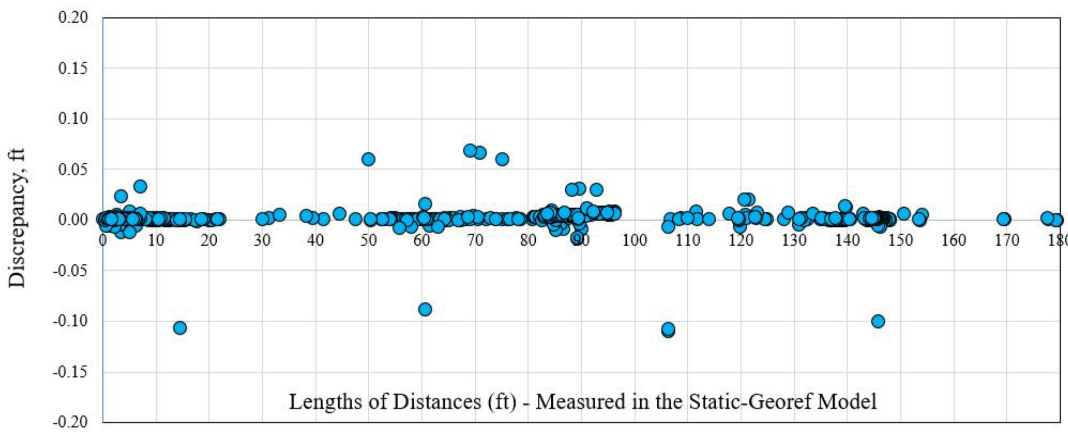

Figure 4. Discrepancies in 630 Measured Distances (**excluding outliers**)
RTK-Georef Model – Static-Georef Model

Table 3

Local and Global Statistics of Distance Discrepancies between the RTK- and the Static-Georef Models (With and Without Outliers)

Center Pts		With Outliers				Without Outliers				Diff., (With - Without)		
Local Set	#	# of Dist. in the Set	STD P Discrep (ft)	STD S Discrep (ft)	RMSV Discrep. (ft)	# of Dist. in the Set	STD P Discrep (ft)	STD S Discrep (ft)	RMSV Discrep. (ft)	Diff. in STD P Discr (ft)	Diff. in STD S Discr (ft)	Diff. in RMSV Discr (ft)
1st	11	99	0.065	0.065	0.065	93	0.007	0.007	0.007	0.058	0.058	0.058
2nd	21	98	0.087	0.088	0.088	92	0.008	0.008	0.008	0.079	0.080	0.080
3rd	35	97	0.073	0.073	0.074	91	0.008	0.008	0.008	0.065	0.065	0.066
4th	50	96	0.086	0.087	0.087	90	0.007	0.007	0.007	0.079	0.079	0.080
5th	70	95	0.058	0.059	0.059	89	0.013	0.013	0.013	0.046	0.046	0.046
6th	85	94	0.100	0.100	0.100	88	0.015	0.015	0.015	0.085	0.085	0.085
7th	100	93	0.099	0.100	0.100	87	0.016	0.016	0.016	0.083	0.084	0.084
		Total = 672				Total = 630						
		Local Ave	0.081	0.082	0.082	Local Ave	0.011	0.011	0.011	0.071	0.071	0.071
		Global #	0.083	0.083	**0.083**	Global #	0.011	0.011	**0.011**	0.071	0.071	0.072

Table 3 indicates that the removal of the 6 outliers caused a substantial decrement in all statistical values. This reduction is by a factor of 7.5, from ~0.083 ft (~1.0 in or ~25.3 mm) to ~0.011 ft (~0.13 in or 3.4 mm). To interpret the resulting statistics, the values corresponding to 1*σ (where σ is the STD of distance discrepancies), 2*σ and 3*σ were determined to assist in applying the 68-95-99.7 Empirical Rule. From the global statistics, σ = 0.083 ft for discrepancies with outliers, and σ = 0.011 ft for discrepancies without outliers. The corresponding values for the 1*σ, 2*σ, and 3*σ levels are shown in table 4, where it can be observed that 99.7% of the distance-discrepancy magnitudes are less than 5.99 inches (i.e., ≤ 151,9 mm) when including outliers, and less than 0.81 inches (i.e., ≤ 20.5 mm) when excluding outliers.

Table 4

68-95-99.7 Empirical Rule for ~Zero-Mean Normal Distribution

Level	With Outliers			Without Outliers			With Outliers	Without Outliers	Band width	With Outliers	Without Outliers	Included Population
	ft	inch	mm	ft	inch	mm	Interval (in)	Interval (in)		inch	inch	Percent
1*σ =	0.083	1.00	25.3	0.011	0.13	3.4	[-1.00, +1.00]	[-0.13, +0.13]	2*σ	1.99	0.27	68.3%
2*σ =	0.166	1.99	50.6	0.022	0.27	6.9	[-1.99, +1.99]	[-0.27, +0.27]	4*σ	3.99	0.54	95.5%
3*σ =	0.249	2.99	76.0	0.034	0.40	10.3	[-2.99, +2.99]	[-0.40, +0.40]	6*σ	5.98	0.81	99.7%

Summary, Final Remarks and Conclusions

This study compared numerous pairs of virtual distances (672 with outliers or 630 without outliers), ranging from ~0 to ~180 ft (i.e., to ~55m). They were measured among 100 virtual points in two 3D, T-LiDAR-based, point-cloud models. Each model encompassed the same spatial geometry but was georeferenced using different procedures. One employed a rapid RTK-GNSS approach and was designated as the RTK-Georef model. The other was georeferenced via a more accurate, but slower, Static-GNSS procedure and was referred to as the Static-Georef model. The considered distances were in 7 local groups, each with a central point (CP) randomly selected from the original 100 points. Each pair of virtual distances contained one length measured in the RTK-Georef model, and another length (slightly different) measured in the Static-Georef model. The overall standard deviation (STD=σ), or the almost equally valued, RMSV (≈ σ), of distance discrepancies between both models, is considered a measure of the overall relative error added to the final model by the less accurate RTK-based georeferencing approach. The σ value assists in the interpretation of the results by invoking the 68.3-95.5-99.7 Empirical Rule for Gaussian distributions. This rule indicates that the 2σ interval, [-σ, +σ], contains 68.3% of all measured discrepancies. Similarly, the six-sigma interval, [-3σ, +3σ], contains almost all, 99.7%, discrepancies. After analyzing the acquired virtual distances, it was suspected that the data may contain a few outlying points, possibly due to human errors during the identification of the exact same points in both virtual 3D models and/or during the acquisition and recording of coordinates from each model. This prompted the design and implementation of a procedure to attempt identifying those outliers. This resulted in the identification of 6 outlying points (out of 100) with their 42 associated distances (out of 672). After completion of the statistical analyses, with and without outliers, the following remarks and conclusions are presented:

1. The magnitude of the discrepancies in the position vectors of the 4 ground control points (due to RTK vs Static approaches) ranged from 1.14 in (~29 mm) to 3.80 in (~97 mm). Additionally, by adding the two maximum discrepancies associated to these 4 points (2.1 in + 3.8 in = 5.9 in ≈ 0.49 ft), it was initially inferred that the maximum expected discrepancy, among other distances, was close to that amount 5.9 in ~ 0.49 ft.
2. Regardless of including or excluding the outliers, the discrepancies in the lengths of all measured distances were almost equally distributed in the positive and negative sets of numbers. As expected, this resulted in an almost zero mean value for all calculated discrepancies. Consequently, as all mean values approached zero, all RMSVs approach their respective STDs.

3. The **local statistics** for the discrepancy of all 7 local sets of distances, including the 6 outliers, resulted in an averaged STD ≈ 0.082 ft (i.e., 25.0 mm). Excluding the 6 outliers, the averaged STD ≈ 0.011 ft (i.e., 3.4 mm).
4. The **global statistics** for the discrepancies of all distances, including the 6 outliers, resulted in STD ≈ 0.083 (i.e., 25.3 mm). Excluding the 6 outliers, the global STD ≈ 0.011 ft (i.e., 3.4 mm).
5. The exclusion of the 6 outliers (i.e., exclusion of their associated 42 distances) substantially reduced the STDs of both local and global statistics from ~0.0825 ft (i.e., 25.15 mm) to ~0.011 ft (i.e., 3.4 mm). In both cases, the reduction factor is 7.5.
6. According to the Empirical Rule, considering all points, including outliers, 99.7% of all distances should have |Discrepancy| ≤ 5.98 in (i.e., ≤ 151.9 mm). However, after excluding outliers, 99.7% of all remaining distances should have |Discrepancy| ≤ 0.81 in (i.e., ≤ 20.6 mm).
7. The previous point suggests that the statistics including the outliers are more closely related to the initially expected maximum discrepancy of 5.9 in (see point 1) than the statistics excluding the outliers. This could imply that the actual outliers should have been less than 6, or none. In turn, this prompts to a future new analysis where only 4 outliers are kept (points #3, #6, #15 and #62). That is, if the points associated with |Discrepancy| ≥ 0.5 ft are identified as the only outliers, investigate how this will affect the resulting statistics.

References

Boehler, W., Bordas Vicent, M., & Marbs, A. (2003). Investigating laser scanner accuracy. ISPRS - *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXIV (5)/W15, 696-701.

Gaurav, S. G. (2018). Brief History of LiDAR, Its Evolution and Market Definition. *BCC Research Editorial*, March 20, 2018. https://blog.bccresearch.com/brief-history-of-lidar-evolution-and-market-definition. Accessed on November 14, 2021.

Gillins, D.T. Kerr, D., and Weaver, B. (2019). Evaluation of the Online Positioning User Service for Processing Static GPS Surveys: OPUS-Projects, OPUS-S, OPUS-Net, and OPUS-RS. *Journal of Surveying Engineering, American Society of Civil Engineers*, Vol. 145, Issue 3.

Leica ScanStation C10 Data Sheet (2021a), Leica ScanStation C10. The All-in-One Laser Scanner for Any Application. Available at the below link, accessed on Nov 14, 2021: https://lib.store.yahoo.net/lib/yhst-141816440267150/Leica-ScanStation-C10-DataSheet.pdf

Leica Viva GS14 Data Sheet (2021b), Available at the below link, accessed on Nov 14, 2021: https://www.mainetechnical.com/mc_files/2/Leica_Viva_GS14_DS_us.pdf

Maldonado, G.O., Maghiar, M., Tharp, B., and Patel, D., (2020). Point-Cloud Models of Historic Barns – Spatial Discrepancies of Laser Scanning versus Robotic Total Station. ASC 2020 56th Annual ASC International Conference, (Epic Series in Built Environment, vol 1), pp 292-300.

Maldonado, G.O., Maghiar, M., and Augustine, A., (2021). Comparison of Distance Discrepancies in Georeferenced and Non-Georeferenced Terrestrial LiDAR Models. ASC 2021 57th Annual ASC International Conference, (Epic Series in Built Environment, vol 2), pp 311-319.

OPUS: Online Positioning User Service, *National Geodetic Survey*. Available at the following website: https://geodesy.noaa.gov/OPUS/about.jsp. Accessed on November 14, 2021.

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Construction Productivity Comparison Between Cast-in-Place Concrete and Mass-Timber Framing: A Case Study of the Nation's Largest Mass-Timber Building

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One main barrier to the proliferation of sustainable mass-timber structures across the United States, is construction and development teams' unfamiliarity with scheduling and efficiently managing the construction of mass-timber structural system. A comprehensive understanding of the schedule associated with the construction of mass-timber versus typical concrete structures provides important data metrics for teams deciding on utilizing this material and method. This study compares simulated manpower loaded schedules of traditional concrete construction applications with that of a real-time, mass-timber construction project. The study produces practical outputs that highlight schedule efficiencies in mass-timber applications, when compared to cast-in-place concrete method. The study found that the mass-timber crew erected 2,323 square feet of structure per day, while a concrete crew would erect 1,825 square feet per day. Additionally, the study found that the concrete crew had more than twice as many workers as the mass timber crew with less production.

Key Words: Mass Timber, Productivity, Manpower, Concrete, Cross-Laminated Timber, Glue-Laminated Timber.

Introduction

In 1960, urban populations accounted for 34% of the global population. By 2014, urban populations had surpassed rural populations and accounted for 54% of the total global population (WHO, 2014). As of 2018, there were around 4.2 billion people (55.3%) in urban areas and 3.4 billion (44.7%) in rural areas (Ritchie & Roser, 2019). The number of people in urban areas continues to grow and is projected to increase by an average of 1.64% per year until 2030 (WHO, 2014). It is projected that the number of people living in urban areas will have increased to over 6 billion by the year 2050: up from 3.6 billion in 2011 (Macomber, 2013; Ritchie & Roser, 2019). The current and projected population increases have raised the demand for new urban buildings. To meet the demand for more built spaces, governments and developers must rely on construction alternatives that are fast, economical, and environmentally friendly.

The steady rise in the global population demands a proportional increase in production of goods and services to meet the increased need. Most of our production practices are harmful to the ecosystem and the world climate. A present argument is that human activity is very likely the cause of global warming evidenced since the mid-20th century. Some of the human activities including deforestation, burning of fossil fuels, and increased land use produce greenhouse gases such as carbon dioxide, methane, and nitrous oxide, which have caused much of the observed increase in Earth's temperature over the years (NASA, 2021). Faced with shortages of natural resources and the concern for protecting the environment, there is a shift to more renewable resources that are sustainable. The debate has largely shifted onto ways to reduce further human impact on the environment and to find ways to adapt to the change that has already occurred over the past several decades (UNFCCC, 2021). A huge part of this movement includes the sustainable use of renewable resources such as timber.

Over the past few years, tall wood buildings have been successfully constructed around the world. Proponents of mass timber construction have argued that building taller with wood is not only good for the environment because it reduces carbon emissions, but it is also a viable building method because it is cost effective, contributes to well-being with good thermal and sound insulation, and performs well under fire (FPInnovations and Binational Softwood Lumber Council, 2013). A major argument fronted by mass timber advocates is that the time-to-delivery of a mass timber building can be significantly shorter than that of the conventional methods. The manpower requirement for this construction method is also comparatively lower than that of steel and concrete (WoodWorks, 2021). A shorter schedule coupled with lower manpower requirement, can translate to cost savings and lower carbon footprint during the construction phase of the facility’s life cycle. This paper analyzes the manpower requirement and production rates observed during the framing of the nation’s largest mass timber building and compares it to the manpower and production requirements of a concrete framed structure. The building, located in Cleveland, Ohio, is a $145 million-dollar mixed use, multi-family, high rise building consisting of two hundred and eighty-eight (288) apartments, ten luxurious penthouses, and a multitude of retail spaces, including an event space.

Reinforced Concrete Structures

The first concrete-like structures began to emerge in southern Syria and northern Jordan around 6500 BC (Gromicko & Shepard, 2020). Overtime, technological advances have driven both quality and breadth of application. Currently, concrete is the most widely used material in the world (Chilton, 2016) and plays a significant role in nearly all commercial construction projects. The high strength of concrete (exceeding 10,000 psi in some applications), its ability to withstand harsh climates, its wider availability, and our knowledge of its applications continue to drive consumption even higher. The Fortune Business Forecast Market Research Report (2021) projects an 8.7% annual growth in the concrete market, as rapid urbanization bolsters demand.

Productivity on Concrete-Framed Structures

A main benefit of concrete's long history in commercial applications is the availability of data relative to production. Publications exist in both the purely academic and professional publications that offer robust results. Our study focused on the inclusion of publications that offer real-world case studies as their main data source. The literature points to the standard “pour-and-set” cycle that projects generally follow, dependent on site-specific factors. It is traditionally accepted that the standard production rate for concrete in multi-story applications is five to six working days (Kolchedantsev et al., 2019). The industry status quo is pegged at six working days per floor, depending on size and design (Pietz, 2017). Past projects like “Sixty 11th”, a 28,000 square ft mixed use apartment building, based their plan on six working day pour schedules (Sibley, 2016). The cycles are clear due to the repetitive process and curing required for typical flooring applications.

Faster floor completion cycles are possible in certain applications. Grossman (1986) outlines a 2 day per floor, formwork and reshoring cycle. Specialty provisions and precise execution is required to achieve floor production rates in this range. Interestingly, existing studies discuss production in terms of floors in relation to working days. Presenting on speed of formwork placement, pouring, shoring makeup and repeat (Daniel, 2012). The lack of manpower loading, crew makeup, and universal production rates that provide more detail than “floor” cycle rates is important to note.

Mass Timber Construction

Massive or “mass” timber is a category of engineered wood products typically characterized using large solid wood panels for wall, floor, and roof construction. Mass timber consists of multiple solid wood panels nailed or glued together, providing exceptional strength and stability. The ability of these engineered lumber to carry large loads has made it possible to use mass timber for construction of larger and more complex structures, including high-rise buildings. The continual development and availability of mass timber products is increasingly providing opportunities for the use of lumber instead of steel or concrete in building large commercial and multifamily residential buildings (Anderson, Dawson, & Muszynski, 2021). Wood, unlike concrete and steel, is a renewable material when harvested sustainably. Sustainable forestry guarantees that trees are planted and harvested in a way that ensures the long-term health of our forests, while meeting our need for forest resources like wood. Sustainable forestry coupled with the practice of planting trees as a crop to be harvested for commercial use can massively contribute to the construction of more sustainable built environments (Onsarigo & Mirando, 2021).

Over the past few decades, mass timber has evolved from being a technologically feasible option to a viable alternative to reinforced concrete and steel construction (Evison, Kremer, & Guiver, 2018). In the United States, Mass timber is emerging as a viable option for developers. As of June 2021, there were five-hundred and forty-five (545) mass timber projects either under construction or completed, and an additional six-hundred and twenty-four (624) projects in the design phase (WoodWorks, 2021). The mass timber family of products includes cross-laminated timber (CLT), nail-laminated timber (NLT), glued-laminated timber (GLT), dowel-laminated timber (DLT) and structural composite lumber SCL). The project under study utilized CLT and glulam which are briefly discussed here.

Cross-Laminated Timber (CLT)

CLT consists of three, five, seven, or nine layers of dimension lumber oriented perpendicular to each other and glued together to form panels with superior strength (Figure 1). In certain cases, the layers can be nailed (nail-bonded solid wood wall, also called Massiv-Holz-Mauer or MHM) or dowelled (dowel-bonded CLT) together using hardwood dowels (Anderson, Dawson, & Muszynski, 2021). Because of the cross-laminations, CLT offers two-way span capabilities and is especially suitable for floors, walls, and roofs (reThink Wood, 2016).

Glued-Laminated Timber (glulam).

Glulam consists of dimension lumber that is placed and bonded together using durable, moisture-resistant adhesives (Figure 2). This engineered wood is usually used for beams and columns and can be used for other elements such as floor beams and roof trusses.

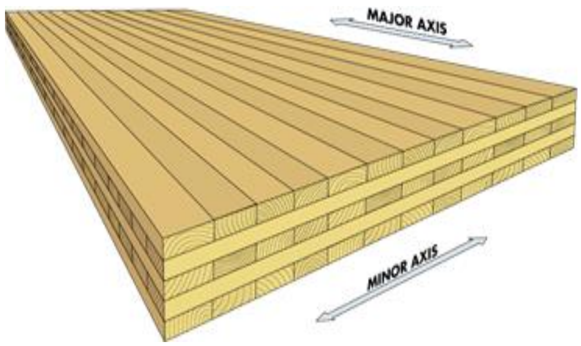


Figure 1. Cross-Laminated Timber (CLT) Panel (Breneman, 2016).

Figure 2. Glulam (Pehlivan, 2019)

Productivity on Mass Timber Construction Projects

Being a relatively new technology in the United States, research on mass timber productivity is limited. However, there is research on this topic relative to other global geographical locations that may not be directly replicated in the US industry. Forsythe and Fard Fini (2019) measured the productivity of CLT site installation in a multi-story building project in Australia. Their study found that the crew of twelve installed an average of 130m^2 (1,400SF) of mass timber per day. They used time-lapse photography to gather site assembly information and statistically analyzed the data to derive productivity rates in meters squared per hour. A significant difference between the Forsythe and Fard Fini (2019) study and the current study is that while Forsythe and Fard Fini (2019) analyzed both load-bearing and non-load bearing elements (mass timber wall and floor panels), the current study examined the load bearing elements of the structure (the current project does not include any mass timber wall panels, but included glulam beams and columns, and CLT floor panels.

In another research, Brisland, Forsythe, and Fard Fini (2019) studied three mass-timber multi-story buildings located in New South Wales (NSW), Australia. Their study found daily productivity of 111.15 m^2 (1196.4SF), 91.95 m^2 (989.7SF), and 66.75 m^2 (718.5SF) for towers A, B, and C respectively. While their study focused on the crane cycles productivity of the installation of mass timber, the current study focused on the entire crew installing the mass timber.

Methodology

When properly monitored and documented, construction projects can offer a plethora of valuable data including project performance, payroll, productivity, and material data. Traditional evaluation methods exist for examining these types of datasets to provide guidance for improved productivity, processes, materials, and systems. This section will outline the data collection process and techniques used to compare the productivity of mass timber and concrete framing.

In order to accurately compare the schedule of mass timber with concrete structures, a baseline production rate for concrete high-rise construction will be established. Since concrete structures have dominated the commercial construction market for so long, data relative to efficiency and schedule is widely available. Professional literature has identified the 6-day floor cycle as status quo, for typical high-rise construction applications (Kolchedantsev et al., 2019; Leung, 2003; Pietz, 2017; Sibley, 2016; Smisek, 2019). In addition to substantive literature review, a local, third-party concrete contractor was solicited to manpower load a schedule for the same zone erected with mass timber.

Data Collection and Analysis

The mass timber was erected in two distinct phases: zones A and B first, followed by zone C (See Appendix A). This was a new technology for the construction crew and consequently, there was an expected learning curve during construction of zones A and B. By the time they were constructing zone C, the crew had gained tremendous experience working with each other and were familiar with the mass-timber installation process, particularly the handling of CLT and glulam, and the different jointing methods. We therefore elected to use the zone C production rates in our comparison study.

Observation and recording of data for zone C was conducted from May 26, 2021, to July 1, 2021. Real-time data was collected through daily reports generated by the onsite foreman, digital photographs taken by two time-lapse cameras placed on the jobsite, and OpenSpace’s 360-degrees construction photo documentation system. Daily reports capture the daily building conditions, weather conditions, manpower expenditures, production levels, and any other significant occurrence impacting construction on the respective day. Too often daily reports are prepared with minimal detail and are never reviewed by onsite management (Pogorilich, 1992). However, the research team in this project pre-planned the data collection process for the carpentry crew installing the mass-timber superstructure to ensure that the critical data was collected and recorded by the site foreman. This ensured detailed daily reporting of the mass timber installation process.

Schedule estimates using concrete were obtained through a number of sources. First, the concrete contractor who performed all concrete specifications on the project, produced a complete schedule, by zone of the whole structure of the project. The schedule simulation was produced as if the contractor would continue the structural work of the entire project. Crews, shoring, equipment, and management would continue from the foundational work that was contracted, and subsequently work floor by floor. The schedule simulation was conducted by one of the biggest concrete contractors in the region and is based on a multitude of past project experience.

Secondly, an extensive literature review was conducted to obtain professional and academic insights relative to floor sequencing and scheduling. The exhaustive literature review encompassed both academic and professional publications. Strength in professional publications relative to real world project data is paramount to consider and include in the data. The review focused on publications that utilized real-world case study projects that were of similar type to our case study.

A simple square-foot comparison of average mass timber installed by a carpenter in one day and concrete installed by a concrete worker was conducted. Evaluating production and efficiency at the square-foot or cubic-foot level is a common practice amongst contractors, architects, and engineers. For instance, unit cost method of estimating construction projects is an industry-wide accepted method of preparing approximate estimates (Peurifoy & Oberlander, 2014).

Findings

The broadness of floor cycle production rates was identified as a weakness of the existing literature. Our study closes the gap by providing extrapolatable, square foot production data. Overall, the mass-timber erection crew completed approximately 2,323 square feet of structural floor, columns, and beams per working day. The contractor simulated concrete structure, pegs overall production at 1,825 square feet, per working day. This represents a 24% production rate difference in favor of mass-timber. Additionally, the mass-timber structure was actually erected in 33 working days; significantly less than the concrete contractor plan of 42 working days.

Table 2

Mass timber v concrete production rates

	Mass timber	**Concrete**
Total zone floor area (square feet)	76,644	76,644
Floor levels	6	6
Square feet per level	12,774	12,774
Total working days	33	42
Total man-days	218	756
Total man-hours	1,744	6,048
Manpower average	6.6	18.0
Square feet per day	2,322.5	1,824.9
Square feet per man-day	351.6	101.4

On an individual tradesman production basis, the mass-timber crew member contributed 352 square foot per day of structural member installation. Conversely, the average concrete tradesman production is roughly a third, or 102 square foot of concrete structure installation per workday (figure 7).

A major finding includes the identification of the massive manpower discrepancy between the construction methodologies. The mass-timber erection crew averaged 7 carpentry tradesmen per working day. The simulated workforce more than doubled that of the actual and would average 18 varying tradesmen per workday.

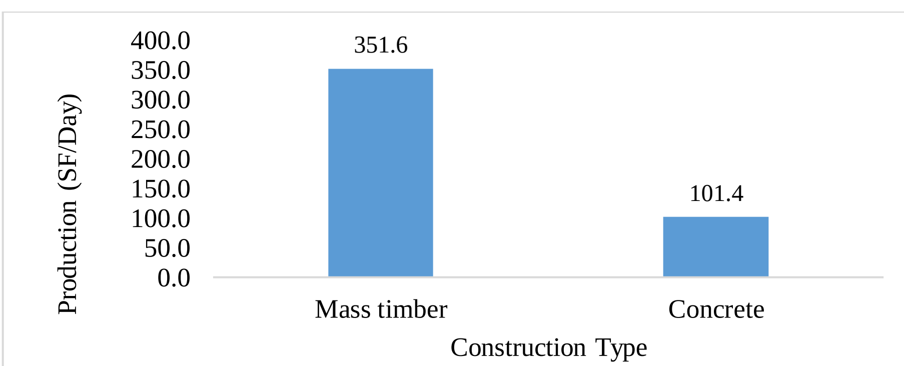


Figure 7. Daily worker production rates

Discussion, Limitations, and Conclusion

The study provides practical and verifiable evidence of increased schedule production rates in mass-timber structural applications versus traditional concrete structures. An overall 24% higher square feet production per day was identified on the real time mass-timber structure. The production difference equates to 9 working days, over 6 stories. The impact in terms of schedule is clear and quantifiable, allowing for broader discussion of the effect on subsequent trades and unforeseen schedule disruption. A major difference between the two construction methodologies is the presence of supporting framework in the concrete application. Cycle rates in the literature and subcontractor simulation represent the relationship between pouring the concrete and next level formwork installation. In concrete applications, each floor leaves behind a pre-engineering shoring system that restricts loading, subsequent subcontractor production, and lowers efficiency due to the repetitive handling of formwork. The mass-timber application requires no need for substantial, 28-day long engineered shoring systems on poured floors. Our project utilized non-structural 2" topping slabs on each CLT deck for sound and fire protection, prior to metal framing. In some applications, framing and MEP layout can begin immediately after setting the mass-timber CLT flooring structure. The lack of long-term shoring systems opens opportunities for trades to safely begin work with reduced lag. Combined with square foot efficiencies identified within this study, the schedule benefit extends past the mass-timber structural system to include faster floor availability for critical trades.

Just as important, this study identified a major manpower difference between the differing methodologies. Mass-timber required an average of 6.6 carpentry tradesmen per working day to erect the structure. The same concrete structure requires approximately 18 varying tradesmen per day, to install less square footage. Trade makeup and type is important to discuss as concrete construction processes require carpenters, laborers, pump operators, finishers, and testing agencies to complete floor cycles. Varying trades, processes, product sensitivity provide barriers to efficiency in concrete construction. These hurdles are less frequent in the consistent, smaller, more efficient carpentry crews.

The variability of site factors including crew makeup, shop drawing availability, delivery methods, location, weather, and managerial approaches can affect realized productivity across applications. It should be noted that construction projects offer unique variables that are difficult to completely quantify. Concrete structures have a broad range of floor, column and beam designs and layouts; as does mass-timber. A degree of variability should be considered when applying the results found here. Additionally, this study utilized data from a single project and a simulation of the same project. The results can be verified with comparison of multiple projects completed using both methods under study once these projects are available. This study does, however, create a baseline for such comparisons and can serve as a basis for more robust investigations.

References

Anderson, R., Dawson, E., & Muszynski, L. (2021). *2021 International Mass Timber Report.* Self-Publishing Services LLC.

Breneman, S. (2016). "Cross-Laminated Timber Structural Floor and Roof Design." Structural Design Jun 2016. Online. <https://www.structuremag.org/?p=10054>.

Brisland, R. E., Forsythe, P., & Fard Fini , A. A. (2019). Mass timber productivity-the significance of reduction in non-value add activities during on-site installation sequence. *Modular and Offsite Construction Summit.* Modular and Offsite Construction Summit.

Daniel, J. S. (2021). High-Rise Building Construction Cycles. Slideshare. Retrieved November 1, 2021, from https://www.slideshare.net/JihadDaniel/jihad-daniel-paper-for-high-rise-building-construction-cycle#:~:text=In%20cast-in-place%20multi-storey%20concrete%20buildings%20a%20%E2%80%9Ctypical%20floor%E2%80%9D,performance%2Fproductivity%20%26%20learning%20curve%20and%20advanced%20planning%20techniques.

Evison, D. C., Kremer, P. D., & Guiver, J. (2018). Mass timber construction in Australia and New Zealand—Status, and economic and environmental influences on adoption. *Wood and Fiber Science*, 50 (Special), 128-138.

Forsythe, P., & Fard Fini, A. A. (2019). *Productivity in Multi-storey Mass Timber Construction.* Sydney: Forest and Wood Product Australia.

Fortune Business Insights. (2021). Ready-Mix Concrete Market Size, Share & Industry Analysis, By Application (Residential, Commercial, Infrastructure, and Others), and Regional Forecast, 2020-2028. Mumbai: Fortune Business Insights.

FPInnovations and Binational Softwood Lumber Council. (2013). *CLT Handbook: cross-laminated timber.* (E. Karacabeyli, & B. Douglas , Eds.) U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, BSLC.

Gromicko, N., & Shepard, K. (2020). "The History of Concrete." *International Association of Certified Home Inspectors*. 15 November 2021. <https://www.nachi.org/history-of-concrete.htm>.

Grossman, J. S. (1986). Two-day construction cycle for high-rise structures based on use of preshores. Building Structural Design Handbook, 1–5. Retrieved November 15, 2021, from https://structurepoint.org/publication/pdf/CI-Two-Day-Cycle-Floor-Construction.pdf.

Kolchedantsev, L., Adamtsevich, A., Stupakova, O., & Drozdov, A. (2018). Measures to reduce construction time of high-rise buildings. E3S Web of Conferences, 33, 03062. https://doi.org/10.1051/e3sconf/20183303062

Leung, A.W. (2003). scheduling for high-rise building construction using simulation techniques.

Macomber, J. D. (2013, July-August). Building Sustainable Cities. *Havard Business Review*(91), pp. 40-50.

NASA. (2021, October 12). The Causes of Climate Change. Retrieved from NASA Global Climate Change: Vital Signs of the Planet: https://climate.nasa.gov/causes/

Onsarigo, L., & Mirando, A. (2021) Construction Productivity on Mass-Timber Framing: A Case Study of the Nation's Largest Mass-Timber Building. *Associated Schools of Construction Region 3 Conference*. ASC

Pehlivan, R. (2019, August 7). *Glued Laminated Timber (Glulam) and Its Advantages*. Retrieved from Aida Swings: https://www.aida-swings.com/glued-laminated-timber-glulam-and-its-advantages

Peurifoy, R. L., & Oberlander, G. D. (2014). *Estimating Construction Costs.* New York: McGraw-Hill.

Pietz, J. (2019, December 5). Five is the new six: Concrete pour cycle GLY Construction. GLY Construction. Retrieved November 14, 2021, from https://www.gly.com/blog/five-is-the-new-six-concrete-pours

Pogorilich, D. A. (1992). The daily report as a job management tool. *Cost Engineering, 34*(2), 23.

reThink Wood. (2016, August). *Mass Timber in North America: Expanding the possibilities of wood building design.* Retrieved from Think Wood: https://www.thinkwood.com/education/mass-timber-north-america

Ritchie, H., & Roser, M. (2019, November). Urbanization. Retrieved from Our World in Data: https://ourworldindata.org/urbanization

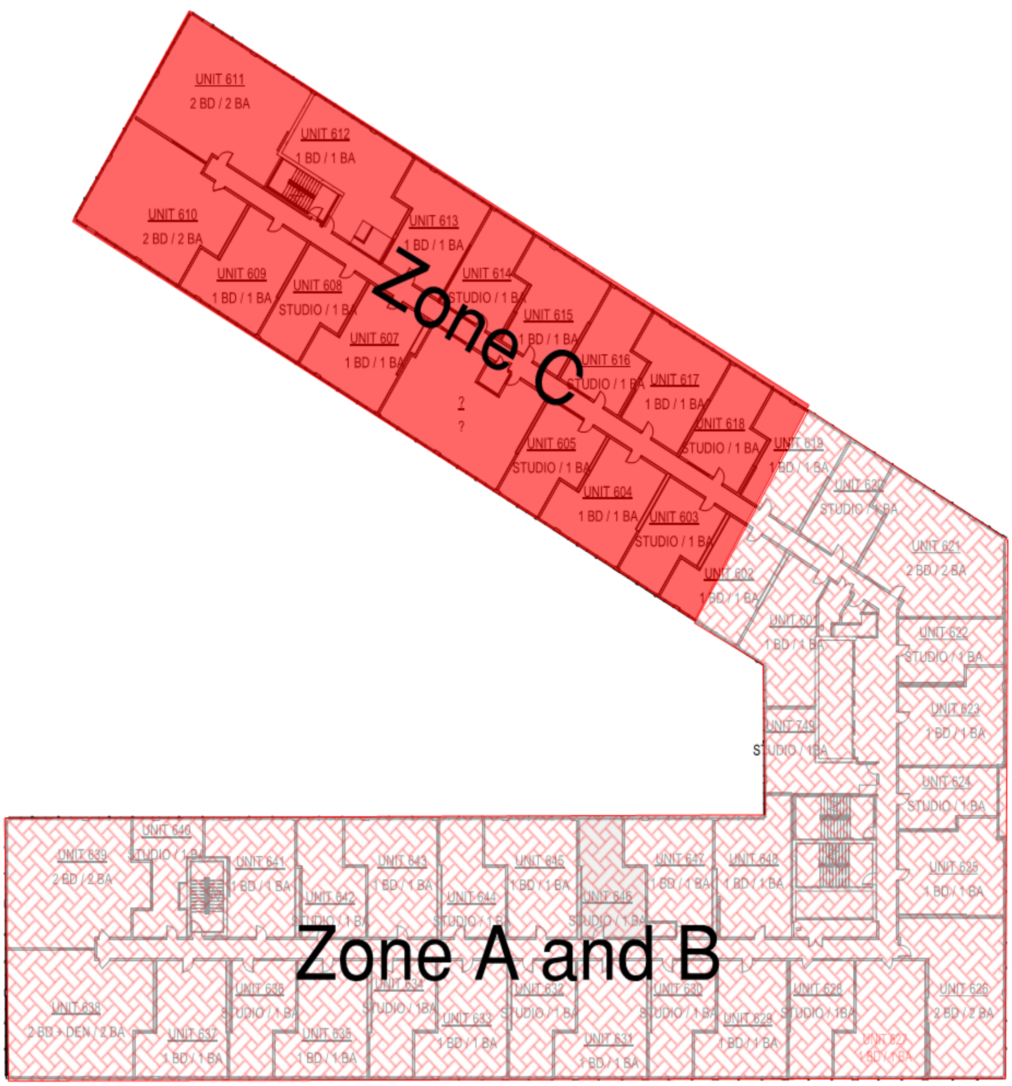
Sibley, T. R. (Ed.). (2016, August 23). Brasfield & Gorrie completes sixty 11th Apartments. Brasfield & Gorrie. Retrieved November 14, 2021, from https://www.brasfieldgorrie.com/news/brasfield-gorrie-completes-sixty-11th-apartments/.

UNFCCC. (2021, October 13). Race To Zero Newsletter. Retrieved from United Nations Framework Convention on Climate Change: https://unfccc.int/climate-action/race-to-zero/race-to-zero-newsletter

WHO. (2014). *Global Health Observatory (GHO) data: Urban Population Growth*. Retrieved from World Health Organization: https://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/

WoodWorks. (2021). U.S. Mass Timber Construction Manual. In WoodWorks, *U.S. Mass Timber Construction Manual* (pp. 21-28). Washingron, DC: Wood Products Council.

Appendix A: Zone Depiction



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Smart Cities' Strategies for Contractors: A Thematic Analysis of Selected Documents

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This paper aims to identify the construction-related strategies in smart cities that could assist contractors in disrupting traditional construction processes using new technologies and processes. In this research, a thematic analysis was conducted to categorize the construction-related strategies in different themes by analyzing the smart cities' documents. The publicly available documents of 24 smart cities in the United States and around the globe, along with four international governments whose action plans will disrupt traditional construction processes, were analyzed. Based on the results, 29 action plans in six different themes were identified, including 1) Modern Infrastructure, 2) Livable Climate, 3) Efficient Mobility, 4) Education/Training, 5) Inclusive Economy, and 6) Affordable Housing. This paper shows that several smart cities have implemented some construction-related action plans, but other cities have no strategies related to the construction industry. The results of this paper could be helpful for further research to identify the future direction of construction in smart cities and define the knowledge and requirements needed for contractors to implement the action plans in smart cities.

Key Words: Construction Strategies, Smart Cities, Thematic Analysis

Introduction

In recent years, several technological advancements have changed traditional construction processes. Robotics application, the proliferation of electrical machines, the introduction of automatic mechanical tools, the introduction of new techniques in construction operations, and application of Artificial Intelligence (AI) and Building Informatics tools have disrupted traditional construction processes significantly in recent decades (Lekan, Aigbavboa, Babatunde, Olabosipo, & Christiana, 2020). Since the construction industry plays an imperative role in solving global warming and pollution of the planet by providing sustainable solutions, it is crucial to take advantage of new technologies to address these challenges through developing construction processes (Block, 2019). Also, disruptive technologies could help construction companies solve their productivity and performance problems (Love, Matthews, & Zhou, 2020). Woodhead, Stephenson, and Morrey (2018) tried to warn construction companies about the transformational process because of the introduction of technologies like the Internet of Things (IoT) and the need to adapt to this transformation.

The new advancements in technologies have changed construction processes in many ways. For instance, Vacanas, Themistocleous, Agapiou, and Hadjimitsis (2015) showed how using Building Information Modeling (BIM) in conjunction with Unmanned Aerial Vehicle (UAV) could change construction management processes through collecting accurate as-built data and demonstrating work progress for purposes like delay analysis and record keeping. Using BIM in construction companies even disrupted organizational settings like recruitment policies, and these organizations had to find new ways to manage this disruption (Ahmad, Hafeez, Ahmad, Aliyu, Rodriguez, & Dawood, 2016). Similarly, Ensafi, Thabet, Devito, and Lewis (2021) demonstrated how using Mixed Reality (MR) platforms such as HoloLive and Trimble Connect could improve the quality control process of as-built BIM models at project handover by verifying the model data and the quality of BIM graphics effectively regardless of the challenges these disruptive technologies could bring up. In 2016, Kothman and Faber studied the impact of 3D printing technology on the construction supply chain. Their findings showed that this new technology could facilitate the construction supply chain process by reducing logistical and production efforts. As another example of disruptive technologies, Labonnote, Ronnquist, Manum, and Ruther (2016) mentioned that additive manufacturing technologies have the potential to be used in the construction industry as a revolutionary solution. In addition, Fiske et al. (2018) investigated the potential of using additive construction to construct shelters for human crews on the Moon or Mars in the future. Moreover, robots can play an essential role in transforming construction processes. For example, four-legged robots can collect data more accurately and consistently and automate construction progress monitoring. These robots would reduce the time and effort needed for data collection in the construction workspaces (Afsari, Halder, Ensafi, DeVito, & Serdakowski, 2021).

Disruptive technologies need a proper place to be implemented, and the smart city is where that comes into play. This paper presents the construction-related strategies considered in smart cities' action plans. The purpose of this study was to provide an informational paper that shows construction-related strategies in different U.S. smart cities and other smart cities around the globe. There are different definitions of the smart city, but Dameri's 2013 comprehensive definition of smart city was used for this study. Dameri's definition states that "A smart city is a well-defined geographical area, in which high technologies such as Information and Communications Technology (ICT), logistics, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development" (p. 2549). Based on this definition, high technologies would be a critical pillar of the smart city, and without them, it is not possible to create benefits for citizens. With this in mind, it is not surprising that smart cities around the globe are trying to incorporate these technologies into their strategic action plans. In this paper, the current construction-related strategies, which include disruptive technologies and processes, are explored to see how contractors can use them to disrupt traditional construction processes in the context of smart cities. Based on this, the research question is:

What strategies could be used by contractors to disrupt traditional construction processes in smart cities?

Methodology

The data used in this research was collected from public documents containing action plans for the economy, neighborhoods, health, education, mobility, environment, and modern infrastructure in smart cities. According to the Smart City Index 2021 reported by Smart City Observatory, 109 smart cities around the globe have been indexed. Also, based on Smart City Tracker Report 1Q18, a report from Navigant Research, there are 355 smart city projects in 221 cities worldwide, of which 55 cities are in the United States and Canada (Citron & Woods, 2018). Therefore, the research population for this study is comprised of the smart cities in these two reports. These two reports were published by the Smart City Observatory and Navigant Research and are considered the preeminent references used to index smart cities around the globe. Purposive sampling was conducted to select the documents for analysis. This type of sampling enables the researcher to focus on a particular portion of the population that has the best potential to answer the research questions (Rai & Thapa, 2015). Data for this research was collected from the publicly available documents of 24 smart cities and four international governments with action plans that will disrupt traditional construction processes (shown in Table 1). Of the 24 smart cities, 11 were in the United States, and 13 were from other countries around the globe.

Table 1

Research Sample

U.S. Cities	Number of documents	International Cities	Number of documents	Governmental documents	Number of documents
Austin, TX	1	Amsterdam	1	Australia	1
Boulder, CO	1	Canterbury-Bankstown	2	China	1
Cedar Rapids, IA	1			European-Parliament	1
Chula Vista, CA	1	Dubai	1		
Columbus, OH	1	Dublin	1	India	2
Dallas, TX	1	London	4		
Fresno, CA	1	North Sydney	1		
Henderson, NV	1	Seoul	1		
New York City, NY	4	Shanghai	1		
Philadelphia, PA	1	Singapore	1		
San Francisco, CA	2	Stockholm	2		
		Tel-Aviv	1		
		Tokyo	1		
		Toronto	1		
Total	15		18		5

Thematic analysis was used to analyze the action plans in each document. This method was chosen because it enables researchers to deal with complex data (i.e., texts in this research) and organize them using codes, categories, and themes (Peel, 2020). Thematic analysis is a common qualitative data analysis approach conducted in predefined steps. The first step in the analysis was a thorough review and identification of construction-related strategies. All construction-related strategies were highlighted in this step. Each highlight was then labeled and assigned codes to organize the highlights. These codes were determined using the main phrases in each highlight. Next, the related codes were assembled in categories based on themes. Then, the themes were reviewed to make sure there was no repetitive or outdated strategy. Finally, the themes were named and described in detail based on the corresponding codes. Two researchers were used in the process of coding, organizing, and reviewing the themes to reduce the possibility of bias associated with the process of thematic analysis. The steps of thematic analysis used for this study are shown in Figure 1.

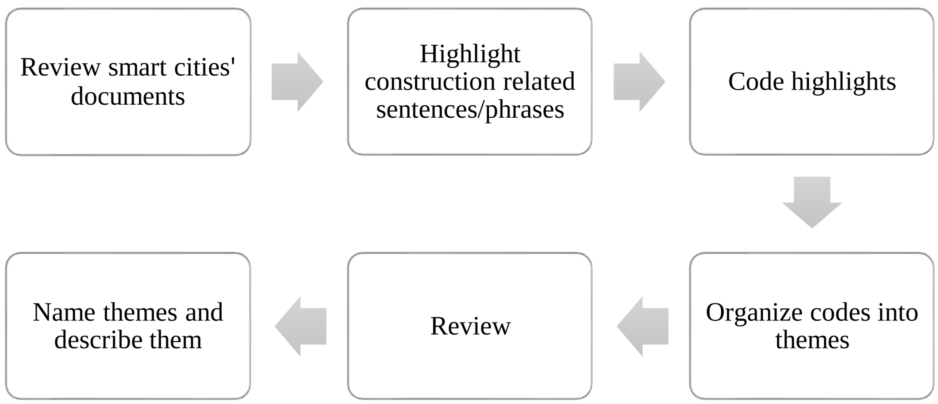

Figure1. The steps of thematic analysis used in this research

Results

A total of 38 documents with smart city-related strategies were reviewed. Of the 15 U.S. smart cities' documents, 18 construction-related strategies were identified from six smart cities, which included New York City, Cedar Rapids, Fresno, San Francisco, Boulder, and Chula Vista. The remaining five cities had no construction-related strategies in their documents. Similarly, of the 18 documents from international cities reviewed, only four cities, Seoul, Stockholm, Tel-Aviv, and London, had construction-related strategies. The remaining nine cities had no strategies related to the construction industry. Lastly, of the five government documents, only two of them contained strategies concerning construction industry challenges. These strategies were found in the Australian government document and the European Parliament document. Table 2 shows the number of strategies identified in each of the smart cities' documents. In the next step, the codes shown in Table 3 were used to label 36 highlights identified in smart cities' documents.

After labeling and coding the highlights, the related strategies were assembled to create the themes. In doing so, six themes were identified. During this step, seven strategies were eliminated after reviewing the themes and relevant strategies because they were repetitive, outdated, or identified as recommendations rather than action plans. Finally, the six themes were named and described as 1) Modern Infrastructure, 2) Livable Climate, 3) Efficient Mobility, 4) Education/Training, 5) Inclusive

Economy, and 6) Affordable Housing. The themes with their description, related codes, and examples are shown in Table 4.

Table 2

Number of construction-related strategies identified in documents of smart cities and governmental documents

U.S. Cities	Number of strategies	International Cities	Number of strategies	Governmental documents	Number of strategies
Boulder, CO	2	London	10	Australia	1
Cedar Rapids, IA	1	Seoul	2	European-Parliament	1
Chula Vista, CA	1	Stockholm	1		
Fresno, CA	2	Tel-Aviv	3		
New York City, NY	11				
San Francisco, CA	1				
Total	18		16		2

Table 3

Codes used to label construction-related strategies

Codes	Abbreviation	Codes	Abbreviation
Zero carbon development	ZCD	3D visualizations of the city's infrastructure	3DV
Noise strategies	NS		
Cut emissions	CE	Innovative construction methods	ICM
Dust control	DC	Using AI	AI
Green construction	GC	Urban delivery and Logistics	UDL
Project management	PM	Delivery of construction related cargo	DCC
Improve cooperation with utilities	ICU		
		Material delivery	MD
Track city's projects	TCP	Construction skills training system	CSTS
Construction standards	CS		
Best practices in building construction	BPBC	Online safety training	OST
		Apprenticeships	APT
Geographic Information System	GIS	Construction skills program	CSP
		Human capital investment	HCI
Data sharing	DS	Affordable housing development	AHD

Table 4

Themes with their description, codes, number of construction-related strategies, and examples

Theme	Description	Codes	Number of strategies	Example

Modern Infrastructure	Includes strategies related to new technologies used for project management, data sharing, track city's projects and infrastructure, and innovative construction methods	PM, ICU, TCP, GIS, DS, 3DV, ICM	11	The Strategic Blueprint for Construction Excellence released by New York City Department of Design and Construction (DDC) including 10 strategies for project management
Livable Climate	Includes strategies related to cut emissions and dust control in construction processes, zero carbon development, waste management, and noise strategies	ZCD, NS, CE, DC, GC	9	Use of recycled materials made entirely of crushed construction waste in municipal construction and infrastructure works in Tel-Aviv
Efficient Mobility	Includes strategies related to delivery of construction materials in a smarter way at predefined times and locations	UDL, DCC, MD	3	Predefined loading and unloading access points using greater traffic data systems in San Francisco
Education/Training	Includes strategies related to construction skills training	CSTS, OST, APT, CSP	4	The Construction Skills program provides different trainings for New Yorkers to improve construction skills and increase career opportunities
Inclusive Economy	Includes strategies related to human capital investment to increase career opportunities for underrepresented groups	HCI	1	Connect more New Yorkers from underrepresented groups to construction jobs created by City investments
Affordable Housing	Includes strategies related to providing affordable housing to citizens in need using innovative housing construction methods	AHD	1	Reduce time and cost in the development of affordable housing in NYC using Modular Construction
Total			29	

Discussion and Conclusions

This paper conducted a thematic analysis to identify the construction-related strategies in smart cities' documents. Based on the results, 29 construction-related strategies were identified in smart cities in the United States and other countries around the globe. These strategies were categorized into six different themes, including Modern Infrastructure, Livable Climate, Efficient Mobility, Education/Training, Inclusive Economy, and Affordable Housing. The first theme is Modern Infrastructure, which consists of action plans related to disruptive technologies used for different purposes such as project management, data sharing between different entities, tracking city's projects and citizens engagement, and innovative construction methods like modular construction. The second theme, Livable Climate, includes action plans related to dust control, cutting emissions on construction sites, noise reduction, waste management on construction projects, and zero-carbon developments. Third is Efficient Mobility, which includes material delivery strategies with predefined times based on location in smart cities. Education/Training is the fourth theme, and it contains construction skills' programs or training systems in smart cities to increase career opportunities for citizens in the industry. Inclusive Economy is the fifth theme, and it is comprised of strategies focused on engaging underrepresented groups in the city's economy by providing career opportunities. The final theme identified is Affordable Housing, and it consists of action plans related to reducing the time and cost of constructing affordable housing by using new methods like modular construction.

To answer the research question, it is worth mentioning that construction-related strategies identified as six themes in this paper will assist contractors in using innovative processes and disruptive technologies in their projects in smart cities. This study shows that several smart cities have started considering specific construction-related strategies in their smart city action plans. However, many cities have no strategies related to the construction industry. Since contractors are important actors in smart cities, there is a need to implement more construction-related strategies. The findings of this study show that the contractors can use the modern infrastructure provided in smart cities for different purposes on their projects. These infrastructures include the Geographic Information System (GIS), 3D visualizations of the city's infrastructure, photo-realistic 3D models, standard project portfolio management software, and a smart city platform. For instance, the city's Geographic Information System (GIS) could be beneficial in the preconstruction phase for different analyses, such as flood hazard risk analysis and emergency response units' analysis (Najmi Sarooghi & McCuen, 2021). The 3D models of the city's infrastructure could help contractors locate utilities easier in their projects. The smart city platform enables contractors to share data related to project progress and even the photo-realistic 3D model of their project. Also, several strategies can improve the environmental aspects of the construction projects, such as using recycled materials in municipal construction and infrastructure works, green construction guidelines, and incentive programs. These programs enable contractors to cut emissions, control dust and noise on construction sites, and use lean construction principles to achieve zero carbon development targets. In addition, the strategies in the efficient mobility theme related to predefined loading and unloading zones and times could improve the material delivery to construction projects, while education/training programs could solve the labor shortage and increase career opportunities in this industry. Moreover, the human capital investment could provide more jobs for underrepresented groups to be involved in construction-related jobs and solve the labor shortage in the industry. Lastly, using modular construction could assist contractors in developing affordable housing quicker in smart cities.

There were some limitations to this study. First, the researchers acknowledge that there may be other construction-related action plans and strategies in smart cities around the globe that were not included in the research sample. Secondly, adding more researchers for coding, organizing, and reviewing the themes could minimize the bias associated with the thematic analysis. Also, the necessity of doing more research to identify the future direction of the construction industry in smart cities and the required knowledge for contractors working in smart cities is undeniable. In addition, a similar study to assess the differences in construction-related strategies between U.S. smart cities and international smart cities is needed.

References

Afsari, K., Halder, S., Ensafi, M., DeVito, S., & Serdakowski, J. (2021). Fundamentals and Prospects of Four-Legged Robot Application in Construction Progress Monitoring. *EPiC Series in Built Environment, 2*, 274-283. https://doi.org/10.29007/cdpd

Ahmad, A. M., Hafeez, M. A., Ahmad, A. M., Aliyu, A. A., Rodriguez, S., & Dawood, N. (2016, December). BIM: A disruptive process towards traditional practice. In *Proceedings of the 16th International Conference on Construction Applications of Virtual Reality* (p. 80). Retrieved from: http://cejcheng.people.ust.hk/convr2016/CONVR2016_proceedings_final.pdf

Block, P. (2019, February). *Digital Master Builders: Disruptive construction technologies*. In Proceedings of the International Conference on the 4th Game Set and Match, Doha, Qatar. http://dx.doi.org/10.29117/gsm4q.2019.0027

Citron, R., Woods, E. (2018). *Smart City Tracker 1Q18*. Navigant Group. Retrieved from: http://www.navigantresearch.com/research/smart-city-tracker-1q18

Dameri, R. P. (2013). Searching for smart city definition: a comprehensive proposal. *International Journal of computers & technology, 11*(5), 2544-2551. https://doi.org/10.24297/ijct.v11i5.1142

Ensafi, M., Thabet, W., Devito, S., & Lewis, A. (2021). Field Testing of Mixed Reality (MR) Technologies for Quality Control of As-Built Models at Project Handover: A Case Study. *EPiC Series in Built Environment, 2*, 246-254. https://doi.org/10.29007/4wrj

Fiske, M., Edmunson, J. E., Weite, E., Fikes, J. C., Johnston, M., Mueller, R. P., & Khoshnevis, B. (2018). The disruptive technology that is additive construction: System development lessons learned for terrestrial and planetary applications. In *2018 AIAA SPACE and Astronautics Forum and Exposition* (p. 5127). https://doi.org/10.2514/6.2018-5127

Kothman, I., & Faber, N. (2016). How 3D printing technology changes the rules of the game: Insights from the construction sector. *Journal of Manufacturing Technology Management, 27*(7), 932-943. https://doi.org/10.1108/JMTM-01-2016-0010

Labonnote, N., Rønnquist, A., Manum, B., & Rüther, P. (2016). Additive construction: State-of-the-art, challenges and opportunities. *Automation in construction, 72*, 347-366. https://doi.org/10.1016/j.autcon.2016.08.026

Lekan, A., Aigbavboa, C., Babatunde, O., Olabosipo, F., & Christiana, A. (2020). Disruptive technological innovations in construction field and fourth industrial revolution intervention in the achievement of the sustainable development goal 9. *International Journal of Construction Management*, 1-12. https://doi.org/10.1080/15623599.2020.1819522

Love, P. E., Matthews, J., & Zhou, J. (2020). Is it just too good to be true? Unearthing the benefits of disruptive technology. *International journal of information management*, *52*, 102096. https://doi.org/10.1016/j.ijinfomgt.2020.102096

Najmi Sarooghi, E., & McCuen, T. (2021). BIM-GIS: Analysis and Integration for Contractors. *EPiC Series in Built Environment, 2*, 255-263. https://doi.org/10.29007/vz55

Peel, K. L. (2020). A beginner's guide to applied educational research using thematic analysis. *Practical Assessment, Research, and Evaluation*, *25*(1), 2. https://doi.org/10.7275/ryr5-k983

Rai, N., & Thapa, B. (2015). A study on purposive sampling method in research. *Kathmandu: Kathmandu School of Law.* Retrieved from: https://www.academia.edu/28087388/A_STUDY_ON_PURPOSIVE_SAMPLING_

Smart City Observatory (2021). *Smart City Index 2021*. Retrieved from: https://www.imd.org/smart-city-observatory/Home/

Vacanas, Y., Themistocleous, K., Agapiou, A., & Hadjimitsis, D. (2015, June). Building Information Modelling (BIM) and Unmanned Aerial Vehicle (UAV) technologies in infrastructure construction project management and delay and disruption analysis. In *Third International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2015)* (Vol. 9535, p. 95350C). International Society for Optics and Photonics. https://doi.org/10.1117/12.2192723

Woodhead, R., Stephenson, P., & Morrey, D. (2018). Digital construction: From point solutions to IoT ecosystem. *Automation in Construction*, *93*, 35-46. https://doi.org/10.1016/j.autcon.2018.05.004

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Eco-efficient Construction: The Utilization of Nanotechnology and 3D Printing in the Sustainable Building Practices of the AEC Industry

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Eco-efficient construction is a broad topic that incorporates many facets of high-performance building practices, sustainability principles, life-cycle analysis considerations, and cost valuation of implementing methods, materials, and processes. New technologies play a significant role in the development of sustainable materials and methods in the architecture, engineering, and construction (AEC) industry. Nanotechnology and 3D printing are on the cutting edge of current research and development and exemplify sustainably focused eco-technologies. The study and implementation of nanotechnology and 3D printing are essentially emphasized by the focus on sustainability. This study investigates the advancement of nanomaterials and 3D printing and seeks to determine their current state of development and implementation in the AEC industry. In addition, concepts of sustainability are reviewed to reveal how they are aligned with eco-construction. Methods of evaluation are explored to better understand how sustainable building practices are supported in the AEC industry.

Keywords: 3D Printing, AEC industry, eco-efficient construction, eco-technology, nanotechnology, sustainable building.

Introduction

Innovation and advancement are often understood as underlying credos in the promotion and implementation of sustainable building practices. Sustainable building practices encompass far more than just the implementation of new technologies; however, it is the innovation in materials and systems technologies that are often hailed as exciting remedies to the problems faced in the built environment. While developments in materials, processes, and performance-based systems in the architecture, engineering, and construction (AEC) industry are integral to the evolvement of industry practices congruent with sustainable objectives, it is important to understand how these improvements play a role in eco-construction as well as the comprehensive concept of sustainability. In 1987, a report called "Our Common Future" was published by the Brundtland Commission and established the principle of the capacity to achieve sustainable development as a paradigmatic pursuit that "ensure(s) that it meets the needs of the present without compromising the ability of future generations to meet their own needs"

(UNGA, 1987). This was an important step in highlighting the need for renewed focus and a change in thinking in design and construction practices. The United Nations General Assembly at the 2005 World Summit described three components of sustainability (Huang et al., 2014) that outlined a collaborative framework of the environment, economy, and society working towards sustainability-derived goals which are further reinforced through cleaner technology, comprehensive decision-making, and education to act as an initiative in moving forward in sustainability across industries and institutions.

Sustainable building practices have become key objectives in the AEC industry. The implementation of sustainable technologies represents a substantial part of the endeavor to integrate sustainable building practices and employ high-performance design. The understanding of this synergism introduces the concept of eco-efficiency. The World Business Council for Sustainable Development drafted its initiatives around the idea of eco-efficiency by highlighting a holistic approach that integrates sustainable objectives with acceptable economic interests of businesses and communities alike (WBCSD, 2006). According to the WBCSD, "eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring the quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity". Eco-construction incorporates eco-efficiency as part of its efforts to achieve high-performance buildings. A high-performance building according to House Resolution 6 (2007) is a building that integrates and optimizes on a life cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations (United States Congress, 2007).

The development of advanced technologies often fundamentally pursues properties or processes that are more efficient and at least indirectly, more sustainable. New technologies such as nanotechnology and 3D printing should not singularly be legitimized by the attainment of scientific and manufacturing achievements but should be understood to act within the comprehensive scope of sustainable development. The U.S. National Nanotechnology Initiative states that "nanotechnology is the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications" (NNI, 2020). 3D printing, also known as additive manufacturing, refers to the various processes of rapid prototyping used to synthesize a 3D object with the support of 3D computer-aided design (CAD) data. In 3D printing, successive layers of material are deposited under computer control to create the desired object (Casini, 2016). The collaboration between eco-technologies and sustainable business practices reinforces the concepts of eco-construction and forces it to provide a construct that goes beyond the confines of the underlying precepts of mere efficiency. Analyzing new technologies or what can be considered "eco-technologies" and how they fit into the overall framework of sustainable AEC industry practices provides a more informed idea of eco-construction and better ways in which it can be implemented in the larger scope of sustainability. Eco-technologies are a series of technologies developed to generate goods or services that meet human needs while minimizing environmental damage. In addition, these technologies are developed to efficiently take advantage of natural and material resources so that we can guarantee their sustainable use (Arquinetpolis, 2020).

The three components of sustainable development—environment, economy, and society all work in collaboration to support sustainable development. The intended outcomes of this whole-systems-based approach are legitimized because the participants of the system are constantly responding to one another and continue to adapt. It is not enough to provide efficient solutions because efficiency only approaches a problem by improving the processes involved and does not address the bigger issue of limited resources or the drawbacks to the pursuit of new technologies without taking into account the whole system of a building and the micro and macro environment to which it is connected. The purpose of this study of available literature and case studies sought to highlight the new and ever-evolving technologies of nanomaterials and 3D printing, their current state of implementation and production, how they fit into what is deemed "eco-construction", and how this supports sustainable building practices in the AEC industry.

Methodology

The methodology of this study took an integrative approach through a critical literature review establishing a narrative with an informed position on sustainable business practices in the realm of eco-construction. Figure 1 illustrates the research process framework used in conducting this study. The process involved first identifying innovative construction techniques and methods. The concept of 3D printing and nanotechnology implementation in the construction industry was identified, and literature was reviewed to begin to understand what these technologies were and what role they played within the AEC industry. In researching articles and case studies, a problem concerning the application of these technologies began to emerge. Terms such as eco-construction and eco-technologies were being boasted much in the same way as terms such as green technologies and sustainability are used glibly, thereby missing key issues in the application of holistic sustainable business practices with a focus on comprehensive positive outcomes across industries.

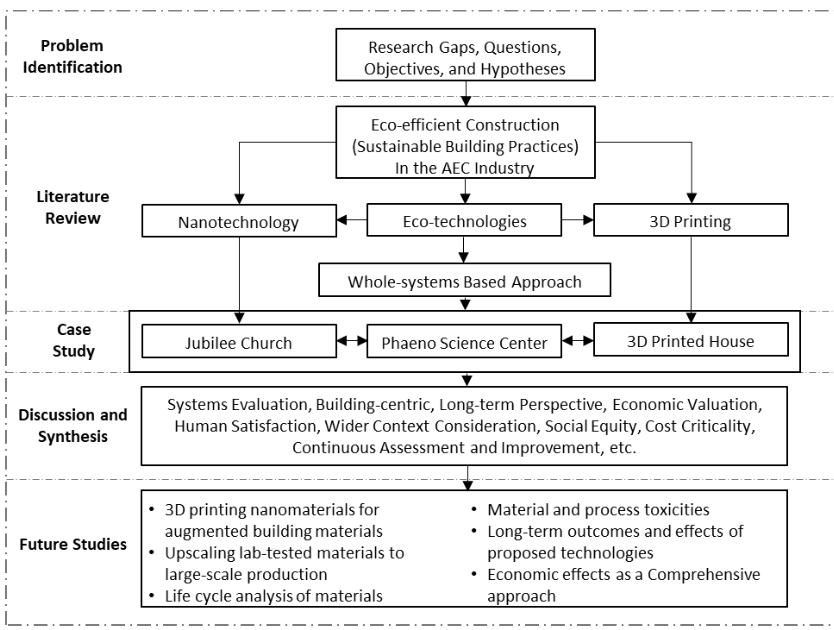

Figure 1: Research Process Framework

Often the prevailing attitudes within the AEC industry and the science and research community focus on one aspect of a generalized definition of sustainability and understanding of efficient use of resources. In addition, immediate economic interests can often be an overshadowing goal leaving all other considerations by the wayside. Within the research, questions were posed to understand the processes in developing and implementing new technologies, and the objective of the research became investigating the outcome of the performance of these eco-technologies in real-world case studies. The investigation was spurred by a hypothesis that reports of new materials or processes and their uses in built projects can often be a contrived delusion ignoring long-term outcomes, missed opportunities, or leave out detrimental effects. Inherent to this problem is the available literature and the presentation of built projects in various forms of media that perpetuate this strategy either deliberately to mislead or through a genuine mistake is failure to consider additional factors. Therefore, the methodology of this research collected a sampling of literature that in part forms a basis of knowledge for the AEC industry. The content presented in the literature and case studies was analyzed in order to develop a narrative of how eco-technologies were being presented in the literature. A synthesis of these viewpoints and findings within the reviewed literature and case studies provided the elements of this narrative that acted as a springboard in beginning to answer the question of how can eco-efficient construction better incorporate new technologies to promote a more comprehensively sustainable building practice.

Whole-systems Based Approach

Integrated building and cross-scale evaluation that uses a whole-systems-based approach provide a better framework for sustainability measures. Conte and Monno (2011) argue that sustainable building evaluation systems such as LEED (Leadership in Energy and Environment Design) are too "building centric" in that these evaluation systems are focused on making assessments detached from the built environment and have questionable value as the focus may be geared towards certification or the acquisition of "eco-technologies" for the sake of being labeled "green". Eco-technologies can be inappropriately used as the sole determinant in sustainability practices (Conte & Monno, 2011). While these eco-technologies may be eco-efficient, the more these eco-technologies are used in buildings does not necessarily correlate to an increase in sustainable cities or environments.

Expanded Scope of Sustainable Building Practices

The labels of sustainability, efficiency, and green building in addition to the idea of new and exciting technologies can be misused and treated as sole pursuits that end in achieving insufficient results. Berardi (2013) claimed that the problem with the building sector's criteria for sustainable development is that it supposes that a building is sustainable if it represents a healthy built environment, based on ecological principles and resource efficiency. This is limiting in that the measure is based on achieving efficiency which is often confined to the systems of the building itself with no regard to its relation to the environment and often in terms that measure or express quantifiable ecological terms (Berardi, 2013). Berardi concluded that a sustainable building has to promote in a long-term perspective its economic value, a neutral environmental impact, human satisfaction, and social equity. It is this expanded scope that encompasses a better representation of sustainable principles. Nanotechnology and 3D printing are complex and are still in their infancy in providing commercially viable products for the building industry which may not be able to offer complete prescriptions for an integrated approach to sustainability and business unless a more long-term value can be assessed.

Nanotechnology and 3D printing as Sustainable and Viable Eco-technologies

New eco-technologies either are not developed enough for use or oftentimes come at a higher price without a commensurate level of benefit. For example, Hanus and Harris (2013) found that at the time of their research the large-scale production of carbon nanotubes for use in cement composites was too costly. However, Pirard et al. (2017) have now claimed four years later that "technological innovations have allowed mass production of high-quality Carbon Nanotubes (CNTs) at a competitive cost and now represent a viable industrial nanomaterial" which allows for use in stronger concretes. Cost is a critical component in the development and use of materials and processes of any aspect in the building industry.

British economist Chris Freeman outlined five criteria in a 1984 article that were paramount in identifying emerging "technologies with the greatest impact" which listed drastic reduction in the costs of many products and services (Archibugi, 2017). In addition to cost, environmental acceptability was listed as the fifth criterion. Pacheco-Torgal et al. (2019) highlighted the importance of the 2030 United Nations Agenda for Sustainable Development's initiative for the construction industry as well as the implications for new technologies such as nanotechnology and 3D printing. New and emerging technologies research, as well as real-world testing, have provided evidence for the positive influence in the future of meeting sustainability goals not only in energy efficiency or reduction but also in improving safety for people and decrease in costs. El-Sayegh et al. (2020) have pointed out that 3D printing is still in its early stages of development and at this time is faced with several challenges and risks that cause barriers to fully realizing anticipated benefits. They further list the benefits of 3D printing in construction and separate these between constructability and sustainability. While there has been gradual progress in 3D printed building technology in the AEC industries, it is still a technology that is not at a stage in development that is able to produce large-scale eco-efficient construction or widespread sustainable impacts in the built environment. In addition, El-Sayegh et al. (2020) noted that the label "construction sustainable design" is to be used to increase quality while reducing the negative impact on the environment and that LEED is used as a quantifier of sustainability in projects. Using this kind of evaluation system is what Conte and Monno (2012) noted as causing a "building-centric" mentality that limited the scope of sustainable building practices.

A summary of this limited look into available literature reveals a wide array of perspectives and interpretations from differing market sectors. There are the material scientists, the AEC industry, and the environmental proponents who all have specific goals –some are in line with each other, merely similar, or completely different altogether. The literature review provided a small picture of how these differing viewpoints found commonalities but also highlighted diverging viewpoints. An examination of selected case studies demonstrated these perspectives on sustainable building practices. The findings are summarized in Table 1 and reveal the result of the endeavors.

Selected Case Study Applications of Nanotechnology and 3D Printing

The Jubilee Church in Rome was designed by Richard Meier in 2003 and was built with photocatalytic, "self-cleaning" precast concrete panels to achieve the gleaming white curved shell- structure (Povoledo, 2006). The self-cleaning properties are derived from nanoparticle titanium dioxide (TiO_2) that was integrated within the concrete along with Carrara marble aggregate (Cardellicchio, 2019). The intended clean white surface was supposed to combat pollution and act as a symbol of the pursuit of a more sustainable future (Traverso, 2019). However, the promise of self-cleaning was not completely met due to unexpected effects with a dirty façade (Cardellicchio, 2019). Rome has pozzolanic dust or a high concentration of volcanic ash made up of silica particles which TiO_2 cannot oxidize and therefore cannot initiate the reaction that is needed for self-cleaning (Cardellicchio, 2019). Cardellicchio pointed out that rain dust or rain that has a high concentration of desert dust caused an abrasive action to occur on the convex surfaces of the façade which increased the bond between the dust particles and concrete leading to diminished aesthetics and increased maintenance costs.

Architect Massimiliano Locatelli in collaboration with Arup Group developed a 3D-printed house with 35 modules printed in 48 hours with specially formulated concrete (Watkin, 2018). This technology would allow for housing to be built for the 1.2 billion people in the world that lack suitable shelter and would support temporary disaster relief housing. The project is named '3D housing 05', a name that refers to the five themes that relate to the house: creativity, sustainability, flexibility, affordability, and rapidity. The architect spoke further about the sustainability of the 3D printed house, which repurposes waste from demolitions — giving the production a zero net impact.

Self-compacting concrete has been developed through nanotechnology and offers concrete that does not need to be vibrated for consolidation which decreases energy, labor cost, and completion time (Babuka, 2016). The Phaeno Science Center in Wolfsburg, Germany was designed by architect Zaha Hadid and completed in 2005 with extreme forms and "tilted walls where concrete cannot be compacted with vibrators" (Tokarz, 2007). Self-compacting concrete not only features sustainable benefits but also offers additional innovation by allowing for the creation of concrete structures that were previously impossible to achieve.

Table 1
Case Study Analysis of Sustainable Business Practices

Jubilee Church	3D Printed House	Phaeno Science Center
Background Information		
• Rome, Italy • Built in 2003	• Milan, Italy • Built in 2018	• Wolfsburg, Germany • Built in 2005
Eco-technology		
• Self-Cleaning Precast Concrete Panels • TiO_2 integrated into concrete • Photocatalytic reaction	• 3D printed house • 35 Modules built in 48 hours • Specially formulated concrete • Built with a specialized printer	• Self-compacting concrete • No vibration for consolidation
Sustainable Building Practice		
• Attempt to employ an innovative material • Supposed to self-clean concrete façade and absorb surrounding air pollution • Symbol for the pursuit of a sustainable future	• Rapid housing production for a large population • Flexibility, affordability, and rapid construction for shelter in disaster relief recovery • Repurposes waste from demolitions	• Decreases energy, labor cost, and completion time
Results/Outcomes		
• Pozzolanic dust in Rome has silica particles which TiO_2 cannot oxidize preventing self-cleaning reaction • TiO_2 was found to convert NH_3 to NO_2 - proliferation of harmful ozone pollution • More maintenance problems with increased staining and negative environmental effects	• Project named '3D housing 05', referring to the five themes that relate to the house: creativity, sustainability, flexibility, affordability, and rapidity • Still in its infancy and yet to find a foothold in widespread implementation	• Innovative design methods to create tilted wall forms • Decreased energy, labor cost, and completion time • Increase in design innovation and environmental impacts

Discussion

Eco-construction has at its base sustainable intentions, but economic output has to be considered which can sometimes counteract sustainable pursuits. A common method used in the AEC industry to validate sustainable practices is the implementation of life-cycle analysis (LCA). Life-Cycle Analysis is a comprehensive method of describing the environmental impacts of a material or product, accounting for all phases of its life from resource extraction through final disposal or reuse. Also called cradle-to-grave analysis (Allen & Iano, 2019). According to Bidokia et al. (2006), eco-efficiency is seen as an effective method in achieving "environmentally friendly" goals that "maximize efficiency while minimizing the impact on the environment", and this includes studying "the lifecycle of a product from cradle to grave." Cucurachi and Rocha (2019) claimed that the LCA could be hampered by generalizations from the scientific community involving sustainability and safety. Nanotechnology still poses unknown risks, particularly with toxicity. It was found that only 8% of LCA studies done on nanomaterials "effectively quantified the effects from potential release and exposure" (Wu et al., 2019). These issues can greatly interfere in efforts to achieve sustainable practices and lead to hazardous situations. For example, in a study done by Kebede et al. (2013), TiO_2 coatings that are meant to clean the surface of concrete and glass and surrounding air of pollutants were found to convert ammonia (NH_3) to nitrogen dioxide (NO_2) which could lead to the proliferation of harmful ozone pollution. In an assessment of nanotechnology in eco-construction, Pacheco-Torgal (2019) claimed that there still has not been enough research or substantial evidential findings regarding the recyclability of nanomaterials or the effects of potential toxic exposures.

The research performed by reviewing selected literature and case studies revealed some prevailing attitudes that often focused on singular claims that simply touted sustainability as a stamp of approval merely in terms of efficiency or through singular implementations of innovative technologies, materials, and processes without performing a more comprehensive critical analysis taking into account important factors including LCA, material and process toxicities, long-term outcomes of proposed technologies, and economic conditions. The AEC industry's employment of eco-efficiency in its pursuit of high-performance design and sustainable building practices can often rely solely on quantifiable evaluation methods such as LEED and LCA. This systems-based approach as well as an overemphasis on the expected benefits of new technologies can misconstrue endeavors to reach a more comprehensive and authentic achievement in sustainability goals. Table 2 summarizes the common themes found within the selected literature and depicts a framework for comparative analysis within the context of eco-technologies used in the case studies presented.

Table 2

Comparative Analysis of Common Eco-technology Themes in Case Study Projects

Jubilee Church	**3D Printed House**	**Phaeno Science Center**
• Systems evaluations such as LEED	• Cost is critical	• Long-term perspective in its economic valuation
• "Building-centric"	• "Progress and the long road -Energy efficiency & safety"	• Human satisfaction and social equity
• Eco-technologies—sole determinant in sustainability practices	• "Evaluation systems -LEED—commonly used -LCA—more comprehensive"	• Wider context to consider

While a whole-systems-based approach provides a better framework for sustainability measures, it can focus too much on the building or project and be what Conte and Monno (2011) referred to as "building-centric" which can evaluate every factor solely from the perspective of how the building is affected. In much of the building sector literature, LEED was used as a quantifier of sustainability. Using this kind of evaluation system is what was noted as causing a "building-centric" mentality that limited the scope of sustainable building practices. This analysis reveals that there is a wider context that must be considered that examines the building, end product, or technological endeavor and its connection to its environment. This means that not only the immediate surroundings must be considered but also the project's connection and influence with the larger local and global community. Cost is a critical component, and implementing new eco-technologies is costly. However, advancement can improve energy efficiency, safety issues, decrease costs, and provide for large-scale commercial production, especially in the long-term perspective.

Conclusion

While further research is needed, there exists great potential for nanotechnology and 3D printing to impact the built environment in positive and sustainable ways. However, it is also evident that a stronger consensus is needed on how eco-construction can better support sustainability. The WBCSD (2006) highlighted the fact that eco-efficiency is not meant to achieve full sustainability ideals on its own. The problem involves exclusively looking to individual methods of assessment, singular technologies, or evaluations based on isolated systems and not integrated connections between building and larger context. The implementation of nanotechnology and 3D printing in the sustainable building practices of the AEC industry is highly influenced by cost and profitability. Within the collaborative framework of environment, economy, and society, costs and profits play a role in achieving sustainability, but perhaps more of a consensus could be reached by integrating Berardi's proposal of long-term economic perspective and social equity.

Other problems with the development of nanotechnology and 3D printing involve long periods of study and development of these technologies. For instance, the advancements currently being made in the processes of 3D printing nanomaterials for the development of augmented building materials offer a glimmer of the possibilities of new and promising technology while illustrating the problem of a lengthy timeline. Upscaling lab-tested materials to large-scale production pose yet another hurdle in reaching viable commercial products or processes. Methods of analyzing the life cycle of materials is also a long process that requires continual assessment, especially under the lens of sustainable building practices and goals. Implementation of eco-technologies should be carefully discerned so that expectations of performance and safety are met. Additionally, understanding of the need for a more complete appreciation and fulfillment of sustainable practices should be affirmed with evaluation methods that follow a whole-systems-based approach. Costs and profits, while integral to the viability of the business and the community, should be realigned with a long-term economic value perspective.

The concerns found to be evident through the qualitative research in the selected literature and case studies noted in this study highlight the need for a more comprehensive strategy of research, reporting, education, and implementation of sustainable business practices involving eco-technologies and eco-construction. The ideas identified through this critical literature review are novel and supportive of successful sustainable business practices but are found to be lacking and at times detrimental to the larger picture of sustainability and efficiency when they become singular pursuits and fail to come together to include all aspects of pursuing sustainable business practices. Future research and plans of action on the part of the AEC industry and scientific community should consistently and as a matter of protocol not only address LCA, material and process toxicities, long-term outcomes and effects of proposed technologies, and economic effects as a comprehensive approach but should also ensure within their research and presentation through published literature and publicized projects that these measures become part of a consistent multi-faceted program in which to pursue new technologies and sustainable eco-construction.

References

Allen, E. & Iano, J. (2019). *Fundamentals of building construction: Materials and methods.* (7th ed.). Hoboken, NJ: John Wiley & Sons.

Archibugi, D. (2017). Blade runner economics: will innovation lead the economic recovery? *Research Policy*, 46(3), 535–543.

Arquinetpolis (2020). Sustainability: How to Use Ecotechnics In An Architectural Project? *Archinopolis*.

Babuka, H. (2016). Application of nanotechnologies in sustainable architecture. *Fourth Student Conference: Energy Efficiency and Sustainable Development, Skopje, Macedonia.*

Berardi, U. (2013). Clarifying the new interpretations of the concept of sustainable building. *Sustainable Cities and Society*, 8, 72–78.

Bidokia, S.M., Wittlinger, R., Alamdara, A.,A., & Burger, J. (2006). Eco-efficiency analysis of textile coating materials. *Journal of the Iranian Chemical Society*, 3(4), 351-359.

Cardellicchio, L. (2020). Self-cleaning and colour-preserving efficiency of photocatalytic concrete: case study of the Jubilee Church in Rome. *Building Research & Information*, 48(2), 160–179.

Casini, M. (2016). *Smart buildings: Advanced materials and nanotechnology to improve energy-efficiency and environmental performance*. Woodhead Publishing.

Conte, E. & Monno, V. (2012). Beyond the buildingcentric approach: A vision for an integrated evaluation of sustainable buildings. *Environmental Impact Assessment Review*, 34, 31–40.

Cucurachi, S., & Rocha, C. F. B. (2019). Life-cycle assessment of engineered nanomaterials. In *Nanotechnology in Eco-efficient Construction* (pp. 815-846). Woodhead Publishing.

El-Sayegh, S., Romdhane, L., & Manjikian, S. (2020). A critical review of 3D printing in construction: Benefits, challenges, and risks. *Archives of Civil and Mechanical Engineering*, *20*(2), 1-25.

Hanus, M. & Harris, A. (2013). Nanotechnology innovations for the construction industry. *Progress in Materials Science*, 58(7), 1056–1102.

Huang, Y., Coelho, V.,R., Massoud, J., Briski, S., Toepel, A., & and Silva, M. (2014). A mathematical decision-making procedure to assist in the development of sustainability plans. *Sustainability Accounting, Management and Policy Journal*, 5(3), 292.

Kebede, M., Varner, M., Scharko, N., Gerber, R., & Raff, J. (2013). Photooxidation of ammonia on TiO2 as a source of NO and NO2 under atmospheric conditions. *Journal of the American Chemical Society*, 135(23), 8606–8615.

United States National Nanotechnology Initiative (NNI). (2020). Nano 101. What it is and How it Works/ What is Nanotechnology. *United States National Nanotechnology Initiative.*

Pacheco-Torgal, F. (2019). Introduction to nanotechnology in eco-efficient construction. In *Nanotechnology in eco-efficient construction* (pp. 1-9). Woodhead Publishing.

Pirard, S., Douven, S., and Pirard, J. (2017). Large-scale industrial manufacturing of carbon nanotubes in a continuous inclined mobile-bed rotating reactor via the catalytic chemical vapor deposition process. *Frontiers of Chemical Science and Engineering*, 11(2), 280–289.

Povoledo, E. (2006), Church on the edge of Rome offers a solution to smog. *The New York Times.*

Tokarz, B. (2007). Phaeno Science Center Wolfsburg, Germany: Avant-garde architecture, innovative construction. *Structural Engineering International*, 17:4, 322-327.

Traverso, V. M. (2019)., "Jubilee Church": A modernist jewel on the outskirts of Rome. *Aletia*.

United Nations General Assembly. (1983). Process of preparation of the environmental perspective to the year 2000 and beyond. *Resolution*, *38*(161), 19.

United Nations General Assembly. (2005). World summit outcome. *Resolution 60/1. 2005. United Nations General Assembly, September 16, 2005*.

United States Congress (2007) *Energy Independence and Security Act of 2007, H. R. 6, 110th Cong., 1st Sess. (2007.*)

Watkin, H. (2018), Famed Italian architect Massimiliano Locatelli to 3d print a house at Milan design week. *All3DP*.

World Business Council for Sustainable Development (WBCSD). (2006). *Eco-efficiency learning module*.

Wu, F., Zhou, Z., & Hicks, A. (2019). Life cycle impact of titanium dioxide nanoparticle synthesis through physical, chemical, and biological routes. *Environmental Science & Technology*, 53(8), 4078–4087.

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Conscious Intelligent Buildings: Envisioning the Next Generation of Smart Buildings

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Abstract

As one of the major industries that consume vast energy annually, the built environment industry is continuously exploring new building designs that would satisfy both occupants and the sustainability requirements. Considered as a new trend of building design for achieving economic, environmental, and occupant satisfaction goals, smart buildings are gaining momentum in research and development. Occupant-based design is considered an innovative idea for smart building automation systems as it aspires to focus on satisfying occupant's needs while saving energy and reducing waste. This positioning paper argues that next in the evolution of buildings is conscious intelligent buildings, characterized by their cognitive capabilities, creativity, and empathy akin to human self-awareness. Based on the literature review which served as the methodology, the evolving advancements in meta-data, Internet of Things (IoT), and Artificial Intelligence (AI) are potentially making this next paradigm possible. As for results, this article proposes a framework for defining conscious intelligent building. Its unique characteristics and underlying vision provide a new paradigm for leveraging big data analytics in the built environment. Enabled with cognitive and empathic interaction with the occupants, this achievement of higher intelligence can alter human-building relationship toward trust and thus increasing occupants' satisfaction and emotional health in the built environment.

1 Introduction

The world population is estimated to become 9 billion within the next 30 years. The number of people moving to urban areas is estimated to increase from 2.5 billion to 3 billion approximately, which results in significantly increased energy consumption by 56% by the end of 2040 (Bakıcı, 2013). As per capita energy and electricity consumption is highly correlated with the quality of life globally (Mazur, 2011), approaches for improving our life quality while reducing the energy consumption per

[*] Revised and completed the first stable version of this document
[†] Created the first draft of this document

person are required for sustainable development (Indrawati, 2017). The most effective way to improve quality of people's life space would be through alternations and innovations on building design and construction, since 30-40% of energy worldwide is consumed within the built environment as humans spend almost 90% of their lifetime inside a building (Park, 2018). Therefore, demand for smart building design which is aimed at providing pleasant, affordable, and aesthetic spaces in a cost and energy-efficient way has been growing tremendously, almost doubling every three years globally (Jia R. J., 2018).

Unlike traditional buildings which may no longer satisfy the requirements of energy saving and NetZero Energy building (NZEB) (Karlessi, 2017), smart building design would become the future trend of the development. There are various definitions of smart buildings which may raise the need for additional clarity of the concept. Additionally, problems including high initial cost of acquisition for technology, increasing concerns for cybersecurity, and convincing stakeholders of the value of smart buildings are still under debates, hindering the development and acceptance of smart buildings. Hence, in order to fully realize the advantages and benefits of smart buildings, these barriers must be overcome. To save energy, the existing smart building automation system should be further evolved. According to the research conducted by the International Energy Agency (IEA) (IEA, 2019), among the six main factors that could cause variations in energy usage (Yoshino, 2017), studies about occupant's behavior are not as broad as the other five factors including climate, building envelope, mechanical and electrical systems, indoor design criteria, and operation & maintenance. That explains why numerous researchers have gained motivations to develop occupant-based design (Anand P. C., 2018) (Anand P. C., 2019) (Anand P. S., 2017). The purpose of this paper is to explore the evolution of buildings, simply clarifying a holistic definition of smart buildings along with their basic traits and establishing a vision for the future of buildings based on the evolution history of buildings and the emerging trends. A new concept of conscious intelligent building is provided for further realizing the occupant-based smart design vision. Conscious intelligent buildings characterized by their self-awareness and connectivity to a larger web of the built-environment infrastructure and meta-data are portrayed in this paper. This paper proposes a framework for conscious intelligent building definitions, its unique characteristics, values, and offers a new paradigm for leveraging big data analytics for increased sustainability in the built environment.

2 Methodology

To make sure the review is comprehensive, according to the guidelines of systematic literature review by (Thomé, 2016), at least four steps are required: problem discovery, database selection, keywords selection and final literature selection. As intelligent and smart buildings are the topic for literature review, the problem formulation focuses on deficiencies of current smart buildings and occupant-based ideas. Based on assessment of impacts for different data sources (Kousha, 2011) (Meho, 2007), articles from four high impact scholarly databases are selected including Google Scholar, Science Direct, Emerald insight, Electrical and Electronics Engineers (IEEE) Xplore. In order to satisfy the needs for selecting keywords which should not only restrict the number of study but also specific enough to contain the required subjects, words of "smart building", "intelligent building" and "occupant-based" are selected. A total of 252, 46, 270, 60 articles are shown individually in Google Scholar, Science Direct, Emerald Insight, and IEEE Xplore, serving as the resources for extracting the smart building definitions and ideas of occupant-based design in construction projects. Following the review and content analysis of articles, we synthesize the identified unique traits for occupant-based design (see Figure 1).

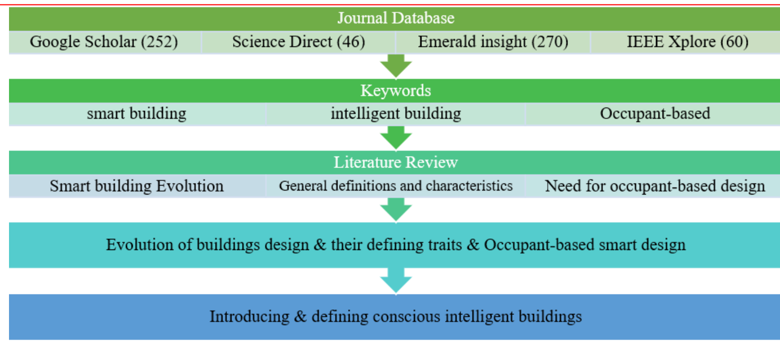

Figure 1: Research Process Leading to the conceptualization of conscious intelligent buildings

3 Literature Review Findings

3.1 Evolution of building design – from "primitive" to "intelligent"

Building design ideas and expected performance have been changing significantly throughout the history of human civilization (Buckman, 2014). According to the evolving process stated by (Fitch, 1960), early buildings are served as shelters which could protect people from unpleasant weather conditions, basically called "primitive buildings". The standards of comfort and information sharing was relatively low, and the materials for construction were as simple as rock and wood. Later on, with the development of construction technology, availability of new materials, and information technology "primitive" buildings evolved into "normal" buildings and then to "automated" buildings (Drewer, 1994) and (Smith, 2007). In an automated smart built-environment, building systems would react to occupant's needs by the means of Internet of Things (IoT) system (Jia M. K., 2019), which is called "adaptive" and "responsive" to proactively satisfy occupants' needs based on the concept of intelligent building design (IBD) (Andrew, 1998). This promising future of buildings are introduced as "intelligent buildings" (see Table 1).

Building sorts	Primitive building	Normal building	Automated building	Intelligent building
Interaction	No interaction	Occupant's fully control	Limited interaction	Highly interactive
Living standard	Low, only as a shelter	Comfortable and controllable	High standard automated	Optimized and sustainable
Materials	Rock or wood	Bricks, steel and concrete	Advanced materials	Advanced & sustainable
Technology level	No technology implementation	Basic electricity supply and MEP devices	IoT system devices, Advanced MEP system	Real-time integration and optimization system
Sources	(Fitch, 1960)	(Drewer, 1994)	(Jia M. K., 2019)	(Buckman, 2014)

Table 1: Evolution process of building design

3.2 General definitions and characteristics of smart buildings

According to different studies, numerous definitions about smart building are presented along with their expected features and functions. Most of these definitions are focused on the features that would benefit owners for smart building operation and maintenance. Here are some of the typical definitions of smart buildings provided by researchers in various scholarly publications.

(Jung, 2020) states that if a building is capable of managing and maintaining higher level of performance while having cognitive abilities similar to humans, the building could be identified as smart or intelligent. (Volkov, 2015b) believes that “learning from inhabitants”, “adapting to their lifestyle” as well as “initiating decisions or actions to change the current status of indoor environment” are the core values for designing and constructing smart buildings. (Arditi, 2015) believe that smart buildings are comfortable, safe, and satisfy the economic goals set by owners. (Volkov, 2015a) makes the same argument and further emphasize the importance of energy saving combined with the increased level of occupants’ comfort for building “smart” considerations. These studies have consensus that economic goals, energy saving, and occupant’s comfort are the key indicators that determine the smartness of buildings. Additionally, (Batov, 2015) pays great attention to the technological implementation inside a smart building; the building could “program itself” by inputting data from monitoring occupants and environments with various sensors. After discovering the behavior patterns of occupants, relevant predictions of future actions are generated accordingly. But, as all the devices inside the building are becoming networked to the Internet, they could also become more vulnerable to cyberattacks. Consequently, new detective and responsive approaches in securing data from cyberthreats should also be considered rather than simply focus on data connectivity.

To sum up, three key aspects are concluded based on all the definitions for determining whether a building could be considered as smart or intelligent. First of all, the building has cognitive abilities and could learn from its occupants’ routine behavior or lifestyle by monitoring through sensors and learning with algorithm. “Responsive actions” are then generated following the learning process. Secondly, three fundamental goals are to satisfy for the purpose of sustainability: decrease in energy consumption, saving in lifecycle costs and improvement of occupants’ living or working standard. Lastly, a large amount of the utilities, equipment, components inside the building are connected and controlled through a cloud-based platform, along with relevant precautions to protect all the data from cyberattacks. Data are collected and stored for analysis, leading to predictions and recommendation for management or visualizations. The intersection of these three aspects makes smart buildings (see Figure 2).

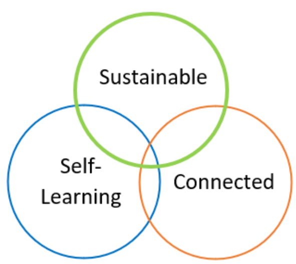

Figure 2: Key attributes of smart buildings

3.3 The need for occupant-based smart building design

Most of the smart building definitions are focused on technologies and functions that would benefit owners for sustainable construction and operation of their buildings. These definitions are seldom concerned with an occupant-based criterion (Janda, 2011). While owners should be satisfied given their time and money investment on the entire project life cycle from design, to construction, to operation, the needs of occupants are equally if not more important. The occupants could range from white-collar staff of office buildings, patients of medical centers, students and faculties of college buildings and residents for apartment or residential buildings, etc. In short, building users are core fabrics of society and their health, comfort, and productivity has immediate impact on the community's economic and social well-being, and yet building occupants' perception of the built-environment are often overlooked (Janda, 2011).

Occupant-based design centered on big data analytics could be a viable approach to further improving building performance (Kjærgaard, 2020). Different studies have demonstrated the significance of occupants' impact on energy consumption and thermal distribution inside buildings (Jia M. S., 2017) & (Dong, 2018). According to (Kjærgaard, 2020), the majority of building energy simulation applications concentrate on the factors embodying physical building design, such as materials, technological systems, and outdoor weather conditions rather than occupant-building interactions. As (Yang, 2014) points out, several traditional building operation approaches adopt schedules for HVAC control based on certain rules like ASHRAE 90.1 standard, resulting in huge energy waste and occupant discomfort and complaints. Consequently, more focus should be shifted on occupant's presence and behavioral actions in order to achieve both the goal of energy efficiency and occupants' comfort for occupant-based smart buildings. In order to demonstrate the increasing focus on occupant-based design, number of articles containing "occupant based" and "occupant centric" published on the mentioned four databases from 2017 to 2021 are displayed due to the increasing interest in this topic (see Figure 3).

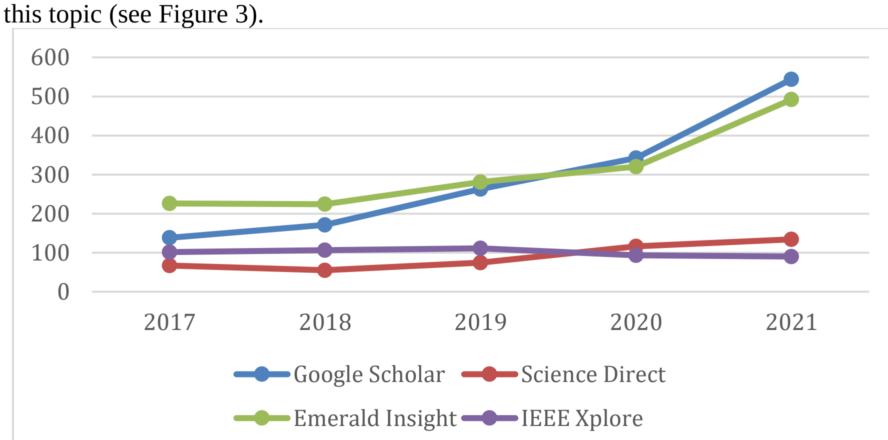

Figure 3: Number of articles concerning "occupant based" and "occupant centric" published on the four databases from 2017 to 2021

3.4 Building systems and requirements of occupant-based smart building design

Current building management systems' goal is to achieve energy efficiency. These control systems are centralized, operated by facility managers, and require high expenses for installation and operation. To enable occupants-based design, additional sensors and actuators are required but it is challenging to add them to current systems (Batra, 2013). Lack of the design for inputting dynamic variables about occupant, such as occupant number, movement and state of comfort, would be the problems that traditional building management system (BMS) are currently facing. For each 6 fundamental systems of traditional BMS, a complimentary element of occupant-based design is suggested accordingly (see Table 2).

Building System	Elements of Occupant-based design	References
HVAC Control System	Personalized ventilation approach,	(Sekhar, 2005)
	Occupancy-based zone-level variable air volume system for improving thermal comfort	(Anand P. S., 2019)
Fire alarm & detection system	Probabilistic occupant response model for fire emergencies	(Zhang, 2014)
Communication System	Sensekit, a modular hardware platform that allows for customized monitoring based on application requirements	(Batra, 2013)
Security System	Personalized warning system based on capacitive proximity sensing	(George, 2008)
Elevator System	Optimal elevator scheduling based on real-time occupancy patterns	(Wang, 2021)
Lighting System	Adaptive lighting control, based on occupancy detection	(Guo, 2010)

Table 2: Elements of occupant-based design for each building system

Figure 4 illustrates a framework for occupant-based building system operation in conjunction with traditional building system management to manage indoor environment (see Figure 4). Traditionally, occupants could control the indoor environment by manually controlling devices to ensure the perfect temperature, ventilation and lighting, with no automation but only manual instructions given from occupants. As for traditional building control system, managers would set the fixed standard including all the controlling parameters. Compared to these two approaches, control system of occupant-based smart design relies on data collected from user interface which reflects occupant's behaviors. By applying relevant algorithms, automatic operations will be generated to adjust indoor environment based on input data from the occupants and outdoor environment.

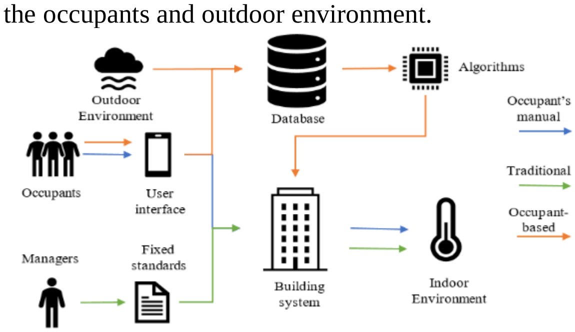

Figure 4: Framework of occupant-based control system

4 Discussion - Envisioning the Next Generation of Conscious Intelligent Buildings

As a dominant and rapidly evolving technology, Artificial Intelligence (AI) has demonstrated outstanding performance in well-defined domains such as image/voice recognition, and behavioral predictions. However, all these AI capabilities are rather primitive compared to those of nature-made intelligent systems such as humans because AI capabilities, in essence, are derived from classification or regression methods (Esmaeilzadeh, H. & Vaezi, R., 2021). Esmaeilzadeh, H. and Vaezi, R. identified four levels of AI intelligence and their corresponding service tasks: mechanical, analytical, intuitive, and empathic. While AI applications currently exist in the first two levels, the AI applications demonstrating intuition and empathy intelligence is still rate and considered to be the next disruptive wave of AI (Esmaeilzadeh, H. & Vaezi, R., 2021).

Similarly, current traits of smart buildings are relatively primitive compared to a futuristic conscious intelligent building this paper introduces, which is characterized by its autonomy and creativity in generating a healthy, comfortable, and sustainable built environment (see Figure 5). Besides being sustainable, connected and self-learning, conscious intelligent building should be cognitively self-aware and creative to occupant's response and requirements.

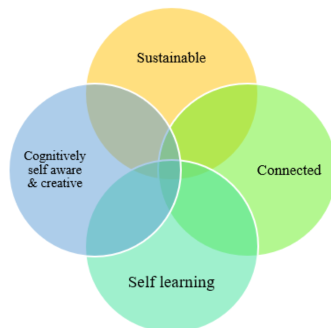

Figure 5: Key attributes of conscious intelligent buildings

From a futuristic perspective, conscious intelligent buildings could be defined as buildings that can "think on their own" with AI consciousness which allow them to be capable of limited decision-making on the basis of learning from occupant's behaviors and can demonstrate cognitive and empathic interaction with the occupants. This achievement of higher intelligence can alter human-building relationship toward trust and thus increasing occupants' satisfaction and emotional health. Through continuous two-way interaction with humans, sufficient data could be collected for controlling building systems automatically according to the occupant's individual habits, guaranteeing the maximum comfort for every occupant by optimizing indoor environment quality. Fundamental features for conscious intelligent buildings are listed (see Table 3).

Characteristic	Function
Occupant–building Interaction	Enrich occupants' living experience
Intuitive	Autonomy in decision making & knowing what's best to do
Empathic	Understand and empathize with occupants' needs
Autonomous	Allow for big data analysis to optimize indoor environment quality
Higher value	Provide better services catered to the occupants with less cost with greater efficiency

Table 3: Characteristic of Conscious Intelligent Buildings

5 Conclusion

This article highlights the evolution of buildings from primitive to regular, to automated, and most recently to occupant-based intelligent buildings. Unique features of the evolving buildings from primitive to intelligent occupant-based design is presented. Additionally, the unique features of occupant-based control system are presented in order to clarify the differences between traditional building system control and this new control system. As for the contribution to the body of knowledge, this paper provides a reflective insight into the evolution of the built environment as well as a vision for the futuristic paradigm of the built environment, which is informed by the emerging trends involving information technology and artificial intelligence and the need for enhanced human consciousness. Conceptual direction for future of the built environment is discussed. Future research experiments are needed to examine if the proposed conscious intelligent buildings would outperform the current occupant-based intelligent buildings both on energy consumption and occupants' health and wellness.

References

Anand, P. C. (2018). An Interaction between Occupnat Related Energy Consumption among different Spaces. *ASHRAE annual conference 2018.*

Anand, P. C. (2019). Energy saving estimation for plug and lighting load using occupancy analysis. *Renewable Energy, 143*, 1143-1161.

Anand, P. S. (2017). Improving the Accuracy of Builfing Energy Simulation Using Real-Time Occupancy Schedule And Metered Electricity Consumption Data. *ASHRAE Annual Conference.* Singapore.

Anand, P. S. (2019). Occupancy-based zone-level VAV system control implications on thermal comfort, ventilation, indoor air quality and building energy efficiency. *Energy and Buildings, 204*(109473).

Andrew, H. E. (1998). *Intelligent Buildings in South East Asia.* London: E & FN SPON.

Arditi, D. M. (2015). Assessing the smartness of buildings. *Facilities, 33*(9/10), 553-572. doi:10.1108/F-10-2013-0076

Bakıcı, T. A. (2013). A smart city initiative: the case of Barcelona. *Journal of the knowledge economy, 4*(2), 135-148.

Batov, E. I. (2015). The Distinctive Features of "Smart" Buildings. *Procedia Engineering, 111*, 103-107. doi:https://doi.org/10.1016/j.proeng.2015.07.061

Batra, N. A. (2013). Experiences with occupancy based building management systems. *2013 IEEE Eighth International Conference on Intelligent Sensors.* Sensor Networks and Information Processing.

Buckman, A. H. (2014). What is a Smart Building? *Smart and Sustainable Built Environment, 3*(2), 92-109. doi:10.1108/SASBE-01-2014-0003

Dong, B. Y. (2018). Modeling occupancy and behavior for better building design and operation--A critical review. *Building Simulation.*

Drewer, S. &. (1994). Smart Buildings. *Facilities*.

Esmaeilzadeh, H. & Vaezi, R. (2021). *Conscious AI.* Retrieved from Cornell University: https://arxiv.org/abs/2105.07879

Fitch, J. M. (1960). Primitive architecture and climate. *Scientific American, 203*(6), 134-145.

George, B. Z. (2008). A warning system for chainsaw personal safety based on capacitive sensing. *SENSORS.* 2008 IEEE.

Guo, X. T. (2010). The performance of occupancy-based lighting control systems: A review. *Lighting Research & Technology, 42*(4), 415-431.

IEA, I. (2019). *World energy balances.* Energy Agency.

Indrawati, R. Y. (2017). Indicators to Measure a Smart Building: An Indonesian Perspective. *International Journal of Computer Theory and Engineering, 9*(6).

Janda, K. B. (2011). Building don't use energy: people do. *Architectural science review, 54*(1), 15-22.

Jia, M. K. (2019). Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction, 101*, 111-126.

Jia, M. S. (2017). From occupancy to occupant behavior: An analytical survey of data acquisition technologies, modeling methodologies and simulation coupling mechanisms for building energy efficiency. *Renewable and Sustainable Energy Reviews, 68*, 525-540.
Jia, R. J. (2018). Design automation for smart building systems. *IEEE*, *106*, pp. 1680-1699.
Jung, Y. M. (2020). A framework for a construction intelligence quotient. *In*, 631-636.
Karlessi, T. K. (2017). The concept of smart and NZEB buildings and the integrated design approach. *Procedia Engineering*, *180*, 1316-1325.
Kjærgaard, M. B. (2020). Current practices and infrastructure for open data based research on occupant-centric design and operation of buildings. *Building and Environment*, *177*(106848).
Kousha, K. T. (2011). Assessing the citation impact of books: The role of Google Books, Google Scholar, and Scopus. *Journal of the American Society for information science and technology, 62*(11), 2147-2164.
Mazur, A. (2011). Does increasing energy or electricity consumption improve quality of life in industrial nations? *Energy Policy, 39*(5), 2568-2572.
Meho, L. I. (2007). Impact of data sources on citation counts and rankings of LIS faculty: Web of Science versus Scopus and Google Scholar. *Journal of the American Society for information science and technology, 58*(13), 2105-2125.
Park, J. Y. (2018). Comprehensive analysis of the relationship between thermal comfort and building control research-A data-driven literature review. *Renewable and Sustainable Energy Reviews, 82*, 2664-2679.
Sekhar, S. G. (2005). Findings of personalized ventilation studies in a hot and humid climate. *HVAC&R Research*, *11*(4), 603-620.
Smith, S. (2007). Intelligent buildings. *In Design and Construction: Routledge*, 60-82.
Thomé, A. M. (2016). Conducting systematic literature review in operations management. *Production Planning & Control*, *27*(5), 408-420.
Volkov, A. A. (2015a). Dynamic Extension of Building Information Model for "Smart" Buildings. *Procedia Engineering, 111*, 849-852. doi:https://doi.org/10.1016/j.proeng.2015.07.157
Volkov, A. A. (2015b). Simulation of Building Operations for Calculating Building Intelligence Quotient. *Procedia Engineering*, *111*, 845-848. doi:https://doi.org/10.1016/j.proeng.2015.07.156
Wang, S. G. (2021). Smart dispatching and optimal elevator group control through real-time occupancy-aware deep learning of usage patterns. *Advanced Engineering Informatics, 48*(101286).
Yang, Z. L.-G. (2014). A systematic approach to occupancy modeling in ambient sensor-rich buildings. *Simulation, 90*(8), 960-977.
Yoshino, H. H. (2017). IEA EBC annex 53: Total energy use in buildings--Analysis and evaluation methods. *Energy and Buildings, 152*, 124-136.
Zhang, X. L. (2014). A probabilistic occupant response model for fire emergencies. *Fire safety journal, 68*, 41-51.

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Unmanned Aerial Systems in the U.S. Construction Industry: Exploratory Study on Current State of Practice

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Recent advancements in the construction industry include the expanding application of Unmanned Aerial Systems (UASs) throughout the lifecycle of construction projects. These advancements result in significant increases in technical capabilities within construction as well as time and money-savings. Despite their abilities to improve efficiency by enhancing construction processes and practices, little is known about the current state of applications and the barriers to UASs successful adoption. The purpose of this exploratory study is to investigate the current state of UASs practice for various applications within the construction industry by providing a literature review and a series of interviews with construction professionals and UAS pilots. The outcome identifies key UASs applications including pre-construction, surveying, project progress monitoring, safety management, and quality management. In addition, the study documents low awareness of UASs applications among construction professionals, and outlines professional training requirements, Federal Aviation Administration (FAA) licensing requirements, capital requirements, and a range of implementation challenges. Understanding the applications of UASs in construction supports construction firms to achieve improved efficiencies in various construction activities where UASs can be deployed.

Keywords: Unmanned Aerial Systems in Construction, UAS in Construction, UAV in Construction, Drones in Construction.

Introduction & Literature Review

Recent construction technological advances introduce smart solutions to solve real-world problems. They help increase productivity, improve collaboration, and enable industry to tackle more complex projects (Tummalapudi et al, 2021). One such technological advancement that has been lately disrupting the construction industry is Unmanned Aircraft System (UAS).

An UAS consists of a remotely piloted flying asset equipped with several sensors through a control system. The Federal Aviation Administration (FAA) requires a UAS operator, or drone pilot, to operate it. UASs have quickly risen to provide a competitive advantage for a wide variety of industrial applications such as agriculture, infrastructure, oil and gas, traffic surveillance, and military. The market size for UASs is expected to exceed $30 billion in the United States by 2026 (Mc Kinsey, 2017).

UASs have opened a wide range of opportunities and applications in the Architecture, Engineering, and Construction (AEC) industry such as landslide monitoring (Yeh and Chuang, 2020), bridge inspections (Hiasa et al 2018), traffic surveillance (Barmpounakis and Geroliminis 2020), historical preservation (Enriquez et al. 2020), to name a few. In construction, UASs are used in a variety of ways- from site progress tracking, to overseeing subcontractors, to keeping stakeholders informed (Albeaino and Gheisari, 2021) and applications are rapidly expanding. It is estimated that the construction industry will invest more than $11 billion in UASs in the next few years (Goldman Sachs, 2017) and extract a $45 billion market value usage (Shakhatreh et al, 2019). Previous studies have reported that implementing UASs have had several advantages with regard to time and cost-saving in surveying activities, obtaining access to difficult-to-access spaces, and improving quality and reducing safety concerns of certain construction tasks (Gheisari and Esmaeili, 2018). This paper aims to further illuminate the current state of practice of the adoption and the barriers for construction firms to implement the adoption of UASs.

Research Methodology

With an objective to synthesize and understand the current state of practice as well as future applications of UASs in the construction industry, the authors designed a study consisting of a literature review and semi-structured qualitative interviews with experienced professionals and drone pilots working in the construction industry. To begin, the authors conducted a literature review of research regarding UASs and their construction applications over the last five years (2017-2021). Building upon these findings, a second phase of the research was to develop a short questionnaire and exploratory interview protocol that focuses on identifying the current state of practice of UASs in construction. The open-ended interview questions mainly focused on current applications, challenges and barriers, future applications, and implications of UASs in the construction industry, as shown in Table 1. Follow-up questions were based on the response of the participants, and are also shown below.

Table 1
Open-Ended Interview questionnaire
Applications of UASs in Construction:
1) What are the different operations/activities your construction firm uses UASs for? Please describe them. 2) Please describe the different types of UASs you use for these operations (Follow up: type, brand, capacity, deliverables produced, software used to convert deliverables) 3) What are the expenses related to using UASs? (Follow up: costs related to UASs purchase, UAV operator, software, conversion charges, operations, and maintenance expenses) 4) What are different construction tasks you're collaborating UASs with other emerging technologies? Please describe how you do that? 5) What are some challenges you experience in using UASs within your construction firm?

The development of interview questions follows DiCicco-Bloom and Crabtree's (2006) recommendations to include experience questions and knowledge questions. To recruit participants for the study, the authors adopted a snowball sampling approach. The authors initially extended invitations to a few known construction professionals using UASs to participate in the research. Each willing interviewee was then asked for further contacts and introductions. This led to introductions to several construction professionals that use UASs as a part of their daily work and eight of them were selected to be a part of the interviews. All participants of the study work in Colorado, and also fit the following criteria:

1) Currently employed in the construction industry;
2) A minimum of 3 years of experience in the construction industry; and
   a) Use UASs as a part of their daily responsibilities; or
   b) Lead UASs (and other emerging technology) initiatives for a construction firm that has been implementing UASs for at least 2 years.

Eligible participants were sent emails containing the interview protocol and consent letter explaining the aims of this research and requesting a probable time slot for the interview. The interviews were conducted synchronously either via Microsoft Teams, Zoom, or phone, depending on the preference of the participant. The interviews were semi-structured, and the purpose of using this approach was to initiate each interview with a set of open-ended questions that would lead to a thoughtful discussion while providing the flexibility to pursue appropriate follow-up probing questions. Table 2 shows the experience levels of participants (ranging from 7 and 28 years). With permission, all interviews were recorded and transcribed for data analysis purposes. Manual thematic coding was used by the authors to analyze the collected data to identify patterns and themes in the qualitative responses. The analysis primarily focused on the trends of different applications of UASs in the construction industry.

Table 2

Participant Information

Participant	**Experience(yrs.)**	**Company Size(employees)**	**Markets**
Participant 1	20	224	Commercial
Participant 2	7	803	Commercial
Participant 3	22	22,000	Heavy Civil
Participant 4	28	700	Commercial
Participant 5	19	172	Commercial
Participant 6	25	3,100	Commercial
Participant 7	13	25	Commercial
Participant 8	15	292	Commercial

While eight interviews is a small sample, according to Mason (2010), the size of the sample in qualitative studies is irrelevant because the value of the study is based on the quality of data. The primary reason for recruiting these eight participants was their experience, expertise, and willingness to participate in the study. Implementing such a strategy, according to Simms and Rogers (2006), increases the richness of data due to the commitment of the interviewees.

Results and Discussion

This study utilized expert interviews to obtain information regarding the current state of practice and barriers to implementing UASs in the construction industry. The expert interviews were conducted during February and April of 2020, and each interview on average took between 40 and 60 minutes.

Current State of Practice

This section presents different types of UASs that are employed, and various construction-related applications the UASs are used for by the participating construction firms.

Types of UASs used in Construction

The construction firms that participated in this research study used four different types of UASs, namely multi-rotor drones, fixed-wing drones, single-rotor drones, and fixed-wing hybrid drones. These different types of drones are shown in Figure 1. (Images Source: Google)

Figure 1. Types of UASs used by participant construction firms

Some firms possess multiple types of these UASs, whereas some firms possess only a single type. The participants mentioned that they select UASs based on needs and applications. It is observed that construction firms predominantly prefer multi-rotor UASs over other types as multi-rotor UASs are cost-friendly and sufficiently powerful as they are flexible and able to vertically take off and land. One participant mentioned, “The multi-rotors have exceptional hovering capabilities, this type of UASs is suitable for both vertical and horizontal constructions” indicating the suitability of multi-rotors across construction sectors. The software applications that are compatible with UASs and used for construction applications, according to research participants include DroneDeploy, Pix4D, Propeller, Ark Aerial, Reality Capture, and UgCS. DroneDeploy was the most frequently mentioned by participants, and one participant explained that “DroneDeploy is a comprehensive application that simplifies, supports, collaborates data collection and processes image/video data collected via UAS for surveying and mapping solutions” indicating its wide usage for surveying operations by construction firms. The initial capital investment to obtain the UASs, annual operation, service, and maintenance cost including software costs for various construction applications ranges between $ 4,000 and $ 35,000 per UAS based on the type and its construction-related applications. One participant mentioned, “Despite high initial costs of UASs, our firm noticed 9X time saving and 4X cost saving in tasks UASs could perform when compared to traditional methods”, indicating how construction firms weigh the cost-benefits of UASs for various applications.

Applications of UASs in Construction

This preliminary study identified various applications of UASs in construction such as aerial photography, photogrammetry, surveying, inspections, cut-fill estimations, quality checks, safety monitoring, among several other applications. Table 2 presents the current state of practice of the participants. To organize these various applications, the authors categorized these applications into four major categories namely

1) Pre-construction Management
2) Quality Management
3) Safety Management
4) Construction Surveying
5) Project Progress Monitoring

Pre-construction management

All participants of this study mentioned that they use UASs the most during preconstruction activities namely site mapping and site layout planning. To develop an effective site layout, the construction team needs to know information such as current site conditions, location, and surrounding constraints. To do this, the project managers usually walk the job site and collect information. The research participants informed that, with the advent of UASs, now they fly a UAS over the job site during the job site walks to collect every minute site detail, thereby making their site layout planning very efficient. "For one of the jobs we bid a few weeks ago, certain areas of the job site were inaccessible, and our drone (aka UAS) collected critical visual information from the inaccessible areas that assisted us plan site logistics very efficiently", quipped a participant informing the practical applications of UASs in site logistics and planning activities. Jiang (2020) reported similar applications of using UASs to improve the efficiency of site layout planning. The next most important application of UAS in pre-construction, as informed by the participants, specifically the Heavy civil construction firms in the calculation of cut/fill volumes for earthwork. "The UAS we have is equipped with a laser scanner, it collects the photogrammetry site data, through which we generate 3D models of the areas, and then by using some software applications, we can calculate accurate cut/fill volumes which we use in our estimates. This has saved us a lot of time as well as effort while being very accurate", informed a participant indicating how UASs improve accuracy in addition to their applications. This is in line with Wang's (2017) findings related to applications of UASs for earthwork calculations.

Quality management

The UASs combined with other latest technologies such as LIDAR and Building Information Modelling (BIM) is used for quality control and management by the contractors interviewed. Approximately 50% of the interviewed contractors explained different ways they use UASs for quality management. "We use UAS for quality management in various ways. For a project in which we had a BIM model, we flew a UAS to collect point cloud of the 'as-is' construction to compare it with the 'as-planned" BIM model to assess quality deviations, if any" informing one of the quality control applications of UAS in construction. This corresponds with Kielhauser's (2020) study that identified various quality control applications of UASs in the construction industry.

Safety management

Some of the participant firms (25%) informed that UASs are used for safety inspections and training at the job sites. "We run UAS safety flights regularly at our job sites to inspect if all employees are following safety standards, and if all required safety measures are taken", specified a participant. These findings corroborate with de Melo's (2017) study that used data collected through UAS for safety inspections to conform with safety standards at the job sites.

Project progress monitoring

About 80% of the participants mentioned using UASs for tracking the daily/weekly construction progress of the job sites. "We collect real-time visual construction progress data of our projects by flying UASs. This information is useful to assess site progress against planned progress. Our project owners and other stakeholders now have progress updates and key milestones frequently without even visiting the site due to UASs. This also helps to document site progress for future purposes", mentioned a participant informing how UASs are applied for progress monitoring and their advantages.

Table 3

Summarized Results on Current State of Practice of UASs in Construction

Participant	Type of UAS used	Total No. of UASs	Company Size (employees)	Annual Expenses ($) per UAS*	Functional Applications
Participant 1	Multi-rotor	3	224	$ 6,000	Earthwork Site progress Photogrammetry
Participant 2	Multi-rotor	1	803	NA	Survey Site logistics Cut-fill logs Safety Inspection
Participant 3	Multi-rotor, Fixed wing, hybrid	30	22, 000	$ 35,000	Quantity control & Inspections Project progress Photogrammetry Safety
Participant 4	Multi-rotor	Confidential	700	$ 5,000	Project progress Communication Quality control Productivity
Participant 5	Multi-rotor	Confidential	172	$ 12,000	Photogrammetry Thermal scanning Building envelope Aerial Imaging
Participant 6	Multi-rotor, fixed wing, hybrid	7	3, 100	$ 14,000	Photogrammetry Quality control Rockfall mitigation Soil erosion
Participant 7	Multi-rotor	1	25	$ 10,000	Photogrammetry Safety Inspections
Participant 8	Multi-rotor	5	292	$ 4,000	Marketing Survey Quality control Site progress check

*UAS costs include equipment and accessories and can vary significantly depending on quality.

Construction surveying

The UASs are widely for site surveying applications in the construction industry. Every participant of this study indicated that they collect aerial photography data of job sites for surveying and layout purposes. “Traditional techniques such as total station takes us a lot of time, effort, and money. While UASs provide faster and less costly construction land surveys as they can collect data and process it much quickly”, informed a participant regarding the efficiency of using UASs for surveying. “Earlier, for an 80-acre job site survey that requires at least 1600 GPS points, we spent 80 hrs. (3 min/point) for data collection, $12,000 for surveyor costs, and waited about 2 weeks for processing. Now, by using UASs, we collect about 1 million GPS points in 2 hours and have the processing done in less than 24 hours, all for $1500”, indicating how adopting UASs for surveying purposes saves time and money.

Barriers for Implementing UASs in Construction

Despite the literature identifying several benefits, the current state of practice suggests that construction firms use UASs for limited applications. To increase mobility and further improve the integration of UASs in the construction industry, it is critical that research investigate the barriers to the wider adoption of UASs in construction. This section of the paper identifies numerous barriers that impede the implementation of UASs in the construction industry. Barriers mentioned by participants included lack of contractor awareness regarding advantages and applications of UASs in construction, lack of technical know-how regarding extraction and processing of UASs data, lack of training, extensive certification and licensing requirements, flying in congested spaces, flying in varying weather conditions, and large initial capital requirements to acquire UASs among several other factors. “The costs associated with starting a UAS program within a construction firm are huge and some contractors are reluctant to make that investment. They have to buy the equipment, purchase the relevant software packages to process the data, train the personnel to use UASs to collect and handle data, obtain licenses and certifications for them. This is a lot of initial investment, which drives away several contractors,” opined a participant informing the costs associated with implementing UAS programs. Another participant mentioned, “UASs are easily affected by tough weather conditions, such as heavy rain, snow or wind. Weather conditions like heavy wind or thick cloud cover can prevent a UAS from flying safely and can stop the right and clear images from being taken. Operating UAS under these kinds of conditions can cause delays and might eventually lead to a collection of wrong data,” indicating limited operability as one of the major barriers for contractors to consider implementing UASs. The general trend of responses from the participants was that the UASs are upgrading the technical capabilities was rapidly making them well suited for construction applications. “I started using UASs 3 years ago, the kind of technical abilities UASs have today, the way they fly longer, and process data accurately are way ahead and different from what I’ve seen in 2018. I am confident this will improve much faster and help construction tasks much better in 2024 or 2025”, said a participant indicating an optimistic outlook regarding overcoming the hurdles to implement UASs as well as the growth of UASs could experience in the construction industry.

Conclusions and Limitations

The objective of this research study was to identify the current state of practice, and barriers for using UASs in the construction industry based on a literature review and interviews with construction professionals and drone experts who use UASs for various construction tasks. The study provided a list of UASs applications, which includes surveying, project progress monitoring, safety management, and quality management. The construction firms that participated in this study used different varieties of UASs such as single rotor, multi-rotor, fixed-wing, and fixed-wing hybrid, while multi-rotor UAS is the most predominan9xtly used among construction firms. The initial investment costs, and annual maintenance expenses for UASs range from $4,000 to $35,000 per UAS based on the different applications the firms use. Noted barriers to using UASs in construction included low awareness of UASs applications among construction professionals, professional training requirements, large initial capital requirements, and issues related to flying in congested areas, night times, and different weather conditions. In the future, UASs can be expanded to integrate with other technological advancements to further improve construction operational efficiency.

The limitations of this study include a small sample size and that all participants were from the same region. Future research is recommended to explore a mixed-methods study to collect data from across the U.S. regarding the current state of practice and will perform a cost-benefit analysis of using UASs in construction. This study contributes to the body of knowledge by identifying application areas, the current state of practice, and barriers to implementing UASs in construction. This information can be utilized by prospective construction firms that want to implement UASs to take informed decision-making regarding the implementation of UASs within their firms.

References

Barmpounakis, E., and Geroliminis, N. (2020). “On the new era of urban traffic monitoring with massive drone data: The pNEUMA large-scale field experiment.” Transportation Research Part C: Emerging Technologies, 111, 50–7

de Melo, R. R. S., Costa, D. B., Álvares, J. S., and Irizarry, J. (2017). Applicability of unmanned aerial system (UAS) for safety inspection on construction sites. Safety Science, 98, 174–185. https://doi.org/10.1016/J.SSCI.2017.06.008

DiCicco-Bloom, B., & Crabtree, B. F. (2006). The qualitative research interviews. Medical Education, 40(4), 314-321. doi: https://doi.org/10.1111/j.1365-2929.2006.02418.x

Enríquez, C., Jurado, J. M., Bailey, A., Callén, D., Collado, M. J., Espina, G., Marroquín, P., Oliva, E., Osla, E., Ramos, M. I., Sarceño, S., and Feito, F. R. (2020). “The UAS-Based 3D Image Characterization of Mozarabic Church Ruins in Bobastro (Malaga), Spain.” Remote Sensing, Multidisciplinary Digital Publishing Institute, 12(15), 2377

Gheisari, M., Rashidi, A., and Esmaeili, B. (2018). “Using Unmanned Aerial Systems for Automated Fall Hazard Monitoring.” Construction Research Congress 2018, American Society of Civil Engineers, New Orleans, Louisiana, 62–72

Goldman Sachs. (2017). Drones:Reporting for work. https://www.goldmansachs.com/insights/technology-driving-innovation/drones/

Hiasa, S., Karaaslan, E., Shattenkirk, W., Mildner, C., & Catbas, F. N. (2018, April). Bridge inspection and condition assessment using image-based technologies with UAVs. In Structures Congress 2018: Bridges, Transportation Structures, and Nonbuilding Structures (pp. 217-228). Reston, VA: American Society of Civil Engineers.

Jiang, W., Zhou, Y., Ding, L., Zhou, C., and Ning, X. (2020). “UAV-based 3D reconstruction for hoist site mapping and layout planning in petrochemical construction.” Automation in Construction, 113, 103137.

Kielhauser, C., Renteria Manzano, R., Hoffman, J. J., & Adey, B. T. (2020). Automated Construction Progress and Quality Monitoring for Commercial Buildings with Unmanned Aerial Systems: An Application Study from Switzerland. Infrastructures, 5(11), 98.

Mason, M. (2010, August). Sample size and saturation in PhD studies using qualitative interviews. In Forum qualitative Sozialforschung/Forum: qualitative social research (Vol. 11, No. 3).

Shakhatreh, H., Sawalmeh, A. H., Al-Fuqaha, A., Dou, Z., Almaita, E., Khalil, I., & Guizani, M. (2019). Unmanned aerial vehicles (UAVs): A survey on civil applications and key research challenges. IEEE Access, 7, 48572-48634.

Simms, C. and Rogers, B. (2006), “The significance of flexibility in improving return on property investment: the UK perspective”, Facilities , Vol. 24 Nos 3-4, pp. 106-119

Tummalapudi, M., Killingsworth, J., Harper, C., & Mehaney, M. (2021). US Construction Industry Managerial Strategies for Economic Recession and Recovery: A Delphi Study. Journal of Construction Engineering and Management, 147(11), 04021146.

Wang, X., Al-Shabbani, Z., Sturgill, R., Kirk, A., & Dadi, G. B. (2017). Estimating earthwork volumes through use of unmanned aerial systems. Transportation Research Record, 2630(1), 1-8.

Yeh, T. W., and Chuang, R. Y. (2020). “Morphological Analysis of Landslides in Extreme Topography by UASSfM: Data Acquisition, 3D Models and Change Detection.” The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Copernicus GmbH, Gottingen, XLIII-B5-2020, 173–178

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A Step Towards Automated Tool Tracking on Construction Sites: Boston Dynamics SPOT and RFID

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Tool tracking and inventory management on a construction project is often more reactive than proactive. It is not that tools are not of value, but to larger firms, a certain comfort level exists with a loss to a relatively small line item, especially when compared to the resources that may be expended to track the tool inventory. With current market construction robotics serving a number of uses, testing multiple applications of autonomous robots creates more return for end-users. This research aims to execute a proof of concept for automated tool tracking using an autonomous robot and RFID technology. The research was carried out with three types of scans namely: Human held RFID reader; Robot mounted RFID reader in manual mode; Robot mounted RFID reader in autonomous mode. A total of 39 tools were tagged using passive UHF RFID tags and the study looked at the average cycle count time it took time to read 39 tags for the three scan types and the reliability of the robot and RFID technology. Results show reliability of the autonomous robot in acquiring RFID information, including zero failures in tag identification and autonomous guidance.

Key Words: Construction Robotics, RFID tags, Autonomous Tool Tracking, Automation

Introduction

Tool loss (aka “shrink”) and inventory management represent variable line items for all construction projects. Although a certain amount of tool depreciation and/or replacement is expected with each project, loss (such as theft) and the costs associated with tracking tools on a jobsite is often an unknown. In 2005, Berg & Hinze studied the effects of theft on jobsites and noted that of 102 firms surveyed, 42 had experienced an incident of tool theft, averaging roughly $1,617 per incident. The result from their work shows that stolen tools, equipment, or materials are rarely recovered, with about a 7% recovery rate. In addition to theft, the cost associated with inventory management is typically placed on an onsite employee who has a multitude of other job requirements Goedert et al. (2009).

Today, tool tracking is still an evolving field. Many tool manufacturers have Bluetooth enabled sensors that are either integrated into the tools or can be placed on the outside of the tool. This technology works well but does have a couple of inherent issues. First, the technology is active, meaning it requires battery power that will drain over time and eventually fail. Second, these Bluetooth sensors are expensive. Depending on quantity purchased, a single external tag can cost $30 or more (Grainger, n.d).

Advancements in passive UHFRFID technology and autonomous mobility platforms has allowed research to improve tool tracking where Bluetooth technology is limited. Passive UHF does not require battery power and the cost associated with each tag runs in the cents, not dollars. With current market construction robotics serving several uses, testing multiple applications of these robots creates more return for end-users. This research explores the use of inventory management through passive UHF and autonomous robotics. The research attempts to address the following questions:

1. Are there any challenges associated with RFID scanning via manual or autonomous terrestrial robots?
2. In an experimental setting, what is the average cycle count time for the three scan types i.e., Human held RFID reader; Robot mounted RFID reader in manual mode; Robot mounted RFID reader in autonomous mode?
3. Is there any failure in capturing the Passive UHF tags for any of the three scan types?

Although the focus of the study was on small tools, the researchers believe that the findings of this proof of concept could be extrapolated to equipment and materials – recognizing that the RFID tags may need to change based on the material makeup of the tagged item.

Literature Review

There is an abundant literature that addresses Real Time Locating Systems (RTLS) technologies. Li et al., (2016) state that Radio frequency identification (RFID), Global positioning system (GPS), Ultra-wideband (UWB), Vision analysis, Wireless local area network (WLAN), Ultrasound, Infrared (IR) are some of the examples of RTLS technologies.

According to (Valero et al., 2015), tool misplacement in the workplace cause undesirable interruptions. On one hand, the workers will be looking for the proper tool on a jobsite, this being a time-consuming task. In other instances, the tool inventory will be enhanced to avoid delays. In either of the settings, there is money that is lost. However, the addition of RFID tags to the equipment can be a useful strategy to optimize the budget.

Lu et al., (2011) also backs that RFID technology can be applied to locating machines and tools; with its strengths of wavelength, and contactless. Goodrum et al., (2006) developed a tool tracking and inventory system which is also capable of storing operation and maintenance (O&M) data using commercially available active radio frequency identification (RFID) tags. The study demonstrated that active RFID can be used to inventory small tools and store pertinent O&M data on the tools in construction environments

Although RFID is neither the most accurate nor the most conveniently deployed RTLS, its application in the construction industry has been researched intensively (Li et al., 2016); 36 out of 90 (total studies selected for RTLS) positioning studies talk about RFID applications in Construction Industry. Li et al., (2016) cites (Ko, 2010; Montaser & Moselhi, 2014) to suggest that the accuracy of RFID can be improved by using different locating techniques and algorithms. For example, Montaser and

Moselhi (2014) compare accuracy by two locating techniques, triangulation, and proximity, while Ko (2010) compares the accuracy of the different algorithms being used.

Sun et. al, (2013) proposes the following applications of RFID in construction industry namely: i. Construction Time and Schedule Management; ii. Construction Quality Management; iii. Construction Supply Chain Management; iv. Construction Safety Management; v. Construction Document Management; vi. Construction Waste Management

In addition to the above, Table 1 summarizes some of the key studies relevant to application of RFID technology within the context of Construction Engineering and Management from before 2010.

Table 1

Notable Secondary Literature in the domain of RFID and Construction Engineering and Management [adopted from (Lu et al., 2011)]

Citation	**Remarks**
Jang and Skibniewski (2009)	Development of a system for tracking construction assets by combining radio and ultrasound signals.
Goodrum (2006)	Employed the technology for tool tracking on construction job sites.
Dziadak et al. (2009)	Using RFID, developed a model for three-dimensional position of underground assets.
Domdouzis et al. (2007)	Exploratory study on utilizing RFID in the construction industry for tracking of pipe and other valued items, and an in-situ inspection.
Tzeng et al. (2008)	Investigated the effect of RFID and interior finishing materials on RFID system recognition.
Yin et al. (2009)	Established a precast production management system using RFID technology
Wang (2008)	Carried an exploratory study to use RFID technology to improve construction quality inspection and management.
Chin et al. (2008)	Combined RFID and 4D CAD to logistics and progress management using an information system approach.

Methodology

The aim of this exploratory study was to execute and present a proof of concept that involves testing passive UHF with the aid of an autonomous, terrestrial robot for inventory management through an operational experiment carried out at Robins and Morton Construction Field Laboratory, Auburn University. The test was carried out to verify a proposed conceptual mechanism of integrating autonomous robot and a RFID scanner mounted on the robot. The equipment used are "off-the-shelf" and available to the public.

Autonomous Robot

The autonomous robot used in this study is a Boston Dynamics SPOT. SPOT was selected for this research for two reasons; the robots capabilities and the availability of the robot to the researchers. During the experiment, the robot was carrying 4 payloads – A pan/tilt/zoom camera as a mount, a Zebra RFD8500 handheld RFID reader, and a Velodyne LiDAR scanner and SPOTCore processor to improve the autonomous vision of the robot during the autonomous walk. Figure 1 presents the payload layout during the experiment.

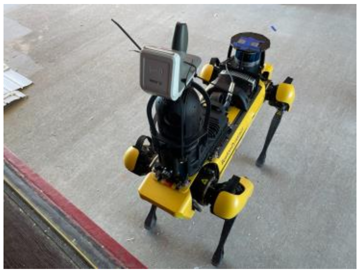

Figure 1. RFID Reader Mounted on top of SPOT

RFID

There are several hundred options for inlays for passive UHF RFID inlays. Performance of a passive UHF RFID system is determined by the RFID reader, the transmit and receive antenna attached to the reader, any environmental factors between the reader antenna and the RFID inlay, and the type of material the RFID inlay is attached to. For the purposes of this research, a combination RFID reader/antenna unit was used, which we will refer to collectively as the "reader".

The RFID reader was a Zebra RFD8500. There were a variety of tools to be tagged. Because the tools are manufactured with various combinations of rubber, plastic, metal, and other materials, it was challenging to find a consistent tagging location across all tool types to apply the inlay. In a full deployment, specially cased RFID inlays can be selected to offset the effects of the different material types. However, for feasibility testing and use case validation we selected a general-purpose inlay.

The Avery Dennison Dogbone R6 is a midsize inlay with generally even performance across various types of materials. The product data sheet is attached which illustrates theoretical read range across a variety of material types. In testing through various projects at the Auburn RFID Lab, the Dogbone is generally considered a solid first choice option for testing tagged items with a variety of unspecified material types and configurations.

In full deployment, it is likely possible that smaller inlays may be used as well. It is recommended to select a tagging location across all tool types in which the inlay can be applied to a consistent material type, and to use a ruggedized inlay, encased in plastic or rubber material, to protect the inlay from damage, and to offset the inlay from the tool for improved performance.
For the purposes of this testing, the Dogbone R6 inlays scanned on all products tagged in each testing scenario.

The Experiment

The research looked at three scan types, using 10 scans for each type:

a) Human held RFID reader
b) Robot mounted RFID reader in manual mode
c) Robot mounted RFID reader in autonomous mode

As shown in Figure 2, the tools are stored in an 8'W x 40' L x 8' H Conex. The tagged tools within the Conex are located on the floor and wall mounted in a space roughly 6.5' H x 16' L. A total of 39 tools were tagged.

Figure 2. Tagged Tools in Conex

The experiment was designed in a manner to first establish a control study (Human held RFID reader) and then compared with that of the SPOT's performance in two modes i.e., Guided and Autonomous. Time taken to register all 39 tags was chosen as the performance metric while also verifying that all 39 tags were read properly, and the robot did not have any issue with the autonomous actions.

Data Collection

Each scan type began from the same point, roughly 15 feet from the threshold of the Conex box where the tools are stored. The cycle count time clock was started once the human researcher took their first step towards the Conex with the reader activated. For the robot, the cycle count time was started when the robot took its first step in manual mode or when the user pushed "play" to active the autonomous mode. This distinction is important, as the autonomous robot often has a delay in its first steps (~3 seconds) while it downloads the guidance and data packages from the handheld where that information is stored.

Human held RFID reader

The first scan was carried out by two of the researchers using a RFID Scanner and a stopwatch. The cycle count time was started as soon as the Human held scanner started moving towards the Conex and stopped as soon as all 39 tags were recorded. This was repeated 10 times.

Robot mounted RFID reader in Manual Mode

As shown in Figure 1, the RFID reader was placed atop the robot's PTZ camera in order to elevate it. The manual mode scan was carried out by a team comprising of three researchers – a timekeeper, a researcher watching the tag counts, and a robot pilot. The cycle count time was started as soon as the robot started moving towards the Conex and stopped as soon as all 39 tags were recorded. This was repeated 10 times.

Robot mounted RFID reader in autonomous mode

The final scan type was carried out by utilizing the autonomous mobility function of SPOT i.e., Robot mounted RFID reader in autonomous mode. The robot was trained to walk the same route as the human and manual robot. The cycle count time clock was started as soon as the robot pilot activated the autonomous mode. This was repeated 10 times.

Results

Q1: Are there any challenges associated with RFID scanning via manual or autonomous terrestrial robots?

The research did not encounter any issues with the robot in manual or autonomous mode. As a proof of concept, the research yielded strong results; however, the number of robot-based runs (20 in total), the controlled/lab-based setting (i.e. no obstructions or variability), and the short distances all played a role in the reliability of the robot. Future research will continue to add complexity to the robot's abilities in manual and autonomous mode.

Q2: In an experimental setting, what is the average cycle count time for the three scan types i.e., Human held RFID reader; Robot mounted RFID reader in manual mode; Robot mounted RFID reader in autonomous mode?

The analysis results are presented in three forms namely: i. Box-Whisker plot to visualize the variation in recorded data for all three types of scans respectively; ii. Descriptive analysis for the cycle count time data gathered, iii. Trend analysis for the cycle count times for the total of 10 runs conducted for each of three scans respectively. Table 2 summarizes the descriptive statistics for the 10 test runs that were conducted for each of three scan types.

Table 2

Descriptive Statistics for each of the three scanning strategies in Cycle Count Time

Run Number	Human held RFID reader (sec)	Robot mounted RFID reader in manual mode (sec)	Robot mounted RFID reader in autonomous mode (sec)
Run 1	6.49	5.16	7.57
Run 2	6.18	5.38	6.54
Run 3	4.04	4.69	7.67
Run 4	6.03	4.47	8.24
Run 5	4.76	4.87	5.97
Run 6	4.47	4.56	7.84
Run 7	4.83	4.54	9.17
Run 8	5.74	5.58	11.00
Run 9	4.83	4.56	6.2
Run 10	8.51	4.88	9.46
Mean	**5.59**	**4.87**	**7.97**
Min	4.04	4.47	5.97
Max	8.51	5.58	11.00
SD	**1.31**	**0.39**	**1.58**

To point out the key result of the experiment, the second scan type i.e., Robot mounted RFID reader in manual mode was the quickest on average (Mean Cycle Time: 4.87 seconds) and with relatively lesser deviation in performance (SD: 0.39 seconds).

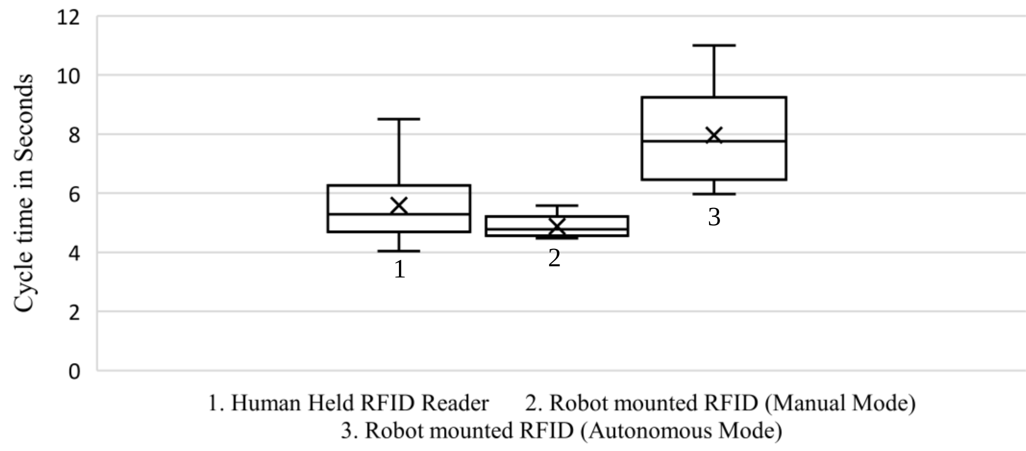

Figure 3: Box-Whisker Plot for Three Scanning Strategies

Observing Figure 3, the robot mounted reader in manual mode has the least amount of variation, and all the cycle count times vary to a small extent. The researchers conjecture a couple of reasons for these results:

1. A RFID Reader generally requires the user to agitate the field. Often this is done with the user "painting" the air with an up-and-down motion with the reader in their hand. While mounted on the robot, this painting motion is not possible; however, the robot does have a natural agitation that occurs while it is walking. Perhaps the gait and speed of the robot provided the agitation the reader required more efficiently than the broader painting motion the human researcher was using.
2. Although the three scan types took the same route to the tags, the human held RFID reader was likely positioned differently to begin each cycle count time. At the initiation of a cycle count, the handheld was often waist-side by the user. This is a natural and unintentional starting point, but perhaps played a role in the time for the reader to identify all the tags. On the robot, because of the mount being placed forward facing, at the initiation of the cycle count time, the handheld was already facing the tags.

The maximum variation was related to the robot mounted RFID reader in autonomous mode. This delay is a function of the data packages sent from the handheld to the robot. Upon receiving the start command, there is a small initiation sequence that the robot must perform. All time delays such as these, were included in cycle count time observations for this option. It was believed that all these intermediate steps are part and parcel of the cycle count time and therefore must be recorded.

Figure 4 further reiterates this data, showing a comparison of cycle count times graphically.

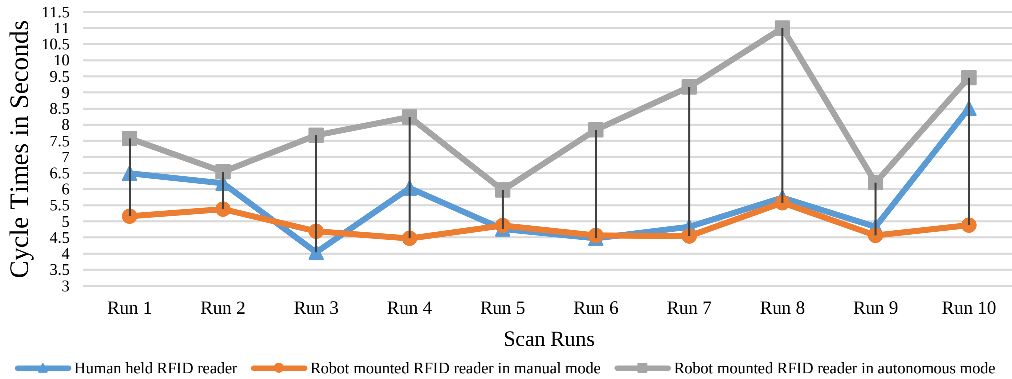

Figure 4. Relative performance of each run and scan type

Q3: Is there any failure in capturing the Passive UHF tags for any of the three scan types?

There were no UHF tag or reader failures during the experiment. In every run, all 39 tags were found within an acceptable timeframe.

Conclusions and Recommendations

At the conclusion of the proof of concept, the following conclusions and recommendations can be put forward.

Overall, terrestrial, autonomous robotics does appear to be a potential use for tool tracking. In terms of reliability, both the RFID technology and the robotics technology executed the scope of this research without fail. However, with all 30 runs in a lab-based setting, future research should look at more challenging and robust use cases. When evaluating efficiency (cycle count time), it can be concluded that on an average the 'robot mounted RFID reader in manual mode' was the quickest. It is worth mentioning that the respective cycle count times were almost certainly time dependent on the skill of the operator. Since the operator was extremely skillful, the least standard deviation is reflective of similar performance for the 10 scans that were conducted. Furthermore, after the initial few scans, the variability between the performances in 'human held RFID reader' and 'robot mounted RFID reader in manual mode' reduced considerably. Although the autonomous robot was the slowest, in practice, this number is irrelevant. In this proof of concept, the research showed the robot can be used autonomously for tool tracking. Without the need for human intervention, a slower cycle count time doesn't matter. As long as the cycle count time doesn't exceed the roughly 90-minute battery life of the robot, the productivity savings for a human; stands at 100%. It is worth noting that the costs associated with the robot and scanning equipment are significant and would certainly play a factor in the economics of a construction project. However, history has shown that often these types of technologies become cheaper as the tech improves. In addition, as more use cases are developed for both autonomous robotics and RFID on construction products, the productivity savings begin to offset the initial and lifecycle costs of these technologies.

With a successful proof of concept, the authors believe the following recommendations will pave the way for more robust autonomous tool tracking on construction sites. Future research could include:

- Variable placement settings for tagged tools, such as placing them inside a gang box or truck.

- Height limitations and the use of collaborative robotics (i.e., drones + terrestrial robots)
- Different types of RFID tags to understand the impact on performance.
- Test under on-site conditions, including muddy, rough terrain, longer distances, weather issues, variable materials, etc.

References

Berg, R., & Hinze, J. (2005). Theft and Vandalism on Construction Sites. *Journal of Construction Engineering and Management*, *131*(7), 826–833. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:7(826)

Bluetooth Tool and Equipment Tracker, Attachment Glue, Screw, Strap, Rivet. (n.d.). Grainger. Retrieved November 11, 2021, from https://www.grainger.com/product/MILWAUKEE-Bluetooth-Tool-and-Equipment-53GK35

Chin, S., Yoon, S., Choi, C., & Cho, C. (2008). RFID+ 4 D CAD for progress management of structural steel works in high-rise buildings. *Journal of Computing in Civil Engineering*, *22*(2), 74-89.

Domdouzis, K., Kumar, B., & Anumba, C. (2007). Radio-Frequency Identification (RFID) applications: A brief introduction. *Advanced Engineering Informatics*, *21*(4), 350-355.

Dziadak, K., Kumar, B., & Sommerville, J. (2009). Model for the 3D location of buried assets based on RFID technology. *Journal of Computing in Civil Engineering*, *23*(3), 148-159.

Goedert, J. D., Foster, E. T., Jewell, J., & Bartek, J. (2009). Automated Tool Tracking on the Construction Site. *International Journal of Construction Education and Research*, *5*(1), 12–23. https://doi.org/10.1080/15578770902717535

Goodrum, P. M., McLaren, M. A., & Durfee, A. (2006). The application of active radio frequency identification technology for tool tracking on construction job sites. *Automation in Construction*, *15*(3), 292–302. https://doi.org/10.1016/j.autcon.2005.06.004

Jang, W. S., & Skibniewski, M. J. (2009). Embedded system for construction asset tracking combining radio and ultrasound signals. *Journal of Computing in Civil Engineering*, *23*(4), 221-229.

Ko, C.-H. (2010). RFID 3D location sensing algorithms. *Automation in Construction*, *19*(5), 588–595. https://doi.org/10.1016/j.autcon.2010.02.003

Li, H., Chan, G., Wong, J. K. W., & Skitmore, M. (2016). Real-time locating systems applications in construction. *Automation in Construction*, *63*, 37–47. https://doi.org/10.1016/j.autcon.2015.12.001

Lu, W., Huang, G. Q., & Li, H. (2011). Scenarios for applying RFID technology in construction project management. *Automation in Construction*, *20*(2), 101–106. https://doi.org/10.1016/j.autcon.2010.09.007

Montaser, A., & Moselhi, O. (2014). RFID indoor location identification for construction projects. *Automation in Construction*, *39*, 167–179. https://doi.org/10.1016/j.autcon.2013.06.012

Tzeng, C. T., Chiang, Y. C., Chiang, C. M., & Lai, C. M. (2008). Combination of radio frequency identification (RFID) and field verification tests of interior decorating materials. *Automation in Construction*, *18*(1), 16-23.

Valero, E., Adán, A., & Cerrada, C. (2015). Evolution of RFID Applications in Construction: A Literature Review. *Sensors (Basel, Switzerland)*, *15*(7), 15988–16008. https://doi.org/10.3390/s150715988

Wang, L. C. (2008). Enhancing construction quality inspection and management using RFID technology. *Automation in construction*, *17*(4), 467-479.

Yin, S. Y., Tserng, H. P., Wang, J. C., & Tsai, S. C. (2009). Developing a precast production management system using RFID technology. *Automation in construction*, *18*(5), 677-691.

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Integration of a UAS-Photogrammetry Module in a Technology-based Construction Management Course

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The significantly increased usage of Unmanned Aerial Systems (UASs) and photogrammetry technologies in the construction industry underlines the need to integrate such technologies within the educational curricula. This paper presents the lessons learned from a recent effort to integrate a UAS-Photogrammetry module in a technology-based construction management course. Specifically, the goal was to enable students to better understand the generated point clouds through interpreting and comparing their visual quality differences while studying how common flight parameters [i.e., ground sampling distance (GSD), image angle, image combination] might affect them. This course module consisted of a theoretical knowledge part followed by a hands-on training part. As a part of this module, students generated point clouds, performed photogrammetric measurements, and conducted detailed comparisons based on different flight parameters. The module could provide construction students an opportunity to better understand and assess the effects of different UAS flight parameters on the quality of the generated photogrammetric point clouds.

Key Words: Unmanned Aerial Systems, Surveying, Photogrammetry, Structure-from-Motion (SfM), Construction Education

Introduction

Technological advancements have enabled Unmanned Aerial Systems (UASs) to become more inexpensive and widely used on construction jobsites within the past ten years (Albeaino, Gheisari, & Franz, 2019; Rakha & Gorodetsky, 2018). These aerial vehicles can easily access hard-to-reach locations while safely, cost-efficiently, and timely accomplishing various tasks, including structural and infrastructure inspection, safety management, progress monitoring, and building maintenance (Albeaino & Gheisari, 2021). Such growth in UAS-mediated applications constitutes a driving force for educational construction programs to train and prepare graduating students to use UAS technology in this setting (Albeaino, Eiris, Gheisari, & Issa, 2021; Eiris, Zhou, & Gheisari, 2018). Training future generations of construction professionals is critical, especially with the current lack of skilled UAS pilots and safety managers available on jobsites (Golizadeh et al., 2019; Park, Kim, & Cho, 2017). In fact, while almost all construction companies purchase UAS equipment instead of designing their own aerial platforms, safety managers and UAS operators are needed on every jobsite to ensure the safe deployment of UASs especially over workers and other construction personnel to avoid, for example, struck-by and fall accidents (Martinez, Albeaino, Gheisari, Issa, & Alarcón, 2021). This becomes particularly important with the wide deployment of UAS, the applications of which are expected to expand even more in the future.

Regardless of the construction task type, three steps are required when deploying UASs on jobsites. Step one consists of pre-planning the flight mission(s). Pre-planning tasks include setting flight parameters and navigation style and ensuring that the mission(s) are performed safely and as per the Federal Aviation Administration (FAA) Part 107 requirements (US Department of Transportation, 2016). Step two entails the collection of visual (e.g., images, videos) information of the intended facility. Finally, step three involves post-processing the UAS-acquired visualizations for further analysis and interpretation, depending on the construction task (Albeaino et al., 2019; Rakha & Gorodetsky, 2018). Collected UAS visuals can be: (1) relied upon as standalone images and videos; (2) combined with computer vision and other machine learning techniques; or (3) processed using Structure-from-Motion (SfM) to generate different photogrammetric products (e.g., point clouds, digital surface models, digital elevation models, orthophotos) (Rakha & Gorodetsky, 2018). The latter technique is considered one of the most popular methods for processing UAS-captured data. For this purpose, there is a need to integrate the concepts of UAS-Photogrammetry within construction engineering and management curricula (Albeaino et al., 2021; Eiris et al., 2018).

Multiple studies have focused on the integration of UASs in education. In geomatics and geology, geospatial thinking enabled students to collect UAS images and process them (Al-Tahir, 2015; Jordan, 2015; Sharma & Hulsey, 2014). In engineering, Molina et al. (2014) recruited a team of undergraduate mechanical, electrical and computer engineering students to solve range- and endurance-related issues that quadrotors typically encounter in closed perimeters. Wlodyka & Dulat (2015) asked undergraduate engineering students to design and model different UAS payload configurations before fabricating and installing them on actual aerial platforms. Eiris et al. (2018) and Williamson III and Gage (2019) introduced undergraduate construction students to UASs through course modules and class activities. In both studies, students were exposed to the entire UAS-mediated photogrammetry process, ranging from UAS pre-flight planning and deployment to data collection and processing. Upon processing the UAS-collected data, students also combined photogrammetry with building information modeling (BIM) (Eiris et al., 2018). Recently, Albeaino et al. (2021) developed a virtual reality environment to safely train construction students to perform building inspections using UASs. Many of these studies focused on improving students' UAS piloting skills. Some others have even introduced students to the general processes of SfM and photogrammetry. However, none of these studies had specifically exposed undergraduate students as to how different flight parameters used on site might affect the visual quality of the generated photogrammetric point clouds. Students' abilities to understand how, for example, image angle, image combinations, and ground sampling distance (GSD), affect the resulting visual quality of the point cloud is of particular importance, especially since many UAS applications in construction necessitate generating high-quality 3D point clouds and models to accurately interpret the obtained results and draw meaningful conclusions. These factors – among others – constitute a field of research in geomatics and surveying, and given the increased use of UASs in construction, researchers have recently started to use different combinations to improve the quality of the generated point clouds (Martinez, Albeaino, Gheisari, Volkmann, & Alarcón, 2021). To satisfy this pedagogical need, this study focuses on creating a UAS-Photogrammetry module that provides students with a good understanding of how different flight parameters (i.e., GSD, image angle, image combination) might affect the generated 3D point clouds and models. The module specifically aims at preparing students who can plan UAS flights, operate aerial vehicles, and process corresponding acquired visuals to compare the effects of different flight parameters on the visual quality of the photogrammetrically-generated point clouds. First, details on the UAS-Photogrammetry module in the technology-based course, along with students' learning objectives and expected outcomes, are presented. Details related to the theoretical (lecture-based introduction targeting different UAS-related concepts) and the hands-on (performed flight missions together with collected and SfM-processed UAS data) components constituting the UAS-Photogrammetry module are then provided. Finally, lessons learned from the course module are presented, and future research is proposed.

Methodology

Course Description and UAS-Photogrammetry Module Integration

The UAS-Photogrammetry module, for which four sessions (total of six hours) were dedicated, was integrated into the *BCN4252: Introduction to Building Information Modeling* course offered as an undergraduate-level course at the Rinker School of Construction Management (University of Florida). In this course, construction management students get introduced to BIM-based workflows and advanced technologies such as BIM-based clash detection, BIM-based quantity takeoffs, BIM-based site planning and walkthroughs, mixed/virtual/augmented reality, 360-degree photo/videography, laser scanning, and photogrammetry using UASs. Each module in this course – including the UAS-Photogrammetry module – consists of two parts: theoretical knowledge and hands-on training. The following paragraphs summarize the theoretical knowledge and hands-on training parts of the UAS-Photogrammetry course module, reflecting students' learning objectives and expected outcomes out of these 6-hr sessions (Table 1).

For the UAS-Photogrammetry module, the theoretical knowledge component focused on introducing students to the concepts of point clouds, photogrammetry and laser scanning, which are two data collection methods typically adopted to generate point clouds. The advantages and disadvantages of these data collection methods and their relationship with UASs were also discussed. The theoretical knowledge also introduces students to the concept of UASs and UAVs (Unmanned Aerial Vehicles), their types (e.g., rotary-wing vehicles, fixed-wing vehicles, blimps) along with advantages and disadvantages about each type, their software and hardware components (including common payloads such as GPS, altimeters, inertial measurement units, barometers), technical requirements, and autonomous features (e.g., auto takeoff/landing, waypoint navigation, return home) typically used in construction. Students were also able to recognize current UAS-related FAA Part 107 regulations in addition to the topics that Part 107 covers to obtain a certificate and commercially fly a UAS in the United States. These topics mainly included airspace classification, flight restrictions, operation requirements, as well as aviation weather sources and forecasts. Finally, different UAS-mediated application examples within the AEC domain, the potential safety challenges of UAS flights, and commonly used point cloud generation software were also presented. The hands-on training part consisted of flight operation and visual data collection, followed by point cloud generation. The following sections summarize each of these hands-on training steps in detail.

Table 1. Students' theoretical and hands-on practical knowledge learning objectives

Theoretical Knowledge (two 1-hr sessions)	Hands-on Practical Knowledge (two 2-hr sessions)
Student learning objectives: • Define a point cloud. • Describe photogrammetry and laser scanning.	*Student learning objectives:* • Fly a UAS autonomously and manually • Collect different sets of visuals from different angles, heights, and positions.

- Identify the advantages and disadvantages of photogrammetry and laser scanning.
- Define the concept of UAV/UAS/Drone.
- Indicate the technical requirements of UASs.
- Recognize the FAA's basic regulations and where to find more information about them.
- Discuss current UAS applications in the Architecture, Engineering, and Construction (AEC) domain.
- Explain safety challenges a UAS might present in a construction jobsite.
- List a few software tools to create point clouds.
- Use SfM processing software to generate 3D models and orthophotos.
- Perform comparative analyses on the visual quality of the generated point clouds.

Flight Operation and Visual Data Collection

The goal behind performing the hands-on training was to train students on how to (Figure 1): (1) fly using both autonomous (i.e., pre-planned flight missions using flight planning software) and manual control; (2) collect different sets of visuals based on different image combinations (e.g., high, low, and oblique): different angles (i.e., nadir or at a 45° angle) and heights [i.e., ground sampling distances (GSDs): 0.05 cm/px or 1 cm/px]; (3) use structure-from-motion (SfM) processing software to generate three-dimensional (3D) point clouds and orthophotos based on the acquired UAS images; and (4) analyze and compare the effects of image angle, height, and combination on the generated point cloud visual quality.

During the knowledge part discussed in the previous section, students had already been exposed to the entire SfM- and photogrammetry-based point cloud generation workflow process. Due to COVID-19 implications, which forced our course to be instructed online, students could not conduct the planned flight operations in person but were able to perform all other hands-on tasks (Figure 1 – steps 2 and 3). For this reason, graduate assistants who were licensed UAS Part 107 remote pilots performed the data collection and provided the UAS-acquired visuals to students for point cloud generation and data analysis.

Different UAS flights were conducted at a University of Florida building, located at The Energy Research and Education Park in Gainesville, FL (Figure 1). The building has a total surface area of 924 m^2 and was selected based on the following reasons: (1) flying UASs in that location was neither part of any FAA-restricted airspace nor did it need to follow any UAS operational guidelines from the University of Florida's Department of Environmental Health and Safety; (2) the building together with its surrounding area had no vegetation (i.e., trees), metallic structures, and any other facilities that could otherwise negatively affect novice students' piloting judgment and potentially cause unsafe UAS-related situations (e.g., collisions, struck-by accidents).

A total of three flights (two autonomous and one manual) were performed during the data collection to cover all three image combinations (i.e., high, low, and oblique). High images were collected by capturing nadir type of images with a GSD of 1 cm/pixel; low images were also acquired as nadir images, but with a GSD of 0.05 cm/ pixel; and oblique images were captured at a 45° camera angle. Table 2 summarizes different UAS flight parameters adopted during the data collection process. The

DJI® Phantom 4 Pro quadcopter was used as the data collection platform due to its popularity and wide usage within the AEC domain (Albeaino et al., 2019). In addition, the Pix4Dcapture® software was relied upon to plan for each of these three flight missions. The platform, which was programmed to fly at a speed of 3 m/s, weighs 1.34 kg (including propellers and batteries), has a camera resolution of 5,472 × 3,648 pixels, and can operate for 25-30 minutes. All three flights were conducted on the same day, between 11:00 and 13:00, to minimize the effect of shadow on acquired images. The following section discusses the data processing workflow, in which students had to use Structure-from-Motion (SfM) and photogrammetry-based image processing software for the point cloud generation.

Figure 1. Data collection location and hands-on training workflow

Table 2. UAS flight parameters

Flight* #	Flying style	Image type	Height (in m) AGL*	Front overlap (%)	Side overlap (%)	# of images
1 (Low)	Autonomous	Nadir	18	80%	72%	86
2 (High)	Autonomous	Nadir	36	80%	72%	37
3 (Oblique)	Manual	Oblique (45°)	22	N/A	N/A	70

** Flight mode: Double-grid, ** Above Ground Level*

Point Cloud Generation

Students were provided with detailed instructions on how to process the 193 collected UAS-acquired images using photogrammetry and SfM to generate two different point clouds based on two different image combinations as follows (Figure 2): Point cloud #1 – generated using low (GSD = 0.05 cm/pixel) images only; Point cloud #2 – generated using high (i.e., GSD = 1 cm/pixel), low (GSD = 0.05 cm/pixel), and oblique images (45° angle). The goal behind these two sets of point cloud generation was to help students better understand the effect of different flight parameters on the resulting point cloud visual quality. Students were asked to use DroneDeploy®, one of the most commonly used cloud-based UAS management and point cloud generation software in construction (Albeaino & Gheisari, 2021). First, students were instructed to set up an account, explore different UAS applications examples that the software already provides in the construction domain, and create a new project to upload the UAS-captured images. To create a new project, students were asked to input the project location, which helps accurately position the UAS-acquired images on an actual map. Since these UAS images already contain positioning coordinates, manually geo-locating them on the map was unnecessary, and simply adding the data collection location (i.e., zip code) was sufficient. Upon project creation, students were asked to explore different software capabilities, which range from pre-flight planning (e.g., setting flight parameters such as operation height; programming autonomous flight missions by defining GPS waypoints) to cloud-based post-processing (e.g., point cloud and orthophotos generation) and collaboration (i.e., UAS team members managing and collaborating on generated SfM and photogrammetric solutions). Using the "Create a Map or Model" option, the UAS-acquired images were uploaded, and the corresponding point clouds were generated using cloud-based image processing. This process was repeated twice to generate both point clouds (Figure 2).

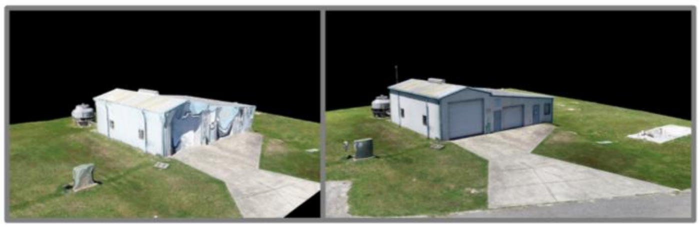

Figure 2. Generated point clouds [left: point cloud #1 (generated using low images); right: point cloud #2 (generated using low, high, and oblique images)]

Module Assessment

Students' theoretical knowledge and material comprehension were evaluated through a knowledge test consisting of 14 questions based on the topics covered in the module. In addition, each student's SfM and photogrammetry knowledge was also assessed using a project interpretation assignment where students had to individually interpret and discuss the differences between the two generated point clouds. Specifically, each student was asked to: (1) submit a screenshot of 3D point clouds generated using both low (i.e., point cloud #1) and low, high, and oblique (i.e., point cloud #2) images; (2) compare both point clouds and describe the visual quality differences between them; (3) justify why the 3D point cloud generated using different image combinations (i.e., low, high, and oblique) was denser and more visually complete compared with the one generated using low images only; and (4) explain the concept of GSD and how it affects the resulting point cloud visual quality. Through these photogrammetry- and SfM-related questions, students would be able to better understand the effect of different flight parameters (i.e., image angle, height or GSD, image combinations) on the resulting point cloud visual quality.

Results

A total of 15 construction management students enrolled in this course module. Overall, the knowledge test results showed that participants had a good understanding of different UAS-related topics (i.e., UASs, UAS components, technical requirements, autonomous features, applications in construction, FAA regulations and weather reports, SfM and Photogrammetry), as evidenced by their high average score (94.3 over 100) on the 14-questions test. Acquiring such knowledge enables students to: (1) have a good understanding of UASs, SfM and Photogrammetry and how these technologies and techniques are being used in construction; (2) meet the needs of the construction industry, which currently relies on UASs to accomplish different tasks; (3) improve their decision-making skills by distinguishing unsafe UAS practices and safety-related challenges that would cause hazardous UAS-related accidents; and (4) understand current FAA regulations for UAS deployment on jobsites. Furthermore, the hands-on practice part of the course module, together with the project interpretation assignment, enabled students to enhance their understanding of UAS-mediated SfM and Photogrammetry in construction. This was evidenced by their high average score (99.46 over 100) obtained on the project interpretation assignment. Such training also helped them generate point clouds, perform different measurements in the models, generate elevation maps, and analyze the effect(s) of image combinations, angle, and height on the resulting point cloud visual quality.

Specifically, almost all students noticed the visual quality differences between both point clouds. For example, one student responded that: *"[…] The 3D point cloud generated using the high, low, and oblique images had a better texture representation compared to the model generated using only the low images. In addition, while exploring the tools and using the distance tool to measure the exact same distance, the measurements were different for the model generated using low vs. high, low, and oblique images. It is also important to note that the model generated using the high, low, and oblique images is more complete and less distorted. There is also a difference in accuracy in the two models with the model generated using only the low images being less accurate. A greater map area of 0.38 acres is also observed in the model generated using high, low, and oblique images as compared to 0.211 acres generated using only low images. […]".* Another student indicated that the point cloud generated using only low images was *"not crisp at all"*, and that *"much of the building looked deformed and blurry […] edges were rounded and not sharp and it was hard to notice features of the building such as windows, doors and wall patterns."* For the point cloud generated using high, low, and oblique images, students indicated that *"it was the complete opposite"* and that *"the building was clear and very realistic with nothing looking deformed or blurry and edges were sharp and one could easily notice features such as doors and windows of the building."* In addition, the majority of students associated the visual completeness of the 3D models with the camera position (i.e., camera angle), the GSD (camera height), as well as the number of images used during the image processing in their justification on why the low, high, and oblique point cloud was denser and more visually complete compared with the one generated using low images only. As an example, one student indicated that *"[…] the use of more images helps capture many more aspects of the building when compared to the other point cloud […]"*. Other student responses include: *"the high, low, and oblique images can capture more points for the point cloud as it takes pictures from a larger range of angles"* and that the point cloud generated using high, low, and oblique images was more accurate indicating that *"it is easier to calculate points in space if one has multiple different angles of the same point."* Finally, all students were able to define GSD, and successfully relate its effect on the visual quality of the generated point clouds. This was evidenced by participants' responses which include: *"[…] point cloud image quality is directly impacted by ground sampling distance […]"*; *"[…] GSD is related to the flight height, which means the higher the GSD, the higher the altitude of the flight. The higher the GSD value is results in a lower quality resolution of the image […]"*; and *"[…] Lower GSD values produce clearer images […]".*

Conclusion, Limitations, and Future Work

This module provided students with an opportunity to learn more about and apply the entire SfM and Photogrammetry process that construction professionals typically rely on in construction jobsites to analyze UAS-acquired data. They were able to use the provided UAS visuals and generate, using SfM- and Photogrammetry-driven UAS management software, orthophotos, and point clouds before analyzing and comparing the obtained results. Students were also able to qualitatively interpret the visual quality differences between different point clouds while studying how common flight parameters (i.e., GSD, image angle, and image combination) affect the resulting 3D model quality.

Because of the COVID public health concerns, students did not have the chance to conduct the planned flight operations in person. Despite exhaustively describing all the steps involved in the data collection process, multiple students expressed interest in performing data collection, and some of them even sent emails requesting permission to have real-world experience with this part of the assignment. For example, two students indicated that *"[…] It is unfortunate that COVID is not allowing us to fly the drones and have a more hands-on experience […]"* and then asked the following *"[…] Is there any chance I could use my own drone, and complete the required flights and image capturing of a building for this assignment? I think it would be a lot of fun to take my drone out with […] and each capture the sets of images ourselves for the assignment and each turn the assignment in […]"*. While using virtual reality training environments allows students (especially novice pilots) to improve their UAS piloting skills (Albeaino et al., 2021), capturing real-world UAS visuals – an essential step in photogrammetry workflow – within a virtual reality environment remains a challenge. Given current pandemic-related relief measures and the expected transition toward normalcy (i.e., pre-pandemic in-person education), construction management students will soon be able to have hands-on UAS flying experience to autonomously and manually collect, process, generate, and analyze UAS-acquired data.

While the advantages of the adopted UAS management software include cloud-based computation which does not require hardware-heavy workstations for image processing, students did not get exposed to other processing parameters that might affect the resulting point cloud accuracy and visual quality. Examples of these processing parameters include aligning images, optimizing the orientation of images, generating dense models and meshes, as well as enabling the rolling shutter compensation option. In future semesters, additional software packages that allow inputting and modifying different flight parameter values will be used to expand students' understanding of the potential effect(s) of different flight and processing parameters on the generated 3D point clouds. Additional UAS-photogrammetry module activities can be created to compare the effect(s) of image combinations, angles, and heights on the positioning and geometric accuracies of the generated point clouds. High-quality and visually complete point clouds provide users with a complete overview of the intended facility and allow for proper interpretation of its different components (i.e., providing aesthetic information and height data, as well as showing details of complicated areas). However, assessing the positioning and geometric accuracies of point clouds might be extremely helpful, especially when performing fenestration measurements, quality control/quality assurance, or surveying types of construction activities. Future work must also focus on improving students' piloting skills by allocating additional training or practice sessions (in both real-world and virtual reality environments) for such course modules. Doing so will help in better preparing construction graduates for the needs of the construction industry and the expected growth in UAS adoption and safe human-UAS interaction within the domain. Future course modules should also introduce mounting UASs with different sensors (e.g., light detection, and imaging devices) to: (1) compare corresponding point cloud visual, positioning, and geometric accuracies; and (2) explore and apply UASs for different types of construction applications (e.g., thermal leakage detection, underground pipeline inspections, bridge inspection). Finally, user-centered within- and between-subject experiments should be conducted to: (1) assess and show the extent of the affect the module had on student learning; and (2) compare differences in learning from using different approaches to teaching the module.

References

Albeaino, G., Eiris, R., Gheisari, M., & Issa, R. R. (2021). DroneSim: A VR-based flight training simulator for drone-mediated building inspections. *Construction Innovation, ahead-of-print*(ahead-of-print). https://doi.org/10.1108/CI-03-2021-0049

Albeaino, G., & Gheisari, M. (2021). Trends, benefits, and barriers of unmanned aerial systems in the construction industry: A survey study in the United States. *Journal of Information Technology in Construction (ITcon), 26*, 84–111. https://doi.org/10.36680/j.itcon.2021.006

Albeaino, G., Gheisari, M., & Franz, B. W. (2019). A systematic review of unmanned aerial vehicle application areas and technologies in the AEC domain. *Journal of Information Technology in Construction (ITcon), 24*, 381–405. https://www.itcon.org/2019/20

Al-Tahir, R. (2015). Integrating Uav Into Geomatics Curriculum. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XL1*, 387–390. https://doi.org/10.5194/isprsarchives-XL-1-W4-387-2015

Eiris, R., Zhou, S., & Gheisari, M. (2018). Integrating the Use of UAVs and Photogrammetry into a Construction Management Course: Lessons Learned. *Proceedings of the 35th International Symposium on Automation and Robotics in Construction*. https://doi.org/10.22260/ISARC2018/0061

Golizadeh, H., Hosseini, M. R., Edwards, D. J., Abrishami, S., Taghavi, N., & Banihashemi, S. (2019). Barriers to adoption of RPAs on construction projects: A task–technology fit perspective. *Construction Innovation*, *19*(2), 149–169. https://doi.org/10.1108/CI-09-2018-0074

Jordan, B. R. (2015). A bird's-eye view of geology: The use of micro drones/UAVs in geologic fieldwork and education. *GSA Today*, *25*(7), 50–52.

Martinez, J. G., Albeaino, G., Gheisari, M., Issa, R. R. A., & Alarcón, L. F. (2021). ISafeUAS: An unmanned aerial system for construction safety inspection. *Automation in Construction*, *125*, 103595. https://doi.org/10.1016/j.autcon.2021.103595

Martinez, J. G., Albeaino, G., Gheisari, M., Volkmann, W., & Alarcón, L. F. (2021). UAS Point Cloud Accuracy Assessment Using Structure from Motion–Based Photogrammetry and PPK Georeferencing Technique for Building Surveying Applications. *Journal of Computing in Civil Engineering*, *35*(1), 05020004. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000936

Molina, C., Belfort, R., Pol, R., Chacón, O., Rivera, L., Ramos, D., & Rivera, E. I. O. (2014). The use of unmanned aerial vehicles for an interdisciplinary undergraduate education: Solving quadrotors limitations. *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, 1–6. https://doi.org/10.1109/FIE.2014.7044443

Park, J., Kim, K., & Cho, Y. K. (2017). Framework of Automated Construction-Safety Monitoring Using Cloud-Enabled BIM and BLE Mobile Tracking Sensors. *Journal of Construction Engineering and Management*, *143*(2), 1–12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001223

Rakha, T., & Gorodetsky, A. (2018). Review of Unmanned Aerial System (UAS) applications in the built environment: Towards automated building inspection procedures using drones. *Automation in Construction*, *93*, 252–264. https://doi.org/10.1016/J.AUTCON.2018.05.002

Sharma, J., & Hulsey, D. (2014). Integrating the UAS in Undergraduate Teaching and Research-Opportunities and Challenges at University of North Georgia. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *40*(1), 377.

US Department of Transportation. (2016). *Advisory Circular 107-2—Small Unmanned Aircraft Systems (sUAS)*. Retrieved from https://www.faa.gov/documentlibrary/media/advisory_circular/ac_107-2.pdf

Williamson III, K. C., & Gage, G. (2019). Important Considerations for Implementing a Drone-based Activity within a Construction Surveying Course. *55th ASC Annual International Conference Proceedings*. Presented at the Denver, Colorado. Denver, Colorado.

Wlodyka, M., & Dulat, M. (2015). Experience with A Small UAV in the Engineering Design Class at Capilano University–A Novel Approach to First Year Engineering Design. *Proceedings of the Canadian Engineering Education Association (CEEA)*.

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Integrating Learning Management Systems and Faculty Performance Evaluation for Continuous Program Assessment and Improvement

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The use of technology and learning management systems (LMS) has significantly advanced program assessment in higher education. Accreditors and researchers have affirmed that systematic approaches to program assessment are paramount for improving student learning and making strategic decisions in academic units. These structured approaches contribute to providing consistent and reliable data that can be used to make more informed decisions for planning and determining resource allocations. One of the challenges institutions face is creating a system that is adaptable and can be used across academic units and accrediting bodies. Another challenge is finding new ways to encourage or incentivize faculty to actively engage in assessment related activities. This study focusses on the development and implementation of an assessment framework for three construction related degree programs. The system was designed to be adaptable to accommodate the reporting needs of multiple accrediting bodies and to encourage faculty engagement in the process. The framework has been implemented and used in writing an accreditation self-study. The system has undergone a complete implementation cycle with most courses in the curriculum and this study can be viewed as ongoing in nature.

Key Words: Program Assessment, Accreditation, Construction Education

Introduction

The advancement of education software and curriculum design practices in higher education are enhancing the means by which academic programs are developed and assessed. Digitized rubrics, learning management systems (LMS) and outcome measurement software are now widely used in higher education. The dynamic nature of software and the increasing need for colleges and universities to be responsive to market demands has emphasized the need for program assessment frameworks that are adaptable and versatile for two key reasons. First, the dynamic nature of software has emphasized the need for assessment frameworks that are capable of adapting to changes and upgrades made by software vendors. Changes in software can impact data exchange and analytics, publication of reports, system functionality and user interface. Second, as colleges and universities seek to be more responsive to the demands of higher education markets there is a need for a framework that is versatile across disciplines and increases the speed at which information may be accessed for strategic decisions. Program changes may need to be adopted quickly without impacting established assessment systems.

Programs such as construction management which frequently have external accrediting agencies also need assessment systems that are responsive to the data collection, analysis and reporting needs of the accrediting body. Furthermore, assessment must be valued internally which can be accomplished by adding assessment contributions to annual faculty performance evaluations. The focus of this study is on the development and deployment of an assessment framework for an undergraduate construction management program that utilizes LMS software, is flexible and adaptable to the three main accrediting agencies for construction management programs and is embedded in annual performance evaluations for faculty.

Literature Review

Assessment

Program and student achievement assessment has been a vital responsibility of academic administrators for years. While assessment is an important part of what administrators are charged to manage and an integral component of regional and professional accreditation, the underlying purpose of assessment is continuous program improvement and better student learning (Jankowski et al, 2018). Having effective assessment systems in place is empowering and provides valuable information for administrators to make decisions related to program offerings, curriculum design course rigor and teaching/learning effectiveness (Jacobsen et al, 2018). If assessment becomes a matter of compliance with accreditation requirements the benefits of assessment will be compromised. Advantages of having effective assessment are maximized when there is accurate, intuitive, and timely data within a flexible, responsive system.

Accurate reporting provides assurance that the data is reliable and that decisions may be made confidently based on the analysis and interpretation of that data. Intuitive reporting ensures there is clarity and the people who need the data for decision making and compliance reports can easily understand the system. Timely reporting ensures the information can be accessed when it is needed and when it can have the greatest impact. Consistently measuring objectives with regard to reporting is paramount for ensuring the information can be put to best use for improving the student learning experience.

Assessment systems vary widely among academic institutions and can also vary widely among units within a single institution. The differences among practices may make it difficult for individual academic units to learn from one another. As new software emerges, best practices are identified, leadership changes and assessment responsibilities shift, the system that was initially designed will no longer look the way it once did, and it can be difficult to generate the reports needed to make decisions regarding program improvements and student learning. Another complicating factor relates to changes that are made to assessment procedures as responsibilities shift from one role or person to another. These challenges are further complicated if the management of the university assessment procedures are decentralized. Having a centralized process for directing assessment procedures is one of the most effective safeguards for preserving the integrity of the assessment procedures and protocols (Dandan et al, 2017).

Faculty Performance Evaluation

Conflicting demands of using performance evaluations to make salary and promotion decisions as well as identify professional development needs diminish their usefulness (Murphy, 2020). Performance evaluation systems for faculty typically use some type of categorical assessment (e.g., needs improvement, meets expectations, exceeds expectations), with several subcategories of evidence used to determine the appropriate category in research, teaching and service. In systems which allow merit pay increases for top performing faculty, the average salary increase ends up virtually identical to average performers or poor performers. This is especially true if pay increases are split between across-the board market adjustments and discretionary increases from a merit pool. Such systems breed more cynicism than motivation (Murphy et al, 2018).

Sulkowski et al (2020) note that performance appraisals with heavy parameterization of evaluation criteria serve to disenfranchise service-oriented faculty. This can be particularly problematic in universities with a long history of public service missions such as the land grant universities and the old “normal” schools in the United States. As these institutions attempt to adopt modern performance appraisal systems modeled on best business practices, they can demotivate faculty who chose the position out of a sense of public service. The authors review data from interviews with university administrators who note the lack of consequence for poor performance and the demotivation of faculty meeting expectations in teaching and research but not recognized for prosocial behaviors and public service, including service to the institution.

Brown et al (2018) reviewed 230 articles on the subject of performance management and found that 62.6% of the articles investigated Performance Assessment, but only 10% researched the importance of aligning employee goals with the overall institutional goals. They note an overall lack of holistic approaches to performance management with most institutions relying instead on Performance Appraisals that are not clearly linked to non-parametric measures such as ethical behavior, good citizenship, and teamwork. This is an important finding for implementing effective assessment systems. If an institution has a high-priority goal of effective assessment, then performance appraisals should place a high weight on evaluating faculty contributions to assessment.

Based on the literature review (Brown et al, 2018), it appears that performance appraisals in higher education have limited effectiveness in rewarding high performing faculty, may demotivate faculty who embrace a public service motivation and provide no realistic system for attaching negative consequences to poor performance. This is particularly problematic for administrators charged with the assessment of programs in their units. Assessment is a program-level activity that requires a high level of integration between individual classes and instructors. In other words, faculty participation in program assessment is part of the non-parametric evaluation problem alluded to by Brown et al (2018). Therefore, administrators charged with developing and maintaining effective assessment programs need to have systems in place that minimize faculty time, are repeatable over time, and can be easily evaluated and extrinsically rewarded.

The following sections outline an integrated assessment program in an academic unit (the School) with three construction programs. The integrated assessment program utilizes common syllabi, critical course assignments, learning management software, data queries of the gradebook embedded within the course shell housed in the LMS, and formal review of effective assessment as part of the annual performance evaluations of faculty within the School.

Program Description

The School was created in 2016 from the merger of three separate programs, a residential construction management program and a commercial construction management program in the Department of Engineering Technology and the concrete construction management program which was a stand-alone program. The merger required a revision of curricula in all three programs to eliminate duplication of similar courses and develop a more unified set of program goals and School mission. The faculty and staff of the newly formed School developed curriculum change proposals and new structures in academic years 2016/2017 and 2017/2018. The unified curriculum was launched in Fall 2018 with the addition of four new cross-disciplinary courses required for all students along with specialized courses in the individual programs. A significant revision to Program Learning Objectives and Student Learning Objectives was undertaken in 2018 with the following goals:

- Work with Industry Advisory Boards to develop individual PLO’s for the programs
- Develop a smaller, more uniform set of SLO’s for the programs while retaining some unique SLO’s in each program pertinent to the specific disciplines.
- Map the SLO’s onto the new curriculum and develop course learning objectives (CLO’s) for each course
- Identify Critical Assignments in each course that would be used consistently to measure CLO’s
- Track performance on CLO’s over time to assess Program/Student Learning Objectives
- Integrate the School assessment plan with the University student objectives
- Develop an assessment plan that would adhere to the requirements of the three main accrediting agencies for construction management programs with only minor modifications.

Figure 1 below is a graphical representation of the process started in 2018:

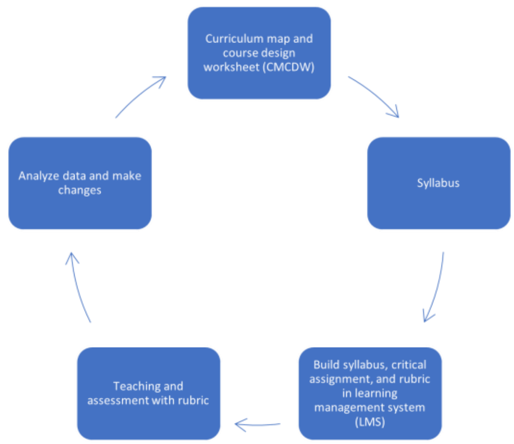

Figure 1: Program Assessment and Continuous Improvement

Curriculum Map and Course Design Worksheet (CMCDW)

The comprehensive assessment program development began by examining the university level outcomes that are developed by administrators at the institutional level. Next, it was imperative to examine outcomes and competencies that are prescribed by the regional and professional accrediting bodies. These requirements guided the development of the Program Goals and Student Learning Outcomes. The overall framework was developed to work across the three most active professional accreditors for construction related programs while simultaneously fulfilling the reporting needs for the regional accreditor for efficiency.

Once the Program Goals and Student Learning Outcomes were identified, the first step in developing the School's assessment plan was to develop course learning outcomes (CLO) that aligned with University Student Outcomes, Program Goals, and the Student Learning Objectives of each CM program. Next, each course was assigned a "lead faculty" who was charged with identifying and assigning required resources, texts, and materials. The lead faculty was also asked to develop a learning activity matrix that included a critical assignment and assessment rubric with at least one grading dimension for every course learning outcome.

Syllabus

Once the Course Design Worksheet was completed for each class, the lead faculty developed a course syllabus that included course ID, course title, units, catalog course description, course learning outcomes, course resources, course prerequisites, course co-requisites, and course assignments from using a common template for all classes in the School. The syllabus identified point values and due dates for assignments, projects, and required learning activities, including the critical assignments that were to be used for assessment purposes. Lastly, a weekly course schedule was added noting which topics would be covered during the fifteen week semester and the class rotation for an academic year.

The template provided consistency for student learning, but also enhanced the process for faculty as they seek to update syllabi each semester and occasionally need to add standard language implemented by the institution.

Build syllabus, critical assignment, and rubric in the Learning Management System

After the course structure and syllabus were developed, the course material needed to be loaded into the LMS. The master course template in LMS used placeholder entries for generic information such as instructor, office hours, and for due dates on the assignment breakdown and course schedule. Course sections in LMS can be generated from the master course template to specific course sections each semester. This allows for sections to be taught by various faculty with a common syllabus and more importantly, a common critical assignment for assessment. Create an entry in the LMS gradebook for the critical assignment and attach a rubric from the model that was developed in the CMCDW. This process also creates efficiencies for faculty as they update courses each semester. Rather than building courses each semester faculty now update the master template and copy that template to their course sections each semester.

Teaching and assessment with rubric

Once the course was set up in the LMS, the course was offered for instruction. The critical assignment was distributed, collected and evaluated using the assessment rubric in the LMS.

Analyze data and make changes

After all courses have been delivered at least once, the faculty member assigned responsibility for assessment generated reports using LMS rubric analytics. This data was analyzed and evaluated to determine student performance in the Learning Outcome areas for both the School and the University. These findings were reported in the university's assessment program and in the self-study report for the accrediting body, along with action plans for enhancing the student learning experience. The data reports are created by the LMS and downloaded into Excel files. From these files the student data is organized by concentration so data can be tracked in this manner for assessment reporting purposes. Breaking assessment data down by concentration allows for a more detailed analysis to determine how well students are being served by the curriculum and whether modifications need to be made at the course or program level.

Implementation

Since Fall of 2018, the faculty and staff at the School have been working on implementation of the integrated assessment plan described above. The framework has been fully implemented and the courses in this system have all gone through a complete cycle. Approximately half of the classes are fully integrated into the new assessment plan with critical assignment rubrics being incorporated into LMS grading shells or formulas for converting student performance data into the assessment metric. One of the goals is to have a rubric embedded in class offerings within the LMS to reduce faculty burden. Such efficiencies should lead to a more sustainable assessment process over time and reduce data loss associated with faculty attrition and replacement.

The system is robust with assessments integrated into regular class offerings and standard assignments. Faculty grade and assess the critical assignment as part of the standard teaching duties. Embedding the graded and assessed critical assignment into the course gradebook housed in the LMS eliminates the need for separate archiving of assessment data. The gradebook in the LMS can be queried to extract student performance on the the critical assignment and sort it by declared major for reporting in the individual programs. The query language can also analyze the data to determine if Student Learning Objectives (performance targets) have been met. The standard 1-4 assessment rubric that is developed for each critical assignment can be transformed from however many points are assigned by the instructor. Class learning objectives and critical assignments do not vary by instructor or over time, allowing for stable and accurate scoring, intuitive reporting, and timely data analysis. A redacted example of a portion of extracted assessment data is provided in Table 1 below.

	Excel Schedule (CLO 1) 75% will score above 3	**Network Diagram (CLO 2) 75% will score above 3**	**MS Project schedule (CLO 3) 75% will score above 3**	**Master format ID Quiz (CLO 4) 75% will score above 3**
CCM	3.00	4.00	1.00	3.00
CCM	4.00	3.00	4.00	4.00
CCM	3.00	4.00	2.00	3.00
CCM	4.00	3.00	3.00	2.00
CCM	2.00	3.00	2.00	4.00
CCM	2.00	2.00	4.00	4.00
% above 3	67%	83%	50%	83%
Meet Target?	**NO**	**YES**	**NO**	**YES**
LDRB	4.00	4.00	3.00	4.00
LDRB	3.00	1.00	1.00	2.00
LDRB	4.00	3.00	4.00	4.00
LDRB	1.00	3.00	2.00	3.00
LDRB	4.00	1.00	1.00	3.00
% above 3	80%	60%	40%	80%
Meet Target?	**YES**	**NO**	**NO**	**YES**

Table 1: Assessment Data Extracted From Gradebook in Learning Management System

The example above is for the Scheduling class taught to all construction management students in Commercial Construction Management (CCM) and Land Development and Residential Building (LDRB). There are four critical assignments in the scheduling class that are used for both class assignments and program assessment. The scheduling class addresses several Student Learning Outcomes:

- Students will be able to demonstrate the ability to apply mathematical concepts to the interpretation and analysis of quantitative information in order to solve a wide range of problems. This SLO is assessed by two critical assignments, the Excel Schedule assignment and the Network Diagram assignment.
- Students will be able to recognize when information is needed and have the ability to locate, evaluate, and use the needed information for a wide range of purposes. This SLO is assessed by one critical assignment, the MS Project Schedule assignment.

- Students will be able to think in a way that is clear, reasoned, and reflective, informed by evidence and aimed at deciding what to believe or do. This SLO is assessed by one critical assignment, the CSI MasterFormat Quiz.

In the gradebook set up in the LMS, each of these assignments was given a set number of points based on the difficulty and time required to complete the assignment. For instance, the CSI quiz is worth 40 points, and the MSProject schedule is worth 150 points. These two critical assignments were both extracted from the gradebook and converted to a common 1-4 scoring rubric based on ranges. For the CSI quiz, students scoring 35-40 were placed in category 4, students scoring 25-34 were in category 3, those scoring 15-24 were in in category 2, and those scoring 0-14 were in category 1. The target criteria for success was that 75% of the students achieved a category score of 3 or higher.

For each CM class in the curriculum, the query language extracts scores for critical assignments from the gradebook in the LMS, categorizes the student grade into a category 1-4 corresponding to a uniform assessment rubric, sorts the scores by major (residential or commercial), calculates the percentage of students achieving the target, and creates simple YES/NO cells on whether targets were met or not by major. This system allows administrators to quickly determine which SLO's are being met for each of the programs in the School and develop a continuous improvement plan to address deficiencies.

To facilitate implementation of the new assessment program at the School, assessment performance was made part of the annual performance review for all instructional faculty. The annual review asks faculty to provide the Director a copy of their syllabus, which is reviewed to make sure class learning objectives are clearly identified, the critical assignment is included in the syllabus as a graded assignment worth an appropriate amount of points to motivate student performance, and the syllabus conforms to the School's standard template. In some cases, the Director is added as a reviewer to the LMS course shell in order to review the set-up of the gradebook to allow for data extraction. Spring 2021 was the first time assessment performance was included in the annual performance review. The next step in the performance review will be to set up a series of extrinsic and intrinsic rewards for completing the critical assignment, maintaining a conforming syllabus and participating in the analysis of the data. Some of the rewards under consideration include making additional travel funds available to faculty who fully participate in assessment, recognizing faculty who participate fully at an "assessment appreciation lunch" as well as through newsletters, updates to the Dean, and at faculty meetings. The inclusion of assessment performance in the annual review also allows the Director to note needs for improvement in the review letters of all faculty who do not fully participate in assessment and to set up professional development action plans to reduce deficiencies.

Conclusion

Challenges remain to implementation of the integrated assessment system at the School. One of the biggest challenges is explaining the system to new faculty and to adjuncts. The assessment system will be added to the on-boarding protocol for new hires starting next year. Embedding the assessment in regular course assignments is a good first step in motivating students to perform well, but student motivation remains a concern. Many of the critical assignments come near the end of the term in several classes, and student performance on the assignment may not be a robust measure of learning due to student fatigue, satisfaction with anticipated course grade or conflicting priorities in other classes. The faculty are asked to explain the importance of best efforts on the critical assignments to mitigate these concerns. Another challenge is to get faculty to fully commit to using the LMS and to participate in university training programs to become better at utilizing course shells to deliver content and archive performance data.

Approximately 100% of full-time non-tenure track and tenure-track faculty have fully implemented the system in their courses. Interestingly, approximately 33% of tenured faculty have fully implemented the system. There is optimism that seeing the benefits of the system with regard to curriculum enhancements (for the betterment of student learning) and implications for performance reviews and funding will increase engagement among tenured faculty. Administrative support for the extrinsic rewards will remain challenging in times of tight budgets, but aligning faculty performance in assessment to the School's goals requires that scarce resources be allocated where they can have the most impact in achieving effective assessment and continuous program improvement. This study is ongoing in nature and future papers will build on this work by providing comparative analyses to the legacy system – highlighting challenges and program related enhancements.

References

Brown, T.C., O'Kane, P., Mazumdar, B., and McCracken, M. (2018). "Performance Management: A Scoping Review of the Literature and an Agenda for Future Research.*" Human Resource Development Review*, https://doi.org/10.1177%2F1534484318798533, 1-39.

Dandan, H, Yajuan, Z., Junfeng, L., Chen, L., Mo, X., and Zhihai, S. (2017). Research on Centralized Data-Sharing Model Based on Master Data Management. MATEC Web Conf., 139 (2017) 00195. DOI: https://doi.org/10.1051/matecconf/201713900195.

Jacobsen, M., Eaton, S., Brown, B., Simmons, M. & McDermott, M. (2018). Action Research for Graduate Program Improvements: A Response to Curriculum Mapping and Review. *Canadian Journal of Higher Education* / *Revue Canadienne d'enseignement Supérieur*, 48(1), 82–98. https://doi.org/10.7202/1050843ar.

Jankowski, N. A., Timmer, J. D., Kinzie, J., & Kuh, G. D. (2018, January). Assessment that matters: Trending toward practices that document authentic student learning. Urbana, IL: University of Illinois and Indiana University, National Institute for Learning Outcomes Assessment (NILOA).

Murphy, K. R., Cleveland, J. N., & Hanscom, M. (2018*). Performance appraisal and management: Why does it fail and how can it be fixed?* Thousand Oaks, CA: Sage.

Murphy, K.R. (2020). "Performance Evaluation Will Not Die But It Should" *Human Resource Management Journal,* Vol 30, pp. 13-21.

Sulkowski, L., Przytula, S., Borg, C. and Kulikowski, K. (2020). Performance Appraisal in Universities—Assessing the Tension in Public Service Motivation (PSM). *Education Science,* 10(174) pp. 1-19.

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Enhancing Student Learning Experience by Incorporating Virtual Reality into Construction Safety and Risk Management Class

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For years, the construction industry was notorious for being slow in adopting new technologies. However, in the past decade, this trend started to change. Technologies such as building information modeling (BIM), drone, autonomous equipment, 3D printing, artificial intelligence (AI), virtual reality (VR), and augmented reality (AR) were developed and used by the industry at a breakneck speed. While VR/AR technologies have been around for quite a long time, they have been gaining more attention by the AEC (Architecture, Engineering, and Construction) industry recently. These technologies have proven to benefit construction projects in many ways. From preconstruction to construction, they can add value and save time and money. One of the great advantages of these technologies is training for jobsite safety and hazard recognition. To create more interactive learning experience and prepare students for a rapidly changing industry, VR technology was utilized in Construction Safety and Risk Management class in the Construction Management program at Wentworth Institute of Technology. This paper describes how VR technology was incorporated as a pilot study into the class curriculum and provided students with a different and more engaging learning experience, as well as how it helped them learn the subject matter better.

Key Words: Virtual Reality (VR), Advanced Technologies, Jobsite Safety, Construction Management Curriculum, Construction Education.

Introduction

Traditional methods of construction safety education and certifications are based on lecturing or presenting information that requires students to passively learn the content (McCall et al. 2019). The incorporation of Virtual Reality (VR) and Augmented Reality (AR) technologies into education, provides a better opportunity to develop a better curriculum to promote active and collaborative educational methodologies. Active education is when the student is an active participant in the learning process; while collaborative is best explained as group work where the students work together to generate solutions to problems (McCall et al. 2019). These methods have been proven to be more effective over the lecture driven education (Fogarty et al. 2018). Using technology such as

VR/AR can help further expand both effective teaching styles and promote student engagement (Lucas 2018). This is especially relevant in the realm of recognizing unsafe actions and hazardous conditions on busy and dynamic construction sites.

While the classroom environment is a great medium for embedding the hard facts, specific OSHA regulations, and statistics associated with construction safety, it falls short on effectively engaging the students to recognize potential hazards in a real-world environment. Albert et al. (2014) reported that recent graduates were the least adept at identifying job site hazards and on average, they were only able to effectively recognize 43% of hazards in the construction environment. The ability for personnel to detect unsafe conditions directly correlates with an industry that is historically plagued with one of the leading fatality rates across industries (Albert et al. 2014). In the United States alone, the incident rates related to the construction industry are double that of the national industrial average (Rita and Man 2018). The low efficacy of safety trainings in the industry, that is leading one of the highest injury rates, creates a perfect domain for serious incidents to occur.

Increasing the effectiveness of construction safety training through the use of VR/AR technology will not only help to create a safe and more efficient work environment, but also gives employers very real monetary reasons to seek out this educational resource. Even minor incidents can lead to large expenditures in terms of both human and monetary capital. Small accidents can result in major bodily harm or even prove to be fatal. Studies have shown that an accident without a medical treatment on average costs 1,100 USD per worker and when medical treatment occurs, the costs escalate to 42,000 USD. If the mishap results in a fatality, then the cost is significantly greater at approximately 1,450,000 USD, in addition to the lost time and damage to moral which compound with the monetary determents (Pena, Ragan, and Kang 2019, National Safety Council 2021). VR technology provides an opportunity for the users to experience the hectic, fluid, and dangerous nature of construction sites without the risk of injury to self or others.

Literature Review

VR History:

While the terms VR and AR initially conjure images of modern labs and other technological advancements of the 21st century, VR has been around considerably longer than one would initially think. The very first application of VR developed by Morton Heilig in 1957 (Dumay, 2001). Heilig's design was the initial instance in which a simulation was able to successfully render three dimensional images that replicated real life physical environments (Li, 2018). Nearly a decade would follow before the first head mounted iteration would follow Heilig's model. Ivan Sutherland was the first to utilizes VR combined with a head mounted device (HMD) connected to a computer. By combining the real-life environments generated by the VR system with the HMD interface, Sutherland allowed individuals to see and experience the virtual world (Li, 2018). Initially access to VR systems were barred by lofty financial barriers which meant that the technology was only adopted by firms that were already well established (Delgado et al. 2020). Current VR/AR markets are rapidly growing with the estimated market size that continuously exceeds projections (Delgado et al. 2020). Fast forward to present day and VR is now more accessible than ever. Innovations across the broad spectrum of computer technologies have ensured that anyone can access to the power of VR with a smartphone and a cardboard box (Li, 2018).

VR Feasibility:

The advent of VR was heavily influenced by entertainment purposes. As the technology of VR progressed, more utilization became available with more feasible cost. When looking to see if VR is feasible for educational pursuits, the cost and useability should be considered. The cost of VR systems ranges drastically depending on the system used. Google glasses, Oculus, Vive and others are on the market with a wide price range. The VR system used in this study was the Vive Pro, where the MSRP for the full kit is around 1,599 USD (Vive 2021). This price can increase if a compatible laptop is required. When comparing the cost of investing in the VR system to the monetary cost of a jobsite incident, the VR costs are negligible. The prevention of one accident without medical involvement is equivalent to the costs of a VR unit and prevention of more serious incidents which results in tremendous savings. The current generation of students have grown up inundated with technology. Studies have shown that VR maintains a high usability rating when using the System Usability Scale (SUS), which is a standardized questionnaire to help assess the user's perceived usability (Lewis 2018). The SUS average score is considered 68 and mirrors the standard letter grading system. VR experiments using students have obtained scores ranging from 75.50 to 81.25, which is considered above average (Lewis 2018; Pena et al. 2019). This demonstrates the student’s ability to use the VR system as an educational tool.

VR in Education:

VR use in education has been implemented in many industries. The industries use VR training to produce trainings that minimize risk and incidents. Notable industries are airlines, medicine, machining, welding, and mining. The ability to create and change scenarios that mimic the real-world situations, provides an opportunity to put participants in high-risk situations and practice the training protocols without any risk of injury or equipment damage (Kessler et al. 2020). Airlines have been using flight simulators to provide pilots with an extremely difficult simulations to help prepare for the worst-case scenarios. Mines within the UK and US have both adopted VR/AR use in training in case of disaster in mines. The results from these VR trainings have proven that participants have better performance at locating emergency exit routes (Li et al. 2020). The real-life situations that these simulations represent rarely occur in practice. In the rare chance an occurrence does happen, prior experience in a simulation helps produce appropriate responses of the involved parties, hopefully resulting in saving lives. Within the manufacturing industries, the improvements demonstrated a reduction in errors, task completion time, as well as an increase in viable experience from the VR training (Osti et al. 2020). Both nursing and mining industries have also integrated VR training in limited capacities to their training curriculums with the hopes of lowering incidents and increasing the amount of applicable experience that individuals have. When the training is expensive or has limited availability of material/equipment; VR provides a cost-effective tool to provide students with more realistic training experience prior to hands on training.

VR Benefits in Construction Education:

Utilizing VR in construction education has been limited by technology or the labor-intensive process if project specific models are used. The benefit of VR shines when generic programs are created to teach concepts that are difficult to envision through traditional teaching or 2-D models (Fogarty et al. 2018). Traditional teaching methods especially in safety are considered dry and yield minimum levels of engagement by students whereas VR brings excitement, participation, and interest into learning from the experience (McCall et al. 2019). After these new concepts are experienced with VR, the classroom setting allows for debriefing afterwards in collaborative manner to reinforce the knowledge. VR provides an opportunity for the user to interact with the subject matter which promotes active and collaborative learning. These types of learning methods have been shown to be more effective and provide better understanding and knowledge retention. Lucas (2018) showed that students who experienced VR in the academic setting were receptive to the use of VR and expressed their desire to see further use of the technology.

VR and Construction Safety:

The implementation of VR in the construction industry has been slower than other industries. As the technology of VR has been expanded so has the applications for use within construction and safety education (Froehlich et al. 2016). The industry within construction can use VR in many ways. For instance, VR/AR can help project team catch design flaws before construction begins or obtain project end-user comments. They can serve as virtual mockups and help with installation of high-end or complex finishes. They can also assist project managers with the sequencing elements in the project schedule or coordination of MEP (Mechanical, Electrical, and Plumbing) activities. Moreover, these technologies have shown great advantage for jobsite safety, heavy equipment operation, or offsite workforce trainings. The construction education is in its infancy stages utilizing VR as a teaching tool and still heavily relying on traditional instructional methods to teach safety. According to Pereira et al. (2018), there is a common trend of dissatisfaction and known ineffectiveness of the current OSHA safety courses. This area is where VR can be used to improve the traditional teaching style and move towards a system shown to provide a more retentive learning method. VR provides an immersive learning environment and can provide users with the sights of a typical construction site without the exposure to possible danger or coordination of a class site tour.

Research Methodology:

To examine the effectiveness of VR technology in teaching construction safety topics to college students, the Construction Safety and Risk Management class that was offered in Summer 2021 at Wentworth Institute of Technology with 17 Construction Management (CM) students was selected as pilot study. The experiment used the 3M Fundamentals of Fall Protection Virtual Training program (3M 2021) along with a Vive Pro Eye headset (Vive 2021) and a VR ready Razer laptop. The 3M virtual reality safety training activities were chosen since the company is one of the leaders in safety training and promoting safe practices in the construction industry. All the activities mimic the real scenarios that construction workers may experience in the field. The program includes four activities: (1) Check Site Hazards, (2) Check Anchorage Installations, (3) Erect Steel Beam, and (4) Install Corrugated Board (Figure 1).

Figure 1: 3M Fundamentals of Fall Protection Virtual Training Program

In this research, two separate quantitative data analyses were implemented following Delgado (2020) method to portray the relationship between the data collected and the experience of the participant. This allowed for multiple aspects of the experiment to be reviewed and contextualized. Each student was allotted 45 minutes to complete multiple VR activities. The sequence of activities was the same for each student and ordered from what was determined to be from least to most difficult interactions of VR. The first activity (Check Site Hazards) mirrors a site safety manager conducting a site safety walkthrough. This provided the students with basic VR movements and interactions with avatars, who represent different workforce personnel, to inspect and provide any missing PPE based on the activity being conducted. The second activity (Check Anchorage Installations) was the inspection of different fall protection anchorage points. This experience allowed the user to move around a construction site inspecting anchor points and connections for proper use, placement, and installation. The third scenario (Erect Steel Beam) provided a superb VR interaction experience. This scenario allowed the user to operate an ariel lift to a reach a steel beam. Once at the beam level, the user had to properly exit the lift bucket while complying with 100% tie off procedure and walk a few steps along the beam. Once in position at the end of the beam, a crane brought in another beam for connection to columns. The user had to guide the beam and secure it in place with bolts and a wrench. Once completed with beam, the user returned to the aerial lift to complete the scenario. The last scenario (Install Corrugated Board) focused on working in harmony with virtual coworkers to properly install a corrugated board while complying with safety protocols.

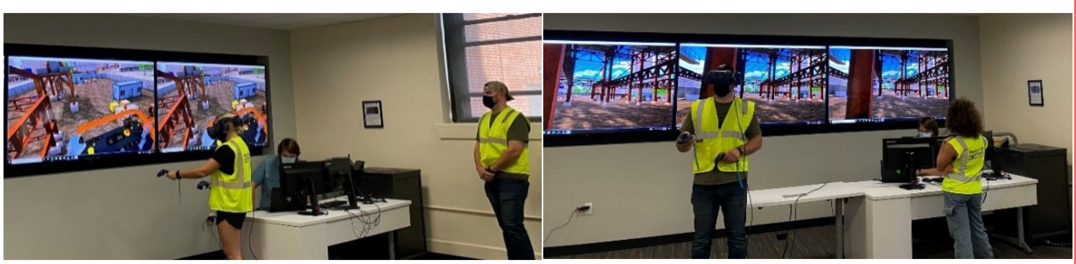

Figure 2: Students during the VR Training

The first quantitative analysis allowed for the identification of data trends from pre- and post- VR tests and the second one allowed for a numerical representation of the participants' opinions of the VR experience. In order to gauge the retention of information and knowledge learned from the VR experience, the time difference between pre- and post-VR tests were set to 3 weeks. The goal was to determine if the VR experience benefited the students academically, while also helping gauge the user's opinion on if the VR activities were beneficial. With these two data sets, it would be possible to examine whether (1) the VR learning activities improved students' test scores, (2) the VR was deemed beneficial learning approach by the students, and (3) the VR provided a significant improvement in the testing grades and was viewed positively by them. The quantitative data was gathered by giving the participating students two short tests at different times, one before and one after their VR experience. This allowed the pretest to be used as a baseline for the students' performance with the scores being compared between the two tests. To avoid biases, the students were not told that the quizzes and VR experience were related. Also, students were not informed about either of the tests to minimize biases associated with possible study before the tests.

Results:

The pre- and post-VR tests had a max score of 70 points and of the 17 students participating, 15 showed improvements (Figure 3). To perform the statistical analysis, the test scores' scale adjusted from 70 to 100 to reflect standard grading system for the course. As illustrated in Figure 3, student 17 missed the post-VR test and student 13 scored lower than the pre-VR test. The analysis of all the participants showed an increase in test scores of 8 points, reflecting an improvement from 86% to 94%. When the data on student 17 was removed, it did not impact the results. This data suggests that the VR activities improved the students' knowledge of proper PPE required for construction activities based off their testing. Later, the two-sample t-test was performed at 5.0% level of significance (α= 0.05) and since the ratio of variances of two samples were less than 2, equal variances was assumed (Table 1). The statistical analysis showed a significant difference between the two samples with the P-Value of 0.000099.

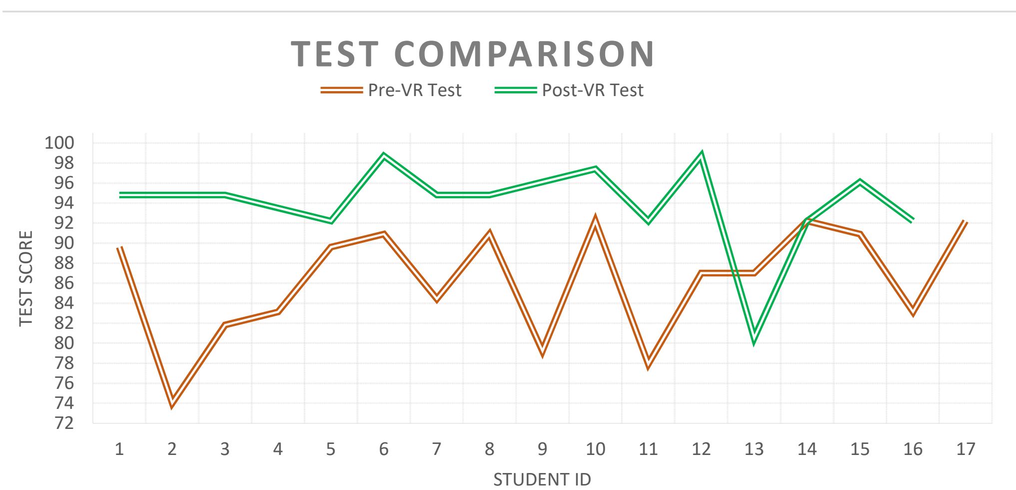

Figure 3: Comparison of Pre-VR and Post-VR Test Scores

Table 1: t-Test Analysis Results

t-Test: Two-Sample Assuming Equal Variances	Pre-VR Test Score	Post-VR Test Score
Mean	86.25	93.99
Variance	31.63	17.51
Observations	17	16
Pooled Variance	24.80	
Hypothesized Mean Diff.	0	
df	31	
t Stat	-4.464480	
P(T<=t) one-tail	0.000050	
t Critical one-tail	1.695519	
P(T<=t) two-tail	0.000099	
t Critical two-tail	2.039513	

Table 2: Survey Questions & Results

Number	Question	Min	Max	Mean	Mode	Std. Deviation
1	The VR experience was not difficult to use.	10	12	11.40	12	0.74
2	The navigation of the VR experience did not take away from the ability to learn.	10	12	11.40	11	0.63
3	The VR experience encouraged critical thinking.	10	12	11.27	11	0.70
4	The VR experience provided a better understanding of possible site safety issues.	10	12	11.53	12	0.64
5	The VR experience was a good use of learning time.	10	12	11.27	11	0.70
6	I would like to see more VR used in my education.	10	12	11.20	11	0.77
7	The VR experience will be useful in my future career and/or Co-Ops.	10	12	11.13	11	0.74
8	I felt that participating in the VR helped me learn safety concepts.	10	12	11.27	11	0.59
9	The VR experience reinforced/used what was taught during lecture.	10	12	11.20	11	0.68
10	I better understanded safety regulations after the VR experience.	10	12	11.00	11	0.76
11	The situations in the VR experience provided me with realistic situations I would experience.	10	12	11.27	11	0.59
12	I gained a better understanding of safety requirements from the VR scenarios.	10	12	11.20	11	0.68
13	The VR experience created questions about safety to discuss in class.	10	12	11.00	11	0.65

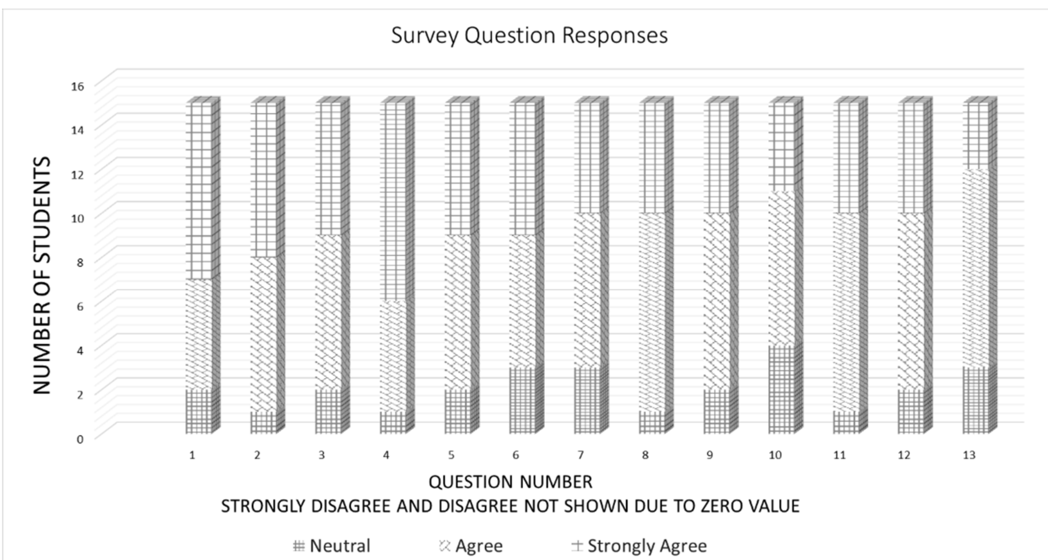

Figure 4: Survey Results

The second quantitative survey focused on participants' reflection upon their experience as well as their opinions on utilizing VR technologies in education and training. These questions had no impact on students' quantitative test results. Instead, they were designed to identify if the participants felt their learning experience was enriched by the presence of VR regardless of whether it had a positive impact on their test score. Several of the questions posed to the participants asked them to reflect upon their experience with the VR safety training and how it directly impacted their understanding of the subject matter. These questions included whether (1) they found the use of VR increased their insight and understanding of key safety concepts, (2) it increased their ability to think critically, and (3) the VR experience increased their understanding of site safety issues.

In addition to questions pertaining to the experience with VR and the possible benefits it poses to education, participants were also asked to reflect on the future of VR and how they expect it will impact them. Participants were asked to indicate if they would like to see more VR in their education, if the experience was able to generate questions and discussions back in the classroom environment, and whether they felt the experience would be valuable to them in their future careers and Co-Ops. The participants were given five different ratings to choose from; Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree with the score of 12, 11, 10, 9, and 8, respectively. Table 2 shows the survey questions, minimum, maximum, mean, mode, and standard deviation. All the participants found the VR training very favorable and felt a positive increase in safety knowledge and critical thinking abilities as a direct result of their VR experience. The minimum and maximum scores for all 13 questions were 10 and 12 which reflects that throughout the entirety of survey, there was not a single instance where a participant indicated "Strongly Disagree" or "Disagree" to any question. The mean of responses to all questions were 11 or higher indicating more responses on "Strongly Agree" and "Agree". The overall very positive attitude towards the experience is evident in the survey records collected by the research team. Figure 4 shows the graphical representation of the second survey results.

There were 3 short response questions at the end of the second survey (Questions 15-17) which allowed for more specific feedback to help future utilization of the VR technology (Table 3). These responses further demonstrated that the students overall had a positive experience and welcomed the VR technology use in the classroom. Question 15 had specific responses for more implementation with greater access to the VR gear. Question 16 resulted in a common trend of courses that are field related, and VR can be utilized to provide field experience. Question 17 results indicated that 78.6% of students suggesting shorter and more frequent VR sessions.

Table 3: Short-Response Questions

Short-Response	
15	What are some improvements that you would want to see with the VR program?
16	Where do you want to see VR used in your education?
17	If there were more VR experiences, what would be the best length of session? Longer, less frequent or Shorter, more frequent

Conclusion:

The analysis of data collected in this study indicated that the VR posed a viable and impactful tool when implemented into the educational environment. The results suggested a clear improvement in the retention and demonstration of knowledge pertaining to construction safety when VR was introduced into the course. Additionally, the atmosphere of the classroom itself experienced a very positive change as well as the introduction of VR peaked the participants interests. Moreover, the VR created a stimulating environment that promoted information absorption and retention. Lastly, participants believed that the VR training was overall beneficial to their educational experience and most believed that the exposure to experiment would have a positive impact on their career.

References:

3M. (2021, June 1). *Virtual Reality Safety Training*. Retrieved from https://www.3m.com/3M/en_US/worker-health-safety-us/3m-ppe-training/virtual-reality/

BLS. (2020, December 16). *Census of Fatal Occupational Injuries Summary, 2019.* Retrieved from U.S. Bureau of Labor Statistics: https://www.bls.gov/news.release/pdf/cfoi.pdf

Delgado, J. M., Oyedele, L., Beach, T., & Demian, P. (2020). Augmented and Virtual Reality in Construction: Drivers and Limitations for Industry Adoption. *American Society of Civil Engineers., 146*(7).

Dumay, A. C. (2001). VEs in Medicine; Medicine in VEs. *Information Technologies in Medicine, Volume I*, 33-56.

Fogarty, J., McCormick, J., & El-Twail, S. (2018). Improving Student Understanding of Complex Spatial Arrangements with Virtual Reality. *Journal of Professional Issues in Engineering Education & Practice, 144 (2)*, 1-10. doi:doi:10.1061/(ASCE)EI.1943-5541.0000349

Lewis, J. R. (2018). Item Benchmarks for the System Usability Scale. *Journal of Usability Studies, 13*(3), 158-167.

Li, R. (2018). Virtual Reality and Construction Safety. In R. Li, *An Economic Analysis on Automated Construction Safety* (pp. 117-136). Singapore: Springer Nature.

Lucas, J. (2018). Student Perceptions and Initial Response to using Virtual Reality for Construction Education. *54th ASC Annual International Confrence* (pp. 1-8). Associated Schools of Construction.

McCall, C., Wetzel, E., Leathem, T., & Collins, W. (2019). Pedagogy for 21th Century Construction Education: Active and Collaborative Learning in Correlation with ACCE Student Learning Outcomes. *55th ASC Annual International Confrence Proceedings* . Associated Schools of Construction.

National Safety Council. (2021, June 15). *Work Injury Costs*. Retrieved from National Safety Council: https://injuryfacts.nsc.org/work/costs/work-injury-costs/

Vive. (2021, May 25). *Vive Pro Eye*. Retrieved from https://business.vive.com/us/product/vive-pro-eye-office/

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Effectiveness of Computer Models on Learning Outcomes in a Dynamics Course – A Pilot Study

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The introductory courses in applied science education are formative and shape problem-solving skills. The application of gained knowledge beyond college is crucial to the success of engineers in the industry. As hands-on, active learning is key to understanding and analyzing a problem, the traditional instructional method often lacks these components. Courses such as Engineering Dynamics are usually deemed hard because the classroom experience does not augment the visualization of parts in motion. In this pilot study, the student's learning outcome in an Engineering Dynamics course was assessed by comparing the students' performance in solving dynamic problems with and without computer simulation models. Measuring student scores in problem-solving exercises, this paper demonstrated that computer-generated simulation models could be beneficial for the students to better grasp the dynamic concepts through engaging in active learning. Statistically significant differences were shown in the score when comparing a student group that used interactive simulation models to solve a dynamic problem with another group that had access to a stationary figure describing the system's initial state.
Key Words: Learning outcome, Student pedagogy, Computer simulation model, Dynamics

Introduction

Learning is a self-initiated continuous process of gaining new understanding, weaving into the existing experience. Encouraging students to take on a Science, Technology, Engineering, and Math (STEM) major has recently been a top priority in the nation's policy-making debates. In applied STEM courses like Construction Science, active learning is crucial to understanding and applying knowledge. Courses that discuss the physics behind systems are often deemed complex and demanding, resulting in high dropout rates (over 40% in the freshman year), and the difficulty in conceptualizing the problems can impede the individuals from pursuing a successful career (Bernold, 2005). The construction industry demands engineers with strong analytical skills to solve open-ended problems. Often, the instructional methods fail to provide the tool enabling them to bolster their understanding (Hermann, 1990, Hernández-de-Menéndez, 2019).

To be able to understand, analyze, and apply the knowledge indicate the effectiveness of learning, as proposed by Bloom and colleagues in 1956 (Benjamin, 1984). The conceptual understanding of problems helps students see the 'big picture' of a system and its components. In the introductory courses related to the mechanical systems of the natural world, statics is discussed at first, where the state of the system does not change with time. Hence, it is easier to conceptualize from a stationary picture presented through the examples in class. But, progressing to dynamics, where time is a variable, students often have difficulties capturing the time component of the problem. A stationary picture fails to provide enough information required to visualize the problem and, therefore, the understanding. In 2001, a report from the U.S. Department of Education found that 87% of engineering professors use lectures as their primary method of teaching (National Center for Education Statistics 2001072, 2001). It is a challenge for the instructors to present innovative approaches that can demonstrate the change of state of the system with time using two-dimensional and pictorial tools traditionally available in the classroom setting. This study assessed the effectiveness of computer-based models that illustrated the motions involved in the problems presented in an Engineering Dynamics class on students' pedagogy.

Literature Review

As computers are omnipresent in today's classrooms and integral to student learning, instructional methods demand the utilization of computing capabilities. To that end, computer-aided interactive simulations of dynamics problems can help learners visualize and fully apprehend the problem. Hailed as the pioneer of dynamic system modeling, Forrester (1968) argued that modeling dynamic problems helps clarify one's mental image of the system and foster comprehensive understanding (Forrester, 1968), as models are created to imitate the natural systems, their components, and the interactions within those components (Kornblugh & Little, 1976). Science education reform efforts, such as Project 2061 of the American Association for the Advancement of Science (1993), talks about using computer simulations "to form a scientific account of the universe" (page 65, Benchmarks for science literacy: Project 2061, 1993). Stratford (1997) presented evidence from earlier studies that student interactions with simulations confront learners with their (mis)conceptions of reality through the extent of the model imitating real-world events (Stratford, 1997). Gorsky and Finegold (1992) designed models using five force simulations to study students' conception of force and found that interacting with the simulations effectively elicited the understanding about forces acting on objects at rest and in motion (Gorsky & Finegold, 1992).

The enhanced learning also relates to meeting the industry expectations from the graduates. Pusca et al. (2017) described ideal engineering education as an "agile system" that can accommodate the changes in technological advancements to ensure graduates are equipped with and exposed to the understanding of the industry's requirements (Pusca et al., 2017). The authors argued that student activities focused on "learning by doing," followed by a reflective understanding of why it was done, prepare students through student-centered, hands-on learning. Anderson et al. (2005) discussed computer-assisted active learning methods in a thermodynamics class to demonstrate better learning outcomes (Anderson et al., 2005). Klahr et al. (2007) noted that virtual, i.e., computer-aided hands-on learning, may not provide the same level of tactile or visual cues as a physical model; it can still offer unique opportunities for practical learning (Klahr et al., 2007). A recent study noted that active learning results in teamwork, problem-solving, and analysis development, leading to increased performance and retention rates (Hernández-de-Menéndez et al., 2019). Lima et al. (2016) discussed how learners construct knowledge based on meaningful activities (Lima et al., 2016).

It is evident that even though modes of active learning have been studied to demonstrate increased learning outcomes, there is a dearth of publications that provide empirical evidence of enhanced learning outcomes in the engineering curriculum. In response, a pilot study with pretest-posttest randomized experiment was designed to answer a) whether using a computer model results in better understanding and learning and b) whether the students find using the computer models helpful studying a 'difficult' course.

Methods

Experiment Design and Data Collection

A series of assessments were put in place to evaluate the effectiveness of interactive computer-generated models of problems in the engineering dynamics class on students' pedagogy. Subjects were 20 sophomore students enrolled in the Engineering Dynamics class. The class was divided into two groups of the same size (10 students in each group), where students were randomly assigned to the groups. Two 'additional' quizzes were defined as extra assignments so that students could decide not to take the quizzes without an impact on their grades. The simulations were created using an open-source application called Algadoo and mainly focused on two-dimensional dynamic systems of bodies connected via ropes, springs, and joints. These models were used to teach dynamics concepts such as force and momentum transfer, work and energy, and generic 2-D motions. The first quiz, which tested these concepts, accompanied one such simulation model. This time, the model was given to one of the groups to study whether the model enhances the student's understanding of the problem, and the other group was not assigned any model. Another set of models was developed to help teach impact, translation, and rotation in dynamic systems, and the question in quiz 2 utilized a model of this kind. To remove the effects of student academic background, the groups swapped for the next quiz such that the second group had access to the model, whereas the first group did not have access to the models. This way, it was ensured that every student could work with the simulations once. Students had the liberty of not using the models without any penalty.

The following assessment was designed in the final exam, where one of the exam problems asked questions from momentum transfer as well as from impact, translation, and rotational motion. Compared to the models developed for the quizzes, a slightly more complex simulation model was developed for this question and posted on Canvas. This final exam consisted of three other problems without any model to visualize the motion. Students were free to choose whether they wanted to study the model without any consequences on their grades. To relate the student performance on that problem to the effectiveness of the simulation, students were asked to report how much time they spent studying the model. Again, this was a self-report without any impact on their grades. This way, the experiments were designed as a pretest-posttest control group experimental design.

Eventually, an evaluation form was developed to appraise whether the simulations were helpful in the students' learning process. Example questions are provided in Annexure 1. The evaluation form comprised questions about the computer models. An introduction was placed on the front page of the evaluation form to describe the intent of the evaluation and issues regarding confidentiality and voluntary participation. No question was asked about the students' identifying information like academic records, including their GPA, rank in class, or the number of credits taken and passed.

As stated, this study was mainly designed to reinforce the idea that visualization and contextualization in engineering courses can foster students' pedagogy and learning outcomes. This research in the current status qualified for an 'exempt review' since it studied normal educational practices in commonly accepted educational settings. Since this project used some student outcome data, approval from the Internal Review Board (IRB) was obtained (IRB number: 20161116539EP, Project ID: 16539).

Data Analysis

18 out of 20 students chose to take the additional quizzes and participate in the subsequent assessment survey. First, the obtained points for the voluntary quizzes were recorded – once when each group did not use any model to answer the questions (pretest), and once when students studied the simulation model for the quiz (posttest). In this randomized pretest-posttest control group design, the comparison was to be made between the grades of the 18 students with and without access to the model to understand the effects of the treatment (i.e., the use of simulation models). Hence, to compare the sample means before and after the treatment was applied, a paired sampled t-test was performed.

Paired sampled t-test can only be used when the difference between the posttest score and pretest scores is normally distributed. Normality assumption can be made for a sample size greater than 30. But for this study, the total number of observations combining the two groups was 18, which did not conform to the normality assumption. A Shapiro-Wilk t-test was conducted on the difference in scores with and without access to the simulation model, testing the null hypothesis that the differences were normally distributed. The p-value obtained from the Shapiro-Wilk t-test was 0.1246, indicating that there was no significant deviation from normality considering a significance level of 0.05. Thus, it was ensured that paired sampled t-tests could be used to assess the efficacy of computer models in learning outcomes for the dynamics class by testing the null hypothesis - there were no significant differences in the mean score after using the model to answer the quiz compared to the mean score for the quiz without the model. One can argue that the difference in understanding of the material in that class until the quizzes were given might influence how the students perceived the models, which was a potential source of bias. To ensure that the two groups of students were not significantly different in terms of background knowledge, a paired t-test was conducted between the two pretest datasets, i.e., grades of both the groups before they used the simulation model for the quiz.

One problem (question 1) was accompanied by a simulation model for the final exam, and three other problems were without any model to study. Comparing the points obtained for question 1 and the other questions revealed whether the model aided in enhanced understanding of the first problem, which, in turn, resulted in a better score than in other questions. Question 1 also had a sub-question attached to it – time spent to study the model where respondents answered on a scale of 1 to 5. Spending no time on the model to answer question 1 was recorded as 1, spending less than 30 minutes was scaled at 2, spending less than an hour was marked as 3, studying the model for less than two hours were marked as 4, and spending more than two hours was recorded as 5. Correlating the student scores with the time spent on the model provided an idea of how helpful the model was in answering question 1. Each student's score for question 1 was sorted according to the duration of the model study by that student. The average scores for these groups were compared to see if spending more time studying the model resulted in a better outcome. Additionally, as students could have different levels of understanding of dynamic problems coming to the final exam, it might be a source of bias needed to be controlled. Hence, the pre-final grade of the students - excluding the additional two quizzes with simulation models were also used to perform an Analysis of Variance (ANOVA) test to shed light on whether the students who did not have very high grades coming to the final exam, benefitted from studying the model in detail. It is noteworthy that spending more time to study the model might not necessarily suggest a better understanding. Also, the sample size for this analysis was 18, which might not be sufficient to establish a relation between the dependent and independent variables conclusively.

Results and Discussion

Comparison of Pretest-Posttest Quiz Scores

A paired t-test was conducted on the pretest data, i.e., the scores of the two groups, when taking the quiz without any model to check for any bias originating from the understanding of dynamic concepts prior to taking the quizzes. Before running the t-test, the normality observation was checked using a Shapiro-Wilk t-test, resulting in a p-value of 0.08 (>0.05), confirming no significant deviation from normality. The result of the t-test that tested the null hypothesis mean difference in score between the groups is zero, indicates that there was no statistically significant difference between the two groups before applying the treatment, as the p-value (0.705) was greater than the significance level (0.05) for the two-tailed t-test.

As it was confirmed that the two groups were identical before taking the quizzes comprising the simulation models explaining the quiz problems, the scores of all the students from both the groups were compared. Figure 1 shows the distribution of scores for all 18 students. Pre-treatment scores indicate the grade for the quiz that any model did not accompany, and post-treatment scores are the grades for the quiz supplemented by a simulation model. The boxplot in Figure 2 demonstrates the difference in the scores pre-and post-treatment. The mean pre-treatment score was 65.8 with a standard deviation of 15.9, and the mean post-treatment score was 80.3 with a standard deviation of 18.4.

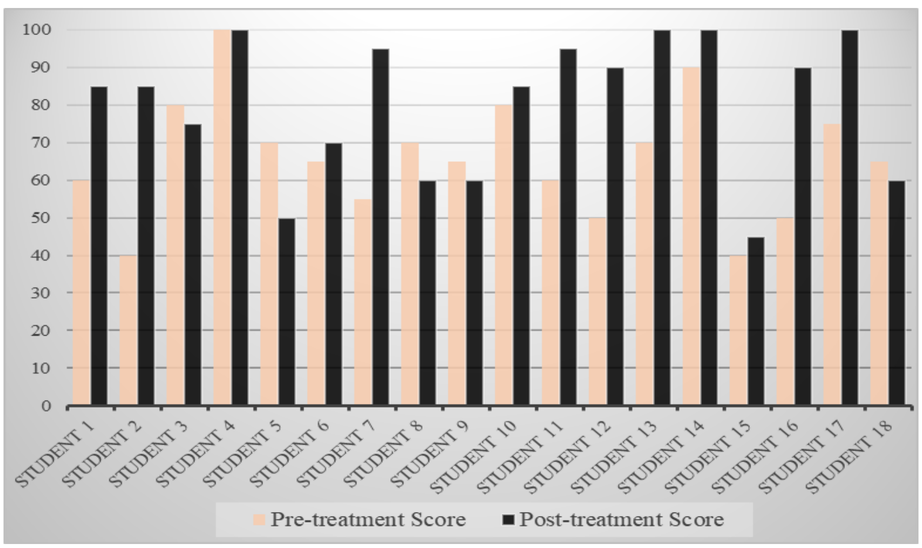

Figure 1: Distribution of Pre- and Post-treatment Scores

To test whether the mean difference in scores in the quizzes before and after the interactive model was provided to help the students visualize the problems, another paired t-test was conducted. The null hypothesis for this test was that the mean difference in scores before and after using the simulation model was zero, which was tested at a significance level of 0.05. The p-value (0.008) obtained from this test result was smaller than the significance level for a two-tailed t-test, indicating a statistically significant difference between the mean score of the two groups. The estimated increase in the average score for the quiz aided by the simulation model was more than 14 points, compared to the pre-treatment case. This finding clearly indicates that using the model was influential in the students' learning outcome, as it helped them understand the problem better. After visualizing the problem through the interactive model, on average, students were able to secure a higher grade than solving the problem using a stationary figure only.

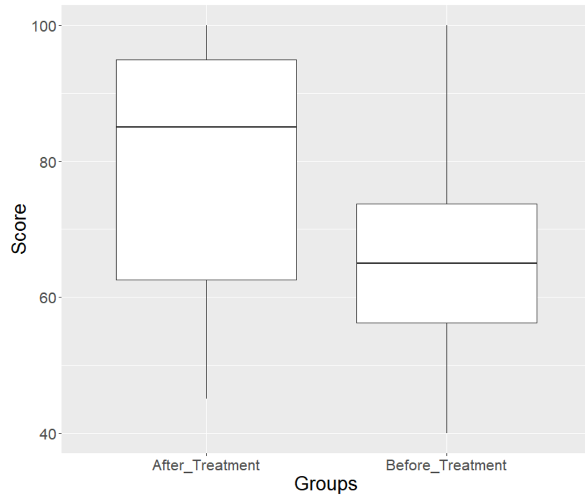

Figure 2: Boxplot of Pre- and Post-treatment Quiz Scores

Assessment of the Final Exam

19 out of 20 students had participated in the assessment associated with the final exam. Question 1 in the final exam was coupled with a simulation model that explained the dynamic motion of the system, which the students could voluntarily use to answer the question. In contrast, problems 2, 3, and 4 had only figures. Table 1 presents the comparison of scores of these questions. It is apparent that on average, question 1 scores were the highest, being the only question where the mean score was greater than 85%. The average scores for the other three questions were less than 70%. It is also noteworthy that the standard deviation of the question 1 scores was the lowest among all the questions, which suggests an enhanced benefit of using the model to solve dynamic problems.

Table 1: Comparison of Scores for Questions with/without Simulation Models

	Question 1	**Question 2**	**Question 3**	**Question 4**
Total Points	15	25	25	25
Average Score	12.84	15.55	13.66	17.21
Average Percentage	85.6%	62.2%	54.6%	68.8%
Standard Deviation	2.58	6.69	7.26	6.26

As mentioned earlier, additional information was requested from the students about the time used for studying the model to answer question 1. Table 2 shows the average grade of students for question 1, grouped according to the amount of time spent on the model. It is noticeable that students who used around 30 min to an hour working with the model had a higher average score in the question. Noticeably, no one spent more than two hours on the model, and only 3 out of 19 respondents chose not to use the model at all. Although this result provides an insight into the usefulness of carefully studying an interactive model to solve a dynamic problem, the generalizability of this finding is under question due to the limited number of observations and the potential bias from students' background knowledge gained from the Engineering Dynamics class throughout the semester.

Table 2: Question 1 score vs. time Spent on the Model

	Time Spent on the Model				
	1 (None)	**2 (< 30 min)**	**3 (< 60 min)**	**4 (<120 min)**	**5 (>120 min)**
No. of students	3	7	7	2	0
Average Score (out of 15)	10.67	12.72	14.14	12	0
Std. Dev.	5.13	2.21	1.21	1.41	0

To alleviate the generalizability threats on the question of whether the existing knowledge about dynamic problems had any role in the way students used (or did not use) the model in the final exam, pre-final grades - excluding that of the voluntary quizzes, were considered as the control. A two-way Analysis of Variance (ANOVA) was performed to determine if time utilized to go through the model and the pre-final grades were significantly related to the outcome, i.e., question 1 marks. Table 3 shows the result of the ANOVA, which suggests that neither the duration of model study nor the pre-final grades were significantly affected the score of question 1 at a significance level of 0.05. Time spent on the model impacts the outcome only when tested at the significance level of 0.1. Thus, these analyses show that even though it can be concluded that using dynamic simulation models for a problem was helpful, there is no evidence that spending more time on the model results in a better learning outcome.

Table 3: ANOVA Table - Effects of Model Study Duration and Pre-final Grade

	df	**Sum of Squares**	**Mean of Sum of Squares**	**F-Statistic**	**p-value**
Model Study Duration	3	24.87	8.29	2.783	0.08
Pre-final grades	1	0.58	0.58	0.195	0.67
Residuals	14	41.7	2.98		

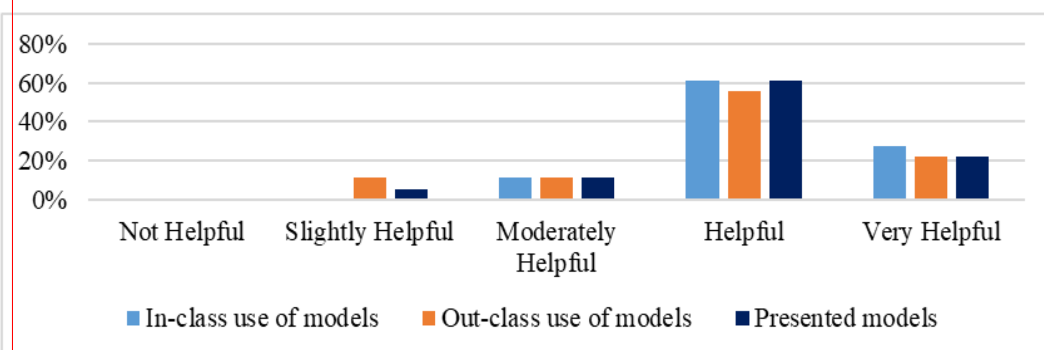

Figure 3: Summary of Assessment Survey

Assessment of Evaluation Survey

The assessment survey, followed by the final exam, was developed to get student feedback on whether using computer-generated models aided in understanding dynamic systems. As Figure 3 shows, in-class use of models for practice problems was hailed as helpful by 61% of the respondents, followed by 28% of the students who found the models extremely helpful. On the question of whether the use of simulation models outside of class was beneficial, 56% of the students agreed, while 22% of them thought the out-of-class use of models to be extremely helpful. Only two students thought using the models outside of the class without explanation was only slightly useful. Integrating models with the lectures was valuable by the majority of the students (11 out of 19), and 4 of them reported that using models with the class lectures was very helpful for them to grasp the concept.

Conclusion and Limitation

This study assessed the effects of active learning through computer-generated dynamic simulation models in students' learning outcomes. Observational and statistical methods were applied to understand whether using simulation models was efficient to bolster student experience and understanding in an introductory Engineering Dynamics class.

It was demonstrated that interactive simulation models result in better learning outcomes, measured in terms of obtained grades in specifically designed problems. The simulation models supposedly helped with visualizing moving systems. The evidence of improvement in learning outcomes was derived by comparing the grades of the same group of learners when they used computer-generated virtual models and when they solved similar problems from a stationary figure of the system at rest. Even though there was no conclusive proof, substantiated by statistical measures, that spending increased time to work with the models was more effective, it was evident that judicious use of the dynamic models helped in increasing the grades for problems concerning bodies in motion.

This was a preliminary pilot study with certain limitations. The small class size consequently affected the power of statistical tests. Still, dividing the students into two groups enabled an increased number of observations for pretest-posttest comparison. Only three simplistic models were derived for this study. More comprehensive models could be developed in the future, involving students in model creation instead of providing the models to them. This study was deemed a pilot study to gain insights into the concept of effectiveness, not to generalize the findings. More comprehensive research involving more students in diverse courses from different universities is planned for subsequent studies related to teaching effectiveness through active learning.

References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: Project 2061*. New York.

Anderson, Edward E., Taraban, Roman, Sharma, M.P. (2005). Implementing and Assessing Computer-based Active Learning Materials in Introductory Thermodynamics. Int. J. Engng Ed, 21(6), 1168-1176.

Benjamin, S. (1984). *Bloom Taxonomy of educational objectives*. Boston, MA: Allyn and Bacon.

Bernold, L. E. (2005). Paradigm Shift in Construction Education is Vital for the Future of Our Profession. *Journal of Construction Engineering and Management*, *131*(5), 533–539.

Forrester, J. W. (1968). *Principles of systems*. Cambridge, MA: Wright-Allen Press.

Gorsky, P., & Finegold, M. (1992). Using computer simulations to restructure students' conceptions of force. *Journal of Computers in Mathematics and Science Teaching*, *11*, 163–178.

Hermann, N. (1990). *The creative brain*. Lake Lure, N.C.: Brain Books.

Hernández-de-Menéndez, M., Vallejo Guevara, A. et al. (2019) Active learning in engineering education. A review of fundamentals, best practices and experiences. *Int J Interact Des Manuf* ,13, 909–922

Klahr, D., Triona, L. M., & Williams, C. (2007). Hands on what? The relative effectiveness of physical versus virtual materials in an engineering design project by middle school children. *Journal of Research in Science Teaching*, *44*(1), 183–203.

Kornblugh, M., & Little, D. (1976). The nature of a computer simulation model. *Technological Forecasting and Social Change*, *9*, 3–26.

Lima, Rui M., Andersson, Pernille H., Saalman, Elisabeth (2017). Active Learning in Engineering Education: a (re)introduction. *European Journal of Engineering Education,* 42(1), 1-4

Pusca, D., Bowers, R. J., & Northwood, D. O. (2017). Hands-on experiences in engineering classes: The need, the implementation and the results. *World Transactions on Engineering and Technology Education*, *15*(1), 12–18.

Stratford, S. J. (1997). A review of computer-based model research in precollege science classrooms. *Journal of Computers in Mathematics and Science Teaching*, *16*(1), 3–23.

The Condition of Education, NCES 2001072, National Center for Education Statistics, U. S. D. of E. (2001). *The context of postsecondary education*. Washington, D.C.

Annexure 1 – Snippets of the Survey Questions

a. Have you ever used any educational computer models in your courses before?
1) Yes 2) No
If yes, for what course(s) and what kind of model(s)?

b. How useful do you find the in-class use of computer-based educational models in helping you understand the concepts of Dynamics course?
1) Not helpful at all 2) Slightly helpful 3) Moderately helpful 4) Helpful 5) Very Helpful

c. How useful do you find the out-class use of computer-based educational models in helping you understand the concepts of Dynamics course?
1) Not helpful at all 2) Slightly helpful 3) Moderately helpful 4) Helpful 5) Very Helpful

d. How useful did you find the dynamic models, presented by the instructor throughout the semester, in helping you grasp the fundamental concepts of dynamics?
1) Not helpful at all 2) Slightly helpful 3) Moderately helpful 4) Helpful 5)Very Helpful

e. If the instructor provides you with some educational models, what would be your preferred way of running those models? (sort the statements using a number from 1 to 4, 1 being the most preferred way and 4 being the least preferred way)
___ on any web browser on laptops, cellphones, tablet (limitation: you have to have access to the internet)
___ on my windows/mac (limitation: you must install the corresponding software first to run the model)
___ on your windows/mac (limitation: you have to download the file as a self-executable file)
___ on universities' machine (limitation: you have access to the models on-campus only)

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Hands-On Approach to Teaching Construction Materials and Methods: A Case Study

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At the University of Oklahoma, the Construction Science Division provides a Hands-on Class in which Construction Management students get the opportunity to learn construction methods and materials while building with their hands. In 2018, the graduate and undergraduate level course constructed two multi-family (2,936 Square Feet) dwellings in Norman, Oklahoma during the Spring semester. The units were purchased from the Norman Housing Authority and now provide housing for low-income citizens within the University community. The goal of this paper is to record and present the Kinesthetic and Collaborative pedagogies used in this unique class. A brief literature review explores the previous research on Kinesthetic and Collaborative pedagogies. The case study includes discussion on how the project was planned, designed, funded, and executed. The case study also presents how the class was coordinated, how student and subcontractor labor was utilized, the challenges faced during this process and future recommendations for similar classes. This case study adds to the body of knowledge by providing a detailed description of a Construction Education course that adds value to the local community by designing and building low-income housing.

Key Words: Kinesthetic, Collaborative, Pedagogy, Construction Education, Community Outreach

Introduction

In the 1963 James Bond film *From Russia with Love*, the fictitious character Rosa Klebb said, “training is useful, but there is no substitute for experience.” With the increasing demands for “industry ready” professionals in the Construction industry, it is indicative that higher learning institutions keep pace and develop students to successfully transition and lead productive careers. The objective of this research is to document the pedagogies used in the Construction Fundamentals Lab at the University of Oklahoma in the Construction Science (CNS) program. This allowed for students to combine their technical and practical skills on an active construction site, in which two multi-family duplexes (named the Hughbert Street Project) were newly constructed. This class experience provided two great outcomes with the students, first learning by doing, on a real construction site, and second, developing meaningful working relationships with professors, fellow students, and industry professionals. This paper presents the case study of this unique hands-on experience and the literature that validates this method of instruction.

Literature Review

The evolution of the construction industry must start with the development of the leaders and the workers that will carry the industry forward. Construction education is critical for the strength of the industry. Most programs offer a variety of courses in construction technology and management philosophy along with courses from other disciplines to strengthen students' knowledge and skills from other perspectives. Furthermore, construction management education focuses on the entire life cycle of a project. This includes initial planning, design, site construction, occupancy and maintenance, condition assessment, retrofit, and renovation or removal (Lee et al. 2013). at the University of Oklahoma in the Construction Science (CNS) program, the undergraduate Construction Science program's mission is to develop, organize, and manage a successful team of the various design and building disciplines requires technical, communication, and teamwork skills (University of Oklahoma, 2019).

According to Mobley and Fisher, learning through movement should be fully incorporated into college pedagogy (Mobley & Fisher, 2014). Equipping students with practical knowledge prepares those students to enter the construction industry and contribute immediately. "Kinesthetic," as used in the study, describes muscular movement in response to visual, auditory, and tactile stimulation, aka hands-on learning (Grant, 1985). Marie Grant states "the Kinesthetic approach to teaching relies on the students' active, physical participation… allowing them to discover their education and individual capabilities." Integrating kinesthetic methods is one solution with the benefit of immediate and deeper learning for students.

Dowling (2012) writes, "the challenge for instructors to create materials that engage students physically, intellectually and emotionally can provide opportunities for individual connections and learning that is retained over time with long-term memory". Learning from hands-on experiences invites experimentation and exploration that engages the hand, body, and brain differently. This shift in pedagogy from traditional lectures provides students with a completely different learning experience. Hands-on learning allows students to engage and invest in their education in new ways and students make the transition from passive learners to active learners (Scott & Ghosh, 2016). This method requires a great deal of planning and additional resources outside of the normal classroom.

In addition, students are often taught to focus on learning their discipline, but they are unaware of how to collaborate with others (O'Brien, et al. 2003). Traditional teaching and learning pedagogies, often at higher learning institutions, are that of a lecturer broadcasting one-way information to the audience. When information is transmitted this way, students are limited in their exposure. Construction Management programs should foster collaborative learning experiences. Gunderson & Adams writes, "in-group cooperative learning environments, students work in a structured group to perform a well-defined task or to understand a particular concept with the purpose of every individual within the group developing his or her academic and social skills to the maximum" (Gunderson and Adams, 2006, p. 2). For the collaborative pedagogical approach to be successful, education professionals must "provide good guidance and an induction session for students immediately prior to the commencement of the projects" (Scott and Ghosh, 2016). The following case study presents a teaching method that provided a hands-on learning experience for construction students.

Case Study

Planning and Stakeholders

The instructor of the Hands-on lab, Professor Bryan Bloom at the Construction Science Division at the University of Oklahoma, also teaches the Materials and Methods II class. Prior to 2018 the hands-on lab only constructed portions of a building, i.e., concrete foundation, CMU wall, portions of MEP systems, and components of the ceiling. The instructor explained that the larger project in the Hands-on lab stemmed from the thought of "why not actually do something, build something that we are going to keep or that is for the community." The instructor set off with the challenge to provide both a learning experience for his students and something for the community. The idea was to provide low-income housing to the city of Norman that was constructed by CNS students.

The first challenge was funding. The instructor communicated with four key stakeholders to get the ball rolling. The first stakeholder, and one of the most important, was an external partner of the CNS program at the University of Oklahoma who would be willing to help with initial funding. The land seemed to be reasonably priced, and the investor thought it was a great idea. The investor provided the equity/cash to purchase an identified piece of property in Norman, OK. The second stakeholder was the Dean of the College of Architecture which houses the CNS division. The Dean, a licensed Architect, and his firm, agreed to provide the architectural plans pro bono.

The Third stakeholder was the Norman Housing Authority (NHA) and the Norman Affordable Housing Coalition Corporation (NAHCC). With a "cold" call to the NHA, the instructor presented the plan to both the NHA and NAHCC to have the CNS students construct affordable housing in the City of Norman. The plan was to design and construct homes in a way that would tailor to a specific tenant that has disabilities or other ailments. In addition, use systems and materials that do not require a lot of maintenance. The NHA saw the vision and was excited that they could also have some input in the design of the homes. The typical NHA model for acquiring homes is to acquire existing housing which often does not allow for occupants with disabilities. With the help of the NHA, the architect was able to develop a design that fulfilled the needs of housing for NHA. Further description of the design is provided below. From the beginning, the NHA seemed to be extremely excited to partner with the University. Upon completion of the housing, the NHA agreed to purchase the buildings for low-income housing.

The final stakeholder was a local bank that would provide a construction loan. The architectural drawings were sent to the bank to show the intended structures. An estimate also had to be provided, which was challenging because the instructor had to estimate how much labor the students would provide. The instructor anticipated that what the students would not be able to complete would need to be completed by subcontractors. Upon hearing the plan from the instructor, the bank approved it and financed the project during construction. The deal was structured so that Mr. Hacker, would own the land and the buildings during construction and it was provided as a non-recourse loan. Mr. Hacker was the owner and developer and at the end of construction, entered into a sales agreement with the Norman Housing Authority, who bought it for the negotiated price.

The project site is located at 115 W Hughbert St, Norman Oklahoma. As it was located on Hughbert St, it began to be referred to as the 'Hughbert project'. The instructor contacted the owner and negotiated the price for the Hughbert Street land. A contract for the project was agreed upon in November 2017, the purchase of the lot was closed in December of 2017, and construction was set to be started during the Spring semester of 2018. The turnaround time for planning from beginning to end was extremely fast. A deal of this nature can sometimes take months or years to close.

Design and Permitting

With a quick turnaround in mind, the design immediately began designing the project once the agreement was entered. With the help of the NHA, the design team was able to meet the low housing income needs with two duplexes on the lot. Each duplex provided two, 1-bedroom ADA accessibility homes, for a total of four low-income homes. Fortunately, the land was zoned multi-family residential (R-2) which allowed for the design of two duplexes on the lots. The design of the duplex can be seen in Figure 1. The total square footage for the four units is 2,936 Square Feet. The most glaring design challenge was the location of the lot directly next to an active railway, to the west. A lot of attention was given to the orientation of the duplexes to create a sound barrier for the west wall on both units. The solution to alleviate some of the sound from the train was to design the entire west wall to be a big shingle wall with no windows. The other side of the shingle wall called for a double stud wall, with a one-inch air gap, and insulated both walls for noise and for thermal resistance. The design team finalized the concept and plans and submitted everything to the City of Norman within two weeks. The residential building permits were applied for immediately after the land was purchased and approved in two weeks. The instructor stated, "Honestly, another partner, on this project, was the City of Norman. They saw what we were trying to accomplish and helped move the process along a little quicker."

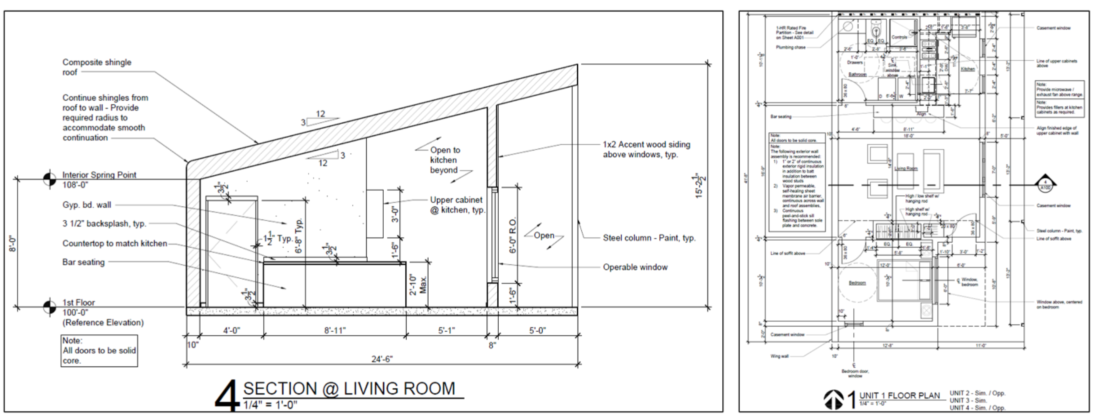

Figure 1. Cross Section and Floor Plan for the Four Units

Class Coordination and Construction

The instructor organized the Hughbert project around two CNS classes, the Materials and Methods II (MMII) class and the Fundamentals Lab class. MMII meets two days a week (Tuesday and Thursday) for 75 minutes in a classroom and the Fundamentals Lab class meets once a week (Friday) for four hours. The instructor used the MMII class times to instruct students on the methods and materials that they would use on the project and would use the Fundamentals Lab time to work exclusively at the construction job site. The classroom lectures, generally, went hand-in-hand with the activities or tasks that were to be completed on the Hughbert project. Having the job site close to campus was a major benefit for students to be able to travel between the site and campus. Most students, in the Materials and Methods II (MMII) and Fundamentals Lab, were experiencing hands-on construction processes for the first time. The objective was not to train students to be carpenters but to provide an experience so they understand what they would be asking of their skilled trades workers.

A 16-week semester allowed for 16 days in which the CNS students would be able to build the houses. The instructor's desire was to allow the students to see as many aspects of the project as possible. The instructor warned the students on the first day of class that the schedule would need to be flexible in the class syllabus. The hope was that the students would be able to experience the construction processes up to the finishes of the interior millwork. The actual schedule ended up falling a couple of weeks behind in comparison to the expected schedule. Ultimately the students would only see construction up until drywall during the spring semester. There were at least two weeks that the students could not work due to spring break, weather delays, and inspections.

The instructor began some of the construction before the spring semester in order to get out of the ground. It was important to get out of the ground as construction can be delayed in the early stages, especially in January when the weather, in Oklahoma, can be very unpredictable. The design of the duplexes allowed for foundation work to occur quickly and without changes. The footings and stem wall were completed prior to the commencement of the Spring semester. The students would still be able to see the groundwork (electrical and plumbing) and concrete with pouring the slab.

Figure 2. Students Framing and Raising Wall

Each lecture session was, generally, structured so the building process introduced in MMII corresponded with the work to be completed in the lab sessions on Friday. During the Tuesday lecture, the materials and methods would be introduced for a new portion of construction. For example, window installation would be introduced on Tuesday in which the instructor would review the window specifications with the class and explain the methods used to install the windows. In Thursday's class, the students would be given an assignment meant to explore the upcoming systems, products, or materials. For windows, the assignment would include confirming measurements of the windows and rough opening, to verify the opening was flashed properly to combat water infiltration, and be sure they understand the techniques for installation. This allowed students to become familiar with that specific process before they would get hands-on experience. The instructor designed each Friday lab with two learning objectives:

1. learn how different systems and products were installed, and
2. engage and work with fellow students and industry professionals

Friday afternoons were designated as lab days. The goal was for students to recall what they learned on Tuesday and Thursday and apply it on Friday, by installing a product or material. During the lab days, students were paired and given directions on the tasks that were to be completed that day. During the lab days, students framed the exterior walls (see Figure 2), installed the exterior sheathing, windows, doors, insulation, and drywall.

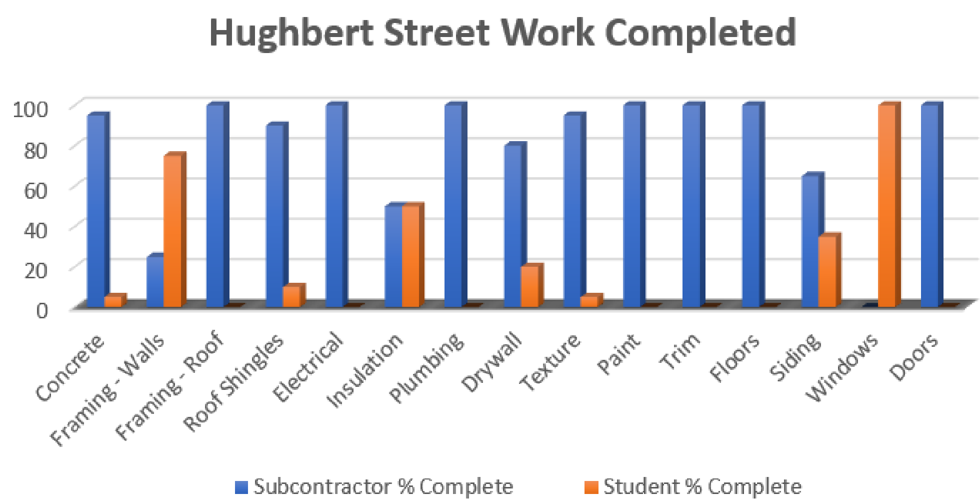

Figure 3. Percentage of work completed on the Hughbert Street project.

To experience multiple portions of the construction process, subcontractors were needed in addition to the student work to stay on schedule. During planning, the instructor identified subcontractors to help on the project as he knew that the students would not be able to complete all work across the project during the 16-week schedule. In addition, subcontracted work that had to be done by licensed trades such as HVAC, electric, and plumbing was included in the initial budget. The instructor selected the subcontractors based on personal relationships developed through his local home building company. The students were able to work on many portions of the project, ultimately subcontractors performed the majority of the work as can be seen in Figure 3. On the project site, an issue for surrounding neighbors was parking. To avoid overcrowding, the instructor instructed the subcontractors to complete their work by Thursday afternoon so the students would be able to work on Fridays. By the end of the semester the students completed the drywall. After the semester, the instructor finished the construction of the duplexes with the subcontractors.

Course Reception and Feedback

Upon completion of the courses, students performed course evaluations through the University. The two courses were found to be two of the most effective courses within the Construction Science department. Table 1 presents four of the questions that are provided in the student evaluation process.

Students are asked to evaluate each question on a 5-Point Likert Scale, with 1- being Strongly Disagree and 5- Strongly Agree. Compared to the Mean within the Construction Science Department, the students found the class to be highly effective. The Mean for both classes were higher than the Department's Mean and the Standard Deviation was much smaller for both classes, which demonstrates the consensus of the students with the courses. Additionally, there were many student comments similar to the following with the case study.

"This was my favorite course this semester. Learning on the job and seeing construction in action was much more effective than any class I have sat in. The Professor did an excellent job at answering questions, fixing problems, and guiding the students along the way. Learning the steps and methods of construction at an actual site was very beneficial."

Student Comment

"A few of the things that I liked about the course was getting hands on experience with an actual project, getting an understanding of certain building materials and actually how to apply them. The Professor taught us by showing us how to do the work and then challenged us to do it ourselves.

Student Comment

Table 1
Student Perception and Impact of the Two Combined CM Courses

	Fundamental Lab Course			Material and Methods Course			Department Courses	
Questions	N	Mean	StDev	N	Mean	StDev	Mean	StDev
In this course I gained a basic understanding of the subject (e.g., factual knowledge, methods, principles, generalizations, theories).	34	4.882	0.327	46	4.826	0.383	4.388	0.884
In this course I learned to apply course material to improve problem solving.	34	4.941	0.238	46	4.761	0.431	4.272	1.016
In this course I learned to critically evaluate ideas.	34	4.794	0.41	46	4.652	0.526	4.144	1.076
Overall, I rate this course as excellent.	34	4.941	0.239	46	4.804	0.401	4.134	1.193

Challenges and Recommendations

Like most construction projects, the major challenges dealt with time and budget. With regards to time, the major challenge was ensuring that the project and materials were ready for the students on Friday. It was difficult to manage time with regards to ensuring that the students had the necessary guidance prior to coming to work on the job. Once the lab started there would typically only be enough room or tools in which smaller groups could work on the project at a certain time. To mitigate overcrowding the students were broken up into groups and would work in sequential order. The instructor was challenged to setting everything up for the first group and then prepare the next group to follow. There was a loss of production between each group during the tight 4-hour time frame. Given the circumstances, the students were not coming back the next day to perform a familiar task, they were coming back seven days later, and facing a completely new task. For example, one week the students would start installing sheathing, and the week after they would be installing windows, and so there was always a new problem or issue to solve with the logistics of the lab. It was difficult to get good momentum during the labs between the different groups of students. In addition, there was a limitation on the number of tools available and students had to share tools. Since the lab only had sixteen scheduled meetings, the design of the structure was simple enough for inexperienced students to build but in retrospect, the design could have been simplified even more. The instructor would recommend a smaller scope of design for future projects.

The balance of the project was funded through a construction loan. Developing and maintaining the budget was the other major challenge. As the students would not be paid for their labor the instructor had to develop the initial budget with estimating how much work would be accomplished by the students and the subcontractors. The budget was a "moving target", because of the unpredictability of the remaining balance to complete the project and to try to meet the NHA buying price. Initially, the instructor provided the bank with a worst-case scenario in which he would have to hire subcontractors to do all the work. With the students participating in the construction of the duplexes, the instructor was able to offset labor costs allowing them to save money. Periodically during the project, the instructor would gather all the construction costs and send it to the bank. In hindsight, the instructor believes being more exact on the estimate would have set the project up better. Since the pre-construction phase had to occur so quickly, he was only able to provide a conceptual estimate, which meant every detail of the estimate was not fully verified. The instructor's experience as a custom home builder gave him the assurance the estimate was within range of the actual cost. However, the instructor would recommend more time during pre-construction in which a more accurate estimate could be developed. Also, securing a buyer and establishing a final price sooner would have been ideal. Knowing the expectations, the NHA may have had, and allowing for more time to plan the project. As it became clearer that the NHA would be purchasing the duplexes the instructor was able to accommodate them more. For example, installing a specific product or installing a ramp.

For this class methodology to be sustainable on a year-to-year basis, funding and the right end-user must be secured. More time will be needed and, possibly, a full year to complete a project of this magnitude. The instructor believes it is critical to involve other disciplines within the college of architecture, including architecture, interior design, and landscape architecture students. This could develop an environment where the design and construction students could engage and establish a collaborative approach during their education. The instructor also recommends that this class should only be for students who are dedicated to something of that magnitude. Having the class be an upper elective or graduate course would ensure that the students that are enrolled in the class are dedicated to the class objectives. When students didn't arrive on time or took longer than planned, that ended up costing more money.

Conclusion

In 2018, the construction science department provided their students with a hands-on experience in which they participated in the construction of low-income housing. The project was spread across two classes in which two duplexes were constructed during a semester. The instructor incorporated Kinesthetic and Collaborative pedagogical approaches into the course and lab. In the end, the instructor received high levels of satisfaction from the students, faculty, and community leaders. The course evaluations demonstrated that the students were very enthusiastic with the approach of instruction. This paper contributes to the body of knowledge by providing a detailed case study of a hands-on course that also served the local community. Including the funding, planning, design, and coordination required. The experience and knowledge gained through this experience would serve valuable for other construction science programs that are looking for a unique hands-on approach to a construction education.

References

Dowling, C. (2012). The Hand: Kinesthetic Creation and the Contemporary Classroom. *The International Journal of Learning*, *18*(8), 51–66.

Grant, S.M. (1985). The Kinesthetic Approach to Teaching: Building a Foundation for Learning. *Journal of Learning Disabilities*, *18*(8), 455–462.

Gunderson, D. E., & Moore, J. D. (2008). Group learning pedagogy and group selection. *International Journal of Construction Education and Research*, *4*(1), 34-45.

Lee, S., Esmaeilzadeh, A., & Lee, D. (2013). Graduate Construction Management Programs in the U.S.: Lessons Learned from Leading Institutions. *KSCE Journal of Civil Engineering*, *17*(7), 1664–1671.

Mobley, K., & Fisher, S. (2014). Ditching the Desks: Kinesthetic Learning in College Classrooms. *The Social Studies*, *105*, 301–309.

O'Brien, W., Soibelman, L., & Elvin, G. (2003). Collaborative design processes: an active-and reflective-learning course in multidisciplinary collaboration. *Journal of Construction Education*, *8*(2), 78-93.

Scott, L., & Ghosh, S. (2016). Collaborative approach in construction education: towards a more constructivist experience. In *Associated Schools of Construction, 52nd Annual Conference Proceedings, New York, NY* (pp. 1-7).

University of Oklahoma. (2019, September). About the Division of Construction Science. Retrieved November 2, 2021, from https://architecture.ou.edu/wp-content/uploads/2019/10/About-the-Division-of-Construction-Science.pdf.

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Assessing Virtual Learning Environments (VLE) for Construction Management Education

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This paper contributes to the current discussions and research on the use of 3D digital technologies in teaching and learning. It specifically focuses on the use of a Virtual Learning Environment (VLE) in construction management higher education. There were three objectives: (1) to check the impact of this approach on student learning (2) to determine which factors increased the perception of immersion (3) to assess whether this type of learning could affect cognitive change. A VLE of a construction site and related scenarios were used to develop a set of learning outcomes focused on soft-skills. Utilizing Virtual Reality (VR) to create an immersive environment, the VLE enables a student to work on a construction site, undertaking real life scenarios and interacting with people to enhance leadership, behavioural health, safety, quality, and productivity skills. A series of individual scenarios were developed to help contextualize the learning outcomes. These scenarios were based around a day managing a construction site. The immersive simulations were underpinned with pedagogical tools and structures, namely the Kolb Experiential learning Model and Gibbs Model of Reflection (Kolb, 1984; Gibbs, 1988). The experiential learning allows the student to make decisions and understand the consequences. The learning takes place in a safe environment which negates impact on a real job site and is reinforced through feedback, knowledge sharing, and mentoring. The assessment involved questionnaires designed to evaluate the impact of experiential learning, assess which aspects of the simulation had the greatest impact in relation to the feeling of immersion, and to assess whether this type of teaching could affect cognitive change. The results indicate that the students perceived the method to be effective and highlighted 3 key factors relating to immersion - the actors, the site office, and the site paperwork. The outcome of the third objective was not conclusive and further research on long term cognitive change is recommended.

Key Words: immersive simulation, scenarios, Virtual Learning Environment (VLE)

Introduction - the Simulation Centre

Coventry University Simulation Centre (www.thesimulationcentre.co.uk) is a VLE (figure 1) that incorporates 3-D VR displayed on a 10m screen, actors, real site cabins and construction assets such as programs and drawings. The pedagogy approach is based on problem-based learning (PBL) and learn by doing.

Figure 1. Images of the Simulation Centre

The students undertake a series of individual, but interlinked, scenarios which have a cohesive narrative to help contextualize the learning outcomes. These scenarios focus on managing a construction site, including the pressures, issues, and interruptions that are experienced on a real building site. The approach allows the students to experiment with ideas and development concepts in the VLE that will have no consequence or risk to themselves or others, it is a 'safe' environment. The outcome is a personalized learning experience, without real world repercussions.

To initiate situations, the students are located in one of eight site offices on a construction site. They can walk through and view the job site on the 10m screen. The interaction with actors and site office assets further enhance the realism. The student utilizes joystick VR locomotion, as this is perceived as easy to use (Costas and Cedergren, 2018) to move through the VR construction site.

To overcome the perceived technology barrier, a "taster" session is the first simulation. This includes a task to discover discrete details relating to the construction site. This encourages the student to search the documentation in the site office, use the telephone, and immerse themselves in the virtual construction site. An actor will also visit the student, with a benign query, one that can be readily resolved, so that the student has experienced the learning process and is more confident with their role. Following this session, there is feedback while student queries are clarified.

Literature Review

Rapid advances in digital technology and a subsequent decrease in the associated costs has enabled educational establishments to invest and incorporate 3D technologies in their teaching (Abulrub, 2011). Although some of these virtual worlds were not initially designed for education, they have been shown to be effective for constructionist learning. They allow students to actively explore, test and extend their understanding. A study undertaken by O. Halabi found that using VR and a project-based approach concurrently led to improved communication and problem-solving skills as compared to a traditional approach (Halabi, 2020). It is also recognized that construction engineering education and training institutions have begun to implement VR due to its perceived benefits of providing immersive and engaging environments (Wang and Wu 2018). Current research tends to focus on how 3D technologies aid a student's understanding of a structure or detection of defects. Examples would include using Building information Modelling or virtual worlds. However, there is limited understanding of the application of VLE from a user-orientated perspective. (Wang and Rui 2020;

Delgado et al., 2020). It is important to recognize that teachers need to understand how to apply learning theories that are relevant to a digital age (Starkey, 2011).

A review of VLE (Mikropoulos and Natsis, 2011) state that visual representations predominate and establish VR and is a useful approach to learning for construction students. VLE have the potential to create virtual world experiences for learning and teaching purposes. Kolb's experiential learning theory states that people gain and transform knowledge through experiences (Kolb, 1984). In construction, learning and teaching can be difficult to gain experiences in the real world. The significance of these new technologies is recognized. However, there remains a lack of empirical evidence specific to the impact that new technology might have on learning behaviour and preferred learning styles. This study surveyed students to identify their preferred learning style before and after a simulation exercise, and which features enhanced the feeling of immersion. The features of a VLE that are thought to contribute to positive learning outcomes include immersion or presence ('sense of being there'), fidelity, flow, active learner participation/motivation and immediacy of control (Chau et al, 2013). They conclude that using a VLE is learner-centred, allowing the learner to construct knowledge by themselves. They also draw attention to the difficulty of measuring actual learning as opposed to perceived learning. To summarize there are technical characteristics, human characteristics, and pedagogical characteristic to consider when creating and using a VLE.

Methodology

Though the Simulation Centre has been running for a number of years, no research has formally been undertaken on its effectiveness. This paper is the first step in addressing the research gaps related to the potential effectiveness of simulation centre training to obtain a base understanding of its effectiveness in terms of self-efficacy.

This study follows a mixed method approach, utilizing two anonymous structured questionnaires, one that the students completed before the simulation and the second completed immediately after the simulation. The cohort consisted of 32 fourth year MEng Civil Engineering students aged between 21-25 years at the School of Energy, Construction and Environment at Coventry University. The first questionnaire contained initial questions related to any prior industrial experience and motivation, and preferred style of learning. This was followed by a series of questions relating to self-efficacy using a Likert 5-point scale.

The second questionnaire was undertaken immediately after the simulation by the same 32 students. They were again asked their preferred learning styles and whether this had changed due to the experiential learning. The subsequent questions (Likert scale) related to the effectiveness of the learning experience with a qualitative question relating to any identifiable skills developed during the simulation. The same questions relating to self-efficacy from the first questionnaire were repeated to measure the impact on the student. The students were also asked to identify, from a list, what factors created the feeling of immersion or presence during the simulation. As such, the questionnaire was both quantitative and qualitative (The Open University, 2007). The balance between both data forms should help to ensure the reliability and validity of the process.

Results – Pre-simulation

The students undertaking the simulation had previously worked in the construction industry, with a range of industry experience from summer jobs to the largest number (22) having undertaken a one-year internship. This enabled the students to rapidly participate in VLE as they were familiar with the job site environment.

When looking at their preferred learning pedagogy, the overwhelming number selected to learn through doing (72%), making the learning opportunities within the VLE applicable and appropriate to them. Only 8% of the students preferred to learn through listening and reading; this is partially accommodated through the feedback being discussed verbally and individual written feedback distributed to each student at the end of the session.

The learning anxiety section investigated whether using a VLE could impact negatively on the learning experience. The results in figure 2 indicate the majority of the students did not have learning anxiety before participating in the VLE. Several students had previously undertaken courses in the simulation centre. This could account for the high percentage that expressed their lack of anxiety. Alternatively, the high degree of construction industry experience could also account for this result, as the simulation was specifically related to working on a construction site.

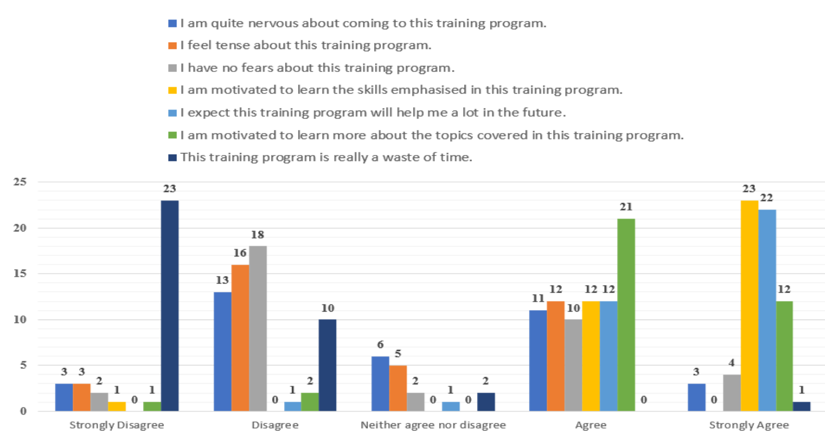

Figure 2. Learning Anxiety and Motivation

Results – Post-simulation

A number of questions were replicated after the simulation to measure any variation, in particular those relating to self-efficacy. The results for the preferred learning style did not alter considerably, as the approach matched the majority of the learners' preferred style of learning.

The questions on the effectiveness of the overall experience are shown in figure 3. This demonstrates that the students' perception of the simulation approach was effective, which coincided with their motivation results before they undertook the simulation.

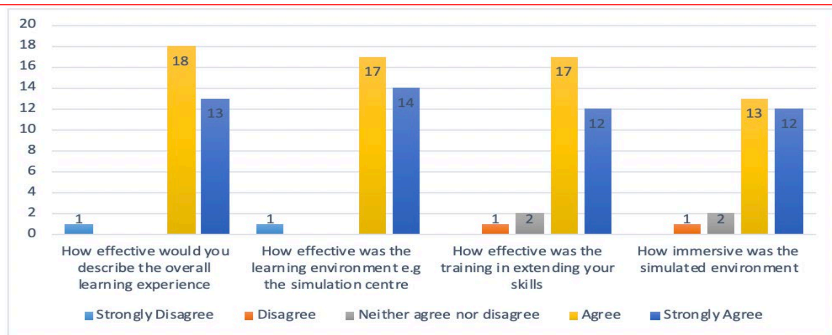

Figure 3. Learning effectiveness

Self-Efficacy Analysis

To fully analyse the impact of the training, a comparison of the separate questions regarding the students' self-efficacy has been undertaken. The eight questions have been collated to show the responses pre and post training to ascertain whether the students' self-efficacy had altered. *Strongly agree* and *agree* have been classified as a positive response, while *strongly disagree, disagree* and *neither agree nor disagree* have been classified as a negative response.

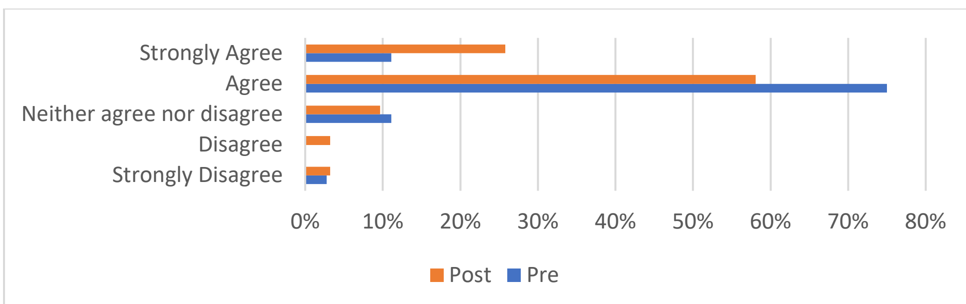

Figure 4. I will be able to achieve most of the work-related goals that I have set for myself.

Figure 4 shows that the results pre and post simulation are similar, before the simulation 86% of the students gave a positive response regarding their ability to achieve work-related goals. After the simulation, this was at a similar level of 84%; however, the percentage strongly agreeing increased from 11% to 26%. The next question focused on facing difficult work tasks.

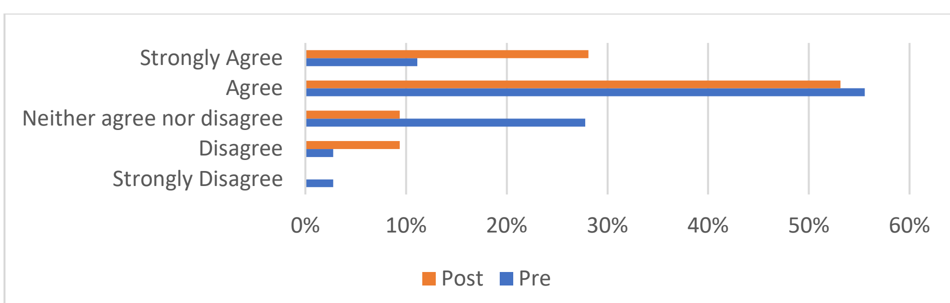

Figure 5. When facing difficult work tasks, I am certain that I will accomplish them.

Figure 5 indicates a greater difference pre and post simulation. Prior to the simulation, 67% of the students were in agreement or strongly agreed that they could accomplish difficult work tasks. This rose to 81% after the simulation, with the *strongly agree* category increasing by 17%. Also, the percentage of students who gave a negative rating decreased by 15%.

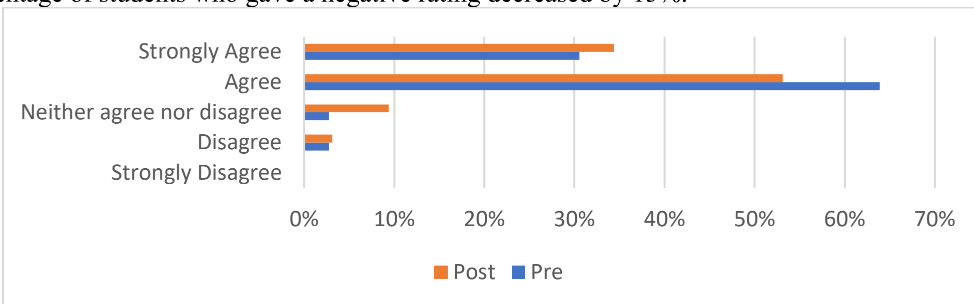

Figure 6. In general, I think that I can obtain work outcomes that are important to me.

Figure 6 indicates a decrease in the students' responses, with 6% reduction in positive responses but a slight increase in the *strongly agree* category. Prior to the simulation, this question had a high positive response (94%). This decrease could be due to the students' self-reflection on their abilities and realizing they might not be as strong as they previously thought after their simulation experience.

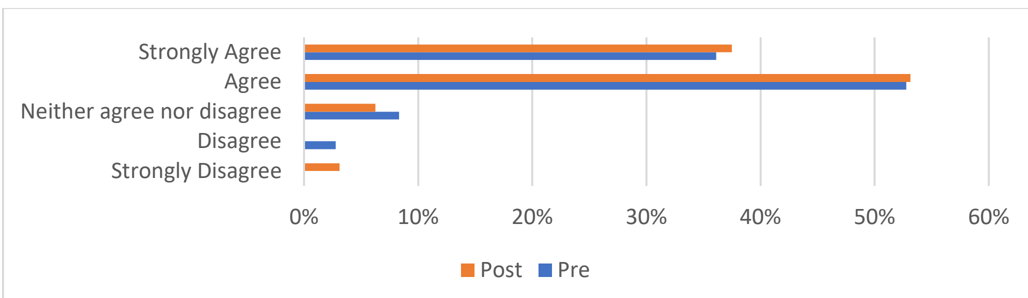

Figure 7. I believe I can succeed at most any work-related endeavour to which I set my mind.

Figure 7 shows that there was no change in the student responses regarding their belief they could succeed at any task they set their mind to with only a 2% change.

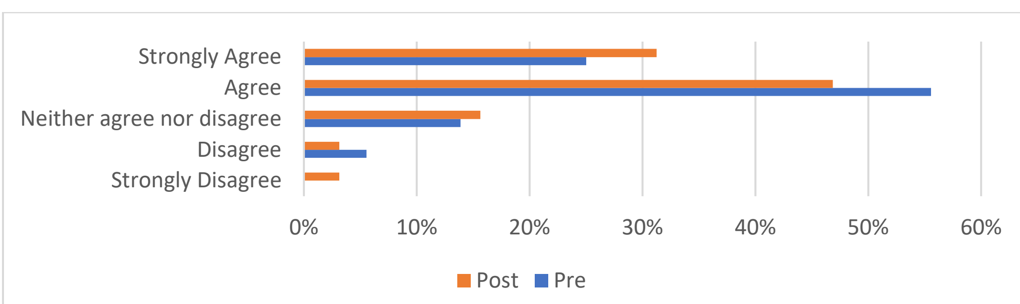

Figure 8. I will be able to successfully overcome many work-related challenges.

Figure 8 indicates a small decrease in positive responses (3%), which could again be attributed to the students' real understanding of their self-efficacy after undertaking the simulation. Again, there has been an increase on the *strongly agree* category (6%).

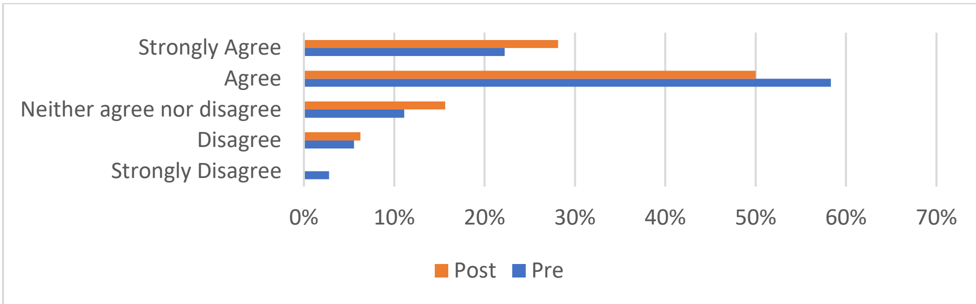

Figure 9. I am confident that I can perform effectively on many different work tasks.

Figure 9 indicates a similar trend. As with the previous question, this showed an increase (9%) with the *strongly agree* category increasing by 11%, a slight change in the students' response after the simulation.

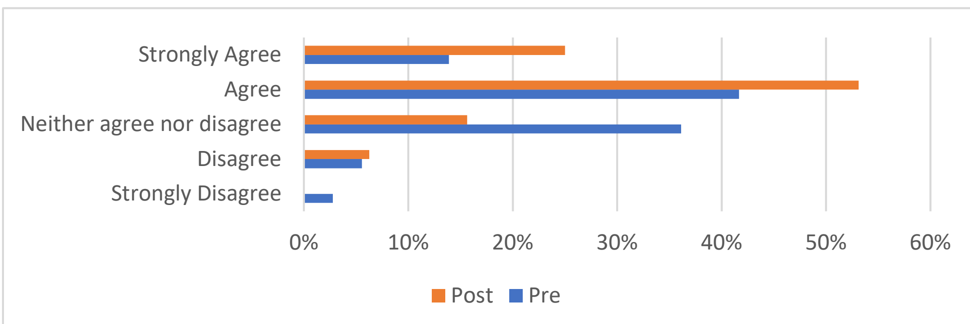

Figure 10. Compared to other people, I can do most work tasks very well.

Figure 10 shows that this increased by 22% following the simulation, a positive outcome of the simulation. This is possibly due to the pedagogy of group feedback and reflection, allowing the students to compare how they undertook the scenarios with one other.

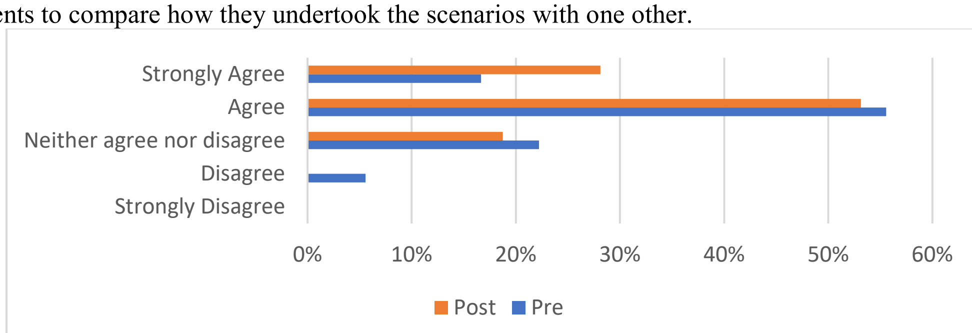

Figure 11. Even when things are tough, I can perform quite well at work.

The final question in figure 11 looked at their performance under tough conditions, something that the Simulation Centre excels at delivering. As with the previous question, this showed an increase (9%) with the *strongly agree* category increasing by 11%.

The results from the self-efficacy questions were supported with the qualitative comments from the students in the second questionnaire when they were asked what specific skills had been developed in the training. The common themes were development around problem solving, communication, people/interpersonal skills, confidence, communication/ listening and leadership. The questionnaire results also included the students' experience regarding empathy, confidence and thinking/understanding.

Factors contributing to Immersion/Presence

A key enabler to a successful learning outcome is ensuring the student is immersed in the VLE. To measure what factors have the greatest impact, we asked the participants to highlight which factors they perceived as integral to the immersive environment. See figure 13. The list of assets and stimuli were garnered from the simulation centre facility. These factors blend together to create the overall immersive environment. The objective was to ascertain which factor(s) had the greatest impression on the learner. Respondents were allowed to tick as many stimuli as they felt helped in the learning experience. Using this information in the future will assist in accelerating the immersion of the learner and could highlight the hierarchy of assets required when using a VLE.

The graph shows that the top three aspects of the simulation centre that create an immersive environment are the actors, the site office and the paperwork. Surprisingly, the VR is ranked fourth. It could be argued that these top three factors could be used to create immersion, without the visualization. However, the results of the visualization and the screen added together would create the highest score. It is not clear to the authors whether this differentiation caused confusion with the participants or whether the two aspects are interlinked. Further analysis of the VR will be beneficial, to ascertain the impact of the screen and visualization. This will investigate whether the visual representation has to be 'ultra' real, which is a true replication of the learner's actual site set up, as well as the extent of whether interaction with the visualisation is necessary.

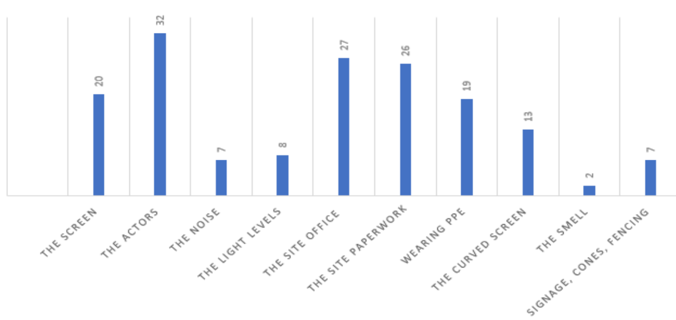

Figure 13. Greatest Impact Factors

Conclusion

This case study investigated three aspects relating to experiential learning in an immersive environment using the Simulation Centre at Coventry University. A general evaluation of the impact on the students after undertaking this type of learning was undertaken as well as an assessment of which factors had the greatest impact relating to the perception of immersion. A majority of the students expressed a preference for this approach, namely learn by doing. This was evident in their responses, specifically their lack of concern before undertaking the simulation and their high degree of motivation to undergo the simulation. The post evaluation again suggests that the students observed this approach as effective in aiding in their soft skills development. There was a clear outcome that the actors, project documents, and site office are essential factors that create the immersion. The VR screen was not as highly ranked as the faculty would have expected. The people-to-people role playing provided the greatest impact. This is a key take away for any ASC school interested in building a simulation centre. It was assumed that the visualisation would be key to the immersion, however, as seen, it was not the primary factor and further analysis of this is suggested.
The third objective was to assess whether this type of learning could affect cognitive change. The results are inconclusive, and it is perhaps the fundamental evaluation, namely permanent cognitive change, that remains to be evaluated in future studies. As previously mentioned, this paper is the first step in addressing the research gaps related to the potential effectiveness of simulation centre training to obtain a base understanding of its effectiveness in terms of self-efficacy. The quantitative data presented here is backed up by further qualitative information obtained in the questionnaires regarding the strengths and weaknesses of the training undertaken. This is further backed up with qualitative information through the reflections submissions that the students produce as part of the assessment linked to the learning. This data and further quantitative data will be collected later from industrial users to allow comparative analysis and possible further research around age, gender and the overall simulation effectiveness. The authors continued to be excited by the popularity of the VR and the impact it is making on students. Through Associated Schools of Construction (ASC), the authors have been able to establish partnerships with other universities for this and future research to aid and support new developments in construction education.

References

Abulrub, A.H.G., Attridge, A., Williams, M. A. (2011). Virtual Reality in Engineering Education: The Future of Creative Learning. International Journal of Emerging Technologies in Learning (iJET), [S.l.], v. 6, n. 4, p. pp. 4-11, nov. 2011. ISSN 1863-0383. Available at: <https://online-journals.org/index.php/i-jet/article/view/1766/2019>.

Chau, M., Wong A., Wang M., Lai S., Chan K.W.Y, Li T.M.H., Chu D., Chan I.K.W., and Sung W. (2013) Using 3D Virtual Environments to Facilitate Students in Constructivist Learning. Decision Support Systems 56 (2013): 115-21. Web.

Costas and Cedergren (2018). VR locomotion in the new era of virtual reality: An empirical comparison of prevalent techniques

Delgado, J.M.D., Oyedele, L., Demian, P., Beach, T. (2020) A research agenda for augmented and virtual reality in architecture, engineering and construction. Advanced Engineering Informatics, Volume 45

Gibbs, G. (1988). Learning by doing: a guide to teaching and learning methods, Oxford

Girvan, C. (2019). Virtual worlds: A new environment for constructionist learning. *Computers in Human Behavior, 99*, 396-414.

Halabi, O. (2020). Immersive virtual reality to enforce teaching in engineering education. *Multimed Tools Appl* 79, 2987–3004. https://doi.org/10.1007/s11042-019-08214-8

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*

Mikropoulos, T.A., Natsis, A., (2011). Educational virtual environments: a ten-year review of empirical research (1999–2009). Comput. Educ. 56, 769–780. https://doi.org/10.1016/j.compedu.2010.10.020.

Open University (2017). https://www.open.edu › openlearn › content-section-8

Starkey, L. (2011). Evaluating learning in the 21st century: a digital age learning matrix, Technology, Pedagogy and Education, 20:1, 19-39, DOI: 10.1080/1475939X.2011.554021

Wang P, Wu P, Wang J, Chi H-L, and Wang X. (2018). A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training. *International Journal of Environmental Research and Public Health*. 2018; 15(6):1204. https://doi.org/10.3390/ijerph15061204

Wang, R., Lowe, R., Newton, S., and Kocaturk, T., (2020). Task complexity and learning styles in situated virtual learning environments for construction higher education, Automation in Construction,Volume 113

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Assessing Industry Estimating Software Utilization Practices to Improve Construction Education

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Estimating is an essential part of any construction firm and a core subject in construction management education. Construction faculty should make every effort to align their courses with the needs of industry. A survey was completed by members of the American Society of Professional Estimators and the McWhorter School of Building Science Industry Advisory Council to determine what software was most prevalently utilized in industry for material quantification and cost estimating. A total of 186 practitioners responded to the survey. On-Screen Takeoff and Bluebeam were found to be the most commonly used software for material quantification and Microsoft Excel for cost estimating. Most respondents did not utilize BIM for material quantification but did consider that functionality as valuable when assessing new software. The results of the survey built on similar previous research both of industry and academic practices. Specific differences in the research findings are highlighted, and recommendations for construction faculty are provided. Future research should seek to understand software utilization by construction estimating faculty to compare with industry practices.

Key Words: Estimating, Construction Education, Software

Introduction and Literature Review

Estimating is an integral and essential part of construction management programs in the United States. For example, the American Council for Construction Education requires that accredited construction programs show how each graduate meets the student learning outcome “Create construction project cost estimates” with “create” being the highest level of cognition. How estimating is taught has changed over time to comply with changes in technology, and the needs of industry. For example, Bender (2004) details how the estimating curriculum was sequenced and taught at Central Washington University, concluding that "Any estimating instruction must include a curriculum that is based on students putting pencil to paper”. More current research has focused on ways to engage students through hands-on experiential learning (Collins & Redden 2021), as well as through technology (Zhu & Issa 2017, Eberhardt et al. 2018, Elliot et al. 2019).

Leveraging computers and their various software platforms to complete daily tasks is standard in almost every industry today, including construction. The marketplace of construction software is vast, sometimes difficult to navigate, and ever changing. Construction firms have been analyzing and incorporating computer technology into their processes since personal computing devices were made widely available in the 1980's. Similarly, construction academics have been diligently integrating technology into their classrooms over the same timeframe and disseminating those practices. For example, early Associated Schools of Construction (ASC) proceedings included publications from Keeter (1987) that discussed teaching project cash flow projections using spreadsheets at East Carolina University, and Hein et al. (1989) that discussed integrating contract management software into classes at Auburn University.

Deciding which software to incorporate into a curriculum or a certain class, is not always an easy choice to make, especially in relation to estimating. A simple search engine query into "best construction estimating software" will provide a myriad of options, including established platforms, and new up and coming solutions. Several authors have sought to cull this list via surveying other construction management programs to determine what they have incorporated. For example, Engelhardt & Suermann (2014) surveyed ASC member schools to discern computer hardware and software traits across construction education providers. They found that over 96 percent of schools utilized Microsoft Excel to teach preliminary planning/cost estimating, based on 56 survey responses (out of 150 ASC member schools). A small percentage of schools utilized On-Screen takeoff (12.5 percent), and Sage Timberline (10.7 percent). Also, Joannides et al. (2012) completed a similar survey and found that 27 percent of construction programs taught Sage Timberline, 23 percent taught using Microsoft Excel, and 19 percent taught using OnScreen takeoff. Additionally, 25 percent of construction schools taught "5D" BIM, where cost is incorporated into the models.

Construction education programs should coordinate their efforts with industry to ensure that requisite coursework is well-defined and meets the specific needs of industry (Badger & Robson, 2000, Ahmed et al., 2014; Ahn et al., 2012; Benhart & Shaurette, 2014). Likewise, construction management faculty should ensure that (1) what they are teaching, and (2) how they are teaching it is pertinent to what a graduate must know and be able to perform once entering the construction industry full time. Hence, understanding what estimating software is most prevalent in industry would be imperative for a faculty member teaching estimating to know to ensure that those software platforms were included in the curriculum. One such data point for construction software utilization is the JB Knowledge annual Construction Technology Report, which is based on an annual construction technology survey. The 2020 report stated that On-Screen Takeoff was the most prevalently utilized takeoff software (43 percent of respondents), followed by Bluebeam (36 percent) and Sage Estimating (11 percent). Additionally, the report stated that Sage Estimating was the most widely used estimating software (19 percent of respondents). It should be noted that only software with a specific construction-related purpose was included in the JB Knowledge survey instrument. Demographics on survey respondents were provided regarding age, gender, title, company size, trade, and general location. No information was provided on sample size.

To summarize, choosing the right software to teach in an estimating course is an important choice for a faculty member to make. This choice should be informed by the needs of industry. Previous research is somewhat dated and has focused more on student perceptions (Eberhardt et al. 2018) and commonalities across construction management programs (Joannides et al. 2012, Engelhardt &

Suermann 2014) as opposed to specific industry feedback on the topic. Furthermore, the results are mixed regarding which software is most prevalently utilized. Lastly, the JB Knowledge annual reports are valuable, but the survey sample size is not clear, and common software such as Microsoft Excel is not even mentioned.

Research Methodology

The purpose of the research was to determine what software applications are most utilized by construction estimators in the United States related to material quantification, and cost estimating. The authors partnered with the American Society of Professional Estimators (ASPE) to conduct this research, as the association has a substantial and experienced membership representing firms across the United States. ASPE is made up of five geographic regions, with over 50 chapters throughout those regions. The exact number of individual members was not provided to the authors by ASPE, but the ASPE website states that the group has over 6,200 members.

The authors first researched all material quantification and cost estimating software platforms on the market. (Note: the specific software platforms are noted in the Results section of this paper.) Next, an initial online survey instrument was developed in Qualtrics by the authors, the contents of which were validated by a group of experienced estimators in the ASPE leadership. The survey included the following questions, along with questions on basic demographic information:

- Q1. What software platform(s) do you typically use to complete quantify takeoff (i.e., the quantification of construction materials)?
- Q2. How often do you utilize BIM models for material quantification? If you use BIM models for material quantification, who develops the BIM models that you use?
- Q3. What software platform(s) do you typically use to create estimates (i.e., determination of project cost based on project quantities, subcontractor quotes, jobsite overhead, corporate overhead, and profit)?

The survey was sent out via email to the ASPE membership once during November of 2019, and twice during December of 2019. Concurrently, the survey was also sent out to members of the McWhorter School of Building Science industry advisory committee. Both surveys were closed in January of 2020.

Results

The authors received 186 complete survey responses, which included 144 ASPE members, and 42 McWhorter School of Building Science industry advisory committee members. The respondents had an average of 28 years of construction industry experience and were in 35 of the 50 states. The respondents average over seven estimates/budgets completed each month with an average cost between $1 million and $5 million. Figure 1 provides a breakdown of respondent firm types. As shown, approximately half of the respondents represented general contracting firms, followed by consulting and specialty contractors/subcontracting firms.

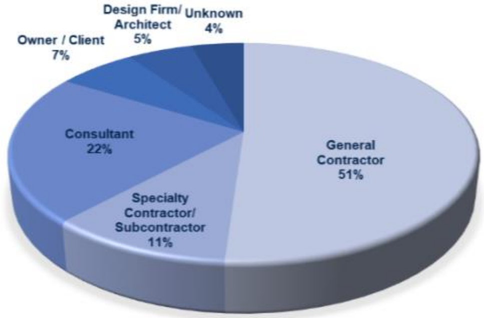

Figure 1. Survey Respondent Firm Type and Prevalence

Q1 - What software platform(s) do you typically use to complete quantify takeoff (i.e., the quantification of construction materials)?

Figure 2 provides a summary of responses regarding what software platforms were most utilized by the respondents for material quantification. As shown, Bluebeam and On-Screen Takeoff were clearly the most utilized. Eight of the respondents (4%) stated that they did not use any software for material quantification.

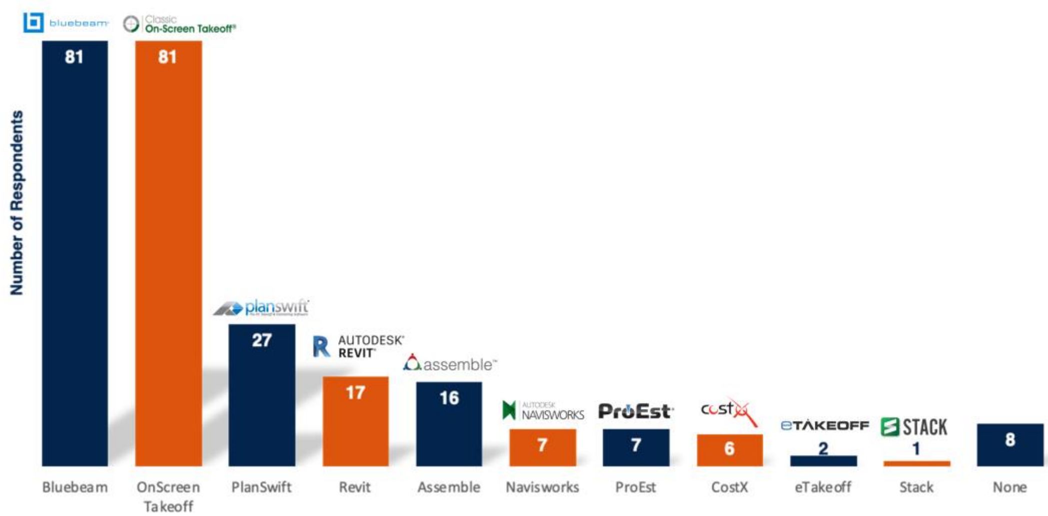

Figure 2. Survey Responses Regarding Software Utilized for Material Quantification

Q2 - How often do you utilize BIM models for material quantification? If you use BIM models for material quantification, who develops the BIM models that you use?

Figure 3 provides a summary of responses regarding how often BIM models are used for material quantification, as well as who typically develops those models. As shown, over 60 percent of respondents never use BIM models for quantification, and approximately 30 percent of respondents sometimes use BIM models for quantification. No respondents always use BIM models for quantification. A majority of the time (60 percent) the models used for material quantification were developed by the project's design team, with a smaller percentage of models being developed by either the respondent's company, their subcontractors or consultants, or themselves.

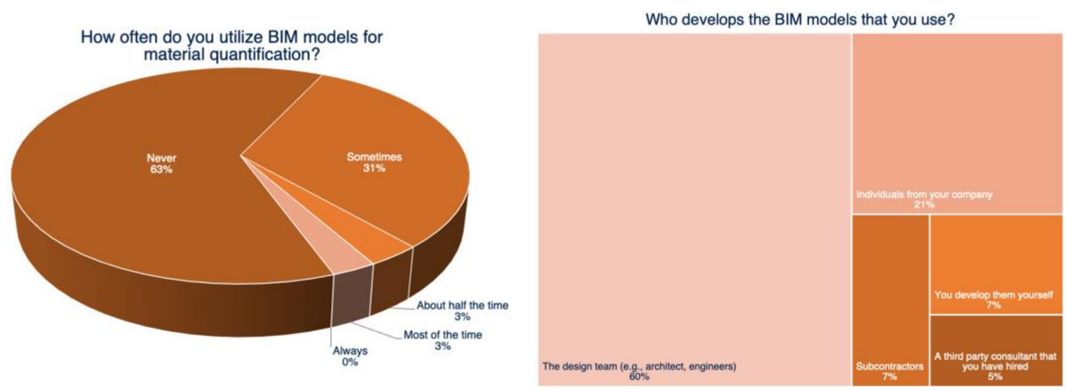

Figure 3. Survey Responses Regarding BIM Usage for Material Quantification

Q3 - What software platform(s) do you typically use to create estimates (i.e., determination of project cost based on project quantities, subcontractor quotes, jobsite overhead, corporate overhead, and profit)?

Figure 4 provides a summary of responses regarding what software platforms were most utilized for creating cost estimates. As shown, Microsoft Excel was clearly the most widely utilized software, followed by Sage Estimating.

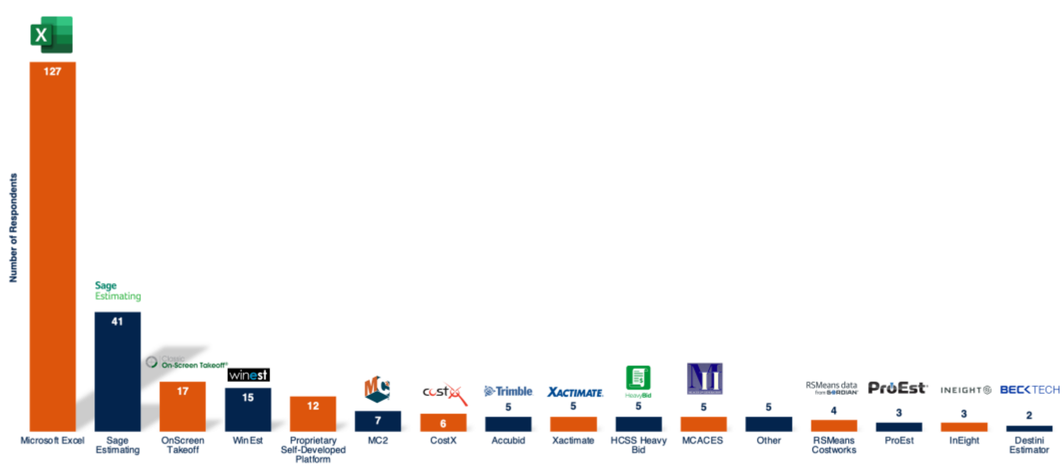

Figure 4. Survey Responses Regarding Software Utilized for Creating Cost Estimates

Discussion of Results

The survey results provided valuable information for construction estimating educators that is grounded in the needs of industry. On-Screen Takeoff and Bluebeam were noted by respondents at the most used software for material quantification, as shown in Figure 2. Notably, both software had an equal number of responses. The results do contradict the JB Knowledge 2020 report, which noted that On-Screen Takeoff was more predominant than Bluebeam. Also, this result provides an update to the body of knowledge, where Bluebeam was not mentioned at all in Joannides et al. (2012) or Engelhardt & Suermann (2014).

The author's opinion would be that in the end, an industry professional choosing On-Screen Takeoff over Bluebeam (or vice versa) comes down to personal preference, since both will provide similar results. This provides an opportunity to construction faculty to make a similar decision (i.e., choosing one vs. the other to incorporate into a class) or to teach both software, and highlight the difference for the students. Furthermore, only eight of the 186 respondents (4 percent) stated that they use no software for material quantification. This result provides credence to the fact that a software (no matter what the faculty preference is) should be taught as part of estimating curriculum.

A majority of survey respondents noted that they never use BIM for material quantification, while approximately 1/3 of respondents stated that they sometimes do. These results highlight for estimating faculty that presently model-based material quantification is still in its infancy and should not be taught as a primary method for material quantification at this time, supporting findings described in Elliot et al. (2019). That being said, as is oftentimes stated by a colleague of the authors, there will not be *less* BIM in the construction industry ten years from now. Faculty should incorporate that software which currently meets the needs of industry, while continually seeking to make students aware of what the future needs of industry may be. This sentiment was echoed by the survey respondents, where several provided general commentaries (outside of the specific questions detailed in the results section of this paper) that as they assess new software on the market, BIM material quantification capabilities is a significant factor being considered.

Lastly, 127 of the 186 survey respondents (68 percent) stated that they utilize Microsoft Excel for creating cost estimates, followed by Sage Estimating and a bevy of other software. This result supports the JB Knowledge 2020 annual Technology Report, where Sage Estimating was shown to be the prevailing software for cost estimating. On the other hand, the results clearly show that a non-construction specific software (i.e., Microsoft Excel) is the most widely used. The authors, based on personal experience and anecdotal evidence, feel this result comes from the fact that (1) many longstanding construction firms began developing their own cost estimate templates in the 1980's with the advent of personal computers and do not feel the need to spend the money and effort switching to other software platforms that provides a similar result, and (2) the low cost, prevalence, and ease of use of Microsoft Excel makes it an easy solution for newer and/or smaller contractors to use. Consistent with the finding of Engelhardt & Suermann (2014), estimating faculty should substantially incorporate Microsoft Excel into their curriculum. Other software such as Sage Estimating can be introduced, with the functionality compared to the capabilities of Microsoft Excel.

Conclusions, Limitations, and Future Research

The purpose of the research was to determine what software applications are most utilized by construction estimators in the United States related to material quantification, and cost estimating. Individuals associated with ASPE and the McWhorter School of Building Science industry advisory council were surveyed. The survey findings showed the On-Screen Takeoff and Bluebeam were the most widely utilized software for material quantification, and Microsoft Excel was the most predominant software for cost estimating. Furthermore, most respondents did not use BIM for material quantification but were considering it when assessing new software. The results of the survey were interpreted, and specific recommendations provided involving ways that construction faculty can incorporate software into their estimating curricula.

The results described are limited to the pool of voluntary respondents associated with ASPE and the McWhorter School of Building Science industry advisory council. Similar results may or may not be found if a different sample was used.

Future research should continue to assess the current trends of industry related to estimating software utilization, as new technologies are rapidly entering the marketplace. Furthermore, construction management faculty could be surveyed (as was completed by Joannides et al. (2012) and Engelhardt & Suermann (2014)) to compare industry vs. academia.

References

Ahmed, S. M., Yaris, C., Farooqui, R. U., & Saqib, M. (2014). Key attributes and skills for curriculum improvement for undergraduate construction management programs. *International Journal of Construction Education and Research*, 10(4), 240–254.

Ahn, Yong H., Kwon, Hyuksoo, Pearce, Annie R. (2012). Key Competencies for U.S. Construction Graduates: Industry Perspective. *Journal of Professional Issues in Engineering Education and Practice*. 138 (2): 123-130.

Badger, W. & Robson, K. (2000). Raising Expectations in Construction Education. *ASCE Construction Congress Proceedings VI*, Reston, VA, 1151-1164.

Benhart, B. L. & Shaurette, M. (2014). Establishing New Graduate Competencies: Purdue University's Construction Management Curriculum Restructuring. *International Journal of Construction Education and Research*, 10:1, 19-38.

Elliot, J., Glick, S., & Valdes-Vazquez, R. (2019) Student perceptions of model-based estimating, *International Journal of Construction Education and Research*, 15:2, 118-135.

Eberhardt, T., Raymond, N., Elliot, J., & Killingsworth, J. (2018). Student Experiences with Virtual Design and Construction Applications for Quantity Takeoff: A Case Study. *54th Annual Associated Schools of Construction Conference Proceedings*. Minneapolis, Minnesota.

Englehardt, A., & Suermann, P. (2014). Evaluating Computer Technology in Construction Education: Hardware and Software. *50th Annual Associated Schools of Construction Conference Proceedings*. Washington, D.C.

Collins, W., & Redden, L. (2021). Improving Student's Estimating Abilities through Experiential Learning, *International Journal of Construction Education and Research*, 17:2, 117-132.

JB Knowledge (2020). The 9th Annual Construction Technology Report. Found at www.jbknowledge.com/report

Joannides, M., Olbina, S., & Issa, R. (2012) Implementation of Building Information Modeling into Accredited Programs in Architecture and Construction Education, *International Journal of Construction Education and Research*, 8:2, 83-100.

Zhu, Y., & Issa, R. (2017). Computer Simulation for Construction Education Using the Structure-Behavior-Function Theory: A Pilot Study on Learning Estimating Concepts, *International Journal of Construction Education and Research*, 13:2, 142-160.

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A Review and Comparison of Associated Schools of Construction (ASC) Capstone Course Content

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A capstone course is the apex of a bachelor's degree. It is an integrative course that embeds professional and business skills and it is based on the application of knowledge to real-world situations. Despite its importance, there is a lack of information about how construction programs organize their capstone offerings and what is included in these offerings. To this point, the present exploratory study surveys construction programs to determine basic course characteristics. To obtain this information, we reviewed 127 ASC-affiliated undergraduate programs in the United States to find that 112 programs had a capstone or capstone-related course. Most programs require only one capstone course, offered for a median of 3 credit hours. Through content analysis of course descriptions, the authors provide the main topics addressed by construction capstones. Main findings suggest oral communication and collaboration as main soft skills covered in capstones; project management, estimating, and scheduling as the top three technical content; and, simulation as the most frequent course format. Findings provide a comprehensive view of how capstones are being offered in construction undergraduate programs in the United States and can be helpful to construction programs' instructors and administrators looking to improve their students' capstone experiences.

Key Words: undergraduate education; capstone course; curriculum; course descriptions; construction management

Introduction

A capstone course is considered the apex of a major's coursework. Students are challenged to demonstrate the knowledge and competencies developed during their undergraduate program. It is often an integrative course, based on knowledge application, but also focusing on professional and business skills. Several disciplines offer capstone experiences – from liberal arts to engineering. Construction is not different and many programs include a capstone course during the senior year. However, in construction, work processes differ depending on the chosen delivery method. For example, the expectations of a construction professional in a design-bid-build arrangement are significantly different than in a design-build arrangement, in which you collaborate with designers from the start of the process. Additionally, the construction industry is a project-based industry, in which graduates collaborate with different teams during the course of a project to create a unique structure. Therefore, the commercialization of a product developed during a student capstone experience and industry partnerships are limited for construction students. Additionally, given that the cost to actually build a building can be prohibitive, it is unclear how construction programs incorporate real-world challenges related to the construction phase in their courses.

To assist faculty of the Associated Schools of Construction (ASC), the authors have developed an exploratory study about capstone experiences in American construction programs guided by the following research question and sub-questions:

- What are the basic characteristics of construction capstone courses in the United States?
    - How are courses organized in the curriculum (number of courses and credit hours)?
    - Which topics are more frequently taught in this type of course?

Findings are relevant to provide a comprehensive view of how capstones are being offered in construction undergraduate programs in the United States. Additionally, our results can be helpful to construction programs' instructors and administrators looking to improve their students' capstone experiences.

Background Literature

Because capstone courses are not exclusive to construction education, the authors started by exploring literature outside of the construction domain. Then, the authors reviewed previous literature related to capstone courses specific to construction. These previous works comprise mainly of case studies that provide further information about how these integrative courses are utilized within the construction curriculum.

The concept of a capstone course

A capstone course is considered the culmination of a major's coursework (Durel, 1993). Often it is an integrative course, during which students are expected to apply technical knowledge, along with business and interpersonal skills (Hoffman, 2014). A capstone course is not exclusive of technical disciplines, being offered in liberal arts disciplines, such as sociology (Durel, 1993) and business (Sonner, 1999). Since the 1990s, several North-American engineering programs include a capstone course in their plan of studies (McKenzie, Trevisan, Davies & Beyerlein, 2002; Todd, Magleby, Sorensen, Swan & Anthony, 1995). Many engineering capstone courses are project-driven, focusing on the design of a product, though depending on the area, the capstone may focus on research (Todd et al., 1995). Also in engineering, several programs have industry-sponsored projects – something noted by Todd et al. (1995) "not only because of the practical experience gained by the students, but also that it builds the confidence of industry in engineering education" (p. 173).

Hoffman (2014) argues that there should be five experiences in a capstone course: focus on "real world" issues and challenges, integration of technical and soft skills, teamwork; project management techniques, and use of oral and written communication. However, due to the specificities of the construction discipline, some of the structure proposed by Hoffman (2014) is not feasible, such as development, fabrication, and testing, though simulation techniques could be used.

Capstone experiences in construction education

There are several published conference proceedings on capstones for construction education. Many of them stress the use of teamwork, industry participation, integration of topics, soft skills, and simulations (Arnold, 2010; Cecere, 2002; Jenkins et al., 2002; Luo & Hyatt, 2020; McIntyre, 2002; Mills & Beliveau, 1999; Sharma & Sriraman, 2012)

One of the first mentions to capstones describes a vertical integration experience at Virginia Tech (Mills & Beliveau, 1999). In their experience, Mills and Beliveau (1999) report the integration of lower-level courses to emphasize leadership and people management skills in senior students. The simulation works with sophomore and junior students acting as subcontractors to senior students during a project simulation throughout a semester.

Teamwork was frequently mentioned in capstone-related previous literature (Cecere, 2002; Jenkins et al., 2002; McIntyre, 2002; Sharma & Sriraman, 2012), however, the reported size of student teams varied. Sometimes groups consisted of students from different Architecture, Engineering, and Construction (AEC) disciplines, as outlined at North Dakota State University (McIntyre, 2002).

In terms of project scope, most capstone courses use a simulation approach. This can sometimes mean answering a request for proposals (Cecere, 2002; Sharma & Sriraman, 2012), a request for qualifications (Jones & Mezo, 2014), a contract (Jenkins et al., 2002), or a problem posed to students (McIntyre, 2002).

Duration of courses varied from one semester (Jenkins et al., 2002; Jones & Mezo, 2014; McIntyre, 2002) to two semesters (Cecere, 2002; Luo & Hyatt, 2020). In some cases, programs have different commitments for capstones in each semester, such as the case presented by Cecere (2002), in which a two-semester capstone is divided into one preparation semester (1 credit hour course) and one development semester (3 credit hour course).

Soft skills, such as teamwork, leadership, and communications are often mentioned as integrated into the capstone and real-world situations. Deliverables typically include written reports and an oral presentation. For examples, see Cecere (2002), Jenkins et al. (2002), Sharma and Sriraman (2012), and Jones and Mezo (2014). However, while some programs choose to emphasize company management skills, such as marketing (for example see Cecere, 2002), others are more interested in construction project management skills (for example, see Jenkins et al., 2002).

Industry involvement is high in this type of course, ranging from guest lectures and judging (Jenkins et al., 2002) to mentorship and coaching opportunities, such as in Sharma and Sriraman (2012) and Jones and Mezo (2014). Still focused on industry engagement, but using a different approach, Arnold (2010) presents a capstone focused on students' review of an ongoing commercial, residential, or civil / infrastructure project. In their case, the capstone course is delivered in two semesters, and students are required to provide their own version of some technical documents for construction, as well as a comparative analysis with the real project. Industry participation is essential for this mode of delivery and can sometimes be a challenge, given that projects can greatly vary in size and complexity.

Most recently, Lee and Kim (2020) provide a framework for the development of a capstone course. To do this, they have reviewed current construction capstone syllabi and course descriptions from eight institutions, surveyed industry professionals, organized course topics and learning outcomes. They conclude with their recommendations on how to deliver the capstone course at Central Connecticut State University, which includes using industry coaches and student teams answering a request for proposals.

Methodology

The present study used a review of existing data as the methodological to answer the posed research questions. Our population is 4-year undergraduate programs in construction in the United States. Our sample population are programs affiliated with the Associated Schools of Construction (ASC) regions 1 through 7, that are located in the United States, and have a program that includes ‘construction’ or ‘building’ in the major name. Construction concentrations within other courses, such as civil engineering, were also not considered in this study. This resulted in the analysis of 127 undergraduate programs of 121 educational institutions being included in the analyzed sample.

The most recent (fall 2021) program of studies and course descriptions were obtained online in each of the programs’ institutions and tabulated for analysis in Excel. Information collected included institution name, program name, course or courses names and prefixes, ideal semester (when available), and course description. Descriptive statistics on the frequency of programs with capstone courses, the number of programs with more than one capstone course, and average credits in a capstone course were collected.

Finally, course descriptions were analyzed in two rounds using a qualitative approach. In the present case, the qualitative approach is particularly helpful to allow for comparisons between courses and identify themes that are common across capstone courses (Patton, 2014). The first utilized descriptive coding to summarize the information contained in course descriptions. Then, a thematic analysis was performed on the initial first-round codes, following the recommendation of Saldaña (2021). Two of the authors coded the dataset, and all discrepancies were resolved using a consensus approach. Results from the thematic analysis include the frequency of themes found on the data as well as a brief explanation of the major themes found in course descriptions.

Results

Construction and construction-related programs came from 45 unique American states. Some states had more programs and academic institutions reviewed than others, such as California and Texas, each with 10 institutions surveyed for the present research. The states of Hawaii, Maine, Maryland, New Jersey, South Dakota, and the District of Columbia did not have institutions surveyed in the present research. We also note that 100 of the 127 programs surveyed were named “construction management” or included both the words “construction” and “management” in their names.

Of the 127 programs surveyed, only 15 programs did not have any course that could be identified as capstone by the researchers. Six programs had courses with descriptions that could not be directly identified as a capstone; but after thorough consideration, the researchers deemed them to include at least one course compatible with a capstone course, and they were included in the present research. And 106 programs had courses that could be clearly identified as having some sort of capstone experience.

A total of 138 courses were identified as being capstones. In the vast majority of programs (n=95), only one capstone course was required of students; in fourteen programs, two capstone courses were required; and only in three programs, three courses were required. Additionally, three institutions offered more than one option that could be considered a capstone, among them, Texas A&M offered 5 different capstone course options. In terms of credit hours, the identified capstones ranged from 1 to 6 credit hours (note that these include quarter-based courses), with a median of 3 credit hours.

Figure 1 summarizes the process of identifying programs with capstone courses, the number of courses per program, and the range and median credit hours for capstone courses identified in the present research.

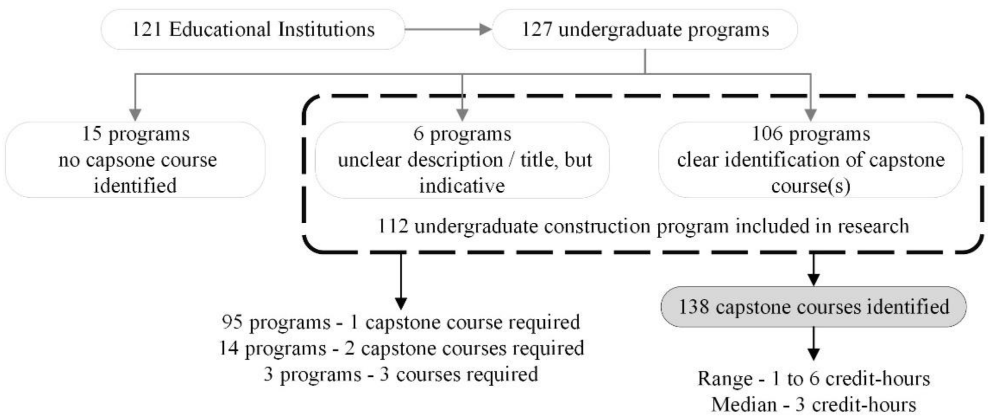

Figure 1. Summary of surveyed programs and identified courses

Additionally, the authors performed a qualitative analysis of course titles and descriptions. For course descriptions, 78 or the 138 courses included the word "capstone" in their course titles, followed by 30 courses named "Senior Design," "Senior Project" or similarly, 21 included titles that related to construction or project management, three mentioned the integration of project, and design and construction. Six courses included names that differed from the others analyzed, and included general titles (such as "senior seminar"), or related to specific sectors (such as commercial, capital projects, or residential), but did not mention management or capstone, and one mentioned a thesis.

Five emerging themes were generated based on the analysis of the course descriptions: process, assessment, technical content, soft skills, and course format. Explanation and further analysis of each code are included in the following paragraphs.

The *integration* code captures the format of the course. The authors were mainly interested in the integrative nature of the course. Therefore, subnodes were created for explicit and implicit mentions to integration. If a course description included the word “integrate,” or a similarly stemmed word, it was coded as "explicit integration". And a course description was coded as "implicit integration" if a course mentioned three or more technical aspects (such as scheduling, estimating, and cost control) or if it mentioned the use of previous knowledge, such as “Utilization of student’s previous coursework to creatively…” Courses that did not include any of the two were coded as “unclear integration.” A course could not have more than one integration subnode. As a result, most courses were deemed to have an implicit integration element (n=90), while the number of courses that clearly mentioned integration was only 26. Few courses (n=22) were identified as having an unclear integration component, meaning some course descriptions were vague to describe how the capstone integrates previous content, such as the following description “Application of team design concepts to the capstone project.” More information in the description could help authors to understand how contents are integrated into capstone courses.

The code *assessment* was created to capture how students were assessed in the courses. It is noted by the authors that the descriptions for 85 courses did not have a clear reference to assessment methods. The 53 descriptions that did mention assessment aspects, were then further analyzed on types of assessment. One course description could have more than one type of assessment. Of those 53 courses, the majority (n=45) included an oral presentation, while 28 include a specific mention of written reports or documents. It was also interesting to note that 18 courses clearly mentioned industry participation in oral presentions or in evaluating students' work.

Following, the authors analyzed mentions of *technical content* in course descriptions. Similarly to assessment, not all courses included mentions to technical contents (n=97). One course description could have more than one technical content. The subnodes help to understand which technical topics are being integrated into construction capstones and results are presented in Table 1. As expected, technical topics mainly include project management procedures, estimating, and scheduling. Interestingly, the fourth topic mentioned is design, and further investigation could explore what type of design are construction students performing.

Table 1

Technical content embedded in course descriptions

Rank	Content	Frequency (n=97)	Rank	Content	Frequency (n=97)
1	Project Management	72	7	Documentation	15
2	Estimating	58	8	Bidding	12
3	Scheduling	56	8	Plans and Specifications	12
4	Design	27	9	Cost Control	11
5	Safety	21		Others[1]	43
6	Contracts	17			

[1] includes sustainability, quality assurance and control, site logistics, company management, risk management, financing and accounting, closeout procedures, computer applications, legal and insurance, and building systems

Mentions to the use of *soft skills* in the courses were also analyzed as a node. Because capstones usually integrate professional and social skills, such as communications, subnodes were created to evaluate which soft skills are being integrated into capstone courses. As expected, several courses (85 out of 138) had a mention to one of the following soft skills: oral communication (n=51), teamwork and collaboration (n=43), written communication (n=30), communication skills in general (not specifying if written or oral) (n=12), leadership (n=10), ethics (n=9) and networking (n=1). Course description could have more than one soft skill subnode and Table 2 presents the findings for this subnode.

Table 2

Soft skills embedded in course descriptions

Rank	Soft Skill	Frequency (n=85)
1	Oral Communication	51
2	Teamwork and collaboration	43
3	Written communication	30
4	Communication skills in general	12
5	Leadership	10
6	Ethics	9
7	Networking	1

Finally, a code related to *the course format* was created. This node captures how the course is taught, and subnodes include case studies, simulations, industry sponsorship, competitions, or third-party exam. Again, some courses (n=39) were not coded in *course format* because they did not have a clear mention of instructional strategies used for teaching, such as the ones previously mentioned. Most of the courses only had one specified format, but 19 of them could be identified with two different formats. Of the 99 courses descriptions that contained information that suggested the format of the course, the overwhelming majority (n=89) indicate they use a simulation approach. Industry sponsorship was also mentioned in 13 course descriptions. In this case, industry sponsorship was considered different than just industry review but also included participating during the course by providing construction scenarios or projects. Five courses mentioned the use of competitions, such as participating in the Associated General Contractors (AGC) competitions. Four courses mentioned the use of case studies, and one course mentioned a seminar format. Though not directly associated with course format, six course descriptions mentioned requiring students to take a third-party certification such as the Associate Construction (AC) exam, from the American Institute of Contractors (AIC) and were included in this subnode because it may guide decisions related to course format. Table 3 presents the results.

Table 3

Capstone course format

Rank	Soft Skill	Frequency (n=99)
1	Simulation	89
2	Industry sponsorship	13
3	Third-party exams	6
4	Competitions	5
5	Case studies	4
6	Seminar	1

Discussion

Our results indicate that most of the ASC-affiliated construction programs have a capstone (or capstone similar) course in their plan of study, which is aligned with information from Todd et al. (1995) for engineering programs. Opposed to engineering (McKenzie et al., 2004), most construction programs have only one course dedicated to the capstone.

Additionally, communication (including oral, written, and general) was mentioned in several courses, along with teamwork and collaboration, project management, and technical content. These areas were identified by Hoffman (2014) as key experiences for capstone courses. Echoing previous literature on construction capstone education, many mentioned grouping students in teams (Cecere, 2002; Jenkins et al., 2002; McIntyre, 2002; Sharma & Sriraman, 2012).

Engagement with industry varied in course descriptions. There were multiple references to industry presentations, which is in accordance with previous research reviewed (Jenkins et al., 2002). Fewer course descriptions mentioned industry sponsorship, which can include a closer partnership between capstone instructors and industry. This partnership was highlighted in previous research to provide opportunities for mentorship and coaching (Sharma & Sriraman, 2012; Jones & Mezo). Finally, similarly to previous case studies published in construction capstone undergraduate education (see

Cecere, 2002; Jenkins et al., 2002; Jones & Mezo, 2014; McIntyre, 2002; Sharma & Sriraman, 2012), an overwhelming majority of courses included a simulation component, which could be simulating a response for a request for proposals, or simulating how to solve construction problems on a construction project.

Conclusions

The present paper presented an analysis of undergraduate ASC-affiliated construction programs' course information. The authors identified 112 of 127 programs that had a capstone or capstone-related experience in their programs and were included in the present research. A total of 138 courses were identified as capstone or capstone-related, given that some programs had more than one option for capstone or had capstone in more than one semester or quarter. Most programs only required one capstone course of their students and that course was usually 3 credit hours.

The authors also analyzed the course descriptions qualitatively concerning integration, assessment, technical content, soft skills, and course format. The majority of identified courses had an implicit mention of integration. Also, many courses did not have a mention to assessment, but when that was included, many mentioned an oral presentation. Oral communication was also the most frequent soft skill mentioned in course descriptions, followed by teamwork and collaboration. For technical content, the top three components included were project management, estimating, and scheduling. For course format, the overwhelming majority of courses use a simulation approach, with a few indicating industry sponsorship of projects.

We note that our analysis is limited to the course names, descriptions, and information available online at the institutions' websites. We also note that, because not all courses were clearly identified as capstones, the authors decided on the inclusion or exclusion of courses on their analysis based on their experience and knowledge. Two of the authors revised and coded independently half of the courses each while reviewing and commenting on the other half, to include inter-rater reliability and minimize biases. Even though limitations apply to the present paper, it provides a current initial state of the practice in terms of capstone courses in construction programs in the United States.

Further studies could survey the ASC-affiliated institutions for further information about their capstone offerings, such as common assessment types, mode of delivery, engagement with industry, and scope of work. Doing so would provide a comparative analysis between industry needs for recent graduates and capstone simulations. Additionally, more in-depth case studies of current construction capstones can provide further guidance about how these courses are taught in different regions of the United States. A common understanding of the role and scope of a capstone course can provide a unified framework that construction programs. This can strengthen the use of such courses for the demonstration of students' mastery in the integration and application of construction topics, and their readiness to graduate.

References

Arnold, A. (2010). Construction industry involvement in the capstone senior design class. In *2010 Annual Conference & Exposition* (pp. 15-315).

Cecere, J. (2002). Capstone course in construction management. In *2002 Annual Conference* (pp. 7-278).

Durel, R. J. (1993). The capstone course: A rite of passage. *Teaching Sociology*, *21*(3), 223-225.

Hoffman, H. F. (2014). Engineering and the capstone course. In *The engineering capstone course* (pp. 1-5). Springer, Cham.

Jenkins, S. R., Pocock, J. B., Zuraski, P. D., Meade, R. B., Mitchell, Z. W., & Farrington, J. J. (2002). Capstone course in an integrated engineering curriculum. *Journal of Professional Issues in Engineering Education and Practice*, *128*(2), 75-82.

Jones, J. W., & Mezo, M. (2014). Capstone= team teaching+ team learning+ industry. In *2014 ASEE Annual Conference & Exposition* (pp. 24-252).

Lee, N., & Kim, S. J. (2020). A Systematic Course Design Approach to Guide the Development of a Construction Engineering and Management Capstone Course. In *2020 Annual Conference Northeast Section (ASEE-NE)* (pp. 1-5). IEEE.

Luo, Y., & Hyatt, B. A. (2020). Capstone Course Design in Construction Management. In *Construction Research Congress 2020: Safety, Workforce, and Education* (pp. 651-659). Reston, VA: American Society of Civil Engineers.

McIntyre, C. (2002). Problem-based learning as applied to the construction and engineering capstone course at North Dakota State University. In *32nd Annual Frontiers in Education* (Vol. 2, pp. F2D-F2D). IEEE.

McKenzie, L. J., Trevisan, M. S., Davis, D. C., & Beyerlein, S. W. (2004, June). Capstone design courses and assessment: A national study. In *Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition* (pp. 1-14).

Mills, T., & Beliveau, Y. (1999). Vertically integrating a capstone experience: A Case Study for a New Strategy. *Journal of Construction Education*, *4*(3), 278-288.

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications.

Saldaña, J. (2021). *The coding manual for qualitative researchers*. sage.

Sharma, V., & Sriraman, V. (2012). Development and implementation of an industry sponsored construction management capstone course. In *2012 ASEE Annual Conference & Exposition* (pp. 25-445).

Sonner, B. S. (1999). Success in the capstone business course—assessing the effectiveness of distance learning. Journal of Education for Business, 74(4), 243-247.

Todd, R. H., Magleby, S. P., Sorensen, C. D., Swan, B. R., & Anthony, D. K. (1995). A survey of capstone engineering courses in North America. Journal of Engineering Education, 84(2), 165-174.

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Do High Impact Educational Practices Translate to Peak Learning Moments? An Introductory Study of Student Experiences in the Built Environment

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Emphasis on universities to increase the value of the education they provide has been mounting for several years. Through the COVID-19 pandemic, students, parents, and educators have become more aware of the value associated with the traditional relational approach of in-person educational experiences. The COVID-19 pandemic provided an unexpected opportunity to conduct a world-wide test drive of online learning, which only highlighted concerns about the return on investment in higher education. High Impact Educational practices have been seen to elevate the student learning experience and have become an initiative for many universities. This study investigated HIP participation by built environment students at one university to better understand the frequency of student participation and the impact of their participation. The results indicated that all students in the built environment disciplines participate in at least one HIP before graduating, and many participate in numerous HIPs. However, less than 20% of students identify HIP participation as a peak learning moment in the college career.

Key Words: Construction Education, Engaged Learning, High Impact Educational Practices, Internship, Study Abroad

Introduction

COVID-19 shifted construction management education to expanded online learning, many faculty have realized the value inherent in the traditional relational approach long-valued within construction management. These relationships take many forms including connections with industry through internships; peer-to-peer connections for students; faculty-student interaction; study abroad; service learning; or opportunities for construction management students to engage with students in architecture or engineering. As college expenses continue to rise for students and parents, on-campus construction management programs have a unique opportunity to differentiate themselves by designing experiences that elevate both learning and the overall college experience for students.

Almost 15 years ago, George Kuh recommended a set of specific educational practices known as High Impact Educational Practices(HIPs) (Kuh, 2008).With the goal of elevating student learning and the student experience, the following practices were identified:

- First-Year Experiences
- Common Intellectual Experiences
- Learning Communities
- Writing-Intensive Courses
- Collaborative Assignments/Projects
- Undergraduate Research
- Diversity/Global Learning
- ePortfolios
- Service Learning, Community-Based Learning
- Internships
- Capstone Courses and Projects

Kuh recognized the value to students who acquired knowledge, found real-world ways to apply it, and then reflected on those experiences. Students who participate in HIPs tend to have higher grades and retain, integrate, and transfer the knowledge gained at higher rates than students who did not engage in HIPs (Nelson et al., 2008). Additional research shows other benefits to students including increased confidence and enhanced cultural competency (Kramer et al., 2007; Peck et al., 2010). HIPs provide built environment students opportunities to engage in diverse experiences, solve difficult problems, encourage metacognition, and create opportunities for peak learning experiences.

Despite the success of HIPs, there are challenges for construction programs who seek to use them to elevate the student experience. First, just because something is called a high impact practice does not make it so. As faculty champions of some of these experiences, we have seen how some HIPs have been extremely impactful for students while others have not. Second, HIPs often require students to self-select to participate in them. Some even require self-selection and additional financial commitments yielding high impact events that are sometimes not accessible or not fully understood by students.

In 2017, Chip and Dan Heath published a book that explored impactful experiences in life, specifically experiences that change a person's perspective and resonated for long after the event (Heath & Heath, 2017). College graduation, winning the state championship basketball game, the birth of a child, the first day of a new job; these types of experiences tend to resonate. Their work indicated that when people reflect on these types of experiences, they tend to recall flagship or peak moments. These peaks are both impactful (as with HIPs) and meaningful (emotional connection). When considering the concept of peak learning experiences, previous research has shown that participating in HIPs alone may not translate to a peak learning experience.

Auburn University has placed a strategic emphasis on "measurable outcomes". Since the fall of 2019, the Campus Engagement and Experience Survey (CEES) has measured HIP participation across the University. The survey asked students to identify if they participated in four specific HIPs:

- Study abroad
- Internships and/or Co-ops (While both represent formal work opportunities, co-ops are students that work and attend school in alternating semesters.)
- Undergraduate Research
- E-portfolios (purposeful collection of a student's work that showcases learning progression and achievement).

In addition, students were asked within the same survey to describe their "peak" educational experience as an undergraduate student through an open-ended qualitative question.

While the CEES provides a wealth of data to examine the student experience at Auburn University, little has been done with the information to date. If the relationship between the HIPs students participate in during undergraduate careers and peak educational moments could be better understood, it may be possible to better support HIPs across the built environment. This study sought to investigate the frequency of HIP participation by built environment students and the relationship of HIPs to student self-identified transformative or peak learning experiences. Specifically, the following research questions were addressed:

- To what degree have built environment students participated in HIPs?
- Are some HIPs more common among specific disciplines within the built environment?
- To what degree are built environment students' self-identified peak educational experiences associated with HIPs?

This introductory research effort analyzed the data over the first four semesters of the CEES specifically for students within the built environment. Majors considered included architecture, construction management, interior design, environmental design, civil engineering, electrical engineering, and mechanical engineering. While the results for this study are confined to a single university, the study contributes to scarce research of HIPs within the built environment. Insight into potential opportunities and challenges for programs across the built environment is provided. And, the study provides a basis for a deeper study to determine if a connection exists between HIPs and transformative educational moments. If a direct linkage could be identified, resources across construction education may better be allocated to meet student needs and elevate the educational experience.

Literature Review

High Impact Educational Practices

In the late 1990s, the Boyer Commission authored ten recommended practices for institutes of higher learning (*Reinventing Undergraduate Education: A Blueprint for America's Research Universities*, 1998). Their recommendations were based on significant concerns about the graduating student at the time of the report that questioned if graduates could "think logically, write clearly, or speak coherently" (*Reinventing Undergraduate Education: A Blueprint for America's Research Universities*, 1998, p. 15). Much of the concern resonated from research which indicated limited student engagement in class and few learning experiences that resonated with the undergraduate student.

The Boyer commission report spurred a series of research articles including the development of high impact educational practices (HIPs) (Kuh, 2008). These "educational practices" were deemed as especially effective in areas of providing opportunities with diversity, solving challenging problems, fostering independent thinking, and motivating students. Kuh's work detailed how each selected practice elevated the student learning experience. Specifically, there was a focus on "deep" learning. This "deep" learning not only focused on acquisition of knowledge but also understanding the meaning of the information and often applying it.

Research indicated that students who participated in these HIPs made better grades, retained information at a higher rate, and integrated the knowledge gained with their overall education (Nelson et al., 2008). As students participate in HIPs, self-perceptions shift, and student confidence increases. Further research notes enhanced ability by students to connect with individuals in unfamiliar communities as well as improved knowledge, skills, and attitudes (Kramer et al., 2007; Peck et al., 2010). Conversely, other studies argue that HIPs do not improve graduation rates among students noting that few studies have examined all ten practices, their relationship to each other, and their connection with college outcomes (Valbrun, 2018).

Transformative Experiences

Chip and Dan Heath's work on "The Power of Moments" (2017) emphasized how defining moments or a series of events that frame a moment of clarity shape our lives. And, they argue that these moments can be created. The concept of moments is based on four fundamental ideas:

1) When individuals consider an encounter, they often focus on key moments within the experience. Often, these occur at peaks, valleys, and times of transition.
2) A transformative moment is both significant and memorable.
3) Moments are created through one or more of four elements: i) elevation, ii) insight, iii) pride, and iv) connection.
4) It is important to recognize, celebrate, and set clear expectations at times of peaks, valleys, and times of transition.

Method

Data Collection

Students graduating in built environment majors were targeted for this research project including students majoring in construction management, architecture, interior design, environmental design, civil engineering, electrical engineering, and mechanical engineering. Data was collected using the CEES over four academic semesters including Fall 2019, Spring 2020, Fall 2020, and Spring 2021. The CEES was administered via the university course management system and consisted of approximately 40 questions that captured areas of demographic information, perceptions on class experiences, time at the university, expectations as a future alumnus, HIP specific experiences, and peak learning experiences. For this research, the authors only examined the portions of the survey related to the five specific HIPs and the open-ended question about transformative, peak learning experiences as an undergrad:

> *Describe a transformative learning experience, while a student at Auburn University, that helped shape the person you are today (a short experience that was both memorable and meaningful). Please be descriptive and note that the moment could take place anywhere (classroom, internship, study abroad, work, athletics, fraternity/sorority, student government, etc.).*

HIPs specifically addressed as part of the CEES included co-op, internships, e-portfolio, study abroad, and undergraduate research. The survey recognized that students may have multiple HIPs over the course of their undergraduate experience. Students were asked specifically which of the five HIPs in which they had participated in, with the option to include multiple HIPs if that was the situation for a given graduating student. For each HIP, students were asked to identify when they participated, why they participated, and what they got out of the experience.

All students who participated in the survey were graduating during the semester in which they completed the CEES. Completing the survey was required as part of the expectations within the zero-credit graduation course, UNIV-4AA0.

Data Analysis

Two of the research members from the Office of Academic Insight at Auburn University collected the data, coded the qualitative data in NVivo, and summarized quantities using an Excel spreadsheet. Data was then analyzed by the researchers to obtain specific responses to the research questions.

Within the qualitative transformational educational experience data, student responses were searched for HIP terms as identified by Kuh using the five HIPs specifically evaluated by the University. Specific search terms within open-ended student responses included the following:

- Co-op: "co-op", "summer-op", "coop", or "co op"
- Internship: "internship" or "intern"
- E-portfolio: "writing", "writing center", "e portfolio", "e-portfolio", or "eportfolio"
- Study abroad: "exchange", "international", or "abroad"
- Undergraduate research: "research"

While peak experiences may have also included other HIPs as identified by Kuh, those peak experiences were not considered by this introductory study. The descriptive statistics for HIP participation were analyzed to identify frequency and percentage of involvement by students.

Results

To what degree have built environment students participated in HIPs?

Among the 963 students, 1205 high impact educational experiences were reported as outlined by major in Table 1. Note that each unique HIP instance is a situation where a single student participated in a HIP. One student could have participated in more than one HIP. For example, a graduating student may have done an internship and study abroad, counting as two unique HIP instances. However, a student participating in two internships would only count as a single HIP instance.

Table 1

Descriptive Statistics – Total Identified HIP Instances by Major

Major	**Total Unique HIP Instances in Each Major**	**Total Students (Avg. HIPs/Student)**
Architecture/Interior Arch.	164	93 (1.8)
Construction Management	215	165 (1.3)
Environmental Design	59	50 (1.2)
Civil Engineering	173	164 (1.1)
Electrical Engineering	139	115 (1.2)

Mechanical Engineering	383	329 (1.2)
Interior Design	72	47 (1.5)
Total	1205	963 (1.3)

On average, students reported less than two (1.3) of the measured HIPs during their undergraduate career.

Are some HIPs more common among specific disciplines within the built environment?

Table 2 shows counts of HIP instances by each major. Percentages shown adjacent to count values in Table 2 were the percent of instances in a specific major that participated in each HIP.

Table 2

Descriptive Statistics - Number of Students Participating in HIP (Average % of graduating students in major participating in that HIP)

Major	Co-op	Internship	e-Portfolio	Study Abroad*	Undergraduate Research
Architecture/ Interior Arch.	1 (1%)	64 (69%)	4 (4%)	71 (76%)	24 (26%)
Construction Management	36 (22%)	135 (82%)	10 (6%)	30 (18%)	4 (2%)
Environmental Design	2 (4%)	13 (26%)	29 (58%)	7 (14%)	8 (16%)
Civil Engineering	41 (25%)	82 (50%)	1 (1%)	11 (7%)	38 (23%)
Electrical Engineering	44 (38%)	44 (38%)	16 (14%)	5 (4%)	30 (26%)
Mechanical Engineering	110 (33%)	157 (48%)	7 (2%)	44 (13%)	65 (20%)
Interior Design	1 (2%)	46 (98%)	6 (13%)	13 (28%)	6 (13%)
Total	235 (24%)	541 (56%)	73 (8%)	181 (19%)	175 (18%)

* Study abroad was impacted in at least two of the four semesters due to COVID-19 limitations

From Table 2, all disciplines except for Environmental Design had instances of work experiences for an average of over 70% of graduates (combined co-op and internships). Work experiences appeared to be the dominant HIP experienced across all built environment majors with 776 students completing co-ops and/or internships. The average percent of students completing an internship exceeded those in co-ops for all majors except electrical engineering where the percentage was equal. Co-ops essentially do not exist in architecture, environmental design, and interior design.

E-portfolio engagement trailed all other measured HIPs for undergraduate students with an average of only 8% of graduating students participating. The e-portfolio was part of the University's Quality Enhancement Plan (QEP) in 2018 for accreditation as the university sought to have students reflect more deeply on their work. Only environmental design with an average of 58% of all graduating students participating seemed to have achieved significant traction in this area.

Architecture graduates had a high percentage of students studying abroad (average of 76% of all graduates). Engineering and architecture majors included the largest percentage of students completing undergraduate research (average of 20-26% of all graduates). In contrast, interior design and construction management programs trailed significantly in the number of instances of undergraduate research.

To what degree do built environment students associate their peak educational experience with HIPs?

Of the 963 graduating students in the built environment, 248 (25.75%) reported a HIP as a peak or transformative educational experience while an undergraduate student. Of those, 199 responses were related to the five HIPs addressed in this research (Table 3). The remaining 719 responses indicated peak or transformative educational experiences related to class projects, friendships, greek life, or significant connections with faculty or staff.

Table 3

Breakdown of Transformative Learning Experiences Associated with HIPs

HIP	Students Reporting HIP as Transformative Experience (% of respondents)
Internship	70 (7%)
Co-op	66 (7%)
Study Abroad	47 (5%)
Undergraduate Research	12 (1%)
E-portfolio	4 (0.4%)
Total	199 (21%)

As shown in Table 4, students indicated the largest number of transformative learning experiences associated with internships, co-ops, and study abroad. Transformative learning experiences in e-portfolios and undergraduate research were limited. When the total number of graduating students was considered, study abroad and co-op appeared to dominate the landscape for transformative learning experiences.

Table 4

Rank of HIP Experiences Identified as Peak Moments

HIP	Total Students Participating in HIP (from Table 2)	% of Graduating Students Reporting HIP as Transformative Experience
Co-op	235	28%
Study Abroad	181	26%
Internship	541	13%
Undergraduate Research	175	6.9%
E-portfolio	73	5.4%

Discussion and Conclusions

Previous research suggests that participating in HIP experiences yields higher grades, retention, integration, and transfer of knowledge at higher rates than students who do not engage in HIPs

(Nelson et al., 2008). When considering the concept of moments, the construct of true HIP experiences bears similar characteristics. However, achieving these benefits requires HIPs to be carefully constructed and executed so they generate the type of momentous experience that triggers these sorts of results. This research set out to investigate the frequency of participation and impact of HIPs on students in the built environment disciplines at Auburn University.

Overall, students in the built environment majors are participating in 1.3 HIPs on average. Internships and co-ops were identified as the most common, with study abroad and undergraduate research lagging behind. However, undergraduate research was overwhelmingly more common for engineering and architecture students than for construction management students. With respect to study abroad participation, it is reasonable to suspect that it was unusually low due to impacts from COVID-19 especially in two of the four semesters measured.

Students also indicated co-ops as one of the more impactful experiences. Interestingly, internships were not cited as often. One explanation could be that co-ops are more structured and have more oversight than internships. In addition, despite the lower overall participation rate, many students reported study abroad as a transformative learning experience. This suggests an opportunity for programs that may be interested in exploring study abroad experiences to offer their students. Given that it was a university focus, it was a bit surprising to see e-portfolios ranked so low – especially considering they are intended to serve as a mechanism for reflection of learning. These results provide a foundation for further exploration.

Future research should look at identifying ways in which we can enhance the student learning experience in the areas of internships, undergraduate research, and other approaches. Evaluating the factors that make co-ops more impactful for students than internships would provide opportunity to improve the internship experience. Studies should investigate how programs like construction management could expand opportunities for students to participate in undergraduate research. If e-portfolio was developed to encourage student reflection, it does not appear to be very popular. Could we look at other ways to get students to reflect on the work they have completed?

Another point that needs to be considered is the 25% of students that indicated HIPs, other than the five focused on in this study, as peak learning experiences. As well, 75% of students identified something other than HIPs as their peak learning experiences. Further research should be done to identify themes associated with these responses, what made them impactful, and how they can be used to improve opportunities for these types of learning experiences for more students.

This study has shown that every student graduating in the built environment disciplines at Auburn University participated in at least one HIP activity, and many participate in multiple HIPs. This is a positive finding when considering one of the noted challenges with HIPs is accessibility to all students. However, it is unclear how these rates compare to the students at whole at the university. This study has also supported previous research that participating in a HIP does not guarantee that it will be a peak experience for students. Further investigation on peak learning experiences should be done to better understand how we as educators can promote more of these types of experiences and consider how we can leverage HIPs to do this.

References

Heath, C., & Heath, D. (2017). *The power of moments: Why certain experiences have extraordinary impact*. Simon & Shuster.

Kramer, P., Ideishi, R., Kearney, P., Cohen, M., Ames, J., Shea, G., Schemm, R., & Blumberg, P. (2007). Achieving Curricular Themes Through Learner-Centered Teaching. *Occupational Therapy in Health Care*, *21*, 185–198. https://doi.org/10.1080/J003v21n01_14

Kuh, G. D. (2008). *High-Impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter*. Association of American Colleges and Universities. http://www.neasc.org/downloads/aacu_high_impact_2008_final.pdf

Nelson, T. E., Shoup, R., Kuh, G. D., & Schwartz, M. J. (2008). The effects of discipline on deep approaches to Student learning and college outcomes. *Research in Higher Education*, *49*(6), 469–494.

Peck, K., Furze, J., Black, L., Flecky, K., & Nebel, A. (2010). Interprofessional collaboration and social responsibility: Utilizing community engagement to assess faculty and student perception. *International Journal of Interdisciplinary Social Sciences*, *5*, 205–221.

Valbrun, M. (2018, April 25). Maybe Not so “High-Impact”? *Inside Higher Education*. https://www.insidehighered.com/news/2018/04/25/study-questions-whether-high-impact-practices-yield-higher-graduation-rates

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Sustainability and Resilience Education Framework for Interdisciplinary Course Development

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Climate change has redirected the global focus towards creating a more sustainable and resilient built environment. As natural disasters have been occurring at a higher frequency, buildings and infrastructure systems need to be prepared to withstand the more disastrous events. Furthermore, with an increase in the world's population and the shortage of resources in various parts of the world, it is necessary to think about sustainability and resilience in conjunction with every aspect of the built environment, including the Architecture, Engineering, and Construction (AEC) education. Therefore, this research study proposes a unique sustainability and resilience educational course structure that improves the understanding of these concepts in the built environment. This research study introduces a framework that can act as a guideline for sustainability and resilience education integration within various courses across any college campus to further the awareness about sustainability and resilience. The study introduces the course structure and development methods in creating new, flexible, and innovative modules that can be customized to the different educational needs and cover several student learning outcomes which can help prepare the new generations to become conceptually, spatially, and temporally aware while they interact and develop the built environment of the future.

Key Words: Sustainability, Resilience, Interdisciplinary Education, Multidisciplinary

Introduction and Background

Challenges such as climate change, increased natural disasters frequency, and income inequality, and other global issues, have compelled the AEC industry to promote, implement and improve sustainability and resilience practices adopted in various building and infrastructure projects. Effective sustainable development improves the three pillars in our built environment: environmental sustainability, social equity, and economic development. However, any sustainable approach is an empty gesture without ensuring a strong resilience adoption. Through resilience, the built environment can overcome natural and man-made disasters and disruptive events to continue its sustainable development. With the current national and global challenges, sustainability and resilience education is imperative for the next generation to develop a sustainable future.

It is essential that educators utilize engaging approach to facilitate active participation from students which can assist with understanding the concepts in a systematic manner. Murray and Cotgrave (2007), in an earlier study, found the presence of policy drivers essential to incorporating sustainability in educational modules across different areas. Although this seemed easily achievable, academia's participation was sparse. Wang (2009) observed the need to develop a standardized course structure focusing on sustainability for construction management students. Wang's study proposed various sustainability topics such as health, atmosphere, ecosystem, energy, land consumption, erosion, and materials, and gathered students' feedback for continuous curriculum improvement. Enhanced collaboration between academia, industry, and researchers is needed to further sustainability curriculum development (Wang, 2009). In addition to the inclusion of sustainability concepts through structured coursework, suggested that existing courses should assimilate these concepts to improve sustainability education in existing coursework (Lim et al., 2015).

Amaratunga et al. (2018) interviewed 87 stakeholders and detailed several key knowledge areas for resilience education namely, legal frameworks, disaster response, contracts, resilience technologies, engineering, knowledge management, social and cultural awareness, sustainability and resilience, ethics, human rights, financing mechanisms, stakeholder approaches, post-disaster project management, and hazard risk assessment. Educating current and future students about disaster resilience is essential to provide them with the necessary skills to initiate positive changes and respond effectively to disaster events (Dufty, 2021). Adhikari et al. (2020) conducted a survey of higher education students on their source and level of knowledge of various disasters and determined that university-level education needs to be improved to be aware of and prepared for future disaster response education.

Some examples on the national level discussed here inform about the need for a comprehensive sustainability and resilience education. The University of Colorado-Boulder offers a "Sustainability and Resilience in Practice" course (ENVM 5041) wherein decision-making strategies supplemented with community engagement are discussed. The University of Washington also offers a "Sustainability, Resilience, and Society" online course which includes five modules that address the broader concepts of sustainability and some resilience aspects. However, both courses do not comprehensively address the sustainability and resilience dimensions. The Sustainability and Resilience course (INPR 2183) at the Northeastern University is more comprehensive in addressing the sustainability and resilience dimensions yet it does not connect the overarching goal of sustainability and resilience (Northeastern University, 2022).

Though some universities and organizations offer courses that capture siloed aspects of resilience and sustainability, seldom does a course capture the sustainability and resilience of the built environment from multiple perspectives while incorporating project-based concepts learning and application approach. This research proposes a novel and simple approach to create a sustainability and resilience coursework with the flexibility to fully or partially integrate into different course modules through a universal toolkit.

Research Study Main Objective and Novelty

Most courses offer a siloed representation of concepts without relaying the interdependent nature of systems and disciplines in a more practical and detailed approach. As discussed previously, sustainability cannot continue without resilience. Therefore, understanding the interconnectivity between these concepts and between the components of the built environment will help elevate the students' comprehension of the concepts and provide a depth of learning. This paper also proposes creating a universal toolkit to widen knowledge sharing across university campuses. To educate a more diverse student population and build effective leaders who can advocate for sustainability and resilience, this paper emphasizes the importance of a multidisciplinary effort to develop more comprehensive sustainability and resilience coursework with some flexible and practical modules which can be shared and implemented across multiple disciplines.

Course Structure and Development Methodology

This paper focuses on developing collaborative, campus-wide sustainability and resilience promotion and adoption. This section will outline the framework structure of an interdisciplinary course and the course development process. Reference Figure 1.

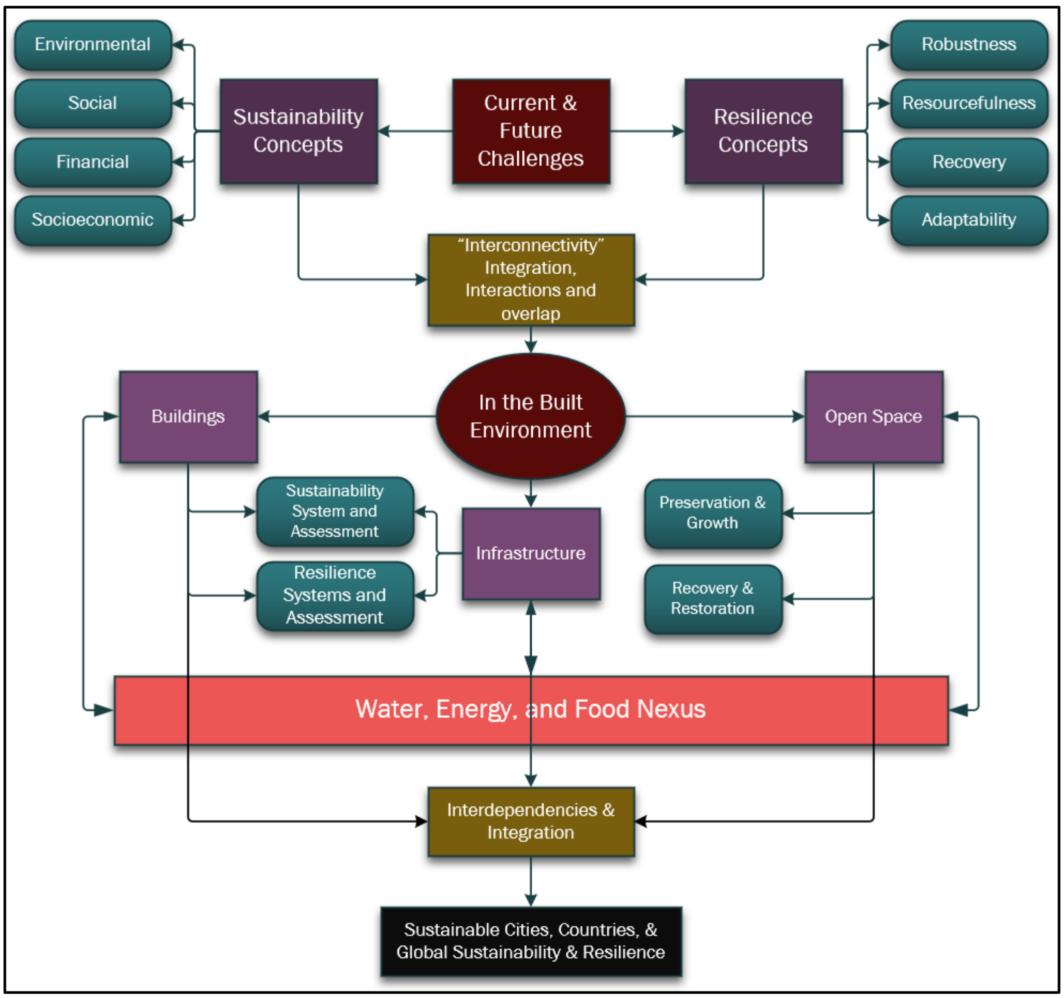

Figure 1 - Course Structure Flowchart

Current challenges, such as climate change and economic inequity, and future challenges, such as food and water security will inform students about the current local, national, and global challenges which is the motivation to understand the concept of sustainable and resilient development. Although, this is not part of the course structure, it is highly advisable that the coursework include these challenges, maybe in the form of a module, as the main introduction to this course which serves as the justification and the purpose of taking these types of modules whether it is a standalone course or several modules in different courses.

As shown in figure 1, the course structure can be divided into 2 phases. The first phase will focus on the sustainability and resilience concepts and their interconnectivity while the second phase will educate the students about how that interaction occurs within the built environment systems (Buildings, open space, and infrastructure).

During the first phase, sustainability and resilience are broken down into their respective dimensions and the interaction of both these concepts will be discussed by studying real-world examples. For example, while constructing a highway, it is imperative to consider the impacts of various natural and man-made disasters which could be experienced throughout the life cycle of the highway project, thus making it more resilient. Meanwhile, it is also important to adopt sustainable strategies such as using materials which have low embodied energy. This can facilitate the reduction of greenhouse gas emissions which can help to control some of the impacts of climate change.

After the interrelationship and importance is established, the second phase will teach students about how the built environment components and interact, and the affect these interactions have to balance sustainability and resilience issues. The integration of food, energy, and water nexus is introduced hereafter, to understand how these different systems interact with the center of basic global livelihood while maintaining a sustainable and resilient future. The final focus of this proposed course will discuss the national and global-level sustainable development and improvement practices.

In addition to a vision outlining the intended course structure, input and feedback from experienced academics and industry professionals is crucial to develop a well-rounded interdisciplinary course structure. The course development process as shown in Figure 2 provides a roadmap for the creation of such interdisciplinary modules.

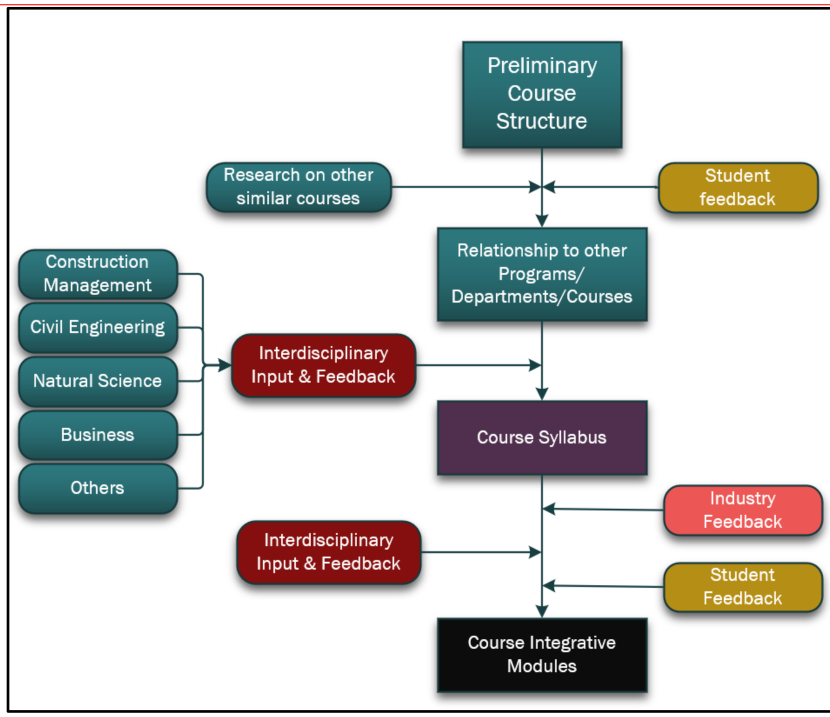

Figure 2 - Course Development Flowchart

The course development process in Figure 2 begins with extensively researching existing courses that address sustainability within the university system such as in the department of natural sciences, ecosystem sciences, construction management, civil engineering, and business among several others. Some global examples include, but are not limited to, Green labs to promote sustainability research course in Harvard (Harvard University, 2021), Co-creating sustainable cities course by TU Delft (TU Delft, 2021), HELSUS co-creation lab at University of Helsinki (Helsinki Institute of Sustainability Science, 2021). Student feedback from former and currently enrolled students (undergraduate and graduate levels) should be sought regarding their opinion of the course content and experience. Second, the course developers should also engage different faculty from the aforementioned schools and departments (if they are available within the university system) to create a diverse interdisciplinary curriculum that can be branched into different modules that are beneficial to different disciplines and courses within those different departments/schools. Finally, thereafter, to ensure practical validation and address current issues, industry and community and campus leaders should also be engaged to provide input and feedback to establish applied and practical sustainability course modules. The tri-level feedback from industry, interdisciplinary faculty, and students can act as a final validation phase to ensure the buy-in from the different stakeholders that can be engaged or benefitting from such course or curriculum modules.

Coursework Integration

In order to have a practical application for such a coursework or curriculum modules, they have to be integrable in different curriculums or courses, offered in an incentivized manner and have the ability to achieve several student learning outcomes (SLOs). The section below will discuss the incentivization process in course offering while being integrated across different curriculums in a universal toolkit model and will also provide an example of addressing several SLOs.

Universal Toolkit Preparation

To develop a universal toolkit as a guidance document for faculty around the campus, and incentivize the course offering, there are three proposed approaches based on the developers' capabilities and resources – (i) in-person and online delivery, (ii) free first module, and (iii) integration fluency of course modules. The proposed course can be more attractive if it is offered in-person and all the lectures were recorded which is a trend that is noted before and after the pandemic experience. The first module of the course can be made available for free, accessible to everyone with internet access, which can pique the interest of different on-campus and online students as well in further pursuing these courses after learning about their potential educational and practical pedigree. This first module will contain an overview of current and future challenges in the society, supplemented by real-world examples, that will identify the need for sustainable and resilient development which should incentivize students to enroll full-time. All course modules should have the ability to be easily merged and adopted within existing courses (e.g. Sustainable practice, design, & construction, Ecological engineering, Ecosystem ecology, Economics of ecosystems and biodiversity, etc.) based on the earlier involvement of the different faculty across the multiple disciplines. Interdisciplinary partners (through input and feedback) will be engaged to encourage adoption of the proposed course's module(s) while a supplemental list of steps and best practices can be made available on the course website for any faculty who would like to incorporate any module(s) into their courses.

Example of Curriculum/Course Modules and SLOs

This section provides a summarized and simplified example of course/curriculum modules which can be utilized and customized based on the developers' capabilities, resources, and educational offerings and concentrations. Table 1 presents general modules example which was also inspired by the course structure introduced in Figure 1. Table 1 serves as one of the many examples of a general course curriculum that can be generated using the course structure and course development methodology introduced in this paper. However, this can be customized towards the need and the capabilities of the educational entity that is trying to implement such as a curriculum or coursework. Therefore, Table 1 is intentionally very generic in nature in order to encompass as many disciplines as possible across a campus university system and maybe also across different universities which are willing to collaborate on creating a comprehensive national or global curriculum or coursework. Table 1 introduces eight different modules and the general intent of the modules.

Table 1

Modules example for general course/curriculum application

	Module General Topics	**Intent**
1	Introduction to sustainability and Resilience Challenges	Understand the national and global challenges (e.g., energy, water scarcity, and climate change, etc.) and how sustainability and resilience application can help in providing practical long-term solutions

2	Sustainability Concepts	Understand the triple bottom line of sustainability (Enviro., Social, Economic) in addition to sustainable institutional policies.
3	Resilience Concepts	Understand the disaster and hazards resilience paradigm including system robustness, resourcefulness, recovery, and adaptability.
4	Sustainability and Resilience interconnectivity	Understand the interrelation between the two concepts and how resilience is essential to achieve sustainable development
5	Built Environment Systems integration	Understand the built environment's main components (Buildings, Infrastructure, and Open space) and the interdependencies between these systems.
6	Sustainability and Resilience Assessment and Application in the Built Environment systems	Understand how to assess qualitatively or quantitatively the sustainability and resilience on the micro (system component) and macro levels (System of systems) within the built environment.
7	Food, Energy, and Water (FEW) Nexus	Understand the broad concept of FEW nexus, its tradeoffs and impacts, and how socioeconomic resilience and sustainability can affect its paradigm.
8	National and Universal/Global Applications and case studies	Apply sustainable and resilience assessment and solutions on national and global case studies and examples

The modules described in Table 1 can have different content depending on the educational settings where they will be taught. For example, in the case of construction engineering and management, sustainability and resiliency modules will focus on building strategies that can achieve sustainability and resilience in buildings or infrastructure systems, civil and structural engineering can address the resiliency concepts from structural robustness and adaptability over time. However, these modules should (to the best of the course developers' ability) embody as much interdisciplinary collaboration and knowledge interchange as possible in order to maximize the educational benefit to the most diverse population as possible.

Student Learning Outcomes SLOs:

Student learning outcomes can vary across the different disciplines according to the accreditation bodies that departments or schools are associated with. However, this section will use a couple of familiar accreditation student learning outcomes as an example represented by the ACCE and ABET as a quick brief example (ABET, 2021; ACCE, 2021).

ACCE SLOs examples: Aside from SLOs 1 "Create written communications appropriate to the construction discipline" and SLO 2 "Create oral presentations appropriate to the construction discipline" which can be easily achieved through assignments or projects across the different modules, the following are several examples within the AEC educational ACCE SLOs.

- ***SLO 6 – "Analyze professional decisions based on ethical principles"***: In a sustainability and resilience-focused curriculum, this SLO can be applied within the conceptual and planning phase when making professional decisions regarding project siting and its impacts (positive or negative) on vulnerable/disadvantage communities based on project-based assessment analysis in ***module 6*** as an example.

- ***SLO 7 – "Analyze construction documents for planning and management of construction processes"***: This SLO can be addressed while analyzing the different sustainable and resilient strategies for application in different systems (buildings or infrastructure) in module ***6*** as an example.
- ***SLO 9 – "Apply construction management skills as an effective member of a multi-disciplinary team"***: This SLO can be easily achieved if the students are interacting within a multidisciplinary team in ***module 8*** as an example.
- ***SLO 13 – "Understand construction risk management"***: This SLO can be addressed in a detailed manner (beyond "understanding" cognition level), especially in the resilience concept ***module 3*** where students learn and understand the concept of system construction robustness which is directly related to risk and vulnerability assessment.
- ***SLO 18 – "Understand the basic principles of sustainable construction"***: This SLO is directly related to the content that can be taught under ***module 2*** and beyond throughout the course/curriculum.

ABET SLOs examples: SLO 7 "ability to acquire and apply new knowledge as needed, using appropriate learning strategies" is directly addressed by all the modules as each module is meant to have a conceptual and an implementation portion. This is to ensure that the students learn the concept and can apply the same to a real-world problem. Following are some more examples of the ABET SLOs being reflected in the proposed course modules:

- ***SLO 1 – "Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics"***. ***Module 6*** directly addresses this SLO as the students will have an opportunity to learn about the assessment of sustainability and resilience and its application to real construction projects.
- ***SLO 3 – "Ability to communicate effectively with a range of audiences"***. This SLO can be achieved through ***modules 7 and 8*** wherein students will have an opportunity to understand and implement the concepts at the national and global levels.
- ***SLO 5 – "Ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives"***. This is similar to ACCE SLO 9.
- ***SLO 7 – "Ability to acquire and apply new knowledge as needed, using appropriate learning strategies"***. This SLO can directly addressed across several modules such as ***modules 6 and 8***.

Conclusion

This research intended to create a standardized framework for integrated sustainability and resilience coursework to help the students to develop a better understanding of the built environment and the necessary concepts required for its sustenance. This research also proposes the creation of a universal sustainability toolkit that could facilitate the integration of all (or portion) of the course modules in multiple courses across diverse types of higher educational entities. The outcomes of this research can help in developing a comprehensive understanding of sustainability and resilience among the students, and how they are incorporated within the built environment. The most recent COP26 conference detailed the importance of creating resilient and sustainable cities as the severe effects of climate change are noticeably affecting by countries, worldwide. Implementing concepts presented in this paper in university undergraduate and graduate curricula can empower the next generation of the AEC industry towards building a more sustainable and resilient built environment. Providing the students with the necessary tools and expertise in the area of resilience and sustainability will produce individuals who are capable of influencing national and global policies. Lastly, the connection of the broader course modules to the ACCE and ABET SLOs will enable faculty to catalog and track the outcomes of the course over a period of time and improve its effectiveness.

The limitations of this proposed educational coursework relate to the available resources within a certain educational institution. For example, a lack of expertise in the area of sustainability and resilience can hinder the adoption of course modules and further development. The absence of graduate schools in many educational institutions may impede the application of the proposed concepts to a real-world problem through a research-oriented solution. Another limitation stems from a lack of industry support to facilitate the learning of these concepts and their application. To provide resiliency against these limitations, the proposed coursework is not a "go, no-go approach", rather it is an effort that can be shaped to suit the educational entity's capabilities and resources.

References

ABET. (2021). *Criteria for Accrediting Engineering Programs, 2019 – 2020*. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3

ACCE. (2021). *Student Learning Outcomes (SLO) and Assessment Measures*. https://www.csuchico.edu/cm/acce-accreditation/slo-assessment-measures.shtml

Adhikari, S., Mosier, R. D., & Langar, S. (2020). Evaluation of Disaster Resilience Preparation in the Construction Education Curriculum. 2020 ASEE Virtual Annual Conference Content AccessAhn, Y. H., Kwon, H., & Pearce, A. R. (2009). Sustainable education for construction students. Proceedings of Associated Schools of Construction Conference,

Amaratunga, D., Malalgoda, C. I., & Keraminiyage, K. (2018). Contextualising mainstreaming of disaster resilience concepts in the construction process. *International journal of disaster resilience in the built environment*.

CU Boulder. (2022). Urban Resilience & Sustainability. Retrieved from https://www.colorado.edu/menv/academics/specializations/urban-resilience-sustainability

Dufty, N. (2021). *Australian Disaster Resilience Handbook Collection*. https://knowledge.aidr.org.au/media/8874/aidr-handbook_dreyp_2021.pdf

Harvard University. (2021). *Green Lab*. https://green.harvard.edu/programs/green-labs

Helsinki Institute of Sustainability Science. (2021). *HELSUS CO-CRE-ATION LAB*. https://www2.helsinki.fi/en/helsinki-institute-of-sustainability-science/helsus-co-creation-lab

Lim, Y. S., Xia, B., Skitmore, M., Gray, J., & Bridge, A. (2015). Education for sustainability in construction management curricula. *International Journal of Construction Management, 15*(4), 321-331.

Murray, P. E., & Cotgrave, A. J. (2007). Sustainability literacy: the future paradigm for construction education? *Structural survey*.

Northeastern University. (2022). INPR 2183: Sustainability and Resilience at Northeastern. Retrieved from https://globalresilience.northeastern.edu/event/inpr-2183-sustainability-resilience-at-northeastern/

TU Delft. (2021). *Co-Creating Sustainable Cities*. https://online-learning.tudelft.nl/courses/citizens-co-creating-sustainable-cities/

UWASH. (2022). Sustainability, Resilience, and Society. Retrieved from https://learning.edx.org/course/course-v1:UWashingtonX+ANTH378x+2T2015/home

Wang, Y. (2009). Sustainability in construction education. *Journal of professional issues in engineering education and practice, 135*(1), 21-30.

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Case Study: Development and Implementation of a Programmable Assessment Matrix

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Abstract

This research details the design and implementation of a programmable assessment matrix that helps educational institutions coordinate their programs for assessment missions. The assessment matrix was developed and applied to support the accreditation of the Construction Management program recently developed at the University of Wyoming. It is organized in a x-y axis format where users can archive and review required assessment documentation over time including grades, instructor's evaluation, course evaluation feedback (indirect assessment), and student work (direct assessment). Observations such as simplicity of reviewing information for each course and holistic display of the curriculum are recurrent advantages identified by instructors and administrators in the program, which led to course and curriculum reviews on a semester-by-semester basis. Drawbacks pertaining to the sophistication of the matrix can be solved by working alongside with computer programming personnel and developing a tutorial video. A utility function of the matrix demonstrated that students not always have an accurate perception of understanding of a specific Student Learning Outcome, which prompted modifications to the course curriculum and assessment surveys. The assessment matrix can be used to enhance any academic program in its accreditation mission.

1 Introduction

Thousands of students dedicate their academic careers to a specific field of study in hopes of acquiring the skills necessary to find successful employment after graduation. Such employment can be based on the composition and measurement of a well-developed degree program. A well-developed degree program should provide evidence of multiple aspects of a student's learning experience, including but not limited to how the student was recruited and admitted to the university and specific program, the cost of study, currency, relevance, and rigor they receive during their

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academic journey. Educational institutions, through the programs they offer, serve a public purpose, and should keep themselves accountable on the quality of education students receive. Various learning commissions and accreditation entities establish guidelines in how to effectively evaluate institutions and their programs on learning; however, benchmarked guidelines can fall short of a quality education. The goal established by learning commissions and accreditation entities is to encourage and impose assessment guidelines to comply with federal and industry standards. Therefore, the purpose of accreditation assessment (to demonstrate students' learning quality based on measurable outcomes according to the stipulations of an accreditation entity) is essential in the continuous improvement of learning which should reflect the involvement of faculty at all levels of learning and the evaluation of ancillary activities. Accreditation assessment should be well grounded in measured evidence of learning through a peer-review process based on high standards to advance the quality of learning. Education institutions and programs, which engage in accreditation assessments, are given the freedom to provide evidence of measures suitable to their unique structure. Thus, accreditation assessment takes on various blueprints that can be a daunting experience to administrators and accreditation reviewers. This research details the development and implementation of a programmable assessment matrix which can be customized to help support educational institutions and programs in their assessment missions. The design of the matrix was prompted by the lack of a customizable assessment platform available to education institutions and programs in their pursuit towards a successful accreditation experience and outcome.

2 Literature Review

2.1 Problem

Literature shows that many higher education institutions and programs in the country meet the requirements stipulated by accreditation entities; however, a lot of them struggle to illustrate a clear representation of the curriculum and measure of learning when requested by those bodies (Tingerthal et al., 2012). The focus of this literature review is to provide support on the need for a programmable assessment matrix capable of illustrating a clear representation of program (ongoing process of gathering information and measuring outcomes for the program as a whole) and student assessment (ongoing process of evaluating students' individual abilities).

The challenge for educational institutions and programs to demonstrate clear representation of their curricula is prevalent across already accredited and new programs seeking accreditation (Veltri et al., 2012; Leathem, 2018; Wijngaards-de Meij & Merx, 2018). In most cases, the documentation to satisfy the needs for accreditation are only archived for institution officials, but not organized nor displayed intelligibly for third parties like accreditation entities (Badiru et al., 2010). Often, programs and curricula designs are simply listed independently without any connections to visualization of the progress in terms of Student Learning Outcomes (SLOs) (Felder & Brent, 2003).

Previous research on assessment matrix platforms has been conducted by Felder & Brent (2003) and Rodriguez-Marek et al. (2008) for accreditation purposes in Accreditation Board for Engineering and Technology (ABET). In their research, the assessment matrix was used to organize the association between courses (rows) and learning outcomes (columns) based on a weighted system (low, medium, or high). Likewise, additional graphical displays to organize Construction Management curricula were proposed by Tingerthal et al. (2012). One of the graphical approaches is to list the courses of the curriculum in a flowchart. This allows students and observers to see the course of study in a time-ordered manner by showing the predecessors and successors of each course. A float-space graphic was also proposed to cope with the unfamiliarity of industry advisory on the format of course design. Additionally, a tree format graphic was introduced to facilitate the association of an SLO to a course without losing perspective of the program. This format not only highlights the learning outcomes for each course but also illustrates the effect of the respective learning outcomes at the program level. Despite the efficiency and simplification of these approaches, their respective assessment platforms do not allow storage of data which may fall short for purposes of accreditation. Thus, a solution for the above shortcomings is to develop a programmable and interactive assessment matrix that allows the storage of data in a methodological sequence over time.

2.2 Applied Fields like Construction

The challenge to comply with accreditation requirements is especially true in applied fields of study like Construction Management. This is the discipline which provided the motivation for the development of a programmable assessment matrix that is steering the focus of this study.

With the expansion of the construction sector, the need to succeed in the construction profession is no longer the same as required in the past. According to reports solicited from the construction industry, construction professions not only require a strong technical foundation of construction skills but also demand other competencies such as leadership, collaboration, creativity, and problem-solving skills (Ahn et al., 2012). As a result, accreditation entities such as ABET, and the American Council for Construction Education (ACCE) are stipulating accreditation guidelines to institutions and Construction Management programs in order to ensure that these competencies are taught in academia. Also, achieving accreditation status is an assurance of the quality of education in a program, its administration, marketing, finance, accounting, and other factors (Arditi & Polat, 2010). The accreditation process encompasses a plethora of planning, implementation and tracking of student learning progress over time and therefore, requires a systematic method to organize the program.

An assessment matrix constitutes to a unifying framework in support of program development and continuous assessment tracking and has the ability to integrate the organization of SLOs relative to each course offered in a program. It contrasts with traditional assessment platforms that lack standardized methodology for collecting and analyzing large amount of data associated with assessment collection and data processing (Mason & Dragovich, 2010). Thus far, no research on an assessment matrix has been conducted for the accreditation of Construction Management programs by ACCE. Understanding the need for a well-developed accreditation matrix, the College of Engineering at the University of Wyoming has developed a programmable assessment matrix that is capable of integrating the organization of the twenty ACCE SLOs to each course offered in the program through a single interface platform.

2.3 ACCE to Bloom’s

Accreditation requirements for already accredited and new programs need to record SLOs, which are translated as skills, knowledge, and behaviors that students are expected to acquire over the course of the program (Anwar & Richards, 2018). In support of this requirement, ACCE formally approved an assessment cluster based on different SLOs. Students who graduate with a Bachelor of Science in Construction Management degree from an ACCE accredited program must demonstrate the ability to execute all twenty SLOs (Mehany & Gebken, 2017). ACCE, in collaboration with industry practitioners and construction educators, adopted the “Bloom’s Taxonomy of Educational Objectives” (shortened to Bloom’s Taxonomy) as a valid benchmark of measuring the different levels of learning and understanding. The Bloom’s Taxonomy divides student learning and understanding into six levels of cognitive domains. Each level increases in complexity in the following order as demonstrated in Figure 1: Remember (lowest), Understand, Apply, Analyze, Evaluate, and Create (highest) (Dymond et al., 2020).

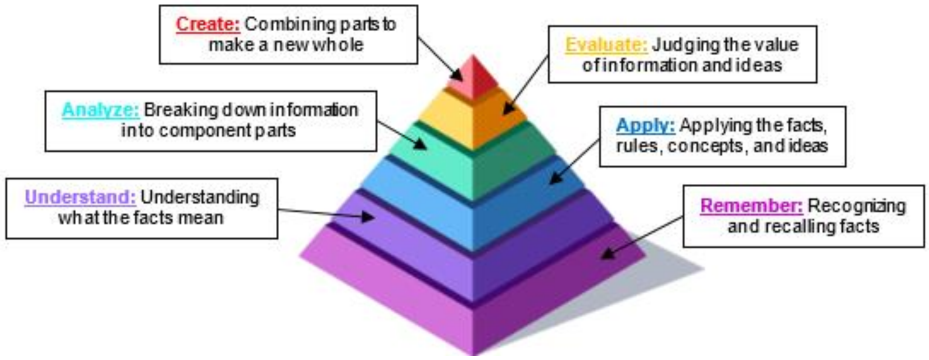

Figure 1: Bloom's Taxonomy in classifying student learning and understanding into six levels of cognitive domains in order of complexity and specificity

The Bloom's Taxonomy suggests that educators should strive to guide their students to the higher levels of the taxonomy, if possible. Regardless the mechanism, a successful assessment platform must provide some measure of how much students are learning with respect to the required SLO (Mason & Dragovich, 2010). A framework for such implementation is to require instructors to include course specific SLOs in every class (Dymond et al., 2020). To assess the effectiveness of a class, successful programs often use a variety of learning assessment schemes, which include indirect measurements such as surveys (where opinions of the students are asked), and direct measurements such as tests and homework (where the performance of the students is evaluated) (Bai & Pigott, 2004). These learning assessment schemes should be analyzed and displayed in an integrated fashion through an assessment platform like a programmable assessment matrix.

3 Programmable Assessment Matrix

The Civil and Architectural Engineering and Construction Management (CAECM) department in the College of Engineering at the University of Wyoming has committed to the development of a four-year Bachelor of Science in Construction Management degree program and to steer the program towards full national accreditation status by the ACCE in 2022 upon graduation of its first senior class. The development of this degree program is intended to eliminate the shortage of a qualified construction workforce in the state. The development and implementation of this degree program required academic administrators to identify and integrate, a total of 40 classes over a four-year period that equates to 120 academic credits needed to fulfill the requirements for a bachelor's degree. Ancillary to the development and implementation of the course work is the integration of a continuous assessment plan that should be capable of measuring the learning and teaching performances of students and instructors towards achieving their respective educational goals. This prompted the program to develop a programmable assessment matrix.

The main interface of the matrix is organized as a mapping between the twenty ACCE SLOs on the y-axis and the Construction Management courses on the x-axis, in which the SLOs are integrated, taught, and measured across all the courses in the program. The matrix was developed through the utilization of C# and JSX programming languages.

The assessment matrix allows users to customize the addition and removal of any course, as well as the order by which they are displayed, preferably in sequence of freshman, sophomore, junior, and senior status. Besides the required Construction Management courses, additional courses in Math and Science, Business, University required, and optional electives courses are also listed across the x-axis.

The programmable uploading function keeps record of course changes over time. For each course, the matrix requires instructors to upload the corresponding syllabus and instructor's evaluation. On the matrix platform, it also requires the instructors to upload the students' feedback data about the course (indirect assessment) and students' work (direct assessment) so that all these documents can be later accessed and visualized in original and full format. This information is important especially to administrators and instructors in support of continued program and course improvements. With the interactive features of this assessment matrix, the display is not restrained by problems related to space, unlike existing mapping platforms, whose interface is either too populated or too simplified. Course evaluations and assessment data on non-construction courses are not uploaded in the matrix. On the y-axis, the twenty SLOs are displayed in different colors, corresponding to the different levels of learning according to the Bloom's Taxonomy pyramid that is displayed at the top left corner of the matrix. The Bloom's Taxonomy pyramid is interactive by providing users with a description of specific student learning measures at each level. The different functionalities of the matrix are illustrated in Figure 2.

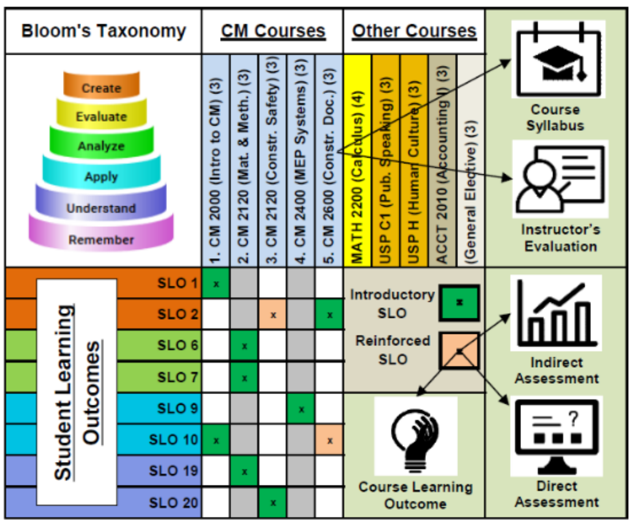

Figure 2: Different functionalities of the assessment matrix (Course Syllabus, Instructor's Evaluation, Indirect Assessment, Direct Assessment, SLOs, and Course Learning Outcomes)

For each of the twenty SLOs, corresponding Course Learning Outcomes (CLOs) were defined as part of the ACCE accreditation requirement. These CLOs were determined by IAB (Industry Advisory Board) members who provided an extensive list of skills, knowledge, and behaviors that they believe would be beneficial for students to learn before entering to the construction industry. The list of CLOs was narrowed down to three per SLO, by allowing instructors to extrapolate upon the listed three CLOs if see fit.

The matrix utility allows users to view the three corresponding CLOs if they press on any one of the listed SLOs. Each of the SLOs with its three corresponding CLOs are integrated across the construction courses taught in the program and reflected on all course syllabi. Each of the twenty program SLOs are first introduced in a course (where students are introduced to the concepts) and then reinforced in an advanced course (where students are tested on the concepts). This sequence is indicated in green (introduced) and in salmon (reinforced) across the matrix. The matrix has the ability to rack assessment data (direct and indirect assessments) associated with each listed SLOs over time by clicking on the interception cells. This utility provides users with access to student work (art effects including exams, quizzes, and projects) as well as indirect assessment data (pre- and post-course survey data) by administering a Qualtrics survey on student's perception of learning in all courses. The pre- and post-course survey data is illustrated in a bar chart for every time a course is taught (Figure 3). It is expected that at the end of a semester (after), there would be an increase in the students' learning perception as compared to the beginning of a semester (before). This difference (Δ) on the students' learning perception is indicated on the matrix in a graphic representation. Additionally, the instructor's evaluation can be extracted from each course. In this document, observations regarding to the positive and negative aspects of the class based on the perception of the instructor are included as well as the class grade distribution for each SLO.

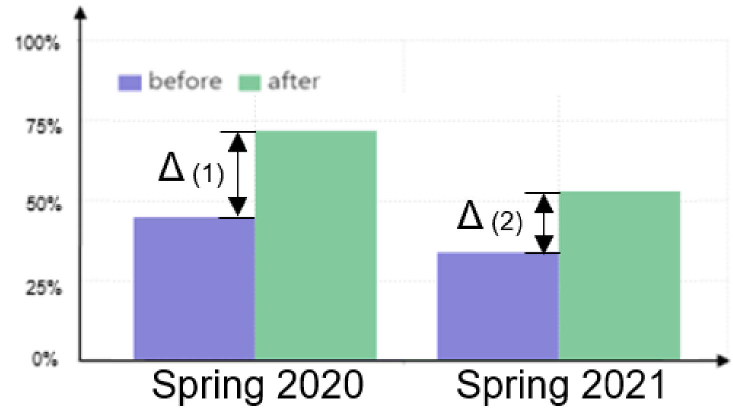

Figure 3: Difference (Δ) between results of an SLO obtained at the beginning and end of the semester for different semesters

4 Results

The functionalities of the assessment matrix were evaluated based on feedback collected from professors and administrators responsible for the Construction Management program at the University of Wyoming for the semesters of Spring 2020, Fall 2020, and Spring 2021. The feedback was obtained during the end-of-semester assessment meetings, where all faculty in the program provided their input on the course their taught. Besides discussing topics on student learning and potential improvements to the courses, their general viewpoint about the matrix was also inquired.

It was reported that two of the most notable benefits of the matrix are its ability to the display the big picture of the curriculum and its simplicity in reviewing all documents associated to each course. These benefits not only allowed the instructors to prepare for the organization of successive courses by revisiting the existing syllabi and art effects for the precedent courses, but also helped administrators to make appropriate changes and improvements on the already taught courses for the following years based on the students' learning perception (indirect assessment) and the instructor's evaluation feedback. Other advantages include the orderly organization of program information, customization of the courses and SLOs, and mutual understanding of the curriculum by different parties involved across the program.

In this program, the holistic matrix display allowed administrators to develop a visual understanding of the student learning experience in the program. This understanding helped in the development of appropriate electives to potentially enhance the current curriculum framework. For instance, two elective courses (CM 3140: Build Environment Market and CM 3230: Construction Economics) were added to the program as students' feedback in previous courses showed an interest in learning more about topics regarding to real estate and construction finance.

In addition, the matrix further highlighted a need to increase student contact hours of the CM 3200: Statics and Structural Systems based on pre- and post-course survey results and instructor's feedback obtained in Fall 2020. Assessment evidence revealed that students had some difficulty in the course especially with reference to SLO 19 (Understand the basic principles of structural behavior) since the average grade for this SLO was only 80% in contrast to the average grade in the class (84%). In addition, the course pre- and post-course survey data showed that there was only a 16% increase in the students' learning perception from before and after taking the course, which is relatively lower than the average (20%) among all reinforced SLOs across the program. As a result of these observations, the program decided to attribute an additional credit to the course and prompted the instructor to make modifications to the course syllabus with specific reference to SLO 19 the next time the course is taught in Fall 2021.

Despite the advantages detailed above, some challenges were encountered during the implementation of the matrix. Due to the sophistication of programming languages used to develop the matrix, only people with expertise in C# and JSX computer languages can troubleshoot bugs and correct malfunctions on the platform. Additionally, because the program is in constant improvement, the personnel with computer language expertise would need to work alongside with the administrators to continuously update the curriculum. Another challenge that the administrators came across was the initial course population of the matrix. Unlike a simplified Excel spreadsheet, a new user would need some guidance to fully understand the different functionalities. In solving this problem, a tutorial video was developed which explains the step-by-step procedure in how to build a curriculum using this assessment matrix.

A more specific problem surfaced where students sometimes do not have an accurate perception of their level of understanding of a specific SLO. In the pre-course surveys administered to students on a Likert scale between 1 (very little) and 5 (very high), an overestimation was frequently observed. This observation was found in many courses where students selected the option 5 even before taking the course. It was also found that several students were not cooperative in this assessment as they spent little time taking the survey before submitting it. These challenges were addressed by removing potentially erroneous data (e.g., students that selected option 5 in all the questions, students who took less than 10 seconds to complete the survey, etc.) before populating the matrix. Moreover, with the intent to collect more accurate results, the survey Likert scale between 1 and 5 was replaced by a scale line that ranges between 0 and 100, where students are required to physically engage in reporting their results by dragging the indicator to the option that corresponds to their learning perception (instead of just clicking on an option in a limited scale).

5 Conclusions and Future Research

Construction Management programs that seek accreditation are required to prepare a self-evaluation study which details information relative to the institution, curriculum, student policies, financial resources, industry among others, to demonstrate full accreditation compliance. Many higher education institutions in the country meet the requirements stipulated by accreditation entities like ACCE; however, most institutions and programs struggle to illustrate a clear representation of their curriculum and measure of learning as requested by accreditation entities.

This research paid attention to the above shortcoming through the development of a programmable assessment matrix that is capable of supporting the measures of learning in a methodological sequence over time, in order to comply with accreditation requirements and standards. To clearly illustrate the curriculum, the main interface of the assessment matrix is organized as a mapping between the ACCE SLOs on the y-axis and the Construction Management courses on the x-axis where syllabi and instructor's evaluation are archived. On the interception cells between SLOs and courses, student art effects (direct assessment) and students' learning perception data (indirect assessment) are stored so that improvements on the program can be made based on these results.

According to the feedback received, the holistic display of the matrix and simplicity in having access to the course documentation are the most significant benefits identified by the instructors and administrators responsible for the Construction Management program at the University of Wyoming. However, due to the sophistication of the matrix, personnel with computer programming skills would be required to work alongside with the program administrators to make potential updates. In addition, the development of a tutorial video would be essential to guide new users in populating the matrix. Furthermore, a utility function of the matrix showed that students not always have the most accurate perception of their understanding in a specific SLO. As result, solutions to solve this problem include the removal of erroneous data and modification of the Likert scale from 1 to 5 to a 0 to 100 scale line that requires students to physically drag the indicator to the option that corresponds to their learning perception. A summary table with the advantages, disadvantages, and proposed solutions for the disadvantages are shown in Table 1.

Advantages	**Disadvantages**	**Solutions**
- Holistic display - Easy revision of documentation	- Requires computer programming expertise	- Work with personnel with programming expertise
- Orderly organization	- Sophisticated functionalities	- Development of a tutorial video
- Customizable - Easily understood by different parties	- Students' inaccurate perception on SLOs	- Removal of erroneous data; modifications on the survey

Table 1: Advantages, disadvantages, and solutions for the disadvantages on the use of the assessment matrix

For future research, more updates will be made based on the suggestions provided by the accreditors during the ACCE accreditation site visit for the Bachelor of Science in Construction Management degree program at the University of Wyoming that will take place in Spring 2022. Additionally, several other ACCE Construction Management programs in candidate status expressed an interest in using the programmable assessment matrix to help organize their curricula. Thus, a website is being developed through which all participating programs can access their respective matrix platforms, with a tutorial video that shows all the functionalities and support contact information. With anticipated minor adjustments, the universal interface platform can contour the specific needs of other academic programs such as nursing, engineering, and music. In fact, plans were already made to use the assessment matrix to organize a Civil and Architectural Engineering program accredited by ABET. In sum, the matrix design and implementation can be viewed as ongoing in nature in providing academic institutions and programs with a formalized assessment platform, which is essential in support of continuous improvement as required by the different accreditation entities.

References

Ahn, Y. H., Pierce, A. R., & Kwon, H. (2012). Key competencies for U.S. construction graduates: industry perspective. Journal of Professional Issues in Engineering Education and Practice, 138(2), 123-130.

Anwar, A. A, & Richards, D. J. (2018). Comparison of EC and ABET accreditation criteria. Journal of Professional Issues in Engineering Education and Practice, 144(3), 06018001.

Arditi, D., & Polat, G. (2010). Graduate education in construction management. Journal of Professional Issues in Engineering Education and Practice, 136(3), 175-179.

Badiru, A. B., Slagley, J. M., & Smith, D. A. (2010). Project management application for engineering program accreditation preparation. Journal of Professional Issues in Engineering Education and Practice, 136(1), 39-47.

Bai, Y., & Pigott, R. (2004). Assessing outcomes using program assessment portfolio approach. Journal of Professional Issues in Engineering Education and Practice, 130(4), 246-254.

Dymond, B. Z., Swenty, M., & Carroll, J. C. (2020). Comparing exam performance in a reinforced concrete design course with Bloom's Taxonomy levels. Journal of Civil Engineering Education, 146(1), 04019001.

Felder, R. M., & Brent, R. (2003). Designing and teaching courses to satisfy the ABET engineering criteria. Journal of Engineering Education, 92(1), 7-25.

Leathem, T. M. (2018). "A curriculum review of a construction management program for consideration of accreditation by the American Council for Construction Education." Ph.D. thesis. Department of Curriculum, Instruction, and Special Education. Mississippi State University.

Mason, G, & Dragovich, J. (2010). Program assessment and evaluation using student grades obtained on outcome-related course learning objectives. Journal of Professional Issues in Engineering Education and Practice, 136(4), 206-214.

Mehany, M. S., & Gebken, R. J. (2017). Construction faculty's perception of the American Council for construction education's Bachelor Degree student learning outcomes. Proceedings of Associated Schools of Construction of the 53rd Annual International Conference, USA, http://ascpro0.ascweb.org/archives/cd/2017/welcome.htm

Rodriguez-Marek, E., Koh, M., & Talarico, C. (2008). Connecting the dots in assessment: from course student learning objectives to educational program outcomes to ABET assessment, Proceedings of ASEE 2008 Annual Conference & Exposition, June 22-25, 2008, Pittsburgh, PA, 316.

Tingerthal, J., Roger, T., & Mead, S. (2012). Visualizing construction curriculum. Associated Schools of Construction Proceedings of the 48th Annual International Conference, Birmingham, U. K., http://ascpro0.ascweb.org/archives/cd/2012/welcome.htm

Veltri, N. F., Webb, H. W., Matveev, A. G., & Zapatero, E. G. (2011). Curriculum mapping as a tool for continuous improvement of IS curriculum. Journal of Information Systems Education, 22(1), 31-42.

Wijngaards-de Meij, L. & Merx, S. (2018). Improving curriculum alignment and achieving learning goals by making the curriculum visible. International Journal for Academic Development. 23(2), 1-13.

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Assessment of the Relationship between Ethical Decision-Making and Human Dimensions of Construction Students

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The construction industry could enormously benefit from the young graduates starting their professional journey well equipped with the necessary ethical principles. This study mainly intended to see if there is a relationship between the personalities of construction engineering students and their views of ethics in the construction industry. It evaluated their perceptions of ethical practices in the industry along with their reactions to an unethical scenario of cost inflating payment games in a company. A total of 127 students from across three universities, University of Kansas, Arizona State University and University of North Carolina at Charlotte, participated in the study. The results showed that the students' views of ethical principles are indeed related to some of their personality descriptors.

Key Words: Human Dimensions, Personality, Emotional Intelligence, Ethics, Construction Industry

Introduction

Ethics are a crucial element of engineering in general. An introduction to professional ethical standards and related code of conduct are often included in institutions of higher education to expose young professionals to ethical principles they will encounter in their professional careers. Students benefit from expanding their knowledge of professional ethics and integrity as it will help them exercise their responsibilities while they work in the professional world (Wang et al., 2010).

The purpose of this study was to assess if there is a relationship between the human dimension characteristics and ethical behaviors of university students in the construction engineering and management field. It was intended to investigate what expectations students had regarding ethical decision-making and general perceptions of the construction industry. Two sets of survey question were distributed to students from the University of Kansas (KU), Arizona State University (ASU) and

University of North Carolina at Charlotte (UNCC). One survey evaluated human dimensions and the second reviewed ethics related views of the participants.

The human dimensions assessment included two major components:

- ***HEXACO Personality Inventory***: a measure of the "Big Six" personality traits
- ***Emotional Intelligence (EI) Diagnostic***: an assessment of the capability of individuals to recognize and manage their own emotions and those of others

The ethics component of the study measured the students' perception of ethics in the construction industry and their own way of looking at an unethical act on a construction project. Student responses were collected via an in-class interactive workshop. It is important to note that the students involved in this study did not have much training regarding ethics in the construction industry prior to participating in the workshop other than their undergraduate education and possible internship experiences. Students were given brief definitions of terms related to the survey questions and were asked for their "raw" or baseline perceptions of ethical standards in the construction industry. Both the human dimensions and ethics data collection are explained in further detail in the methodology section below.

Literature Review

The construction industry plays a critical role in the economic development of any country. It is inevitable that professional ethics standards must be given serious attention in the construction industry. A study by Shah and Alotaibi (2018) reflects on how unethical practice ranks top among the most serious problems the industry faces. The study examined unethical practices that are common in the construction industry and the factors that triggered or invigorated them. Bribery, fraud, bid shopping, claim games, conflict of interest, incompetence, cost inflations, poor work delivery and professional misconduct are among those listed as common unethical practices. The outcomes of these practices may bring about constant uncertain acts that put life and property at risk. They might be decent causes of wealth disparity and subsequently lower quality of life. The construction industry suffers from several factors that are acting as driving forces for ethical problems to arise.

Ho (2016) describes how the construction sector experiences many ethical challenges and how these ethical misconducts has led to the waste of society's resources. The study states that organizations' competitiveness and survival depend on defending these challenges that are persistent in the industry. In today's turbulent construction market these organizations should ensure their employees know how to deal with ethical issues in their everyday work lives and are thus able to make ethical decisions. These ethical decision-making processes require individuals to use their moral base to determine whether a certain issue is right or wrong and the construction industry is in a great need of this quality. Several construction organizations and professional groups collectively agree that ethics is an essential element of professionalism in the construction industry. They emphasize on achieving highest standards of engineering ethics. Most of them have their own codes of conduct and codes of ethics that they swear by. They expect their employees and members to live to these codes.

The United States construction industry doesn't have a stern ethics training requirement to those who apply to become a state certified professional in the field. Most states require only two hours of ethics training from accredited organizations. Ethics education for most construction students is similarly lagging on global and sustainability components. Most higher education institutions have a micro-insert of ethics in their curricula instead of a systematic standalone professional ethical education (Wang and Buckeridge, 2016).

The industry could enormously benefit from the young graduates starting their professional journey well equipped with an understanding of ethical principles and professional codes of conduct that will be relevant in their careers. Civil and construction engineering students need to be trained in developing and applying qualities of high levels of accountability and transparency in the construction industry (Wang and Thompson, 2013). Proper soft skill trainings are virtuous ways that prepare them to face all challenges with confidence (Maali et al., 2020). Leadership trainings will serve as the backbone of their future carriers making them fit for the positions they are expected to run.

Personality is defined as “a pattern of relatively permanent traits and unique characteristics that give both consistency and individuality to a person’s behavior (Feist & Feist, 2006). Using personality tests and assessments in the construction industry is a great way of understanding behavioral traits of professionals (Criteria, 2015) and their behavior responses impacts (Maali et al. 2021). The codes of conducts used by most construction companies are directly related to people’s personalities. Honesty, fairness, reliability, integrity, objectivity, and confidence are few of the most common ethical qualities agreed up on by construction companies and professional associations. Shah and Alotaibi (2018) state that human variables add to the vast majority of value related issues. According to the study, human personalities play a role in encouraging most unethical practices. Knowledge of how people’s personalities are related to workforce development as well as ethical decision-making qualities is essential to act right in the construction industry.

HEXACO is one of the most widely used personality assessment models. It covers different aspects of an individual’s personality tendencies. HEXACO has been used in the context of the construction industry by several previous studies. Emotional intelligence (EI) is another well-known human dimension assessment tool. It is the ability to perceive and express emotion, assimilate emotion, and thought, understand, and reason with emotion, and regulate emotion in the self and others (Jordan et al., 2002).

Ashton et al. (2014) on the other hand discusses ethical and unethical decision making as one of the concepts that is integrated into personality assessment studies. Although it is not a subscale, it is accommodated as a variable that is conceptually relevant to the human dimension assessment domains of HEXACO personality inventory.

Personality and ethics are similarly related amongst university students. According to Mischung et al. (2015), a skill-based Emotional Intelligence (EI) and personality development trainings given to Construction Management students had significant improvements in their individual and team performance levels. The study provided sufficient evidence that higher EI amongst the students resulted in self-improvement and increased group interaction as well as ethical behavior improvements.

This study evaluated the understanding and perception of civil and construction engineering students about ethical practices in the construction industry. It reflects on whether their way of thinking can be intertwined with their personalities or not. Their expectations and ethical decision-making traits as they join the industry was predicted from their personal responses.

Research Methodology

Data Collection

The human dimensions assessment and ethics questions surveys were given to students during their course period. Data collected from a total of 127 students from across the three universities is used for this study. Table 1 summarizes the distribution of the collected data.

Table 1

Number of students that participated in the study and their institutions

Institution	Number of Students Involved in the Study
KU	74
ASU	28
UNCC	25

Human Dimensions Assessment

Two human dimensions questionnaires were filled out by the students:

HEXACO personality inventory. Is a widely used assessment comprising of 60 questions that measure the "Big 6" personality domains (H-, E-, X-, A-, C-, O-). Each of these domains contain four sub-domains which give more specific personality descriptors. The domains and sub domains include ***Honesty-Humility*** *(Sincerity, Fairness, Greed Avoidance and Modesty),* ***Emotionality*** *(Fearfulness, Anxiety, Dependence and Sentimentality),* ***Extraversion*** *(Social Self-Esteem, Social Boldness, Sociability and Liveliness),* ***Agreeableness*** *(Forgiveness, Gentleness, Flexibility and Patience),* ***Conscientiousness*** *(Organization, Diligence, Perfectionism and Prudence),* and ***Openness*** *(Aesthetic Appreciation, Inquisitiveness, Creativity and Unconventionality).* The full information on the HEXACO personality inventory scale descriptions can be found on the open-source document by Ashton and Lee (2009).

Each of the 60 HEXACO questions were measured on a 1 to 5 Likert scale. Note that higher HEXACO scores are not necessarily better nor are lower scores are. Each domain is simply a spectrum or range of personality traits and the high versus the low side of each domain is completely arbitrary. A numerical score in the middle of the HEXACO measurement range would correspond with an individual whose personality tendency is well-balanced between the two extremes of the spectrum for the given personality domain or sub-domain being measured.

emotional intelligence diagnostic. The study used a 28-question diagnostic which provides an overall Emotional Intelligence Quotient (EQ) measured on a scale of 1 to 100. The resulting scores are intended to assess the participant's capability to recognize and manage their own emotions and the emotions of others.

EQ is a compilation of the following four skills:

- **Self-Awareness**: the ability to understand one's emotions as they happen.
- **Self-Management**: the ability to control one's emotional reactions.
- **Social Awareness**: the ability to understand the emotions of other people (even if you do not share the same feelings).

- **Social Management**: the ability to use emotional awareness to create more successful interactions.

Ethics Study

To understand their perception of ethics in the construction industry, the student participants were asked for their opinions regarding the following five statements and their answers were collected using a 5 Point Likert Scale. The values from 1 to 5 were assigned to responses from strongly disagree to strongly agree for the following five questions:

1. The construction industry, in general, is tainted by prevalent illegal acts.
2. The construction industry, in general, is tainted by prevalent unethical acts.
3. To help ensure ethical conduct throughout the industry, there should be more regulations.
4. To help ensure ethical conduct throughout the industry, industry associations should take a leadership position in crafting, and enforcing codes of conduct.
5. To help ensure ethical conduct throughout the industry, there should be more ethics training available.

Participants were similarly provided with a fictitious ethics scenario that analyzes how they would respond to an unethical act at their workplace. The students were given a role of a project manager for a general contractor. On one of their projects, the scenario occurred where a subcontractor approached them to reveal that a colleague had asked them to inflate costs of change orders on a previous project. In the situation, the subcontractor claims to have been approached by another project manager in the GC's company to be part of the payment games such that they would split the extra money between themselves; however, the subcontractor says that they refused the offer. However, the subcontractor does not want this information to reach to the leadership of the company. Once the situation was clearly yThe scenarios presented were follows.

Scenario 1: What their immediate action would be once they are informed about the unethical act happening in their company?

- Would they turn in their colleague in? (the other PM who approached the sub to engage in the inflation of change order costs)
- Would they keep quiet? or
- Would they try to approach the project manager running the whole deal?

Scenario 2: If they were somehow friends with the subcontractor and they trust him, how would that affect their decision-making process?

- It wouldn't.
- They would keep quiet and respect their friend's (the subcontractor) wishes.
- They think if their boss finds out that they did not do anything about it, they would be fired anyways.

Scenario 3: Ups the stakes by revealing that the subcontractor owns a share of the company and is friends with the leadership of the company. Now would that affect their decision?

- Not at all
- A little
- Yes, it definitely would

The responses of the students were recorded which would give an indication of their ethical perception and ethical standards. Again it is noted that the students had not been given substantial ethical training before being presented with this scenario. Therefore, the scenario aims to gauge “raw” or “baseline” ethical perceptions of early career construction students prior to entering the industry on a full-time basis.

Data Analysis

HEXACO and EQ scores were calculated following the data collection. The data was analyzed using Statistical Package for Social Sciences (SPSS). A correlation analysis was run amongst the calculated human dimension scores and the industry perception responses. Kruskal-Wallis Test was run between the ethics scenario data and HEXACO and EI scores to see the differences between groups. Relationships were studied based on a 95% confidence level to test for a valid relationship between these categories.

Results and Discussions

Industry Perception

Student responses for their perceptions of ethics in the construction industry were correlated with their human dimension results. Several statistically significant correlations were identified from the results based on a 95% confidence interval.

Out of the five questions that were presented during the survey, responses to two did not have any significant relationship with the personality of the participants (whether the participants think the construction industry, in general, is tainted by prevalent illegal acts and whether they believe there should be more ethics training available in the industry).

Table 2 presents all relationships that were statistically significant. It does not include any of the relationships involving the above two questions which failed to product statistically significant relationships.

Table 2

Relationship between personality of participants and their perception of ethics in the industry

Human Dimension Descriptor	**Unethical Act in the Industry**		**More Regulations Needed**		**More Codes of Conduct**	
	Correlation Coeff.	P-Value	Correlation Coeff.	P-Value	Correlation Coeff.	P-Value
Modesty	-0.2026	0.0235	-	-	-	-
Honesty/Humility	-0.2122	0.0175	-	-	-	-
Gentleness	-	-	-	-	0.1919	0.035
Perfectionism	-	-	0.2691	0.0024	-	-
Aesthetic Appreciation	-	-	-	-	0.2203	0.0152
Inquisitiveness	-	-	-	-	0.1838	0.0436

Table 2 depicts the human dimension descriptors on the leftmost column and industry perception metrics defined in the methodology section in the topmost row. It is clear that the recorded correlation coefficients for these categories are very small, and this could mainly be due to the relatively small sample size used for the study. These coefficients were used to measure the direction of relationship between categories and these relationships are summarized below:

- Both *modesty* (the tendency to be modest and unassuming) and *honesty/humility* are inversely related to believing that the construction industry is tainted by unethical act.
- Gentleness, the tendency to be mild and lenient in dealings with other people, is directly related to believing that there should be more codes of conduct in the industry.
- Perfectionism is directly related to thinking more regulations are needed in the construction industry. As perfectionism increases people inclined to be more thorough and concerned with details.
- Aesthetic appreciation is directly related to believing that more codes of conduct are needed in the industry.
- People with higher inquisitiveness tend to seek information and gain experience about situations around them. Inquisitiveness is directly related to thinking more codes of conduct are needed in the construction industry.

Ethics Scenario

Kruskal-Wallis H Test was run amongst the ethics scenario responses and human dimension assessment results to see the differences between different groups. The hypotheses tests revealed that the following relationships were statistically significant at a 95% confidence interval.

The relationship between **Flexibility** and **immediate action upon encountering an unethical act at the workplace** was significant with a p-value of *0.019*.

- Students who said they would keep quiet about the situation were *24% more Flexible* compared to those would turn their colleagues in. This may demonstrate that the more flexible people are, the more they may be willing to compromise and cooperate with others to not say anything about the unethical situation.

The relationship between **Fairness** and **Gentleness** with their **decision being affected if a friendship was at stake** were statistically significant with p-values of *0.038 and 0.007* respectively.

- People who said their decision would stay the same even if their friendship with the subcontractor was at stake had a *27% higher Fairness* score compared to those who would keep quiet to save their friendship. Therefore, as fairness increases, people would show more tendency to avoid fraud and corruption. They may have a greater likelihood to do what they think is right no matter what.
- People who chose to keep quiet to protect their friendship were *10.6% Gentler* than those whose decisions would not be affected. Hence as gentleness gets stronger, there was an increased propensity of being mild and lenient in dealings with situations where other people are involved.

The relationship between **Modesty** and **Liveliness** with **owner's involvement in the unethical situation** were statistically significant with p-values of *0.016 and 0.026 respectively*.

- Those whose decision would stay the same whether the owner was involved in the situation or not were *26.6% more Modest* compared to those whose decision would be hugely affected.

According to the responses, the less modest and more pretentious people are, the more they would incline towards benefiting the owner.

- The people whose decision would be affected up on the owner's involvement were *23% less lively* than those who said they would stick to what they think is right. This could be because, the livelier people are the more extraverted they are. They may tend to develop enthusiasm to deal with situations that occur on their projects.

The relationship between **Social Awareness** and **Overall EQ** with **owner's involvement in the unethical situation** were statistically significant both with p-values of *0.045*.

- Students whose decision would be biased up on the owner's involvement in the situation had *26% less social awareness* than those who did not really care if the owner was involved or not. The more socially aware people are, the more they inclined to care about other people and their feelings.
- People who wouldn't be affected by the owner's involvement in the situation had a *26% higher Emotional Intelligence* than those whose decision would be hugely affected. The higher their EQ, the more they recognized and managed their own emotions and the emotions of others. Which might be what led them to stick to their decisions.

Conclusion and Recommendation

The construction industry could enormously benefit from the young graduates starting their professional journey well equipped with an understanding of ethical principles and professional codes of conduct that will be relevant in their careers. Engineering ethics programs are a great way for students to acquire more experience and hands on ethical skills to ensure that the organizations they join operate consistently with the best corporate social responsibility practice (Wang and Thompson, 2013). This study evaluated the perceptions construction engineering and management students have about ethical practice in the construction industry. It simultaneously assessed their reactions to certain unethical scenarios. The results showed that their views of ethical principles in construction are indeed related to some of their personality descriptors.

Universities can use this knowledge to provide their students with trainings that help them develop ethical assets while creating awareness about their personal tendencies and how these tendencies may be relevant in the face of ethical dilemmas that may occur in the workplace. Combining ethical training with personality awareness programs could have an advantage in shaping university students' future careers. This in turn could benefit the construction industry.

This paper presents only a preliminary analysis. One of the limitations related to it was the small sample size. The study is still ongoing and further data collection is in progress amongst the participating universities. More tests could potentially reveal more relationships between the categories that were assessed. It would also be more helpful to add other factors like demographics of the students into consideration to explain the relationships further.

References

Ashton, M. C., & Lee, K. (2009). The HEXACO-60: A Short Measure of the Major Dimensions of Personality. *Journal of Personality Assessment*, *91*, 340-345.

Ashton, M. C., Lee, K., & De Vries, R. E. (2014). The HEXACO Honesty-Humility, Agreeableness, and Emotionality Factors: A Review of Research and Theory. *Personality and Social Psychology Review*, 18(2), 139-152.

Childs, B. R., Weidman, J. E., Farnsworth, C. B., & Christofferson, J. P. (2017). Use of Personality Profile Assessments in the US Commercial Construction Industry. *International Journal of Construction Education and Research*, 13(4), 267-283.

Criteria Corp. (2015). The definitive guide to pre-employment testing. Los Angeles: Criteria Corporation.

Feist, J., & Feist, G. J. (2006). Theories of Personality. New York, NY: McGraw-Hill

Ho, P. H. (2016). Labour and Skill Shortages in Hong Kong's Construction Industry. Engineering, Construction and Architectural Management, 23(4), 533-550

Jordan, P. J., Ashkanasy, N. M., Härtel, C. E., & Hooper, G. S. (2002). Workgroup Emotional Intelligence: Scale Development and Relationship to Team Process Effectiveness and Goal Focus. *Human Resource Management Review*, 12(2), 195-214.

Maali, O., Lines, B., Smithwick, J., Hurtado, K., & Sullivan, K. (2020). Change management practices for adopting new technologies in the design and construction industry. *Journal of Information Technology in Construction*, 25, 325-341.

Maali, O., Shalwani, A., Lines, B., Sullivan, K., & Perrenoud, A. (2021). A Spectrum of Employee Reactions to the Adoption of Organizational Changes in the AEC Industry. *EPiC Series in Built Environment*, 2, 91-99.

Mischung, J. J., Smithwick, J., Sullivan, K. T., & Perrenoud, A. (2015, June). Using Skills-Based Emotional Intelligence Training to Improve Team Performance in Construction Management Programs. In 2015 ASEE Annual Conference & Exposition (pp. 26-1681).

Shah, R. K., & Alotaibi, M. (2018). A study of unethical practices in the construction industry and potential preventive measures. *Journal of Advanced College of Engineering and Management*, 3, 55-77.

Wang, G., Lu, H., & Ren, Z. (2010). Globalization in Construction Engineering and Management Education. *Journal of Applied Research in Higher Education*, 2(2), 51–62.

Wang, G., & Buckeridge, J. S. (2016). Teaching Ethics for Construction Management Majored Students: Standalone or Micro-insert? –Globalization and Sustainability Considerations.

Wang, G., & Thompson, R. G. (2013). Incorporating Global Components into Ethics Education. *Science and Engineering Ethics*, 19(1), 287-298.

Weller, J. A., & Thulin, E. W. (2012). Do Honest People Take Fewer Risks? Personality Correlates of Risk-Taking to Achieve Gains and Avoid Losses in HEXACO Space. Personality and Individual Differences, 53(7), 923-926.

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Student Perceptions of Construction Scheduling Teaching Methods

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To effectively prepare construction and engineering students for their careers as building professionals, it is imperative for educators to understand what teaching methods are effective to enhance student learning in project scheduling. Technical skills, like project scheduling, rely heavily on practical experience and instructors face the difficult task of how to replicate this experience to enhance student learning. This paper provides a summary of the current instructional delivery methods utilized in a scheduling course at a major university and evaluates the delivery methods and what students perceive as most, and least effective in regard to learning how to create, manage and update a project schedule. The major finding, based on student feedback was the demand for additional visual learning experiences to further develop students' understanding of construction scheduling. These visual experiences include the implementation of visuals exploring jobsite examples as well as time-lapse videos showing the processes and sequence of activities. In addition, the overall results of the student surveys are presented, discussed, and evaluated. This information may assist educational and industry programs interested in developing scheduling course material, based on the needs reported by students.

Key Words: project scheduling, experiential learning, student perceptions, virtual learning, construction management

Introduction

A construction schedule is one of the key indicators of a project's success and is one of the primary tasks involved in project management. Effective schedules mitigate uncertainties, risks, and unforeseen conditions, but these schedules require a high level of domain-specific knowledge to generate and manage (Fu, 2018). Before students and practitioners can effectively define a construction schedule, they must understand how a project operates and be able to visualize these complexities. This understanding is necessary for planning, as well as cost forecasting, project control, managing subcontractors, understanding claims, resource planning, and project reporting (Mattila et al., 2006). In construction and engineering education, scheduling is one of the core subjects taught throughout the curriculum (Chinowsky et al., 2006), but it is difficult for students to fully grasp the skills required without prior construction experience as they try to understand what an activity is, its duration, and how it relates to other activities in the schedule (Lindhard, 2014).

To prepare students for engineering and construction careers, it is essential for universities to empower students to make connections between theoretical concepts taught in the classroom and real-world applications (Seifan et al., 2020). As students are introduced to large amounts of knowledge with no previous understanding of the subject, it is increasingly important to relate this new content to practical experience (Paez and Rubio, 2015). This form of experience is particularly important for specific skills like project scheduling, as students need to be exposed to as many real-life projects as possible (Karshenas and Haber, 2012) to fully understand how to manage a project schedule. To create and manage a successful schedule, students must be taught various construction types, phases, durations, means and methods, terminology, activity relationships, and overall planning and logistics. In addition, there are various software systems that must be understood to create a schedule, such as Primavera and Microsoft (MS) project. Scheduling is a skill that has historically been learned through practical experience, but given the demand for this skill among new graduates *(BLS Job Openings and Labor Turnover Summary*, 2021), educators are motivated to define new ways of providing learning experiences to replicate similar learning in the classroom.

Educators are faced with a difficult task on how to replicate these jobsite experiences to better equip their graduates and to evaluate whether their teaching techniques are successful. A few innovative techniques have been explored and evaluated in previous research, such as Kolegraff et al. (2019) who focused on implementing hands-on building activities into a college course to improve student learning. In addition, a number of construction and engineering programs have implemented project-based learning (PBL) and seen the benefits as students are able to work in teams, similar to what they will experience in industry (Gunderson and Moore, 2008). Prior studies show that many aspects of construction can be simulated in a classroom context, but scheduling is particularly challenging as it is the actual construction tasks that are often necessary for learning this content, yet nearly impossible to replicate in the classroom.

The objective of this paper is to examine student perspectives to further develop university scheduling courses and methods of delivery that support their learning needs. This paper provides an evaluation of the traditional instructional delivery methods students perceive as most, and least effective in regard to learning how to create, manage and update a project schedule. This paper also provides a summary of the instructional delivery methods currently utilized in a scheduling course taught at a major university and includes survey findings on students' perspectives. This work contributes to the body of knowledge related to construction scheduling education by documenting the specific learning preferences voiced by students related to different teaching modes and also the specific challenges reported related to different aspects of construction scheduling.

Background

Construction scheduling has historically been taught in a lecture format as a standalone class (Chinowskly, et al, 2006). A common practice for teaching project scheduling is providing students with a set of plans and specifications and requiring them to create a project schedule (Karshenas and Haber, 2012). The typical process of creating a schedule after reviewing the 2D set of drawings is: (1) breaking the project down into activities and durations, (2) transferring activity information into a software system, (3) developing project logic or the sequence of activities, and (4) scheduling project activities. This process requires project experience and the ability to read plans and convey a project schedule, (Karshenas and Sharma 2010) which is paradoxically not a skill that students possess because of their lack of experience. To supplement this lack of experience, researchers have implemented different techniques, such as: creating visual schedule applications (Karshenas and Sharma, 2010), developing 4D interactive models which combine the 3D model and project schedule (Messner et al, 2003), and creating virtual reality (VR) walkthroughs to visualize a jobsite (Eiris and Gheisari, 2018). Preliminary studies illustrate the interest among scholars in trying to innovate in order to improve students' learning of this challenging educational concept.

Understanding students' perspectives is essential for defining teaching strategies for that support their learning preferences, and ultimately their learning gains (Kumar et al, 2004). Kolegraff et al (2019) evaluated which instructional delivery method students perceived as effective in a construction management course. This study discussed the development of hands-on activities and how they improved the overall student perception of the general course but the results evaluated the whole course and did not focus on specific areas, such as scheduling. There has also been extensive research on the overall use of visualization techniques such as augmented reality (AR) and virtual reality (VR) in construction education (Wang et al, 2020) but limited research on students' overall perception of the different types of visualization and teaching methods they prefer in relation to construction scheduling. Evaluating student perceptions in a university scheduling course will provide useful information for educators as well as industry, to understand the tools and methods that need improvement. This paper will provide an integrated approach by evaluating students' overall perceptions as well as analyzing these perceptions compared to the various methods used to teach project scheduling.

Research Methodology

This study aims to provide an exploratory overview of students' perspectives of various instructional delivery methods that are currently being implemented in an existing scheduling course taught at a major university. The course was delivered using a traditional format, and utilized the following teaching methods: lectures, instructor led demonstrations, picture and video examples, readings, and external research. After the course was complete, an email was sent to the entire class asking for their voluntary participation in a survey. The resulting responses were analyzed using a qualitative research methodology to produce conclusions to inform future construction scheduling teaching strategies.

The students were asked for demographic information that included: academic level, major of study, and gender. Next, the students were requested to rate their confidence level with various scheduling concepts before and after completing the course, using a 5-point Likert scale (i.e., extremely unconfident to extremely confident). The targeted topics included: 1) visualizing activities and understanding the work being complete and the phase of construction, 2) understanding durations, 3) understanding scheduling technology, software used to build a schedule, 4) understanding activity relationships/links, and 5) organizing a schedule.

Subsequently, students were asked to identify which teaching mode introduced in the course helped to: identify activities; and understand activity durations. Students could choose from the following options to indicate their perceptions: 1) actual construction examples (ie: photos, videos, real world walkthroughs), 2) verbal description of activity (i.e.: lecture using PowerPoint), 3) readings (ie: textbook, articles, journals), 4) external research (i.e.: internet search). After selecting their preferred modes of learning, students were given free-response follow up questions which asked them to explain how they would want to see their selected teaching mode implemented or improved for future cohorts of students. Prior to sending out the survey, the survey questions were validated through focus groups with other students to illustrate a consistent understanding of question topics.

Once the data was collected, it was evaluated using a thematic analysis. Surveys were an ideal method to evaluate student perspectives and open-end responses provided additional thematic data. The latent level of thematic analysis was used to identify common themes, as well as to identify the underlying ideas and ideologies (Braun and Clarke, 2006). After evaluating the short responses, codes (key phrases) were identified which represented the meanings and patterns observed. The common codes were then grouped into themes which formed the narrative. Themes were identified from the data and not created from the research questions. The resultant themes provided the basis to inform the overarching conclusions from this research.

Results & Discussion

Survey data was conducted over one quarter in a scheduling course, with one instructor providing course instruction. Of the 31 students enrolled, 18 students completed the survey, for a response rate of 58%. The respondents were made up of nine females and nine males, 14 students were majoring in construction management and four were majoring in civil engineering. The respondents were composed of one second year, three third year, eight fourth year, and six fifth year students in their university studies. Students were required to complete similar prerequisites in order to enroll in this upper division scheduling course. Even though the participants varied in year of study, they all had similar scheduling education and courses complete.

The first section of the survey asked students to rank their confidence in their overall scheduling capabilities before and after the course. Prior to taking the course, the confidence rating was a 2.5.

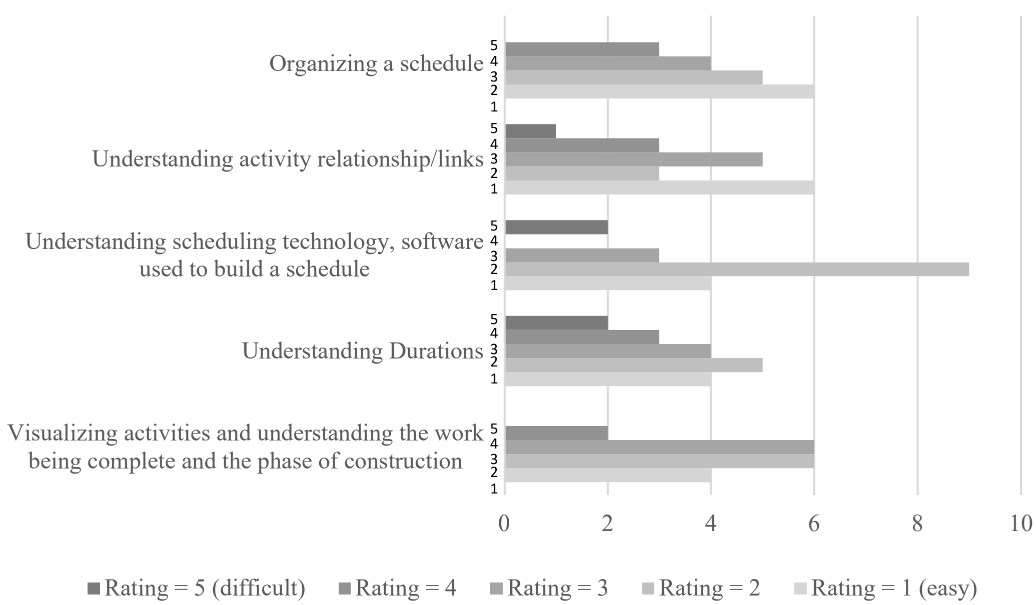

Figure 1. Students' ratings of scheduling tasks

After taking the course, student confidence ratings increased by 1.95 with an overall average rating of 4.45. This was a positive indicator of student overall confidence in the course content, but as educational technologies continue to develop, student learning will need to be improved to align with these new standards rather than with the outdated course structure.

Next, students were asked to rate specific scheduling tasks performed in the course by difficulty, tasks and overall ratings are detailed in Figure 1. Using a five-point Likert scale, a rating of five was perceived most difficult and a one was perceived as easiest. Based on the overall mean rating, students rated understanding durations as the most difficult, second most difficult was understanding activity relationships, and the third most difficult was visualizing activities and understanding the work being complete and the phase of construction. The least difficult, based on student responses was organizing a schedule and the second easiest task for students was understanding scheduling technology that was used to build a project schedule. As shown in Figure 1, the results in each category showed clustered data, but with a spread of overall ratings emphasizing differing opinions. Students perceived that the most difficult tasks were all related to project experience. Results also highlighted the need for practical experience for students to feel better equipped to create and understand a schedule.

The next two questions focused on two of the main challenges and focuses of the course which were: 1) understanding a scheduling activity and 2) properly identifying an activity's duration. Students were asked to select one of the four teaching modes they preferred in order to better understand both tasks. In both responses, the students overwhelmingly selected actual construction examples as there preferred teaching mode, as shown in Figure 2. 89% of respondents selected actual construction examples for the mode that helped them understand an activities identification and 78% of students selected this mode as the preferred method to help them understand an activities duration. To date, extensive research has focused on improving students practical experience based on positive student feedback (Kolegraff et al., 2019; Seifan et al., 2020), and these results show similar findings when relating to project scheduling. Traditional methods both ranked low compared to real-world examples and visual teaching methods. Based on the results, students identified the areas they struggled to understand were related to lack of real-world experiences, that included: visualizing activities, understanding durations, and understanding project relationships/links.

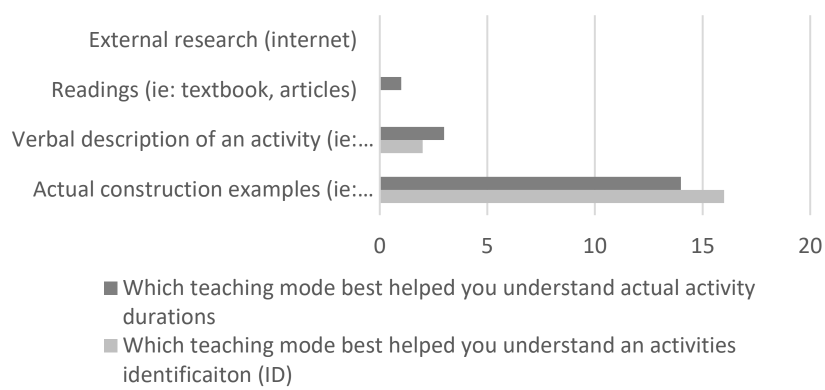

Figure 2. Students' preferred teaching method

There were common themes among the free responses to the follow up questions which asked how the teaching modes students selected can be improved to help students: 1) understand activity identification and 2) understand activity durations. After reviewing the short responses and conducting a thematic analysis, some of the common themes based on student feedback to improve the current instructional methods were: provide visuals of jobsite examples (historical jobsite data), time-lapse videos, and step-by-step video demonstrations.

One observation that came out quite clearly from the free responses was the interest for more real-world examples and visuals providing jobsite experiences. Students clearly recognize the value of project experience and based on their responses realize that without this knowledge it is challenging to create an accurate schedule. Without this experience, they did see the value for implementing visual examples of past projects into the course. They wanted to see what an actual activity looked like, such as concrete formwork or first floor framing instead of trying to visualize these activities from a 2D plan set. For the first question, about 62% of students mentioned the importance of real-world jobsite examples to understand activity identification, some excerpts are:

> “I think something that could be improved on is giving us an idea of how things are built because not everyone may be familiar with it. I really liked the one assignment when you provided us pictures of the project throughout its phases and we had to figure out what was going on.”

> “Workshops of real-life projects that have been completed and recorded to compare schedule vs actual project.”

For the second free response question, which asked how their selected teaching mode can be improved to help with understanding an activities duration, students also highlighted the importance of real-world examples. About 83% of students mentioned the importance of real-world examples, some citations are:

> “Giving more visual examples or maybe having posted jobsite photos for us to see different types of projects.”

> “Perhaps provide students with real schedule examples of different projects done in the past.”

> “I am more of a visual learner, so I need visual aspects in order to understand what is going on.”

Interest in video examples, such as time-lapse videos was also a common theme in the free responses. It was clear that students saw the value of visualizing how a project, or an individual activity was constructed in order to create an accurate schedule. As previously researched, it is difficult to fully understand the sequence and flow of a schedule and students identified one of the preferred ways to fully comprehend a project’s activities and durations is by seeing it first-hand. The importance of visualization, and utilizing tools like a project time-lapse, were highlighted in several responses:

> “I think at this stage in our lives we do not really have the experience of understanding all stages of construction. I think what would be interesting is including a video of a construction project and having students build a schedule based on the video. This would show both sequence of events and could potentially help with durations. This would be helpful in visualizing what an entire build entails.”

> "I want to view an activity in real time or a video showing the start, to completion of a specific activity to see the actual durations and any conflicts that might arise to understand how a schedule either stays on schedule, falls behind, or is ahead."

> "Understanding durations is all about seeing construction take place and the timeline of events. A time lapse video would be great to implement because students would have to break down the different pieces of the video having to understand the order of events and how long each part took place. By visualizing it we might even start to understand key scope durations for a project."

For both questions, students also emphasized a preferred teaching style, which was instructor led recorded video walkthroughs. This gave students the freedom to learn at their own pace, as well as to rewind or pause if they missed any section of the exercise.

> "I think the videos were the best way to teach the class going step by step, because it's a pretty lengthy process, and can get lost in translation pretty quick if taught a different way."

> "I really liked the video walkthroughs used as well as being able to visualize how the construction process works."

Based on student responses and overall survey data, the most difficult tasks throughout the course were all related to project experience. Visualization is one of the major factors that students prefer and deem most important when learning how to project schedule. These results highlight the importance for experiential learning when teaching a practical skill, like scheduling. Students also indicated that at this point in their education, their lack of experience is a limitation and understand the importance of exposure to real-world scenarios to enhance their understanding.

Conclusion

This study investigated student perspectives of project scheduling delivered in a university course. The results clearly indicate the importance of practical experience and highlighted the types of examples students prefer, which were visuals of real-world jobsite examples and time-lapse videos. Students expressed the need to be able to see an activity or a phase of construction to fully understand an activities duration, identification, and relationship. Students saw the value of replicating and gaining as much visual experience possible in order to understand the different elements of a schedule. Despite the limited amount of practical examples currently built into the existing course, as well as no current uses of AR or VR, students strongly agreed that visual examples was a preferred method of learning and also strongly expressed the interest in additional experiential based learning experiences. These results emphasize the importance of introducing students to as many practical experiences as possible by utilizing virtual tools to enhance their scheduling understanding.

The study also revealed a preferred teaching method for project scheduling was instructor led step-by-step video walkthroughs. With these walkthroughs, students are able to learn at their own pace as well as understand the terminology and sequence being covered. Another interesting finding was students felt confident using the software systems and scheduling tools being introduced, which is important to highlight as many courses rely heavily of teaching a specific software system rather than spending valuable course time focusing on content.

This course will continue to implement photo, videos, and field trips, but it will also identify new forms of technology, such as virtual reality (VR) and augmented reality (AR) to focus on the themes that emerged from this study, which was providing additional real-world jobsite data and time-lapse video demonstrations. As these methods are added, further research will evaluate the impacts of these practical methods to enhance student learning. From a holistic perspective, the issue is not whether traditional methods need to be replaced, but rather how to improve these methods with visual experiences. This study can lead to future research focusing on virtual experiences in construction education, as well as ways to merge jobsite examples and video time-lapses into construction courses.

References

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3, 77-101.

Chinowcky, P., Braown, H., Szajnman, A., & Realph, A. (2006). Developing knowledge landscapes through project-based learning. Journal of Professional Issues in Engineering Issues and Practice, 132 (2), 118-124.

Eiris, R., & Gheisari, M. (2018). "Building Intelligent Virtual Agents as Conversational Partners in Digital Construction Sites". In Construction Research Congress 2018 (pp. 200-209).

Fu, M., Liu, R. (2018). *The Application of Virtual Reality and Augmented Reality in Dealing with Project Schedule Risks. Construction Research Congress 2018*, 429-438.

Gunderson, D. E., & Moore, J. D. (2008). Group learning pedagogy and group selection. *International Journal of Construction Education and Research*, *4*(1), 34–45.

Job Openings and Labor Turnover Summary. Released Oct 12, 2021. Retrieved October 28, 2021, from https://www.bls.gov/news.release/jolts.nr0.htm

Karshenas, S., & Haber, D. (2012). Developing a serious game for construction planning and scheduling education. *Construction Research Congress 2012: Construction Challenges in a Flat World*, 2042–2051.

Karshenas, S., & Sharma, A. (2010). Visually scheduling construction projects. *Construction Research Congress 2010: Innovation for Reshaping Construction Practice*, 490–499.

Kolegraff, S. A., Kline, A., & Kelting, S. (2019). Hands-On Building as an Instructional Delivery Method in an Integrated Lab Curriculum. *55th ASC Annual International Conference Proceedings*, 33–40.

Kumar, P., Kumar, A., & Smart, K. (2004). Assessing the impact of instructional methods and information technology on student learning styles. *Issues in Informing Science & Information Technology*, *1*.

Lindhard, S., & Wandahl, S. (2014). Scheduling of large, complex, and constrained construction projects–an exploration of LPS application. *International Journal of Project Organisation and Management*, *6*(3), 237–253.

Mattila, K., Pocock, J., Suermann, P. (2006). Methods to Assist in Teaching Planning and Scheduling. Associated Schools of Construction International Proceedings of the 42nd Annual Conference, 59- 66.

Messner, J., Yerrapathruni, S., Baratta, A., & Whisker, V. (2003). Using virtual reality to improve construction engineering education. *2003 Annual Conference*, 8–1266.

Paez, D., & Rubio, L. A. (2015). The Use of Field Trips in the Context of Engineering Collaborative Teaching: Experiences of Hands-On Geomatics Activities in Colombia. *Wisdom of the Ages to the Challenges of the Modern World Sofia, Bulgaria*, 17–21.

Seifan, M., Dada, O. D., & Berenjian, A. (2020). The Effect of Real and Virtual Construction Field Trips on Students' Perception and Career Aspiration. Sustainability, 12(3), 1200. https://doi.org/10.3390/su12031200

Wang, R., Lowe, R., Newton, S., & Kocaturk, T. (2020). Task complexity and learning styles in situated virtual learning environments for construction higher education. *Automation in Construction*, *113*, 103148. https://doi.org/10.1016/j.autcon.2020.103148

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Immersive Virtual Field Trips with Virtual Reality in Construction Education: A Pilot Study

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Field trips or site visits provide valuable learning opportunities in construction education. However, traditional field trips often face challenges such as accessibility, logistics, weather, safety, to name a few. The recent global pandemic and its stipulations on social distancing add another layer of complexity to implement. Alternative field trips such as virtual field trips (VFTs), which are usually enabled by technology innovations, can help overcome these barriers. Previous VFT researchers shared promising results in providing a rich learning experience to students while also noting the lack of robustness and immersiveness. This study aims to develop a prototype of an immersive VFT solution with virtual reality (VR) to facilitate field knowledge transfer in construction education. The paper presents the VFT development process and shares preliminary results of student learning and user experience data from the first prototype. Findings of this pilot study suggest that a key advantage of VFTs over traditional field trips resides in the opportunity of learning iteration, which is essential to successful knowledge acquisition in the cognitive learning domain. The preliminary analysis on the correlation between student performance and media types of information also provides insights into future VFT design based on the multimedia learning framework.

Key Words: Virtual Field Trip, Construction, Virtual Reality, Immersiveness

Introduction

Field trips to actual project sites form an important component in teaching and learning in many aspects of construction management and civil engineering education (Wilkins & Barrett, 2000). They provide students with real-world experience and valuable exposure to the context to which their technical knowledge gained from classroom learning can be applied. Field trips also help bridge formal and informal learning and prepare students for lifelong learning (Tuthill & Klemm, 2002). However, scheduling and access difficulties may make actual field trips impossible to organize. In addition, organizers need to consider job site safety, transportation, weather, and other logistics challenges (Wilkins & Barrett, 2000; Pham et al., 2018). The emerging health risks under the COVID-19 pandemic have significantly limited field trips' viability.

Research literature suggests that scholars have investigated virtual field trips (VFTs) using videos and other traditional media as alternatives and indicated encouraging outcomes in student learning (Wilkins & Barrett, 2000; Tuthill & Klemm, 2002; Haque et al., 2005; Jaselskis et al., 2010). Compared with physical field trips, VFTs have advantages in flexibility and accessibility but lack robustness and immersiveness (Spicer & Stratford, 2001). Recent advancement in construction information and visualization technology such as building information modeling (BIM) and virtual reality (VR) enables a new genre of VFTs, featuring a digital twin (the digital representation) of the physical project to construct an immersive learning environment where students can obtain valuable field knowledge even with social distancing.

This study aims to develop a prototype of a new VFT solution, distributed via an off-the-shelf online VR platform to facilitate field knowledge transfer in construction education. This is an area that has not been addressed in available VR platforms used for education and training purposes, and has the potential to bridge the equity gap in future education. The proposed VFT prototype consists of field-captured 360-degree photos and other project information obtained with permission from partnering construction and engineering companies. Students can access this VFT prototype via a designated VR platform and experience a self-guided or guided immersive tour with low-cost VR headsets. This paper presents the preliminary findings of the research, which includes the design of the first VFT prototype and results from the initial learning assessments and user experience evaluation.

Background and Literature Review

A VFT in construction education refers to an experience of observing the physical conditions of a construction project via the Internet or other technologies (Finch & Wing, 1996; Jaselskis et al., 2010). As an alternative, it has the potential of offering similar benefits of a traditional field trip without the associated barriers. Previous studies on construction related VFT or VR applications explored a wide range of learning outcomes. Many intended to help students in introductory courses gain a general understanding of their disciplines. These VFTs usually included "random activities, structures, and operations on construction job sites" (Wen & Gheisari, 2020; Finch & Wing, 1996; Mei & Wing, 1999; Wilkins & Barrett, 2000; Dickinson et al., 2004; Jaselskis et al., 2010; Landorf & Ward, 2017; Zhang et al., 2017; Maghool et al., 2018; Quinn et al., 2019). However, some studies took a more focused approach to address specific learning outcomes, such as reinforced concrete construction (Haque et al., 2005), heating, ventilation, and air conditioning (HVAC) systems (Shen et al., 2012), construction safety (Zhao & Lucas, 2014, Pham et al., 2018); structural deformation modes (Fogarty et al., 2018), wood-framed construction techniques (Lucas, 2018), etc. Such VFTs may require more efforts in site selection and tour design to ensure activities are tied to the specific learning outcomes (Wen & Gheisari, 2020).

Despite the fact that early VFTs demonstrated to be a good and enjoyable way to learn, studies also noted their lack of robustness and immersiveness compared to real field trips (Spicer & Stratford, 2001). The recent advancement in computer graphics and visualization and the uprising of cloud computing technology has brought unprecedented learning affordance to higher education, which holds the promise to revitalize the application of VFTs. Wen and Gheisari (2020) classified the technologies used in current construction-related VFTs into two categories: captured-reality technology and virtual reality (VR) technology. The captured-reality technology uses regular or 360-degree images or videos of real-world projects, while the VR technology uses computer-generated simulations of reality (e.g. 3D models). Both have their advantages and limitations. Images and videos offer the highest level of realism but limited interactions with the site due to the fact they are pre-captured or delivered in real-time. On the other hand, a simulated environment gives an instructor full control of learning activity design and allows students to navigate a site freely, which potentially leads to a more active learning experience. However, the limited sense-of-realism and level of details could also prevent students from fully understanding the complexity and context of real-world practices (Wen & Gheisari, 2020).

Research Design

The long-term goal of this research is to develop an enhanced immersive VFT solution to facilitate field knowledge transfer in construction education using both reality-capturing technology and VR technology. Individual VFTs will be constructed with a mixed-use of 2D plans, 3D asset models (imported from mainstream 3D information modeling applications such as Autodesk Revit and Trimble SketchUp), regular or 360-degree images or videos, audio recordings, PDF documents, etc. User activities in this virtual space can be inquiry-based or problem-based to address a wide spectrum of knowledge acquisition or skill development, including 3D spatial exploration and reasoning, design review and communication, code compliance, construction operations, safety, sustainability, etc.

As noted in Mayer's cognitive theory of multimedia learning (2002), humans use a visual/pictorial channel and an auditory/verbal-processing channel for information processing. To optimize learning, it is important to apply effective design strategies to manage cognitive load in multimedia learning materials so the channels are not exceeding their limited capacity. Brame (2016) summarized four best practices to manage cognitive load for educational videos: signaling (to highlight important information), segmenting (to chunk information), weeding (to eliminate extraneous information); and matching modality (by using appropriate channels to convey information). These recommendations were considered during the VFT design in this study.

The team developed the first VFT prototype to investigate two research questions: (1) Can VFTs create a learning environment with sufficient information for students to learn technical knowledge in construction? and (2) How do students respond to this new genre of immersive virtual learning environments? A phased approach was adopted in developing the pilot study as elaborated below:

1. Platform Selection: The team envisions the proposed VFTs to be distributed via a cloud-based open VR platform that supports multimedia and integration with commonly used project design and management tools. To ensure flexibility and affordability, a suitable platform would support not only mainstream VR equipment (e.g., HTC Vive, Vive Pro, Cosmos; Oculus Rift/Go/Quest, Google Cardboard, etc.), but also web browsing on any device. After reviewing a number of available VR platforms such as Unity, Second Life, Sansar, HoloBuilder, Cupix, OpenSpace, etc., the team chose HoloBuilder due to the aforementioned desirable features. This platform is typically used by construction professionals for jobsite progress management by creating a digital replica of their sites.
2. Project Data Collection: To test various features in a VFT, several local projects were identified to address different learning outcomes in early prototypes. A recently completed university research laboratory building was selected as the site for the first VFT prototype. The team obtained a full set of 2D plans and specifications, a Revit 3D model, and a building maintenance manual from the university. In addition, the team arranged multiple guided tours to document the building with 360-degree images using an Insta360 One X camera.
3. Prototype Design and Development: When it comes to the planning of an educational tour (virtual or in-person), it is always helpful for the organizer (or the tour guide) to review the following questions: Who are the audience, what should they learn, and how long is the tour? The first VFT prototype was designed to demonstrate a guided virtual tour of a university laboratory

building. VFTs like this one simulate traditional field trips for students in introductory architecture, engineering, and construction (AEC) courses. The prototype addresses specific topics related to the following two areas:

- Architectural and Structural Design: This includes the building's sustainability/energy performance goals, the structural frame of the building, the composition of the architectural precast concrete wall panels, the glazing system, the difference in design considerations between a dry lab and a wet lab, etc.
- Facility Management: This includes the handling of various chemicals, the unique water infiltration system utilized in this building, etc.

The length of a VFT can also have an impact on learning due to its multimedia nature. On one hand, some users may experience VR sickness after an extended period in an immersive VR environment. On the other hand, studies of multimedia learning have shown that educational videos less than 6 minutes long have a median student engagement rate of 100%. The rate drops to 50% for 9- to12-min videos and even more significantly for longer videos (Guo et al., 2014; Brame, 2016). Keeping VFTs short may help decrease mind wandering and therefore increase student attention to content.

4. Assessment: This study adopted a mixed-methods approach by combining quantitative and qualitative assessments in a post-test survey (available upon request). The intent was to measure the effectiveness of the VFT prototype on learning and gauge students' perception towards this new learning experience.

Results and Findings

Figure 1 provides a sample view of the first VFT prototype. A floor plan is displayed on the top left corner with small circles called "waypoints". Each waypoint is linked to a 360-degree image (i.e., a scene) in the VFT. When a user is viewing a scene, the corresponding waypoint will be highlighted on the floor map indicating where it is located.

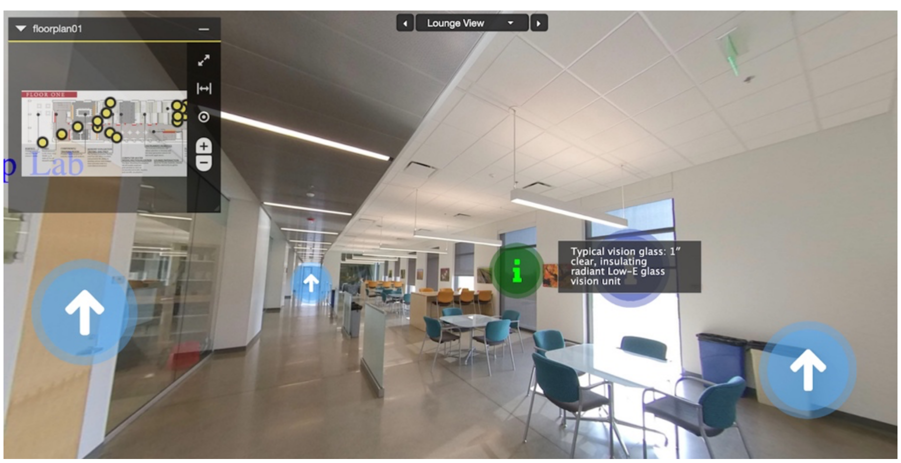

Figure 1. A sample view of the first VFT prototype

In a traditional field trip, a tour guide would stop at multiple locations to discuss specific topics. In a VFT, these stops are called "hotspots". Throughout a tour one will have the opportunity to stop at many hotspots to make observations and interact with various "action objects", meaning special actions will be triggered when a user clicks on or hovers over them. As a result, new content will display, which can be an embedded video, an audio clip, quick text, a 2D image, another 360-degree scene, a PDF file, etc.

A total of 33 construction management (CM) undergraduate students from two introductory CM courses participated in the pilot test of the proposed VFT prototype. Of these participants, 24 (73%) were male and 9 (27%) were female. The average age of the group was 22.4 years old (range = 19-35 years). The majority held junior (39.4%) or freshman (30.3%) class standing. In regard to ethnicity, Hispanic ranked the highest (67%), followed by White (15%) and Asian (12%). The pilot test consisted of simple navigation activities, interaction with building elements and systems, review of project documentation, and completing a simple assessment quiz. The quiz was designed with two parts: Part 1, i.e., Questions 1-8 checked on students' technical knowledge in design and facility management; Part 2, i.e., Questions 9-10 solicited students' feedback on the experience of using the VFT prototype, including the ease of navigation, discovery and information query, and other cognitive explorations. The technical questions in Part 1 are project-specific, which students would not have had prior knowledge of. Therefore, there was no pre-test.

Compared with the instantaneous nature of conventional field trips, an advantage of the VFT is the ability to allow students to revisit and repeat certain activities to facilitate the acquisition of a specific area of knowledge, and/or reinforce knowledge gains via such iteration. According to Holmes et al. (2015) and Corwin et al. (2018), iteration plays an important role in cognitive learning in knowledge acquisition and critical thinking development. In this pilot test, students were encouraged to take the assessment quiz multiple times (the highest grades among these attempts would count as their final score of the quiz) until they felt satisfied with the results, which was aligned with the tenet of competency-based learning. Among the 33 participants, 23 students attempted the quiz twice, 8 students attempted 3 times, and 1 student took it 4 times (this student had already achieved 100% at Attempt 3, so Attempt 4 was redundant and removed from analysis). Table 1 lists the specific technical area(s) each question addresses, how the information was presented, and the percentages of correct answers after each attempt. The percentage of correct answers after each attempt is calculated as the accumulative number of students who answered the question correctly by then divided by the total number of the participants (33). An improvement in percentages over the three attempts can be observed for all questions except Question 5 (where students who answered it wrong did not make more than one attempt) and Question 8 (where no one answered it wrong). Table 2 summarizes the assessment efforts, results at each attempt, and the final results. The average score (arithmetic mean) of Part 1 (Questions 1-8) for the entire group went up from 80.7% of Attempt 1 to 93.9% of Attempt 2, and 96.2% of Attempts 3, which was also the final cohort average score. A total of 25 students finished the quiz with 100.0%, with 7 of the rest students having 87.5%, and 1 student having 75%. The assessment target was set to have more than 80% of the group to score an average of 75% or higher, which was already met in the first attempt (87.9%).

Table 1

Percentages of correct answers after attempt 1, 2, and 3 for Questions 1-8

Question	Tech. Area (Design/FM)	Format of Info.	% After Attempt 1	% After Attempt 2	% After Attempt 3
1	Design	Quick Text	78.8	100	100
2	Design	2D Image	93.9	97.0	100
3	Design	Quick Text	90.9	100	100
4	Design & FM	2D Image	97.0	97.0	100

5	Design	2D Image, 360 Scene	97.0	97.0	97.0
6	FM	PDF, 2D Image	18.2	84.9	84.9
7	Design	2D Image	72.7	75.8	87.9
8	FM	PDF, 360 Scene	100	100	100

Table 2

Student attempts and scores of Part 1 of the assessment quiz

Description	Attempt 1	Attempt 2	Attempt 3	Final
No. of Students	33	23	8	33
Part 1 Average Score (%) (For the entire group of 33 students)	80.7	93.9	96.2	96.2
% Improvement Compared with Attempt 1	N/A	15.4%	18.5%	18.5%
Assessment Target (>80% of the group with 75% average score or better)	87.9%	100%	100%	100%

The most important takeaway from the analysis of students' performance in the assessment quiz was not the score (%) or its distribution, but the apparent improvement of students' performance via iterative learning using the VFT, and the engagement demonstrated via repetitive attempts made by a substantial number of students (23 out of 33, or 69.7%) in taking the quiz more than once.

To further understand students' experience and perception of the VFT prototype, Part 2 (Questions 9-10) of the assessment quiz requested students to reflect on perceived ease of conducting the virtual field, and the efficiency (i.e., how much time) and effectiveness (i.e., how useful) of the VFT experience in supporting them with necessary information needed to complete the assessment quiz. Students were also asked to suggest anything that could be improved to enhance their experience. Among the 33 students, only 3 (9.1%) students indicated some challenges of navigation through the virtual tour. The majority found the virtual tour intuitive and easy to follow through. Immersiveness was constantly brought up as a big excitement to engage them in the tour.

By diving into students' description of their tour experience and reasons for spending a specific amount of time on the tour revealed some additional insights into how students respond to the VFT prototype, and how this trip prepared them for the assessment. First and foremost, compared with the time typically spent on conventional field trips (e.g., 1-2 hours on campus, 2-4 hours off campus), the amount of time necessary for students to gather sufficient information for the assessment via the VFT was significantly shorter. Another key takeaway was that 29 out of the 33 students indicated the need to revisit the VFT to confirm or verify information assessed in the quiz. This was nearly impossible in conventional field trips. Among these 29 students who revisited the VFT, they consistently suggested the value of location-based information that was provided via images and PDF documents, which greatly enhanced their understanding of the project in the proper context. Unlike the sense of time constraints and an urgency of moving on in a conventional field trip, the fact that VFTs allowed students to take their time to observe and digest location-based project data and embedded field knowledge seemed to be one of the key benefits of VFTs.

Recommendations given by students to improve the VFT prototype clustered into three categories: navigation, interaction, and content. Specifically, the feedback on navigation suggested that navigation was a little constrained and did not support walking freely, which was intrinsic to the platform used to host this VFT. For interaction, current activities supported mainly involved passive observation and pop-up prompts for information review. Some students found the interaction could be a little more robust to include voice-over, or markers to allow document markup or note-taking, or route planning. For content, students liked the embedded texts and linked PDF documents, but would prefer more multimedia content such as audio/video clips to provide more dynamic information about the project.

Discussion

The initial assessment results from the first VFT prototype provided valuable insights for future VFT developments. The assessment was conducted during the pandemic when the university moved almost all classes online. As a result, students were not provided with VR headsets during the assessment. However, they were very impressed with the level of immersiveness even though they were only viewing the tour via a web browser on their computers or mobile devices. This shows promise for immersive VFTs to reach a broader user group.

Students appeared to enjoy the convenience of repeating a VFT. Their improved performance over multiple attempts was a strong indicator of the need for repetitions. Another takeaway from this is the repetitions do not have to happen after the tour ends. Same or similar learning topics can be embedded in a VFT at multiple locations and presented via different multimedia types to reinforce knowledge. The area students had to tour in the first VFT prototype was about 10,000 SF. Most of them were able to gather sufficient information for the assessment within 20 min. Not all virtual tours are easy to navigate. Setting a clear path on the floor map and focusing on the intended learning outcomes are essential. As discussed earlier, for a multimedia learning experience, keeping it short may help decrease mind wandering and increase attention to content. Incorporating interactive features (e.g., voice-over, measuring, document markups, etc.) and different multimedia content will create a richer and more engaging learning environment.

Some challenges and limitations were noted during the development of the first VFT prototype. The team initially intended to take advantage of the SplitScreen feature on HoloBuilder which allows users to compare design (3D model) with reality (field images), or project progress images side by side. This is difficult to realize in a traditional field trip, but in a VFT it is doable and opens up new learning opportunities. However, the lack of details in the builder's 3D model made it unsuitable for the virtual tour. It should also be noted that this is not uncommon. The levels of development (LOD) in BIM vary from 100 to 500 with LOD 500 being the highest level of accuracy ("as-built"). As-built models are generally requested by clients as reference for operation and maintenance. Yet for contractors LOD 350 is sufficient for construction documentation. Knowing what types of 3D models are available on a project helps determine the design limitations for a VFT.

The first VFT prototype was also limited on the variety of multimedia content as it did not incorporate any audio or video clips, which are features the team started to explore later while documenting active construction sites.

Conclusions

This study proposes an enhanced immersive VFT solution to facilitate field knowledge transfer in construction education using both reality-capturing technology and VR technology, an area that has not been actively explored in available VR platforms. A pilot study was conducted to develop a VFT prototype on HoloBuilder and collect preliminary results on student learning and user experience. The first VFT was designed to demonstrate a guided virtual tour of a university laboratory building and specifically address architectural/structural design and facility management topics. Information was presented via field-captured 360-degree images, regular 2D images, quick text, and PDFs. According to the post-test survey, the majority of the participants found the virtual tour easy to follow through and greatly enjoyed the immersiveness. Site revisits and multiple attempts on the survey were allowed. Results indicate that the group was able to meet the assessment target in their first attempt. Furthermore, results from multiple attempts suggest that allowing students to revisit and repeat certain activities facilitates the acquisition of a specific area of knowledge, and/or reinforce knowledge gains via such iteration.

While showing great potential, this first VFT prototype was limited on the variety of multimedia and active user interactions. The team is currently experimenting more interactive features and multimedia types and exploring effective learning design in an immersive virtual learning environment. Further research is needed to compare the effectiveness of the proposed VFTs with and without VR headsets.

References

Brame C. J. (2016). Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE—Life Sciences Education*, *15*(4), es6.

Corwin, L. A., Runyon, C. R., Ghanem, E., Sandy, M., Clark, G., Palmer, G. C., Reichler, S., Rodenbusch, S. E., & Dolan, E. L. (2018). Effects of discovery, iteration, and collaboration in laboratory courses on undergraduates' research career intentions fully mediated by student ownership. *CBE—Life Sciences Education*, *17*(2), ar20.

Dickinson, I., Riley, A., Tennant, J., & Ellis R. C. T. (2004). Virtualsite: Photo-realism in the classroom. *COBRA 2004 Proceedings*.

Finch, E., & Wing, R. D. (1996). A navigable walkthrough simulator for built environment education: Archiwalk. *Facilities*.

Fogarty, J., McCormick J., & El-Tawil, S. (2018). Improving student understanding of complex spatial arrangements with virtual reality. *Journal of Professional Issues in Engineering Education and Practice, 144*(2), 04017013.

Guo P. J., Kim J., & Rubin, R. (2014). How video production affects student engagement: An empirical study of MOOC videos. In *Proceedings of the first ACM conference on Learning@ scale conference,* pp. 41-50.

Haque, M., Aluminiumwalla, M., & Saherwala, S. (2005). A virtual walkthrough on reinforced concrete construction details. In *2005 ASEE Annual Conference*, pp.10-108.

Holmes, N. G., Wieman, C. E., & Bonn, D. (2015). Teaching critical thinking. *Proceedings of National Academy of Sciences*, *112*(36), 11199-11204.

Jaselskis, E. J., Jahren, C. T., Jewell, P. G., Floyd, E., & Becker, T. C. (2010). Virtual construction project field trips using remote classroom technology. In *Construction Research Congress 2010:*

Innovation for Reshaping Construction Practice (pp. 236-245).

Landorf, C., & Ward, S. (2017). The learning impact of a 4-dimensional digital construction learning environment. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, *11*(5), 1158-1163.

Lucas, J. D. (2018). Immersive VR in the construction classroom to increase student understanding of sequence, assembly, and space of wood frame construction. *Journal of Information Technology in Construction*, *23*, 179-194.

Maghool, S. A. H., Moeini, S. H. I., & Arefazar, Y. (2018). An educational application based on virtual reality technology for learning architectural details: challenges and benefits. *ArchNet-IJAR: International Journal of Architectural Research*, *12*(3), 246.

Mayer, R. E. (2002). Multimedia learning. *Psychology of learning and motivation*, *41*, pp. 85-139.

Mei, Q., & Wing, R. (1999). Robotic 360/spl deg/photography for virtual site visits. In *1999 IEEE International Conference on Information Visualization (Cat. No. PR00210)* (pp. 214-219). IEEE.

Pham, H. C., Dao, N., Pedro, A., Le, Q. T., Hussain, R., Cho, S., & Park, C.S.I.K. (2018). Virtual field trip for mobile construction safety education using 360-degree panoramic virtual reality. *International Journal of Engineering Education*, 34(4), 1174-1191.

Quinn, D., Cioffi, E., Hill, S., Kor, M., Longford, A. C., Moller, R., & Rathore, P. (2019). Implementing work-integrated learning in online construction management courses. *Journal of University Teaching and Learning Practice*, *16*(1), 9.

Shen, Z., Jiang, L., Grosskopf, K., & Berryman, C. (2012). Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems. *Proceedings of Construction Research Congress 2012: Construction Challenges in a Flat World* (pp. 1212-1221).

Spicer, J. I., & Stratford, J. (2001). Student perceptions of a virtual field trip to replace a real field trip. *Journal of Computer Assisted Learning*, *17*(4), 345-354.

Tuthill, G., & Klemm, E. B. (2002). Virtual field trips: alternatives to actual field trips. *International Journal of Instructional Media*, 29(4), 453-468.

Wen, J., & Gheisari, M. (2020). A review of virtual field trip applications in construction education. In *Construction Research Congress 2020: Safety, Workforce, and Education* (pp. 782-790). Reston, VA: American Society of Civil Engineers.

Wilkins, B., & Barrett, J. (2000). The virtual construction site: a web-based teaching/learning environment in construction technology. *Automation in Construction*, *10*(1), 169-179.

Zhang, C., Lu, Y., Xu, R., Ye, X., Shi, Y., & Lu, P. (2017). Educational tool based on virtual construction site visit game. *Modern Applied Science*, *11*(8), 47-56.

Zhao, D. & Lucas, J. (2015). Virtual reality simulation for construction safety promotion. *International journal of injury control and safety promotion*, *22*(1), pp. 57-67.

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Initial Perceptions of Remote Virtual Inspections in the Residential Construction Industry Sector

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The COVID-19 pandemic created a new set of restrictions and safety protocols for the residential construction industry. Many jurisdictions began placing social distancing practices on building inspectors, limiting their ability to visit the jobsite. This adjustment required residential contractors and inspectors to adapt to virtual inspections using videotelephony, photographs, or recorded videos. As this inspection method gains traction in the residential industry, questions arise regarding its benefits, drawbacks, and industry acceptance. This case study analyzes the perceptions and experiences of five separate homebuilders in Yolo County, California. Semi-structured interviews were conducted with five residential general contractors, transcribed, and thematically analyzed to discover reoccurring patterns and ideas. Throughout the interviews, six significant themes emerged including familiarity with the technology, time and cost impacts, applicability, accuracy, homebuilders' preference, and future considerations. Based on the interviews, homebuilders believe the new technology has potential time and cost savings. There are some concerns with the technology's accuracy as virtual inspections can inhibit the inspector's visibility, in certain scenarios. However, all general contractors interviewed agreed they would like to see a hybrid system in the future that allows for virtual and in-person inspections, and also agreed that not all items are appropriate for remote inspections.

Key Words: Remote Virtual Inspections, Homebuilders, Industry Perception, Construction Industry, Technology

Introduction

As the COVID-19 pandemic spread throughout the United States, many states, counties, and cities completely closed and began enforcing work-from-home mandates to slow the spread of the virus. Although many industries required workers to stay home, California's governor issued Executive Order N-33-20 on March 19, 2020, allowing essential workers to return to work. "Construction workers who support the construction, operation, inspection, and maintenance of construction sites and construction projects" (California For All, 2021) were considered part of the essential workforce, allowing workers, inspectors, and operators to continue working on construction sites, following strict safety protocols for social distancing.

Although construction continued throughout California, many jurisdictions, especially those with high disease transmittance, enforced stricter guidelines on workers and construction sites, stopping all non-essential work. Residential construction remained essential since it was “necessary to maintain safety, sanitation and economic security” (NAHB Now, 2020), with 78% of builders reporting being classified as essential businesses in their geographical area (NAHB Now, 2020). However, many authorities having jurisdiction (AHJs) switched to remote work only, leaving AHJs and builders to develop a solution to inspect ongoing construction without having an inspector physically onsite. In response, the industry quickly adapted existing technologies to conduct remote virtual inspections on projects deemed essential, such as housing, so construction could continue uninterrupted while still following social distancing mandates.

In Yolo County, California, the building inspection services department allowed remote virtual inspections to reduce the number of in-person inspections (Building Inspection Services, 2020). Since inspectors were considered essential workers, homebuilders and inspectors could opt for virtual inspections for their projects. This study analyzes the preliminary perceptions of five residential general contractors located in Yolo County, California regarding the implementation and effectiveness of remote virtual inspections for new residential construction.

Literature Review

The COVID-19 pandemic was shown to have a noticeable adverse effect on homebuilders, as detailed in Figure 1, with 82% of respondents indicating that building departments took longer than normal to respond to requests for inspections (Emrath, 2020). With the median number of separate inspections conducted during the construction of a typical single-family home being eight, and 17% of builders using more than fifteen inspections (Emrath, 2013), delays to timely inspections can adversely impact a company’s profitability.

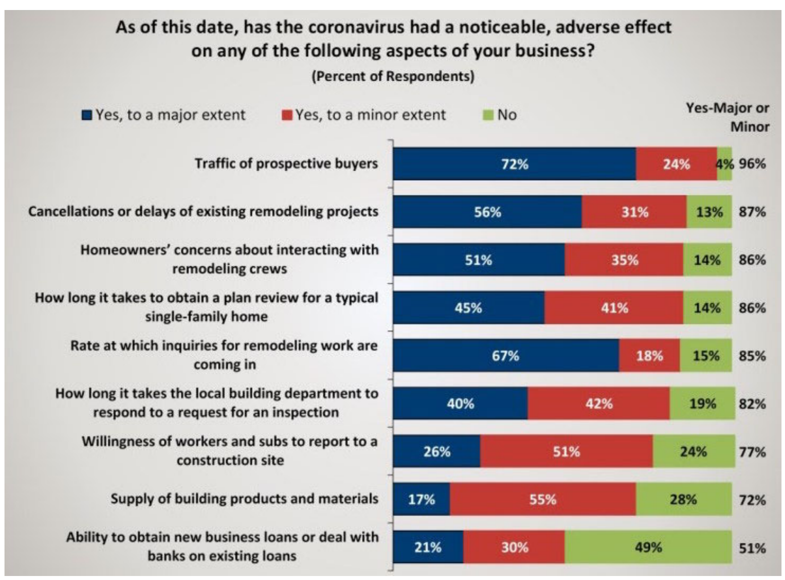

Figure 1: Impact of COVID on Homebuilders. Reprinted from *Virus Now Impacting Traffic for Nearly All Builders*, by Emrath, P., 2020.

To help alleviate this problem, AHJs began to allow the use of third-party private inspections and virtual inspections. As defined by the International Code Council (2020), remote virtual inspections (RVIs) are a "form of visual inspection with uses of visual or electronic aids to allow an inspector or team of inspectors to observe products and/or materials from a distance because the objects are inaccessible or are in dangerous environments, or whereby circumstances or conditions prevent an in-person inspection" (International Code Council, Inc., 2020). In a survey conducted by the National Association of Homebuilders (NAHB) shortly after the pandemic started, 20% of builders stated their local building department adopted the use of RVIs specifically as a response to the pandemic. Prior to the pandemic, only 4% of AHJs used virtual inspections as standard practice (NAHB Now, 2020), as shown in Figure 2.

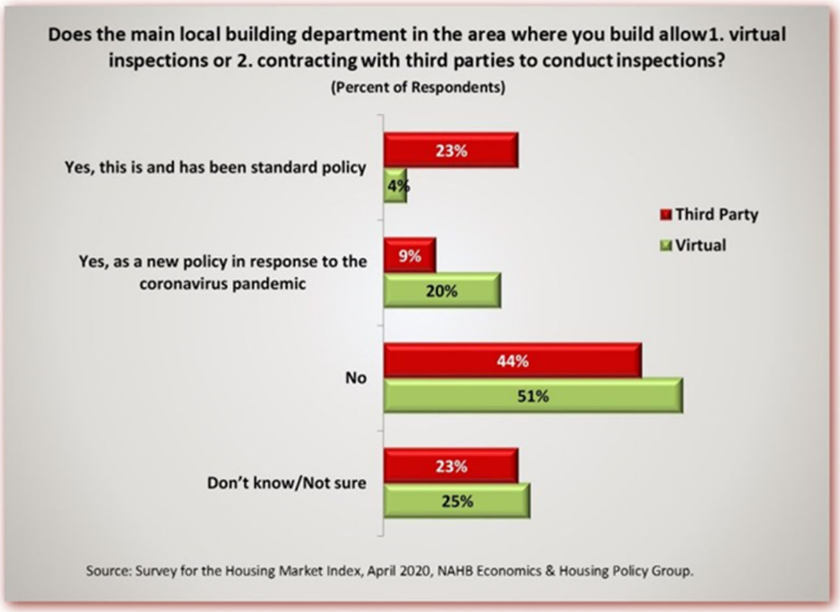

Figure 2: Use of Virtual or Third Party Inspections for Residential Builders. Retrieved from *Some Cities Keep Construction Going Via Virtual Inspections*, by NAHB Now, 2020.

Much of the research regarding RVIs focuses on the development of technologies for unmanned remote inspections of existing facilities to determine anomalies or defects in hard-to-access or high-risk areas, such as the magnetic tomography inspection method for Arctic offshore pipelines (Kamaeva, Kolesnikov, Eremin, & Khusnutdinov, 2019) or the development of unmanned augmented virtual reality for remote inspection of electrical power substations (Mattioli, Cardoso, & Lamounier, 2020). Alternatively, researchers theorize and advocate for digitized systems within the construction industry to facilitate remote inspections, including the widespread use of building information modeling and digital twins (Rotilio & Tudini, 2020) as part of the new industry paradigm Construction 4.0 (Munoz-La Rivera, Mora-Serrano, Valero, & Onate, 2021). However, these technologies have not been fully developed or realized and require substantial investment in time and resources to use for RVIs.

Since these technologies have not been fully tested, and the pandemic happened so abruptly, the construction industry needed low-technology solutions that could quickly and easily be implemented at the field level. Turning to smartphones and small electronic devices, RVIs were a quick solution that could include live-video chats in real-time using videotelephony, recorded videos, or photographs sent to the inspector via email, text message, or an online submission platform. The goal of this paper is to discuss how Yolo County, California, implemented specific technologies to address the need for RVIs. Current research to date does not focus on RVIs in residential construction and this study seeks to analyze the initial perceptions of homebuilders regarding the implementation of RVIs within Yolo County, California.

Methodology

A qualitative data approach was utilized to better understand the detailed perceptions of the participants. Following Polkinghorne's (1989) recommendations for the number of interviews to understand a specific phenomenon, five residential homebuilders were selected to participate in a semi-structured interview to review their perceptions of virtual inspections in the workplace. Each participant held an ownership position at their respective company. The companies were individually selected to fit the criteria requirements defined below.

1. Must be a residential general contractor
2. Must have less than 100 employees
3. Must be located in Yolo County, California
4. Must have some knowledge of virtual inspections

Interview Structure

Semi-structured interviews were recorded over the phone and transcribed. The interviewer did not follow a strict formalized list of yes or no questions; rather several broad, open-ended questions that led to follow-up questions were used, allowing the participants to describe their experiences, following a phenomenological approach (Creswell & Poth, 2018). This semi-structured approach allowed the participants to highlight their perceptions and provide details of their own experiences. The open-ended questions that acted as the framework for each interview are shown below.

- What are some of the benefits of virtual inspections in the residential sector?
- What are some of the disadvantages of virtual inspections in the residential sector?
- When are virtual inspections appropriate to conduct over the traditional method?
- Do you have any concerns with the accuracy of virtual inspections?
- If COVID-19 was not a factor, would you prefer to use in-person inspections or virtual inspections?
- Do you think this technology will take off in the next decade or do you think we are going to see less after the pandemic?

Coding and Data Analysis

The interviews were transcribed digitally to allow for coding and data analysis. Using Charmaz's (2012) initial coding approach as a framework, the data collection was performed inductively as the homebuilder's ideas were analyzed to find industry themes. The transcriptions were labeled with codes using ATLAS.ti Cloud. Once all transcriptions were coded, reoccurring patterns were grouped to determine emergent themes from the interviews, following Saldaña's (2021) coding methods, identifying common and divergent ideas presented by the different interviewees. These themes were then sorted into three larger categories: (1) benefits of RVI, (2) disadvantages of RVIs, and (3) future considerations.

Results and Discussion

All five interviews were digitally transcribed and coded to find reoccurring themes and ideas. Throughout the five interviews, six significant themes emerged. These six themes included (1) familiarity with virtual inspections; (2) time and cost impact; (3) applicability; (4) accuracy; (5) homebuilders preference; and (6) future considerations. While several homebuilders had differing opinions over the implementation and use of virtual inspections, most participants agreed on these six topics. Each theme is expanded upon in the sections that follow.

Familiarity with Virtual Inspections

At the time of the interview, all five residential general contractors had used some form of RVIs, but only two had encountered virtual inspections prior to the pandemic. COVID-19 contributed to the major shift of virtual inspections, where each participant noted they saw a dramatic increase in virtuality. One participant noted, “we have gotten permission in the past to take photographs of the work when it’s a jurisdictional holiday, and the inspector could not make it.” Even though some companies used virtual inspections prior to the pandemic, they were only used in special circumstances and were not the industry standard.

As a result of COVID-19 and social distancing requirements, all five participants transitioned to RVIs on each of their projects. Two participants used only still pictures, taking photographs of items on-site and sending them to the inspector; the remaining three utilized a combination of videotelephony and still pictures.

Time and Cost Impact

All participants agreed that RVIs impacted both time and cost for the general contractor. Some participants stated that time is saved while others disagreed stating that minor inspections required additional resources to complete an RVI.

The interviewed general contractors perceived that time savings occurred for both themselves and the county. For the general contractor, there was less waiting time for the inspector to arrive on-site and, once on site, there was less trivial conversation with the inspector. One contractor elaborated on time savings when he said, “we don’t have to wait around for the inspector to show up. When an inspector comes, we usually need a body on site, and that employee is sitting around doing nothing while he waits.” Another participant agreed by saying, “I usually take pictures before I leave the jobsite, and it takes me five minutes tops. Inspectors talk your ear off, and the inspection can sometimes take close to an hour.” This efficiency provides not only times savings, but also cost savings for the contractor. One participant said, “There will definitely be cost savings. In the past, employees have waited for inspectors for hours, and that employee is on the clock. So, you’re going to save money from that perspective.” Furthermore, another homebuilder mentioned that the time savings made by the virtual inspections directly correlate to costs savings for both the general contractor and the county.

In addition to time savings for the general contractor, all five interviewees mentioned that virtual inspections provide tremendous time savings for the county. With virtual inspections, inspectors don't have to drive around the county and, instead, can inspect a building from their office. Less drive time means they can complete more inspections during a single day.

One contractor had a different perspective, saying more minor virtual inspections can waste time and resources. He said, "on smaller inspections, we do not have to be onsite, and the inspector can perform his task alone. When we do a virtual video-call inspection, we have to be onsite and point the camera around for him to see, which costs us time." This contractor also stated that cost savings apply only to the AHJ, and the general contractor may experience a financial loss due to this added time spent on minor inspections. In addition to time, he also stressed the importance of having in-person inspections as he stated, "there has been a couple of times where a building inspector has called something that we genuinely missed, and I am so thankful because that correction has saved me a lot of money and headache." While these mistakes don't happen frequently, they are more likely to be caught in person and can save the general contractor a financial loss.

Applicability

All five homebuilders agreed that virtual inspections work better in some scenarios but worse in others. Three participants mentioned how virtual inspections should be used for smaller items and in-person inspections should be used for larger items. One participant said, "virtual inspections work best for smaller items such as drywall nail inspection or insulation inspection. When it comes to larger-scale items like roof, foundation, and MEP [mechanical, electrical, plumbing], I think it's more likely that things could get missed." Another homebuilder mentioned that virtual inspections should only be used for items that are exposed. He went on to say, "Framing, mechanical and electrical are all extremely important inspections because once they get buried, it becomes really difficult to get to and fix. Whereas if you miss something and it's exposed, at least we've caught it." The third participant noted that virtual inspections work best in scenarios where you can prove the accuracy of the dimensions. He went on to mention, "I think virtual inspections work in scenarios where you have to confine to a certain set of dimensions. You can use a tape measure in those types of applications to show that you are meeting that requirement. It might get a little bit more difficult when you have to actually test things like electrical, safety and plumbing items." Based on these responses, the general contractors believe that RVIs work best only in specific applications, and should not completely replace in-person field inspections.

Accuracy

Four of the five homebuilders believed that virtual inspections are less accurate than in-person inspections. One participant noted, "If you're not getting a set of eyes physically on something, there are going to be more mistakes." He went on to say, "One example that has been hard to do virtually is when they are inspecting shear nailing for instance, they want to see if that nail has penetrated layers in plywood and it's hard for the project manager to take an accurate picture of that instance." Several participants also noted how virtual inspections contribute to an increase in ethical abuse. One participant mentioned, "I get the general impression that the inspector would rather be on the job, and it's a trust issue. They don't trust us. Anybody can manipulate the camera, and I've heard some inspectors say that general contractors have been manipulating pictures and videos to speed up the process." Another homebuilder agreed with this abuse by saying, "A lot of GCs [general contractors] try to schedule a rough inspection on a Friday afternoon because they know the inspector is going to be looking forward to the weekend and not pay as much attention. And so there's always been strategies like that to make things easier, but this one, I suppose, would be open to more abuse." One homebuilder also mentioned his concern for legal repercussions by stating, "I am concerned with some of the liability issues that might come up down the road if something was missed because it wasn't thoroughly inspected. As an owner of the company, I want to take every precaution possible to minimize legal repercussions."

In contrast, one participant made the argument that virtuality does not affect the accuracy of the inspection. He went on to say, "I don't think it affects the accuracy. I think [virtual inspections] could be just as effective if the inspector knows what to look for and is shown the proper footage. It's an odd thing anyway for them to come out here for 15 minutes and think they can find everything in a 6,000 square foot house."

Homebuilders' Preferences

Each participant was asked if they wanted to keep a form of virtual inspection post-pandemic. All five homebuilders agreed they would like to keep the technology in some circumstances. For example, one participant noted, "I would like to see a hybrid model in the future; the kind where you need to have an inspector on site when it's really critical for them to be there. But virtual inspections on some of the smaller things, that you can document easily and send to inspector would be beneficial." Another homebuilder agreed by saying, "virtual inspections are not as good as in-person inspections, but I suppose I would want to keep the option open for smaller projects."

Two participants noted they would only want to keep one form of the technology used for RVIs. One homebuilder mentioned, "If I had the option, I would want to keep virtual inspections using the picture method just because of the convenience factor, and then I don't have to chat with them for 15 minutes." Another participant mentioned how he would only want to keep the video chat, like FaceTime, method of virtual inspections; "FaceTime did work well in Yolo County. I'm on the jobsite, and I'm able to flash my iPad around, and he would say point me up over there. So FaceTiming is the best and if COVID wasn't a factor, I would want to keep that method."

Future Considerations

All five homebuilders agreed that the use of virtual inspections will grow in the residential construction sector. One participant said, "I think it's going to be more in use, and I think the technology is going to be better. I just think the Zoom calls are going to evolve, and that's not going away. We are going to refine this and make it more effective." Another participant agreed by saying, "I see this hybrid model working to our advantage and taking off in the future." He went on to say, "With the change in technology and the way that the digital era is going, it's going to be beneficial, and I think it's going to go in that direction. I truly believe there will be a hybrid model that would have the inspector come to certain critical inspections or larger structural inspections. But for the residential sector, I think it makes a lot of sense, especially if it's something simple."

Another participant saw the potential of the technology but was hesitant about the implementation. He said, "I think jurisdictions would be smart to adopt some kind of hybrid model. And that being said, if it makes sense, and would save money, then the government probably won't do it." One homebuilder also mentioned the technology can grow but never replace humans; "I think in-person inspections has a level of fluidity that is impossible to accomplish with technology." Even though these two participants were hesitant about future growth, they both agreed that a hybrid model would be more favorable. The uncertainties centered on implementation and complete virtuality.

Conclusion

This study analyzed the preliminary perceptions of five residential general contractors located in Yolo County, California, regarding the implementation and utility of RVIs for new residential construction. A majority of the contractors interviewed perceived that virtual inspections save time for both the general contractor and the inspecting agency. However, one homebuilder mentioned that there are reduced time savings for the general contractor during minor inspections when the general contractor must be onsite to video chat with the inspector. In cost savings, most participants believed that virtual inspections save both the general contractor and the AHJ money. However, one opposing theme was that RVIs may not be as thorough as on-site inspections, which could result in major items being missed, resulting in future repair costs.

All five participants agreed that virtual inspections should only be used in certain situations. These situations include smaller trades along with inspections that don't require testing. There was also a majority consensus that virtual inspections are less accurate than in-person inspections. The accuracy concerns include its susceptibility to abuse, the inspector's lack of vision, and the inability to take accurate photographs. Despite the accuracy concerns, all five general contractors agreed that they want to keep a form of virtual inspection and believed the technology will continue to grow in the future. This study was an in-depth analysis of five specific companies in the Yolo County area but does not accurately reflect the entire industry perception or the inspecting agency's perspective.

Future research could expand this study beyond initial perceptions in one geographical area, and explore homebuilders' perception of RVIs throughout the residential construction industry. Additionally, future research could further explore some of the themes presented, including time and cost impact, types of inspections that are better suited for RVIs, ethical implications, accuracy of inspections, or adoption of RVIs and standard practices developed by AHJs.

References

Building Inspection Services. (2020). "Yolo County." *Building Inspection Services | Yolo County*, www.yolocounty.org/government/general-government-departments/community-services/building-inspection-services.

California For All. (2021, September 22). *Essential Workforce*. https://covid19.ca.gov/essential-workforce/

Charmaz, K. (2012). *Constructing Grounded Theory* (2nd ed.). London: Sage.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative Inquiry and Research Design: Choosing Among Five* Approaches. Los Angeles: Sage.

Emrath, P. (2013, October 2). NAHB Eye on Housing. *Amid Cutbacks, Construction Inspections Are on the Rise*. https://eyeonhousing.org/2013/10/amid-cutbacks-construction-inspections-are-on-the-rise/

Emrath, P. (2020, April 9). *Virus Not Impacting Traffic for Nearly All Builders*. https://eyeonhousing.org/2020/04/virus-now-impacting-traffic-for-nearly-all-builders/

International Code Council, Inc. (2020, May). *Recommended Practices for Remove Virtual Inspections (RVI)*. http://media.iccsafe.org/2020_MarComm/Remote_Video_Insp_FINAL_w_Covers.pdf

Kamaeva, S. S., Kolesnikov, I. S., Eremin, N. A., & Khusnutdinov, L. A. (2019). Remote insepction by the magnetic tomography method (MTM) to prevent the risks imposed by exploitation of Arctic offshore pipelines. *IOP Conference Series: Materials Science and Engineering*, 1-10.

Mattioli, L., Cardoso, A., & Lamounier, E. (2020). 2D-3D Spatial Registration for Remote Inspection of Power Substations. *Energies*, 1-24.

Munoz-La Rivera, F., Mora-Serrano, J., Valero, I., & Onate, E. (2021). Methodological-Technological Framework for Construction 4.0. *Archives of Computational Methods in Engineering*, 689-711.

NAHB Now. (2020, March 28). *DHS Designates Residential Construction as 'Essential Infrastructure Business'.* https://nahbnow.com/2020/03/dhs-designates-residential-construction-as-essential-infrastructure-business/

NAHB Now. (2020, April 22). *Some Cities Keep Construction Going Via Virtual Inspections.* https://nahbnow.com/2020/04/some-cities-keep-construction-going-via-virtual-inspections/?_ga=2.19283453.439816919.1636572877-1418192254.1633123606

Polkinghorne, D.E. (1989). Phenomenological Research Methods. In R.S. Valle & S. Halling (Eds.), *Existential phenomenological perspectives in psychology* (pp. 41-60). New York, NY: Plenum Press.

Rotilio, M., & Tudini, B. (2020). The role of digitization in post-disaster reconstruction. *Geoinformation for Disaster Management* (pp. 125-130). Sydney: The International Archives of the Photogrammetry, Remote Sensing, and Spacial Information Sciences.

Saldaña, J. (2021). *The Coding Manual for Qualitative Researchers*. Los Angeles: Sage.

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Integrating Virtual Reality (VR) Into Construction Engineering and Management (CEM) Courses-A Case Study

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Construction projects are spatially and temporally dual-dynamic in nature. One of the technical challenges in teaching the construction process is how to describe the spatial layout of construction components. Virtual reality (VR) combined with Building Information Modeling (BIM) technology (BIM-VR) has been adopted in the construction industry for years as a communication tool between stakeholders. The technology can be used to create simulations that allow employees to get an immersive experience of a construction process that has not started, to identify potential problems before construction start, and prepare construction workers for hazards that may occur on construction sites. In this paper, the author reports the findings on evaluating the effectiveness of BIM-VR technology in enhancing students' spatial cognition skills of building and construction components. The evaluation was conducted using two different quantitative approaches. First, the before and after scores of students' spatial cognition skills were measured. The statistics of score changes were used to evaluate the effectiveness of the technology. Then, an assessment was conducted in which a survey was sent to students after completion of the course to gauge their feedback on the effectiveness of the BIM-VR application which had a positive trend.

Keywords: BIM, VR, Revit, visualization, construction engineering and management, education

Introduction

Building Information Modeling (BIM) and Virtual Reality (VR) have recently become useful tools in the architecture, engineering, and construction (AEC) industry (Kim, 2012). These tools provide many benefits including increased communication among stakeholders leading to more efficient project delivery, visualization benefits, lifecycle optimization and management, and greater accuracy for quantity takeoffs (Filzmoser et al., 2015). BIM has become more widely adopted in the industry in recent years, and this calls for increased adoption of classes highlighting BIM uses at the undergraduate and graduate levels (Ferrandiz, et al., 2018).

BIM Application in Education

Several studies have been done regarding the utility of BIM in undergraduate and graduate education. The methods of analysis for these studies include either qualitative analysis, quantitative analysis, or a mix of both. The qualitative approaches to these studies included methods such as surveys, questionnaires, course evaluations, and open discussions with participants in the BIM-related courses (Ferrandiz, et al., 2018). These qualitative measures were meant to gauge student motivation, perceived usefulness of BIM, and improved performance (Hyatt, 2011; Adamu & Thorpe, 2016; Sharag-Eldin & Nawari, 2010). For these studies, the general structure of the course was to introduce BIM as an additional learning tool, then provide the survey or questionnaire at the end of the course for the students to answer. In general, student responses were positive, and they had an increased sense of motivation to use these tools, as well as increased performance when completing projects and assignments (Huang, 2018; Fonseca, Falip, Valls, & Redondo, 2014).

The quantitative approaches for these studies include analyzing participant improvements by comparing scores or percentage of improvement before and after introduction to BIM (Hu, 2019; Irizarry, et al.,2012). Some studies also included applied statistical analysis such as t-tests to check for improvements when BIM was utilized (Kim, 2012; Ferrandiz, Banawi, & Pena, 2018). The study with the heaviest quantitative analysis held the purpose of analyzing the difference between traditional quantity takeoff methods versus methods involving the use of BIM. Their research found that 3D visualization alone can improve the efficiency and accuracy of completing quantity takeoffs. This paper goes into expansive statistical analysis using a multi-attribute utility model which considers evaluations from all four project parameters, which are generality, flexibility, efficiency, and accuracy. The authors conclude by explaining that the BIM-assisted detailed estimating (BADE) tools significantly improved students' ability to generate quantity takeoffs (Shen, et al., 2010).

BIM-VR Application in Education and AEC Industry

Virtual Reality (VR) has been used in classes for years as a supplemental visualization tool. However, the AEC is still exploring possible applications for VR technology. VR provides the ability to further build on BIM application by enabling the participant to be fully immersed in the 3D model virtually. This immersion allows for enhanced spatial recognition. Furthermore, VR when incorporated with BIM will provide added benefits to time, cost, quality, and safety in all phases of construction (Alizadehsalehi, et al., 2020; Ku, et al., 2011).

Many of the studies conducted regarding VR or BIM-VR application in the AEC industry and education field were qualitative in nature. There studies were meant to gauge people's interest and attitudes in using BIM-VR technology. In a study that focused on the application of VR in the construction industry, the authors explored applying VR combined with BIM into the education environment and concluded from student feedback that VR has a positive influence over the learning experience in the construction process (Alizadehsalehi, et al., 2019). In another study, when VR was introduced to AEC professionals with varying years of experience, they all showed positive attitude towards the application of VR for simulation of construction site walkthroughs (Gheisari, et al., 2016).

Some papers had a quantitative approach to the evaluation method. For instance, some researchers developed a VR course to explore its possible applications in engineering education. The paper included very detailed description of the course content, schedule, and equipment utilized. The students were assigned several projects to assess their performance in the course, and their progress was recorded. However, there was no significant data analysis but only simple observation of student satisfaction and adequate grades (Häfner, et al., 2015). In another paper, the authors explored BIM-VR application in a construction engineering education environment. Student performance was first evaluated in reference to BIM, and if its utilization enhanced performance compared to traditional 2D methods. The students' scores were compared before and after application of BIM, and there was significant improvement in performance. Next, the value of adding VR to BIM was tested, and it was found that the students reacted positively to the experience (Whisker, et al., 2003).

Although these studies measured people's eagerness to use this technology, and some even utilized scores as a quantitative analysis method, more intensive analysis and data is needed to determine whether BIM-VR provides benefit to efficiency, cost, or quality of construction projects.

Problem Statement

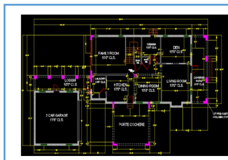
Building projects are complex and consist of multiple disciplines including landscape/civil, architecture, structural, mechanical, electrical, and plumbing. Transforming a 2D plan to 3D requires practitioners' full understanding of the spatial layout of the building. Although qualitative data can be useful for assessing people's motivation to use BIM-VR technology, however, little to no research exists on the utility of BIM-VR for construction blueprint reading. Our study plans to use quantitative data to determine if BIM/VR can aid in increasing the efficiency and accuracy of the blueprint reading process. This course and evaluation method were developed to prove the effectiveness of BIM-VR as a visualization and spatial recognition tool, and if it will help newcomers to the industry compensate for minimal experience with the technology application of BIM-VR. Also, the paper covers the gap of studying both BIM and VR applications simultaneously which has been minimally explored. Therefore, the quantitative set of data and results explored in this research provide a useful insight into BIM-VR application.

The Course

**** is an entry-level CAD and BIM course of the CEM program at the University of ****. The course was developed for sophomore students who have little or no prior experience of plan reading and CAD drafting. The primary goal of the course is to help students develop an understanding of construction drawing plans and be familiar with the use of CAD for developing drawings and the use of BIM for modeling, virtualization, and management of construction projects. Upon the completion of the course, the students are expected to be able to: 1) Develop an understanding of basic knowledge of CAD and BIM. 2) Develop a plan, profile, and cross-section views of 3D objects in CAD. 3) Understand how to interpret construction plans. 4) Develop a 3D representation of a facility in BIM.

The research study was conducted in fall 2019. A total of 33 students were enrolled. The course was taught on a lecture and lab basis. The mechanism was that the instructor delivered the technical details in lectures and then the students did hands-on exercises in lab sections.

The labs were typically small exercises and were intended to help students be prepared for the relatively more complex course projects. All assignments are independent work. There was no quiz and exam, so the students were primarily assessed based on the assignments. As shown in (Figure 1), a project-based learning approach was adopted in this course where it was divided into three phases with a project assigned at the end of each phase for evaluation. Also, the figure shows details on the software used, expected deliverables, scope, and samples of the final product. The blueprints of the projects were all from actual construction projects.

	Phase 1	Phase 2	Phase 3
Content	Blueprint reading. Developing 2D drawings.	Developing 3D architecture BIM model.	Developing 3D structural and site BIM model.
Software	AutoCAD 2020	Revit 2020 + Enscape	Revit 2020 + Enscape
Deliverable	Project 1: a small residential house 2D plans + weekly labs	Project 2: a small residential house 3D model + weekly labs	Project 3: a small commercial building 3D model + weekly labs
Purpose	1. Practice reading plans. 2. Familiarize students with different views (plans, sections, elevations and callouts).	1. Practice transforming 2D to 3D. 2. Develop a basement plan to participate in interior design.	1. Build a 3D model from a complete set of drawings and specifications. 2. Familiarize students with reading structural plans (ex. foundation and steel framing plans).
Product			

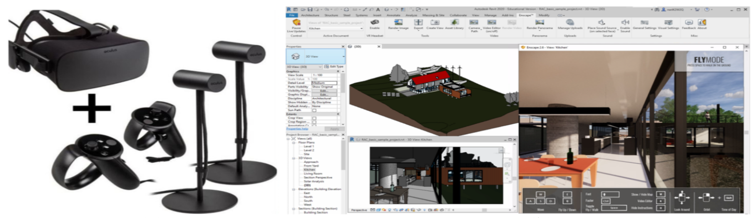
Week 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Figure 1. The workflow of the CAD and BIM course

Methodology

Most students of the class were sophomores and had no relevant experience in the industry yet. The ability to read and interpret blueprints correctly became a useful and important skill for the students. In this case, VR was integrated into the class in combination with BIM to enhance their spatial cognition skills. All students in this class were provided with chances to explore the simulated immersive environment of the sample projects as well as their models (Figure 2). The intent is to help students understand the spatial relationship of the projects and avoid errors in blueprint reading and modeling. Our VR method is to use Oculus Rift plus Revit/Enscape. Oculus Rift is the first generation of Oculus VR products (Figure 3a). It has a resolution of 1080×1200 per eye. Enscape is a Revit plug-in and was used for rendering and enabling the immersive background (Figure 3b).

Figure 2. Virtual walkthrough of student project.



(a) (b)

Figure 3. (a) Oculus Rift Virtual Reality Headset and (b) Revit + Enscape Interface

The performance of BIM-VR in enhancing students' spatial cognition skills was evaluated by the two tests:

> Test 1: the students were provided with one floor and four elevation plans of a one-story building (Figure 4) at the end of phase 1 (Figure 1). Then the students were required to sketch the same rooftop plan of the building. The students were provided chances to explore the model of the same building using BIM-VR after test1.
> Test 2: one-floor plan and four elevation plans of a similar building were assigned to the students (Figure 5) at the end of the semester in phase 3. At this time, the students had completed Project1 and several BIM labs, so they had more exposure to BIM and VR. The students were asked to sketch the rooftop plan of the second building. The test solutions can be found in Appendix A.

The student answers were quantitatively assessed. The students got credit for every correct line. The student scores were calculated by dividing the credits earned by the total credit. To compare the test results, a one-tailed paired T-test was conducted at a significance level of 0.05. The null hypothesis H_0 is $\mu_D=0$. The alternative hypothesis Ha is $\mu_D < 0$, where μ_D is the expected difference between X and Y, the score from the first and the second observations respectively; D is the difference between the two tests. 19 out of 33 students in this class participated in both tests. The data from the other 14 students were excluded from the paired T-test.

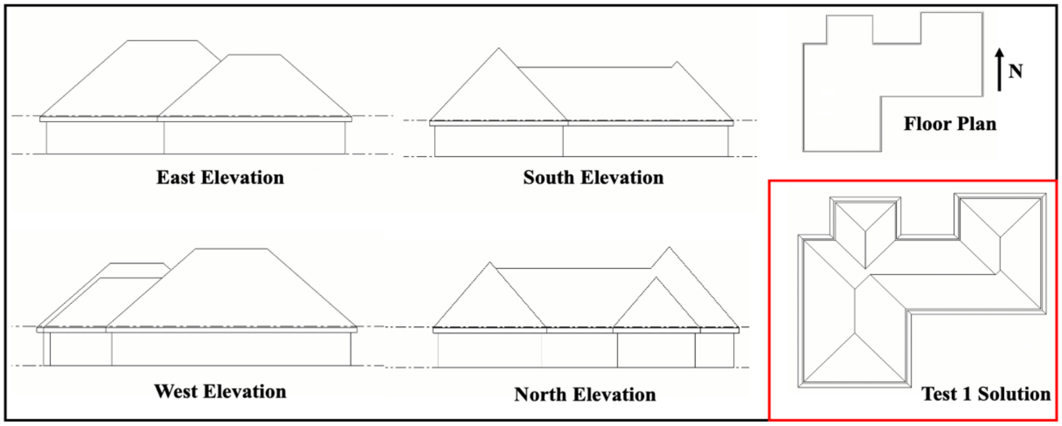


Figure 4. The floor and elevation plans of test 1.

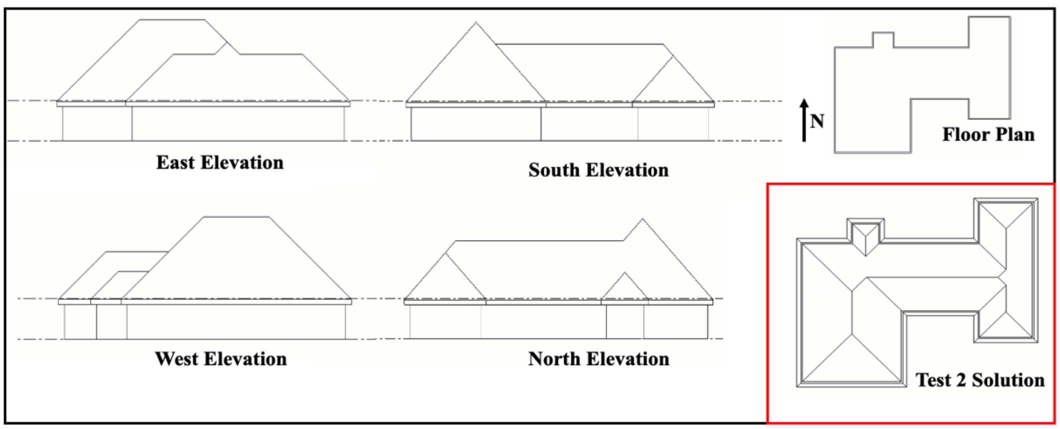


Figure 5. The floor and elevation plans of test 2.

Results and Discussion

The score of the two tests and the result of paired T-test were summarized (Figure 6) and (Table 1) respectively. The P-value is 4.8E-06, which is much less than the significance level of 0.05, thus the null hypothesis was rejected. In other words, the BIM-VR application did have a positive impact on enhancing student spatial cognition skills. The increase of the mean is more than 17%. It was also found that the variance of the test 2 score was much less than that of the test one, which indicates that after the BIM-VR application, the overall spatial cognition level of the sample students transitioned from a dispersed state to a relatively more concentrated state. This improvement can also be attributed to the fact that students could read the plan more proficiently later in the semester. This will be further investigated through collecting more data in phase 1 and phase 3 without using BIM-VR. As a supplement to the first statistically motivated quantitative study, another quantitative study was also conducted in which a survey on the VR application was sent to the students at the end of the semester. 30 out of the 33 students responded to the survey. The survey consists of 12 questions which a small summary of the intent behind and student feedback is shown in (Figure 7).

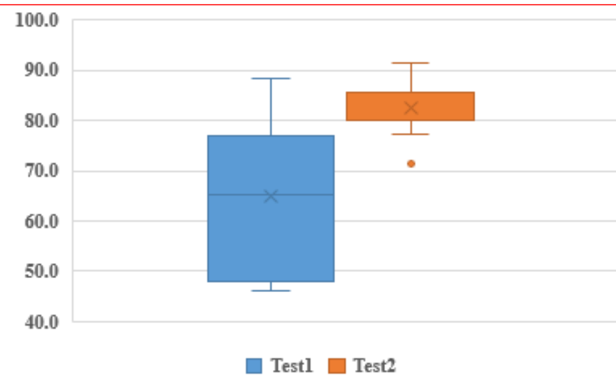


Figure 6. Box Plot of Test1 and Test2 Score.

Table 1

Paired T-test Result

Test #	Test 1	Test 2
Mean	64.98	82.41
Standard Error	3.35	1.26
Median	65.38	80.00
Standard Deviation	14.61	5.49
Sample Variance	213.50	30.17
Range	42.31	20.00
Minimum, Maximum	46.15, 88.46	71.43, 91.43
Confidence Level (95.0%)	7.04	2.65
Hypothesized Mean Difference	0	
Df (18)	18	
t Stat	-6.08	
P(T<=t) one-tail	4.8E-06	
t Critical one-tail	1.734064	

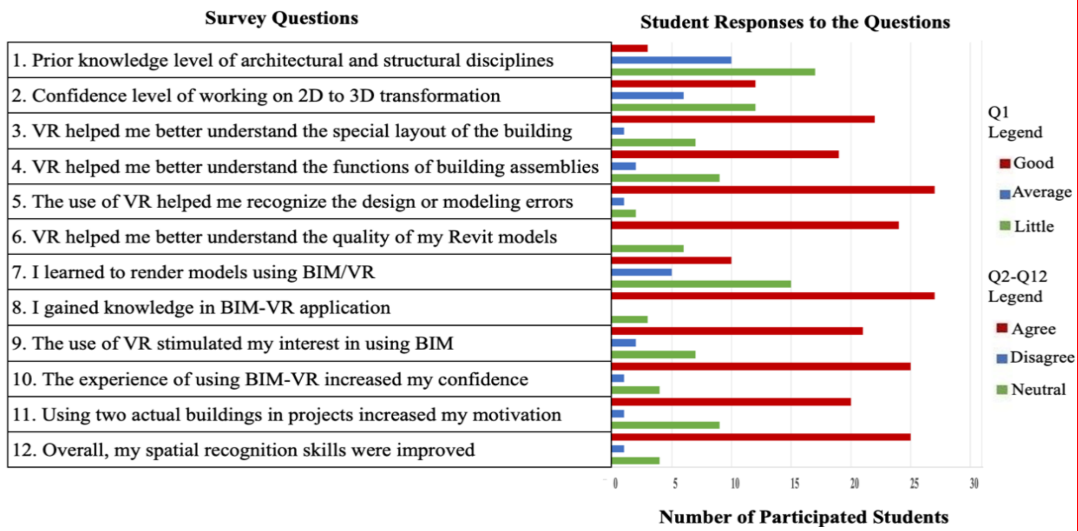


Figure 7. Student Responses to the survey on VR application (Responded/Enrolled=30/33)

Key findings of the questionnaire are as follows:

More students tended to agree that they have little to average relevant prior relevant knowledge before taking the course. It was surprising to see that more than one-third of the sample students believed that they could create an error-free model without checking them in 3D view or VR. But in the later actual practice, we found many modeling errors when doing the virtual walkthroughs indicating that the students were overestimating their abilities. Most students found BIM-VR an effective and useful tool that increased their interest in BIM and prepared them for their future careers. Overall, we received positive feedback from the students.

Conclusions and future study

The paper presents a case study of integrating BIM-VR integration into one entry-level construction engineering course. The intent is to provide an immersive environment of construction projects to help students better understand spatially complex building systems. Two quantitative assessments were conducted. In the first quantitative study, the students' spatial recognition skills were rated before and after BIM-VR application through a rooftop plan test respectively. A paired T-test was used to compare the results of the two tests. The statistics result indicates that the BIM-VR solution significantly improved the students' skills of interpreting blueprints. As for the second quantitative study was conducted through a survey with twelve questions. Overall, positive feedbacks were received from the students. The presented course is the first course that has implemented VR technology in the CEM curriculum at the University of ****. A limitation was that the data size was limited to the number of students participating in the class, which was only 33 while a larger sample size would provide for better and more concrete results. In the future study, when there are enough participants, a control group and an experiment group would have been possible to set up. This would have helped with clarifying if the reduced variance in test results was due to increased experience throughout the course, or due to BIM-VR application. As part of the long-term plan, BIM and VR are going to be integrated into the other construction courses, including construction means and methods, construction safety, and senior design. BIM-VR implementation throughout the CEM curriculum is going to be further studied and its effectiveness will be evaluated depending on the application within the curriculum of the course. Finally, the paper focused mostly on the addition BIM and/or BIM-VR provides to blueprint reading when compared to 2D. However, BIM was not compared to BIM-VR application to evaluate the addition VR provides when combined with BIM, this will be addressed in future studies and research.

References

Adamu Zulfikar and Thorpe Anthony How Universities are teaching BIM: A review and case study from the UK [Journal] // Journal of INformatino Technology in Construction. - 2016. - Vol. 21.

Alizadehsalehi Sepehr, Hadavi Ahmad and Huang Joseph Chuenhuei From BIM to extended reality in AEC industry [Journal] // Automation in Construction. - 2020. - Vol. 116.

Alizadehsalehi Sepehr, Hadavi Ahmad and Huang Joseph Virtual Reality for Design and Construction Education Environment [Journal] // Construction Engineering and Management. - 2019.

Ferrandiz Jose, Banawi Abdulaziz and Pena Enric Evaluating the benefits of introducing ‘‘BIM’’ based on Revit [Journal] // Universal Access in the Information Society. - 2018. - Vol. 17. - pp. 491-501.

Fonseca David [et al.] Motivation assessment in engineering students using hybrid technologies for 3D visualization [Conference] // 2014 International Symposium on Computers in Education. - Logrono : IEEE, 2014.

Gheisari Masoud [et al.] Integrating BIM and Panorama to Create a Semi-Augmented-Reality Experience of a Construction Site [Journal] // INTERNATIONAL JOURNAL OF CONSTRUCTION EDUCATION AND RESEARCH. - 2016. - 4 : Vol. 12. - pp. 303-316.

Häfner Polina, Häfner Victor and Ovtcharova Jivka Teaching Methodology for Virtual Reality Practical Course in Engineering Education [Journal] // Procedia Computer Science. - [s.l.] : ScienceDirect, 2015. - Vol. 25. - pp. 251-260.

Hu Ming BIM-Enabled Pedagogy Approach: Using BIM as an Instructional Tool in Technology Courses [Journal] // Journal of Professional Issues in Engineering Education and Practice. - 2019. - 1 : Vol. 145.

Huang Yilei Developing a Modular Advanced BIM Course in Construction Management [Journal] // Journal of Building Construction and Planning Research. - [s.l.] : Scientific Research Publishing, 2018. - Vol. 6. - pp. 198-214.

Hyatt Bradley A. A Case Study in Integrating Lean, Green, BIM into an Undergraduate Construction Management Scheduling Course [Conference] // 47th ASC Annual International Conference Proceesings. - 2011.

Irizarry Javier [et al.] Exploring Applications of Building Information Modeling for Enhancing Visualization and Information Access in Engineering and Construction Education Environments [Journal] // International Journal of Construction Education and Research. - 2012. - 2 : Vol. 8. - pp. 119-145.

Kim Jin-Lee Use of BIM for Effective Visualization Teaching [Journal] // JOURNAL OF PROFESSIONAL ISSUES IN ENGINEERING EDUCATION & PRACTICE. - 2012. - 3 : Vol. 138. - pp. 214-223.

Ku Kihong and Mahabaleshwarkar Pushkar S. BUILDING INTERACTIVE MODELING FOR CONSTRUCTION EDUCATION IN VIRTUAL WORLDS [Journal] // Information Technology in Construction. - 2011. - Vol. 13.

Sharag-Eldin Adil and Nawari Nawari BIM in AEC Education [Conference] // Structures Congress 2010. - 2010.

Shen Zhigang and Issa Raja R. A. Quantitative Evaluation of the BIM-Assisted Construction Detailed Cost Estimates [Journal] // Electronic Journal of Information Technology in Construction. - 2010. - Vol. 15. - pp. 234 - 257.

Whisker Vaughn [et al.] Using Virtual Reality To Improve Construction Engineering Education [Conference] // Construction Engineering Advances I. - Nashville, Tennessee : ASEE, 2003.

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Pragmatic Development of a Cybersecurity Module for Construction Education

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Technology use has significantly increased in the construction industry. The industry creates large amounts of confidential, sensitive, or proprietary information which is susceptible to unauthorized access by cybercriminals and access to network infrastructure can create havoc on construction companies. Construction students must apply electronic-based technology to manage the construction process, but based on various cyber incidents, construction students should also understand their responsibility regarding cybersecurity when working with the various technology. The problem is that it is already difficult to incorporate new content in an already tight construction curriculum and there is no academic literature that provides guidance on how to teach this type of topic. Therefore, the purpose of this paper is to provide the course development process undertaken to develop a module on cybersecurity for construction. Using this framework in combination with a three-phase framework, the authors have outlined the assumptions about the learner and society; the aims and objectives; content or subject matter with its selection, scope and sequence; modes of transaction; and evaluation methods for the module. The authors expect that this module will be used by educators to further cybersecurity instruction which will hopefully mitigate cybersecurity incidences in the construction industry.

Key Words: Cybersecurity, Cyber-risk, Construction, Education, Construction 4.0

Introduction & Background

The use of technology in construction, "offers the potential for revolutionary change in the effectiveness with which construction related activities are executed and the value they add to construction industry stakeholders" (Gallaher et al., 2004, p. iii) and opportunities offered by emerging technology for the construction industry should be fully exploited (Froese, 2010; Sands, Fiori, & Suh 2018). What was once known as a low-tech industry or "one that has been slow to adopt process and technology innovations" (Agarwal, Chandrasekaran & Sridhar, 2016) has in large part evolved into a highly digitalized, automated, and technologically capable industry. The industry is shifting toward Construction 4.0 which is the movement toward digitization and having connected systems at every stage in the lifecycle of a construction project (Mantha & Garcia de Soto, 2019).

This shift toward more digitization improves workflows throughout a construction company's operations.

The construction industry tends to create large amounts of highly confidential, sensitive, or proprietary information (Mantha & Garcia de Soto, 2019). There are a variety of sensitive data housed and exchanged within company databases which may include, design documents or other highly sensitive project data types. Also, data in company databases may include bidding strategies that is essential to a company's competitive advantage and other organizational information such as employees' social security numbers, home addresses and/or medical information. There are vast amounts of data that are at risk and organizations need to understand the inherent risk of working in a new digital world, especially when considering that globally, the average cost of a data breach can cost a company $3.9 million according to the Ponemon Institute (2019).

Information exchange is a key process in the construction industry and according to Blakley, McDermott & Geer (2001), securing the information we exchange is important in proportion to an organization's dependence on information technology. Information and other advanced construction technologies are becoming heavily reliant on digital environments and operating in digital environments make industries prone to technological risk such as cyberattacks (Li et al., 2017; Liu et al., 2017; Mantha & Garcia de Soto, 2019). As the construction industry gets more involved with advanced technology, the more susceptible it will become. According to the senior director of IT at Warfel Construction (with 230 employees and $235 million in revenue), the construction industry is unprepared to face such cyber-attacks (Sawyer & Rubenstone, 2019). Adding to this, according to Welsh (2018), of the 2,800+ construction professionals surveyed, roughly 14% of survey participants indicate that they or their companies have experienced a cyber-attack. This number may in fact be higher as an M-Trends report conducted by Mandiant Consulting (2019) which provides annual data on the industries targeted by cybercriminals often found that in 2019, 4% of all cyberattacks were on the construction and engineering industries and as the industry engages in more connected technology, that number is sure to rise.

Direct Impact on the Industry

There are a variety of examples of cyberattacks on the construction industry, many of which are not publicly shared as victims decline to share any details about the incident (Sawyer & Rubenstone, 2019). One such incident discussed by Sawyer and Rubenstone (2019) includes how Brothers Construction of Willoughby, Ohio had not received payment of $1.7 million from St. Ambrose Roman Catholic Church (owner). The owner had been paying; however, at some point as transactions were being made, a hacker was able to access the email system of the owner and change routing numbers for wire transfer payments so in essence, the $1.7 million disappeared. Sawyer and Rubenstone (2019) also recounts how Turner Construction Co. in 2016 had sensitive data stolen due to cybercrime.

O'Connor (2016) highlights multiple cyber-incidents related to the construction industry. A major U.S retailer known as the 'Target Corporation', had credit cards and personal data of approximately 110 million customers exposed. The breach occurred due to stolen credentials obtained by cybercriminals from Fazio Mechanical Services, an HVAC contractor. The attack appears to have been the result of a malware-embedded email phishing attack sent to employees of the contractor. Another case described by O'Connor includes the theft of plans of an Australian secret intelligence center being stolen while the center was still under construction and it was reported to increase the time of the project while increasing the cost of the project by $132.6 million. Additionally, O'Connor points out how AECOM had current and former employee records stolen due to hackers. In addition to these examples of external cyber-incidents, it has been reported that cyber-risks also involve employees (current and former) and external contractors working on project sites. Also, a recent incident described by Medina (2019) highlights how a 'scammer' took $640,000 after sending an invoice directing payment to a fraudulent bank account that was meant for a contractor.

In addition to risk associated with information and cybersecurity, digitally connected equipment and device security poses another major threat to the construction industry. Rubenstone (2019) discusses a Trend Micro research study which highlights the vulnerability of digitally connected equipment such as cranes, to being 'hacked' or accessed without authorization. There were 17 brands of wireless controllers associated with crane operations at sites in the U.S., Europe and China that were susceptible to attacks, which included one called a replay attack to get cranes to perform actions that it has done before.

Significance of Cybersecurity Education for Construction Students

According to the American Council for Construction Education (ACCE, 2020, p.13), construction students must be able to "apply electronic-based technology to manage the construction process." Understanding that there is a growing trend toward the use of technology in construction, educational program who wish to be accredited needs to provide electronic-based technology instruction to their students; however, there's no specific requirement to educate students on the risks that use of technological innovation pose to their future employers. As educators, we have a duty to provide students with knowledge that will help them to be as efficient and as innovative as possible through the use of various technologies, but we must equip students with the tools that will allow them to be as safe as possible in their professional environments. It can be physical safety or virtually to protect themselves and their companies from cyber threats.

Educators can support students not only understand the nature of cyber threats, but they can also provide education that will improve their cyber security habits. According to McCrohan, Engel, & Harvey (2010), it was concluded that when users were educated on cyber threats and were trained about proper security practices, their behavior could be changed to enhance online security for themselves and the firms where they are employed.

Problem

Construction Students & Cybersecurity Issues

To get an understanding of undergraduate student competency with regard to cybersecurity in construction, the authors surveyed 56 junior and senior undergraduate construction students. The survey indicates that only 28% of students were aware of the dangers of information security using construction technology and 79% of students pointed out the need of training for cyber-security for construction technologies.

In addition to this initial investigation, two students who have worked for construction companies through their cooperative education program have reported that they and their companies have personally experienced a significant cyber-attack. The attacks were described as ‘ransomware attacks’ where a cybercriminal was able to take control over their IT systems and demand a ransom of a certain amount of Bitcoin in order to return control to the organization. A few students are already experiencing the significant impact of cybersecurity in construction.

Construction Curriculum

With the advent of the connected construction company, it is important that every construction professional using electronically connected devices has education on cybersecurity and cyber risk and construction education should be part of this effort; however, barriers to adopt and teach cybersecurity education may include squeezing another topic in an already constrained curriculum to a resistant faculty (Sinha et al. 2007; Sands, Fiori, & Suh, 2018). Also, there is very limited literature that provides guidance on how and what to teach construction students topics on cybersecurity.

Purpose

The purpose of this paper is to provide insight into how the authors have used the systematic course development framework (Mager and Beach, 1967; Ahn et al., 2009) and Graves’ (1996) framework of course development processes in addition to Eash’s (1991) curriculum components to develop an introductory cybersecurity module for construction students.

Curriculum Development in Construction Education

A review of ASC proceedings; in addition to electronic databases, provides insight to curriculum development in construction. Research with regard to development of curriculum elements is not a new concept in construction education. Ahn et al. (2009) focused on the systematic course development process for building a course in sustainable construction for construction students. Ahn, Cho, and Lee (2013) discusses how the systematic course development process was used for the creation of a BIM course suitable for construction and engineering students. Mostly related to this particular research is Sands, Suh and Fiori (2018) which focuses on the re-development of an IT for construction course. Review of this research guided this process and have led the authors to adopt the frameworks described and used within.

Approach to Teaching Cybersecurity

The authors suggest a modular approach to educate students about several issues related to cybersecurity in construction. It allows for content to be incorporated into any relevant construction course, such as a building information modeling (BIM) course, project management course, a construction business management course (for risk control) or a stand-alone IT for Construction course. To develop this module, the authors operationalize Eash’s (1991) curriculum components as the conceptual framework for the module development which include: (a) framework of assumptions about the learner and society; (b) aims and objectives; (c) content or subject matter with its selection, scope and sequence; (d) modes of transaction, for example, methodology and learning environments; and (e) evaluation.

Additionally, the systematic course development framework focuses on three phases; preparation, development, and improvement (Mager & Beach, 1967; Ahn et al., 2009) while Graves' (1996) framework focuses on the elements of; needs assessment, course objectives, conceptualizing and organizing content, materials, and activities, evaluation techniques, and understanding available resources and constraints. Combining these frameworks allows to fully define and refine the module.

Phase I: Preparation

Needs assessment

During the preparation phase, the authors performed a needs assessment. First, external requirements were assessed. Guidance and insight were provided from professional organizations, advisors, industry councils, literature, and seminars/webinars to understand the necessary competencies of our students.

Assumptions about the learner

Assumptions about the learner should be made. The authors assumed that students will be involved in the construction industry upon graduation and they will be exposed to environments that use electronically connected technology. In addition to this assumption, it is assumed that these students do not have any significant knowledge regarding the impact of cybersecurity issues in the construction industry as evidenced by the initial survey completed.

Phase II: Development

Assessment of resources and constraints

The authors assessed the resources and constraints to the development and incorporation of a cybersecurity module. The major resource necessary to prepare the module is a significant amount of time to compile the resources into an appropriate lesson plan. Access to various professional and educational literature/articles are also a significant resource needed. The ability to download videos from online resources is also useful as a resource. A significant constraint of this module is determining where to place this module in the curriculum. For this case, an IT for construction class was observed to be the easiest way to integrate this content into the construction curriculum.

Content or subject matter and activities

The content for the module is based on a 2-hour 40-minute class session and is separated into seven topics (see Table 1.). The lesson plan is based on a slide presentation with integrated videos, cases and activities. The module begins with an introduction to cybersecurity and a brief discussion on the impact of cyber incidents on the construction related industry. Further discussion gives students a broad overview of cybersecurity and then begins to move into construction specific topics pertaining to items of 'Construction 4.0,' the internet of things (IoT), and electronically connected devices. A significant case study is reviewed and discussed. The means of prevention and reaction to a cyber issue is discussed as well and a phishing email activity is done to complete the session as it is a significant means of unauthorized access into network infrastructure by cybercriminals (see Figure 1.).

Table 1

Organization of Content Coverage for a 3-hour module

#	Topic	Significance	Resource
1	Introduction to Cybersecurity	What is cybersecurity? Noting that Construction/Engineering is the 5th most targeted industry by cybercriminals in 2019	M-Trends (2020)
2	What are we protecting?	Sensitive employee data Sensitive client data Network and infrastructural access	Goodman (2020)
3	Who are we protecting from?	White Hat vs. Black Hat Hackers	Caldwell (2011) Norton (2017)
4	Relevance to construction	Cyber risk and the industry. Radio Frequency (RF) Controllers and Hacking of Cranes	Constructible (2018) ENR (2019) Brewster (2019)
5	Case Study Review	Target & Fazio Mechanical	Krebs on Security (2014)
6	Protecting Your Company	Cyber Liability Policy Training & Education	Risk & Insurance (2018) Beyer & Brummel (2015) DHG (2016)
7	Phishing Email Activity	Identify Phishing Attack Risk	See Table 1.

Activity. Figure 1. provides a screenshot of an activity used to help students understand how to identify a spear-phishing email based on various identifiable features (Yahoo, 2020).

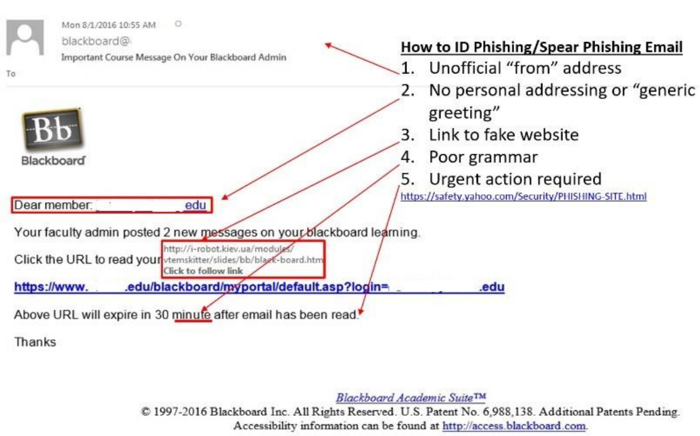

Figure 1. Student activity: review of phishing email

Modes of Transaction

The authors suggest using the structure outlined in Table 1. as a module in a construction course. The module can and has been offered in two modalities, via live face-to-face instruction and via an asynchronous online environment. In both cases, an electronic learning management system (LMS) is used and all content are made electronically available to student.

Evaluation

The authors suggest incorporating test questions pertaining to the module into an existing evaluation technique that would allow for integration into established course to observe if objectives of this course module were met. Additionally, a mini quiz with spear-phishing email activities may also be useful.

Phase III: Improvement

There is always a need to continue improving any courses, particularly with regard to a technology-based module. As iterations of the course are offered, new case studies have been added due to new cyber-attacks on construction organizations. In addition to this, new resources/sources of information and online video contents have been incorporated into the module.

Conclusion

Construction students must be able to apply electronic-based technology to manage the construction process (ACCE, 2020) and the industry is moving toward the use of more technology and electronically online devices. With this and further advancements of Construction 4.0, the construction industry is becoming more susceptible to cybersecurity risk and students need to understand the risks and the means of preventing and/or preparing for cybersecurity threats. The problem is that there is limited guidance from academic literature or otherwise as to how educators are to teach cybersecurity to construction students.

Through the use of the course development process in conjunction with the framework for course development processes, the authors have presented a pedagogical strategy for teaching cybersecurity to construction students as a module that can be incorporated into a technology-based construction course. The content covers the broad topic of cybersecurity and then moves toward a more specific review of the impact of cybersecurity in construction, the cases that support this review and ways to protect organizations from cybersecurity incidences. The module ends with a spear-phishing email activity that will give students the fundamental skills of being able to recognize an email of this nature. Therefore, this module will serve as a resource to construction educators to support them with teaching the important topic of cybersecurity in their construction classes. In the future, the authors hope to investigate construction programs that incorporate cybersecurity teaching in their curriculum in hopes to collaboratively improve on the module.

References

Ahn, Y. H., Cho, C. S., & Lee, N. (2013). Building information modeling: Systematic course development for undergraduate construction students. *Journal of professional issues in engineering education and practice*, *139*(4), 290-300.

Ahn, Y. H., Kwon, H., Pearce, A. R., and Wells, J. G. (2009). The systematic course development process: Building a course in sustainable construction for students in the U.S.A. *Journal of Green Building*, 4(1), 169-182.

American Council for Construction Education (ACCE) (2020). Standards and criteria for the accreditation of bachelor's degree construction education programs. Retrieved from https://683b8d30-e51d49ba9440a5669f44051b.usrfiles.com/ugd/683b8d_92a40873c33d4413a776063e873f52a.pdf

Agarwal, R., Chandrasekaran, S. and Sridhar, M., (2016). Imagining construction's digital future. McKinsey Productivity Sciences Center. Retrieved from https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future

Beyer, R. E., & Brummel, B. J. (2015). Implementing effective cyber security training for end users of computer networks. *SHRM-SIOP Science of HR Series: Promoting Evidence-Based HR*.

Brewster, T. (2019). Crane hacking pt. 1 [Video]. YouTube. https://www.youtube.com/watch?v=k8F7glmbCNg&feature=youtu.be

Caldwell, T. (2011). Ethical hackers: putting on the white hat. *Network Security*, *2011*(7), 10-13.

Constructible (2018). Cybersecurity in construction, what you need to know. Retrieved from https://constructible.trimble.com/construction-industry/cybersecurity-in-construction-what-you-need-to-know.

DHG (2016). A cybersecurity risk in the construction industry. Retrieved from http://www.dhg.com/Portals/0/ResourceMedia/publications/Construction_Cybersecurity_DHG-Views.pdf

Eash, M.J. (1991) *Curriculum components.* The international encyclopedia of curriculum (pp. 67-69). Elmsford, NY: Pergamon Press, 1991.

Engineering News Record (ENR) (2019). Construction cybercrime is on the rise. Retrieved from https://www.enr.com/articles/46832-construction-cybercrime-is-on-the-rise

Froese, T. M. (2010). The impact of emerging information technology on project management for construction. Automation in construction, 19(5), 531-538.

Gallaher, M. P., O'Connor, A. C., Dettbarn, J. L., and Gilday, L. T. (2004). Cost analysis of inadequate interoperability in the U.S. capital facilities industry. Retrieved from http://www.fire.nist.gov/bfrlpubs/build04/PDF/b04022.pdf

Goodman, J. (2020). Cybersecurity expert: All construction data is an asset and should be protected. Retrieved from https://www.constructiondive.com/news/cybersecurity-expert-all-construction-data-is-an-asset-and-should-be-prot/573037/

Graves, K. (1996). *Teachers as course developers.* Cambridge University Press, Cambridge.

Krebs on security (2014). Target hackers broke in via HVAC company. Retrieved from https://krebsonsecurity.com/2014/02/target-hackers-broke-in-via-hvac-company/

Mager, R.F. and Beach, K. M. (1967). *Developing Vocational Instruction*, Fearon Publishers, Palo Alto, CA.

Mantha, B.R. and Garcia de Soto, B. (2019). Cyber security challenges and vulnerability assessment in the construction industry. *Proceedings of the Creative Construction Conference*, Jun. 29 – Jul. 2 2019, Budapest, Hungary

Mandiant Services (2020). M-Trends 2020. Retrieved from https://content.fireeye.com/m-trends/rpt-m-trends-2020

McCrohan, K. F., Engel, K., & Harvey, J. W. (2010). Influence of awareness and training on cyber security. *Journal of internet Commerce*, *9*(1), 23-41.

Norton (2017). What is the difference between black, white and grey hat hackers? Retrieved from https://us.norton.com/internetsecurity-emerging-threats-what-is-the-difference-between-black-white-and-grey-hat-hackers.html

Ponemon Institute (2019) Cost of a Data Breach Report 2019. Retrieved from https://databreachcalculator.mybluemix.net/

Risk & Insurance (2018). The case for cyber coverage in the construction industry. Retrieved from https://riskandinsurance.com/case-cyber-coverage-construction-industry/

Sands, K.S., Fiori, C.M. and Suh, M.J., (2018) Beyond BIM: The Evolution of an IT for Construction Course. *Proceedings of the Construction Research Congress 2018*, 54-64.

Sinha, S. K., Thomas, H. R., and Kulka, J. R. (2007). "Integrating ethics into the engineered construction curriculum." *Journal of Professional Issues in Engineering Education and Practice*, 133(4), 291-299.

Sawyer, T. and Rubenstone, J. (2019) Construction cybercrime is on the rise. Engineereing News Record. Retrieved from https://www.enr.com/articles/46832-construction-cybercrime-is-on-the-rise

Yahoo (2020). How can I identify a phishing website or email? Retrieved from https://safety.yahoo.com/Security/PHISHING-SITE.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAADpJElzVBcpp0Iu_9YpHJ1zXy0xkc38K7W8yGImBQCP16dCNMvo6GjSgcDkk1SrCpqIJqtiCHLx18xnXHOSlwku_0YnEMyAlXiSZ7Zna-srvyfLKJa4qzBZhyGIVKzeya-tpqKEJI--Ph5U88L8HC7TC2ZjU9eNwcV6SKyTETcW6

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The Role of Self-Determination Theory within a Redesigned Construction Management Technology Curriculum

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College graduates entering the workforce today are being trained to meet the future needs of their rapidly evolving industries. As such, educators are constantly adapting their curriculum to the dynamic changes to prepare well-rounded professionals. Some are leveraging classroom teaching strategies that include new and hybrid learning methods such as flipped classrooms and self-paced independent studies. The Construction Management Technology (CMT) program at Purdue University underwent a sweeping change in its curriculum four years ago, with courses redesigned to better fit the dynamic expectations of the construction industry. However, such radical changes can unintentionally create a learning environment which affects students' motivation to learn and their self-determination. This study dives into the learners' perspectives using Small Group Instructional Diagnoses (SGIDs) and connects it to self-determination theory (SDT). Ethnographic data from 334 students across five courses were collected. Data were conceptually and thematically linked to three student motivation factors based on SDT. It was found that learners were approving of the structure of the redesigned curriculum. Findings also showed that while the students' motivation was mainly built around competency and autonomy, students also identified relatedness as a supporting factor for success.

Key Words: Self-determination Theory, Student Evaluation, Small Group Instructional Diagnoses, Innovative Teaching and Learning

Introduction

In the United States (US), students have a myriad of options on which training institutes and schools to attend for the advancement of their careers. According to Henriques et al. (2018), work and career opportunities, location and proximity to job options, tuition costs, reputation, and available academic majors or research areas are some of the elements contributing to their decisions. In response, although many colleges and universities still follow orthodox learning models, some schools are gradually moving toward new teaching methods that focus on the learner to attract students (Borrego & Henderson, 2014). According to Strimel et al. (2020), if students become too focused on coursework that is centered on the instructor, they may not be well-prepared for real-world dynamic jobsites. This can be particularly true for students in science, technology, engineering, and mathematics majors (Strimel et al., 2020).

According to Huchel (2020), reputed academic centers such as Purdue University has consistently focused on transformational learning methods through grand challenges. In Spring of 2018, the CMT program took up such a challenge and introduced the transformative new curriculum. The initiative has been detailed in multiple studies (Benhart et al., 2017; Benhart & Shaurette, 2012; Santon et al., 2018). Instead of the traditional 3-credit course, the program radically shifted to 6- and 9- credit hour courses which are taught by multiple instructors instead of just one, thus introducing a realistic element of complicacy in construction education. The new courses employ jobsite-like hands-on training, while encouraging students to work independently, in small teams, and also in larger groups. Although the new curriculum is well documented, there is no data yet on how learners perceive the new curriculum. Generally, end-of-term course evaluations are distributed to students to determine their perceptions on their instructors and course material. However, course evaluations may be flawed in situations where there are multiple instructors teaching a course over fifteen weeks, as might be the case with the courses in this redesigned curriculum.

In 2003, Filak and Sheldon introduced self-determination theory (SDT) for effective course evaluation. However, it has only been used in traditional courses which are usually taught by one professor. Although students' perceptions about their knowledge and their professors are mildly related according to Clayson (2009), any constructive feedback can help in improving course material for future students. Other factors that help in the feedback process are focused discussions, faculty surveys, competency exams, etc. (Dagenais et al., 2003; Persky et al., 2019; Walkington, 2002). Thus, this study utilizes five different courses and investigates students' perceptions using small group instructional diagnoses or 'SGIDs' as an evaluation and feedback mechanism. The data was then thematically connected to self-determination theory (Filak and Sheldon, 2003). The Center for Instructional Excellence (CIE) at Purdue University assisted with the study by creating discussions through specific leading questions to the learners about their positive and negative perceptions of the course and the manner in which it was taught to them. The research questions that are being investigated by this paper are:

- What are the perceived strengths and weaknesses of transformative curriculum redesigns?
- What role does self-determination play in student perceptions of transformative curriculum redesigns?

Literature Review

The current American education system is centered around a nineteenth century concept of the weekly credit-hour system, where each learner must complete a predefined number of easily transferable credit hours to graduate (Shedd, 2003). Typically, towards the end of a term, students are asked to provide feedback on their courses and instructors. The effectiveness of classroom instructors along with their course material is usually inferred from such student evaluations of their professors. According to Berk and Theall (2006), a combination of different sources can provide a much more reliable idea of the effectiveness of instructors. These sources can be student interviews, peer evaluations, videos, and teaching awards, among others. On the other hand, assessing educators using an indirect measure such as student performances is not as accurate. Student ratings are often biased towards certain instructors or educational techniques, which provides an inaccurate description of how effective an instructor has been while teaching the material, thus rendering the feedback unreliable (Clayson, 2009; Simpson & Siguaw, 2000; Zabaleta, 2007).

The Standardized Higher-Education Model in the US

The credit hour system was adopted by high schools, colleges, and universities to standardize the educational model in the United States. This meant that students could, irrespective of which college or university they studied in, graduate in a predetermined duration of time consisting of a certain number of credit hours (Heffernan, 1973). This helped to normalize graduation and admission rates, workloads, and academic records across the country. The stability of the system over the decades post World War II increased the faith that educators had in the system, and this came to be known as the full-time equivalent faculty designation (FTE). Universities began (and still continue) to traditionally offer one to three credit hour courses, while the 9-credit course as described in the study remains quite rare in educational settings.

Innovative Teaching Strategies and SDT

Four years ago, the CMT department at Purdue shifted to 9-credit hour course blocks from 3-credit courses. Topics such as cost estimating, building information modeling (BIM), land surveying and layout, mechanical, electrical, and plumbing (MEP) systems, the strength of materials and soils, etc. are now taught to students multiple times at varying levels of increasing complexity from level 150 (first–year or freshman level) to 450 (senior level). The new curriculum is more project-based like construction jobsites and involves active- and scaffolded-learning methods unlike the previous courses which taught individual subjects as an entire unit. Traditional teaching methods in science, technology, engineering, and mathematics (STEM) classrooms are gravitating towards more hybrid mechanisms such as discussions, flipped classroom lectures, self-paced 'flexible' models, independent studies, individual rotation models, enriched virtual classrooms, massive open online courses (MOOCs), and prior learning assessments, among others. Some institutions have also started to focus on competency-based learning to stress learning outcomes instead of seat time (Nodine, 2016). All these attempts are predominantly focused on improving student motivation and their self-determination.

Richard Ryan and Ed Deci built the self-determination theory in the 1970s as a tool intended to delve into learners' motivation and determination (Ryan & Deci, 2019). The theory creates an easily applicable and replicable framework from internal (e.g., emotions, needs, and drive) and external (e.g., social, cultural, and environmental) factors that may or may not contribute to an individual's motivation. SDT has three primary needs:

- Autonomy: the belief that one can control their actions
- Competency: confidence in one's own ability and knowledge, and
- Relatedness: a sense of connection between peers or between a learner and their instructor (such as respect, care, etc. (Filak & Sheldon, 2003).

Methodology

We chose ethnography as the research method for this study. An ethnographic research approach can utilize qualitative analysis to define and describe contextualized data (Harvey & Myers, 1995) Ethnography allows continuous data collection through an active presence of the ethnographer. The CIE at Purdue University facilitated this process by observing undergraduate students inside their classrooms from a neutral standpoint. CIE representatives continued to collect data through leading group discussions, engaged listening, and documentation of the responses from the learners in the classroom (Forsey, 2010).

Five redesigned courses (with 334 students in total) were selected for the study. The five chosen courses were CM-150 or 'Construction Management Fundamentals' with 46 students, CM-200 or 'Intermediate Pre-construction Management' with 108 students, CM-250 or 'Intermediate Construction Management' with 69 students, CM-300 or 'Advanced Pre-construction Management' with 70 students, and CM-350 or 'Advanced Construction Management with' 41 students. As this study focused exclusively on redesigned curricula, courses following the older curriculum were not included in the study. Some students were counted twice as CMT students at Purdue University are allowed to take 200- and 300-level courses simultaneously, however, data shows that less than 15% of learners usually do so each semester.

The tool used for data collection was SGID. SGID can collect data on the structure, organization, course material, and instruction formats of any educational course during the semester (Diamond, 2004). This was assisted by group discussions led by CIE, a neutral third party, and often a graduate assistant or a colleague who does not teach the course. The participants discussed the pros and cons of teaching strategies of the course in small groups. CIE representatives used two leading questions to facilitate the discussions without narrowing the spectrum of student responses (Berk & Theall, 2006), which the students discussed within their small groups. Following that, the representatives summed up the outcomes before the entire class for their common opinion. The two leading questions from the CIE were:

- What about the environment, activities, and structure of this course are helping your learning?
- What specific suggestions do you have on changing the environment, activities, or structure of the course to better help your learning?

After the discussion, the CIE facilitators took notes on the following *five* areas and submitted the anonymous dataset to the CMT faculty for further investigation, namely, Course Organization and Structure, Course Content, Instructor Characteristics, Teaching Techniques, and Assessment and Grading. Researchers thematically investigated the consolidated dataset to develop any identifying descriptive patterns present in the statistics. Thematic analysis is a specific research method that can be used to show similarities and identify patterns in a data set. Such methods are flexible, applicable, and easy to use in research and educational contexts and can depict contrasting perceptions among participants (Braun & Clarke, 2006).

Table 1

Steps followed in the thematic analysis

Steps	Description
1. Getting familiar with the data	Transcribing data, iteratively reading data, noting down initial ideas.
2. Generating initial codes	Systematically coding interesting features of the data, collating those relevant to each code.
3. Searching for themes	Collating data and codes into potential themes.
4. Reviewing themes	Checking if the themes work with the coded extracts and entire data set, generating a thematic map of the analysis.
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, the overall story from the analysis, generating clear definitions/names for each theme.
6. Producing the report	Final analysis, select vivid and compelling extract examples, relating it back to research question and literature, and producing a scholarly report.

The responses were first sorted and coded into the previously mentioned five categories by the CIE representatives. We then utilized two independent raters who independently analyzed the provided data using SDT dimensions (one being the principal investigator of the study, along with a graduate researcher experienced in SDT). Both separately decided how the responses were affiliated to a dimension of SDT, whether it could be described as autonomy, competency, or relatedness. From McHugh (2012), the concept of Cohen's Kappa (κ) statistic was used to interrelate the results of the two researchers. The values varied as:

- ≤ 0 indicated no agreement at all,
- 0.01–0.20 as none to slight agreement,
- 0.21–0.40 as fair agreement,
- 0.41–0.60 as moderate agreement,
- 0.61–0.80 as substantial agreement, and
- 0.81– 1.00 as near perfect agreement

The data in this study found that the reliability statistic across all three SDT dimensions between the two raters were $\kappa = 0.73$ for autonomy, $\kappa = 0.69$ for competency, and $\kappa = 0.62$ for relatedness. The results showed that 'substantial agreement' existed between the two raters for each of the three SDT dimensions. This provided a concrete idea of how the learners perceived the changed curriculum being offered to them

Findings

A total of 116 responses were provided by each participant in the study, of which 33 were about helpful attributes of the course that contributed to their experience, and the remaining 83 were comments and suggestions on further improvement of the curriculum. For example, students stated that they preferred to include "*more field trips/site visits*" in their courses, which can be related to 'competency' under SDT. Site visits are always an intrinsic part of construction management education, and it helps students understand and relate to classroom material better when they were able to *see* them on jobsites. Additionally, students also stated that "*better organization of Brightspace content*" (Brightspace being their primary online learning/course management system) helped greatly, and this can be attributed to 'autonomy'. This improvement in online material structuring helped the students find course material pertaining to each week more efficiently and made the course load easier for them. "*Good collaboration between Professors or Instructors and content*" was found to be an example of 'relatedness' for the students. According to Diamond (2004), contextual feedback like this can help instructors improve courses in the future by incorporating features that can motivate students and help them learn effectively

Student Perceptions from SGID Data

The SGID data showed that the learners had various suggestions about the structure and presentation of the course material (approximately 30% of their suggestions). Their next concern was course content which was the topic of about 28% of their comments, which included '*hands on lab sessions*', '*more in-class activities*' and having definite '*areas of concentration such as Mechanical, Electrical and Plumbing (MEP), Healthcare, Residential, etc.)*'. It is essential that the learners' perception of their courses is factored into its design as it can have a significant impact on student success and their motivation towards learning (Sherry et al., 1998). Table 2 below shows all the findings based on the five SGID factors from all five undergraduate CMT courses.

Table 2

Student perceptions of overall courses based on number of responses/comments

	Course Organization / Structure	Course Content	Instructor Characteristic	Teaching Techniques	Assessment and Grading
Course 1	0	5	0	6	2
Course 2	10	7	6	3	4
Course 3	11	7	1	2	5
Course 4	3	7	2	5	4
Course 5	11	6	3	3	3
	35 (30%)	32 (28%)	12 (10%)	19 (16%)	18 (16%)

Students of Course 1 were CMT freshmen, and they were found to be mainly concerned with teaching techniques and practices. They also thought that scaffolding issues were not taught for long enough during laboratory classes. The concerns of students from Courses 2, 3, and 4 were equally distributed between the importance of both course structures and course content. In Course 5, it was found that the students' apprehensions focused greatly on team collaboration, learning together in groups, and hands-on activities as they felt that those contributed to their knowledge levels and competency.

The Role of SDT in Education

Self-determination theory can help course instructors and researchers understand which specific factors can motivate a learner toward their education and make them successful. This study only focuses on how SDT can assist instructors in recognizing how students perceive a completely redesigned course curriculum. The motivations for each of the three SDT factors were found to be 54% for competency, 30% for autonomy, and 16% for relatedness. According to (Filak & Sheldon, 2003), satisfying all three factors will ensure that the students are pushed to their full potential. If a learning environment can fulfill all three SDT factors, then students' motivations towards their education have been found to also increase (Jungert et al., 2019). Figure 1 below depicts the three thematic SDT factors distributed over the five corresponding CMT courses.

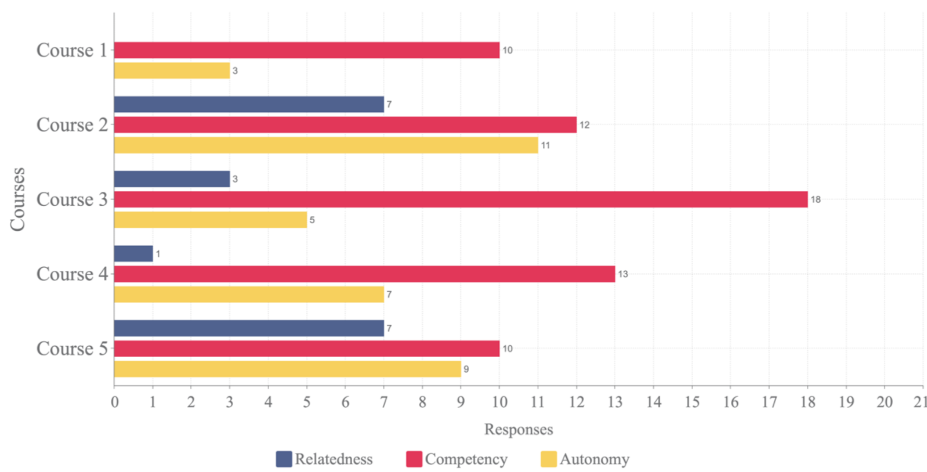

Figure 1: Thematic SDT factors for each course

It was important for the researchers to understand whether students believed that they had volitional control over how they learn and what they learn. Competency, autonomy, and relatedness must all be encouraged and carefully enforced in a learning environment for students to feel involved in and motivated towards their education and 'heard' by their instructors. This also helps build a good rapport and a level of trust between students and their mentors or instructors (in this case, professors). Competency and autonomy help in building necessary skills of learners, and relatedness makes learners feel connected to their peers and the course material, and thus this can greatly contribute to how much they learn from it. This assists in interpersonal development as well as professional improvement in students and can make the course work more solid and quantifiable in the learners' eyes. Additionally, these quantified perceptions can help course instructors think of ways to improve the course material for future semesters.

Conclusions

In an educational context, self-determination theory is extremely useful for educators and course instructors (Reeve, 2002). In this study, SDT was successfully utilized to understand students' perceptions in an educational setting involving a redesigned curriculum. Additionally, SDT can help educators thematically understand their students' perceptions beyond their course evaluations which can often be undependable (Clayson, 2009). The Center for Instructional Excellence, a neutral third party from Purdue University, facilitated an ethnographic data collection by using SGIDs in accordance with the specific research questions of this study. Following that, researchers at Purdue analyzed the data thematically as described earlier in the paper.

The collected data was aggregated for thematic analysis by the two raters. The findings showed that students were highly intuitive about their courses and how they were affected by teaching strategies. Concerns ranged from structural issues with the course, to communication methods, and course content. They were focused on various aspects of the CMT courses, starting from incorporation of field visits in their curriculum to collaboration between peers. It was found that students in different years of their degree also had stark differences in their concerns. The study found that self-determination theory is well-connected to educational coursework and how students react to changes in their course material. The 'relatedness' factor successfully determined areas which made students feel connected and relatable to others. The other two factors, i.e., 'autonomy' and 'competency' helped the researchers identify certain aspects of their construction management courses at Purdue which encouraged student learning. The factors can interfere with the students' motivation toward their education and help them learn the material on their own. Keeping the findings in mind, one can ensure that their teaching environments are interesting, encouraging, and help the students grow both professionally and personally.

Limitations

There are limitations in the scope of this study that future studies can investigate further. Students with stronger personalities may unintentionally 'push' their opinions on their peers during group discussions. This can subdue opinions from introverted or quieter participants, thus causing the collected data to be biased toward a certain demographic. However, SGIDs have the capacity to extract data from such settings by changing the power dynamics that may exist between peers, and thus can assist instructors in schools and colleges. Additionally, as this study was specific to construction management technology students at Purdue University, the results of this paper may not be strictly applicable to other majors and may not be easily generalized for other schools. However, the study can still be modified and can be scaled-up to fit the needs of other non-related scientific fields. The research questions included in this study can be customized depending on the educational settings of other majors. Comparative studies can also be conducted in the future to establish relationships between past courses and newer redesigned courses. Long term longitudinal studies can also show how such curriculum changes impact student motivations over time, and whether students' attitudes towards such courses and their effectiveness change or evolve over time.

References

Benhart, Brad L, Cabral, J. A., Ph, D., Hubbard, B. J., Ph, D., Metzinger, J. R., Santon, S. D. (2017). Construction Management Curriculum Transformation through Project-Based Learning; Part 1 of a Progressive Case Study. *ASC Proceedings of the 53rd Annual Conference*, 19–27.

Benhart, Bradley L, & Shaurette, M. (2012). Restructuring Purdue University's Construction Management Curriculum Utilizing Graduate Competencies and American Council for Construction Education Standards. *48th ASC Annual International Conference Proceedings*.

Berk, R. A., & Theall, M. (2006). *Thirteen strategies to measure college teaching: a consumer's guide to rating scale construction, assessment, and decision making for faculty, administrators, and clinicians*. Stylus Publishing, LLC.

Borrego, M., & Henderson, C. (2014). Increasing the use of evidence-based teaching in STEM higher education: A comparison of eight change strategies. *Journal of Engineering Education*, *103*, 220–252.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*, 77–101.

Clayson, D. E. (2009). Student evaluations of teaching: Are they related to what students learn?: A meta-analysis and review of the literature. *Journal of Marketing Education*, *31*, 16–30.

Dagenais, M. E., Hawley, D., & Lund, J. P. (2003). Assessing the Effectiveness of a New Curriculum: Part I. *Journal of Dental Education*, *67*, 47–54.

Diamond, M. R. (2004). The usefulness of structured mid-term feedback as a catalyst for change in higher education classes. *Active Learning in Higher Education*, *5*, 217–231.

Filak, V. F., & Sheldon, K. M. (2003). Student Psychological Need Satisfaction and College Teacher-Course Evaluations. *Educational Psychology*, *23*, 235–247.

Forsey, M. G. (2010). Ethnography as participant listening. *Ethnography*, *11*, 558–572.

Harvey, L. J., & Myers, M. D. (1995). Scholarship and practice: The contribution of ethnographic research methods to bridging the gap. *Information Technology & People*, *8*, 13–27.

Heffernan, J. M. (1973). The Credibility of the Credit Hour: The History, Use, and Shortcomings of the Credit System. *The Journal of Higher Education*, *44*, 61–72.

Henriques, P. L., Matos, P. V., Jerónimo, H. M., Mosquera, P., da Silva, F. P., & Bacalhau, J. (2018). University or polytechnic? A fuzzy-set approach of prospective students' choice and its implications for higher education institutions' managers. *Journal of Business Research*, *89*, 435–441.

Huchel, B. (2020). Purdue using Lilly Endowment grant to create innovation engine for transforming higher ed learning. Retrieved from https://www.purdue.edu/newsroom/releases/2020/Q4/purdue-using-lilly-endowment-grant-to-create-innovation-engine-for-transforming-higher-ed-learning.html

Jungert, T., Hubbard, K., Dedic, H., & Rosenfield, S. (2019). Systemizing and the gender gap: examining academic achievement and perseverance in STEM. *European Journal of Psychology of Education*, *34*, 479–500.

McHugh, M. L. (2012). Lessons in biostatistics interrater reliability: the kappa statistic. *Biochemica Medica*, *22*, 276–282.

Nodine, T. R. (2016). How did we get here? A brief history of competency-based higher education in the United States. *The Journal of Competency-Based Education*, *1*, 5–11.

Persky, A. M., Greene, J. M., Anksorus, H., Fuller, K. A., & McLaughlin, J. E. (2019). Developing a comprehensive first-year capstone to assess and inform student learning and curriculum effectiveness. *American Journal of Pharmaceutical Education*, *83*, 804–813.

Reeve, J. (2002). Self-determination theory applied to educational settings. In *Handbook of self-determination research* (pp. 183–204). Rochester, NY: University of Rochester Press.

Ryan, R. M., & Deci, E. L. (2019). *In A. J. Elliot (Ed.), Brick by brick: The origins, development, and future of self-determination theory.* Cambridge, MA: Elsevier Inc.

Santon, S. D., Metzinger, J. R., Cabral, J. A., Benhart, B. L., & Morgan, P. C. (2018). Construction Management Curriculum Transformation through Project-Based Learning: Part 2 of a Progressive Case Study. *54th ASC Annual International Conference Proceedings*, 23–31.

Shedd, J. M. (2003). The History of the Student Credit Hour. *New Directions for Higher Education, (122)*, 5–12. https://doi.org/10.1002/he.106

Sherry, A. C., Fulford, C. P., & Zhang, S. (1998). Assessing distance learners' satisfaction with instruction: A quantitative and a qualitative measure. *American Journal of Distance Education*, *21*, 4–28.

Simpson, P. M., & Siguaw, J. A. (2000). Student Evaluations of Teaching: An Exploratory Study of the Faculty Response. *Journal of Marketing Education*, *22*, 199–213.

Strimel, G. J., Krause, L., Bosman, L., Serban, S., & Harrell, S. (2020). The Next Generation for Manufacturing Competitiveness?: Investigating the Influence of Industry-Driven Outreach on Children Career Perceptions. *Journal of STEM Education Research*, 1–27.

Walkington, J. (2002). A process for curriculum change in engineering education. *European Journal of Engineering Education*, *27*, 133–148.

Zabaleta, F. (2007). The use and misuse of student evaluations of teaching. *Teaching in Higher Education*, *12*, 55–76.

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Effectiveness of Collaborative Learning in a CM Flipped Online Course: A Case Study

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The collaborative learning has been used for Construction Management (CM) courses to enhance students' learning. Few existing studies reported the effectiveness of collaborative learning in terms of assessment score in CM online courses: existing literature found the effectiveness of collaborative learning in CM courses based on students' perception. This research aimed to study the effectiveness of collaborative learning in an online CM course in two ways: in terms of 1) student's assessment score and 2) students' perception. Students in a CM course taught by the first author were grouped into two: the experimental group with collaborative learning experience and the control group without collaborative learning experience. Their assessment scores and perceptions on collaborative learning experience were examined in this study. The test scores and students' response to the questionnaire survey showed a mixed result. While the students in the experimental group perceived that collaborative learning was helpful in their learning, there was no significant difference in the assessment scores between the two groups. The finding from this study can help CM educators by providing a quantitative and qualitative study on the effectiveness of collaborative learning in online CM courses.

Key Words: Collaborative Learning, Synchronous Online Class, Flipped Classroom

Introduction

Collaborative learning can be defined as "an instructional method in which students at various performance levels work together in small groups towards a common academic goal" (Gokhale, 1995). Many researchers and educators have reported that collaborative learning can be beneficial to students in many aspects such as students' knowledge construction and building team management skills. Thus, collaborative learning has been widely used across face-to-face, online and hybrid courses (Lee et al., 2006). Also, collaborative learning has been adopted and used for construction education (Chan and Sher, 2014).

The remote learning approach has been adopted and employed for construction education, specifically during the COVID-19 pandemic. Students can take lessons, complete assignments, and work together with their classmates through online tools such as a learning management system (LMS) without physically being in a classroom. However, the remote course delivery approach has several limitations such as interaction between students, between student and teacher, and collaboration for students' group assignments (Sobko et al. 2019; Adhiikari et al., 2021). Advancement in information technology has allowed students in online classes to communicate and collaborate with their peers more efficiently in diverse formats in online classes such as through a LMS discussion forum, email, video conference, etc. Synchronous online teaching became available due to advancement in information technology as well; students can join a virtual classroom and take lessons without being in a classroom in-person.

The authors' institution required that all the courses should be delivered remotely under the COVID-19 pandemic, specifically since the second half of the Spring 2020 semester. The first author transformed his courses abruptly from face-to-face format to the online format in the semester. The lectures were pre-recorded and shared through a LMS, and the students were required to finish assignments remotely. All the homework assignments in the courses were done individually and remotely. The courses were taught in an asynchronous approach. The students in the courses barely interacted with their classmates in the asynchronous format of course delivery, and the author received negative feedback from students on the missed learning components. Thus, the first author changed the course delivery method from asynchronous online to synchronous online for his courses in the Fall 2020 semester.

While benefits of collaborative learning in higher education have been studied, few studies found these benefits of collaborative learning on students' learning in synchronous online classes for construction education. This research aimed to explore the effectiveness of the collaborative learning approach on students' learning in the first author's synchronous online construction course.

Literature Review

Benefits of Collaborative Learning

Collaborative learning allows students to work together at various performance levels (Gokhale, 1995) and enables students to link their experiences with those of their peers (McNamara and Brown, 2008). It has been reported that the collaborative learning approach is a more effective teaching method than the traditional teaching method (Coffey and Clarke, 2021). In addition, benefits of the collaborative learning approach have been reported in diverse aspects: improvement in academic achievement (Stump et al., 2011), stronger learner satisfaction (Springer et al., 1999), effective delivery of generic skills (Johnson and Johnson, 2009), improved interpersonal skills (Johnson and Johnson, 2009), development of better critical thinking skill (Palloff and Pratt 2005), development of a sense of community (Palloff and Pratt 2005), and development of social skills needed for future professional work (Scager et al. 2016).

Also, other existing literature reported that the improvement in students' learning through the collaborative learning approach could be obtained through: communication and knowledge exchange (Chiong and Jovanovich, 2012), discussion with their peers and faculty (Goold et al., 2006), high quality social interaction and engagement between students (Visschers-Pleijers et al., 2006), and fostering a diversity of thought from other students (Laux et al., 2016-1)

Collaborative Learning in Online Classes

Due to advancement in information technology, collaborative learning has been increasingly used for online courses (Lee et al., 2006). The ease to share what is created and communicated online made the collaboration in online courses more affordable (Sobko et al. 2019). Additionally, several other researchers reported advantages of online collaborative learning compared to face-to-face collaborative learning: task completion and effectiveness of work (Morsi and Assem, 2021), more cognitive load and collaboration (NireLan et al., 2019), and higher level of equity in students' participation in class activities (Fowler, 2014). Due to the benefits of collaborative remote teaching, Adhiikari et al. (2021) recommended more collaborative activities in CM online courses, specifically during the pandemic.

Online courses can be taught synchronously or asynchronously. In a synchronous online class, students are required to join a class meeting at a specified time through an online tool such as Zoom and complete real-time class online. On the other hand, students in an asynchronous online class can finish all required learning tasks at their convenient time. Online synchronous learning involves a real-time, instructor-led learning environment where students can interact with their instructor(s) and other participants at the same time. Benefits of synchronous learning were identified as increased student focus on tasks (Chen and You, 2007), a larger sense of participation by students (Mabrito, 2006), better task competition rates by students and better control of the interactions in class by teachers (Hrastinski, 2010).

However, the synchronous online class may be more teacher oriented (Murphy et al., 2011), thus, diverse class activities are recommended to broaden the scope of communication and interaction between students (Perveen, 2016). One solution to more students' interaction and active learning opportunities is to "flip" the classroom. By moving direct instruction from the group learning space (class time) to individual learning space (pre-class assignment), more class time can be used for a dynamic and interactive learning environment (The Flipped Learning Network, 2014).

Effectiveness of Collaborative Learning in Synchronous CM Online Classes

Effectiveness of collaboration on students' learning has been of interest to researchers and teachers for construction education. Chan and Sher (2014) studied benefits of collaborative learning in Architecture-Engineering-Construction (AEC) courses and identified that the collaborative learning approach could provide enhanced academic knowledge and general skill. However, the result was based on students' perception through a questionnaire survey, and the AEC courses in which the effectiveness of the collaborative learning was studied were not in an online format. Dong and Guo (2013) reported that the collaborative learning methods in their online courses led to higher satisfaction in students' learning from two questionnaire surveys administered pre-collaboration and post-collaboration. Zheng et al. (2018) studied the effectiveness of the collaborative learning in their non-online courses through comparison of test scores between two groups and concluded that the collaborative learning increased students' knowledge. However, the collaborative learning activity in their study was limited to discussion through an online discussion board in the learning management system. Laux et al. (2016-2) reported that the collaborative learning approach impacted students' learning positively in a non-online class. Their conclusion was also based on students' perception, not on the direct assessment of students' learning outcome.

Existing literature includes only a few studies on effectiveness of collaboration on students' learning in a synchronous online course. Akarasriworn and Ku (2013) used an online synchronous video conferencing application which includes functions of video, audio, chatting, and whiteboard in an online class and concluded the tool promoted students' knowledge construction. Sobko et al. (2019) studied the effectiveness of collaboration in their online class where a synchronous video conference application was used for discussion and reported that students' knowledge construction was improved by the synchronous engagement tool. However, the findings from these studies are based on students' perception through questionnaire surveys, not based on direct assessment of students' learning outcome.

While it has been reported that online collaboration enhances students' learning achievement, few empirical studies have examined the effectiveness of synchronously collaborative learning approach on students' learning through direct assessment of students' learning outcome in CM courses.

Research Question

The objective of this research is to explore benefits of collaborative learning on students' learning in a synchronous online CM class. Specifically, this study aims to find the answer to the question, *how effective is collaborative learning on students' learning in a synchronous online CM class?* The research question is divided into the following sub-questions to fulfill the research objective:

1) How does the collaborative learning approach affect students' test scores before and after the collaborative learning experience?
2) How do students perceive the effectiveness of collaboration on their learning?

Methodology

The Construction Scheduling course which was taught by the first author in the Fall 2020 semester was transformed to a "flipped classroom" to allow more collaboration and real-time feedback in a synchronous online format. The "flipped" format in the course includes the following key features:

1) Lecture videos and online quizzes before class: short lecture videos (maximum time was 15 minutes) were recorded to introduce a new topic to students and students were required to watch the videos before the class. They were also requested to take online quizzes after watching the lecture videos. The main purpose of the pre-class online quizzes was to encourage the students to study the content before the class.
2) Quick review session and class activities during class: at the beginning of each class, the course instructor reviewed the lecture for the class quickly, and student were provided with two types of class activities as followings.
   - Instructor-guided problem solving: the course instructor explained how to apply the knowledge which was introduced in the lecture video(s) in a real-world problem.
   - Student-led work example problem: After the instructor-guided problem solving, another real-world problem was assigned to students. They were asked to turn in the assignment near the end of the class. The student-led work problems were typically a more complex application of the basic content so that students' knowledge could be expanded or enhanced.

Several tools and applications were used to support the synchronous online format and synchronous collaboration in the course: a learning management system for sharing lecture videos, quizzes, in-class work problems, and students' grades, a video conferencing application (Zoom) for real-time lecture and communication including the *Breakout Room* function, *Microsoft Class Notebook* for instant feedback of students' in-class problem solving, an online whiteboard application (*Mural*) for presentation of solutions to complexed problems such as network diagrams for a construction schedule, and *Citrix Remote Desktop and Virtual Apps* for the access to the scheduling software (*Microsoft Project*).

Measurement of the Effectiveness of the Collaboration through Two Student Groups

To measure the effectiveness of collaborative learning in a synchronous online CM class (the research question #1), students in the course were divided into two groups. One group was asked to complete all the class assignments (or in-class problem solving) with collaboration (the experimental group), and the students in the other group were asked to complete all the in-class assignments individually. Change in each student's assessment scores before and after in-class activities (or assignments) were statistically compared through a student's t-test.

The course had two sections in Fall 2020. The first section (Section 01) was the experimental group, and the other section (Section 02) was treated as the control group. The students in the experimental group were required to form a group of two students and complete all in-class assignments (or activities). To help students in the Section 01 stay accountable for their group work, the students were required to complete and submit a peer-evaluation for each assignment as suggested by Kim et al. (2008). A total of 13 pre-class online quizzes were assigned to the students in both groups. Table 1 compares the required work between the two groups.

Table 1

Required student's work

	Before class	During class	Assessment
Section 01: with collaboration	13 Individual pre-class assignments for both sections	Collaborative in-class problem solving	Individual exam
Section 02: without collaboration		Individual in-class problem solving	

Students in both the experimental and control groups were required to take pre-class online quizzes individually before the in-class learning activities and an individual exam at the end of the semester. This research aimed to explore how the collaborative learning activities in the experimental group would affect students' learning. The effectiveness of the collaborative learning was to be assessed through the change in assessment scores (pre-class online quiz score and exam score after the collaboration). Then, the changes in the two student groups were compared if there is any significant difference.

The students in the course were required to take total 13 pre-class online quizzes. The average score for the pre-class online quizzes was calculated. While the pre-class online quizzes typically were less than 10 simple questions, the exam was the only test which counted for 25 percent of a student's final grade and included questions about all the topics learned through the semester. Thus, it was expected that a student's exam score would be lower than the pre-class online quiz score for the student. The change between the two scores is calculated as ***exam score – pre-class online quiz score*** in this research. The null hypothesis was that there would be no significant difference in the change between the two scores between the two groups.

Students' Perception on Collaborative Learning

In addition to quantitative measurement of the effectiveness of the collaborative learning on students' learning (the research question #1), a questionnaire survey was administered to find how students perceived the collaborative learning experience in the course (the research question #2) only to the students in the experimental group. The only question in the survey was how students agree to the statement, *Collaboration has been helpful for me to understand/expand the key concepts and to solve the problems in the in-class assignments.* The question was asked to only the students in the experimental group through the *Microsoft Forms* at the end of the semester.

Results

There were 26 students enrolled in the Section 01 (the experimental group), and 23 students enrolled in the Section 02 (the control group). All the scores for both the pre-class online quizzes and the exam were collected and graded through the course learning management system. Students' response to the survey question were collected through the *Microsoft Forms*. A total of 25 responses out of the 26 enrolled students in the experimental group were collected and 23 responses were collected in the control group.

Effectiveness of the Collaboration on Students' Learning through Exam Score

The Figure 1 below shows the average scores for pre-class online quizzes and the average exam scores for the two student groups. In both groups the (average) exam scores were lower than those in the pre-class quizzes.

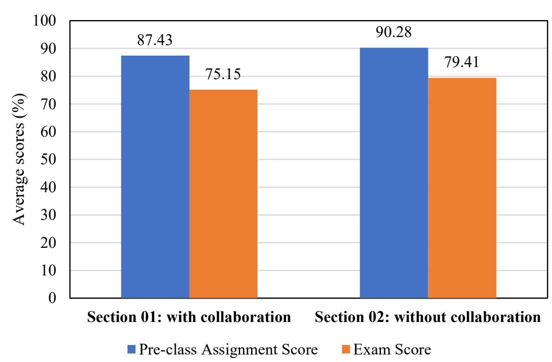

Figure 1: Assessment results between the two groups.

The two average scores in each class section were investigated to see whether there was a significant difference between the two sections through a student t-test. The average pre-class assignment scores (87.43% in the experimental group and 90.28% in the control group) are not statistically different. Also, the average exam scores between the two groups (75.15% in the experimental group and 79.41% in the control group) are not significantly different.

The changes between the exam score and pre-class online quiz score [*exam score- pre-class online quiz score*] in the two class sections were analyzed through a student t-test. The null hypothesis was that there is no significant difference in the change between the two scores between the two groups. The p-value is greater than the alpha value (0.05), so the null hypothesis cannot be rejected: the changes between the exam score (average score) and the pre-class quiz score (average score) between the two student groups are not significantly different. The results indicate that the collaborative learning activities in the course were not more effective on students' learning than the individual learning approach.

Students' Perception on the Effectiveness of the Collaborative Learning

The Figure 2 shows students' responses to the survey question about helpfulness of the collaborative learning activities in the class (the experimental group). 80% of the students perceived that the collaborative learning approach was helpful (52% for "Strongly Agree" and 28% for "Somewhat Agree").

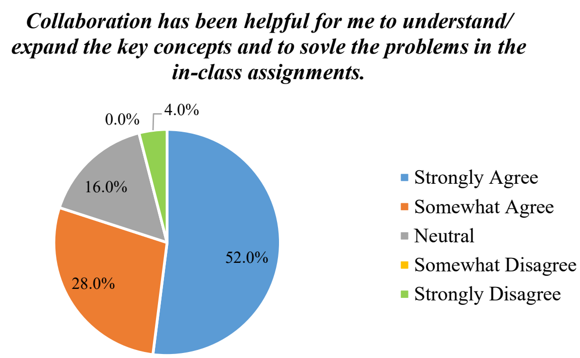

Figure 2: Students' response on degree of helpfulness of the collaboration.

Discussion

The students' assessment scores and their answers to the questionnaire survey in this study show mixed results. While students perceived that collaborative learning was effective on their learning, the assessment scores (for both exam score and online quiz scores) show that the collaborative learning was not more effective than individual learning approach. One of the limitations in this research is the small sample size, and this limitation may have caused the mixed results.

Conclusions

The collaborative learning approach has many advantages such as improved academic performance and stronger student satisfaction, and this approach is recommended for active learning for construction education. Recently, the online course delivery method has become more popular due to advancement in information technology. Also, online course delivery method was requested during the COVID-19 pandemic, specifically in the Spring 2020 semester. In an online course delivery approach, collaborative learning activities were recommended to enhance the students' learning. Advancement in information technology allowed more diverse formats of real-time collaborative learning experiences in synchronous online class. However, few existing literature studied the effectiveness of collaborative learning experience on students' learning in synchronous online CM courses, specifically directly measured from assessment of student learning outcomes. Thus, this study aimed to investigate the effectiveness of collaborative learning on students' learning in a synchronous online CM course through a case study. One CM course at the authors' institution was transformed to a format of synchronous online flipped class in the Fall 2020 semester for the case study. The students in one section of the course were taught with collaborative learning activities (the experimental group), while the students in the other section finished class activities without collaboration (the control group). The change in each student's assessment score before and after the class activities was compared between the two student groups, and it was concluded that the collaborative learning approach was not more effective than the typical individual learning approach. However, students who finished the course with the collaborative learning activities perceived that the collaboration in the class was helpful. These mixed results need future research with large samples. This finding can be helpful to construction educators because this is the first research on effectiveness of collaborative learning which was assessed directly from students' tests a in synchronous online CM course.

References

Adhikari, S., Mosier, R., and Langar, S. (2021). Challenge of Delivering Construction Courses in an Online Environment Based on Faculty Experiences. ASC 2021. 57th Annual Associated Schools of Construction International Conference, Vol 2, pages 451-459

Akarasriworn, C., and Ku, H. (2013). Graduate Students' Knowledge Construction and Attitudes toward Online Synchronous Videoconferencing Collaborative Learning Environments. *The Quarterly Review of Distance Education*, 14(1), pp. 35-48.

An, H., Kim, S., and Kim, B., (2008). Teacher perspectives on online collaborative learning: Factors perceived as facilitating and impeding successful online group work. *Contemporary Issues in Technology and Teacher Education*, 8(1), 65-83.

Center for Teaching Innovation at Cornell University, Collaborative Learning, https://teaching.cornell.edu/teaching-resources/active-collaborative-learning/collaborative-learning

Chan, C.T.W., and Sher, W. (2014). Exploring AEC education through collaborative learning. *Engineering, Construction and Architectural Management*, 21(5), pp.532-550

Chen, W., & You, M. (2007). The differences between the influences of synchronous and asynchronous modes on collaborative learning project of industrial design. In D. Schuler (Ed.), *Online communities and social computing* (pp. 275–283). Berlin Heidelberg Springer.

Chiong, R., & Jovanonic, J. (2012). Collaborative learning in online study groups: An evolutionary game theory perspective. *Journal of Information Technology Education: Research,* 11, 81-101.

Coffey, R. and Clarke, S. (2021). Construction Management Teaching Methods and Assignments: Perception versus Reality. Proceedings for the 57th Associated Schools of Construction (ASC) Annual International Conference. Volume 2, page 377-386

Dong, J., and Guo, H., (2013). Effective Collaborative Inquiry-based Learning in Undergraduate Computer Networking Curriculum. 120th ASEE Annual Conference & Exposition, June 23-26k, 2013, Atlanta, Ga

Flipped Learning Network (FLN). (2014) The Four Pillars of F-L-I-P™, https://flippedlearning.org/definition-of-flipped-learning/

Fowler, R. (2014). Talking Teams: Increased Equity in Participation in Online Compared to Face-to-Face Team Discussions. 121st ASEE Annual Conference & Exposition, Indianapolis, IN, June 15-18

Gokhale, A.A. (1995). Collaborative learning enhances critical thinking. *Journal of Technology Education*, 7(1), pp. 22-30.

Goold, A., Augar, N., & Farmer, J. 2006. Learning in virtual teams: Exploring the student experience. *Journal of Information Technology Education, 5*, 477-490.

Hrastinski, S. (2010). How do e-learners participate in synchronous online discussions? Evolutionary and social psychological perspectives. In N. Kock (Ed.), *Evolutionary psychology and information systems research.* pp. 119–147. Springer.

Johnson, D.W. and Johnson, R.T. (2009). An educational psychology success story: social interdependence theory and cooperative learning. *Educational Researcher*, 38(5), pp. 365-379.

Lan, Ch., Sheng, M., Hsu, Y., and Shiue, Y. (2019). Learning Style on Cognitive Load and Engagement in a Health Introductory Course, Proceedings of the third International Conference on Medical and Health Informatics 2019l, Xiamen, China. Pp. 142-148.

Laux, D, Luse, A., and Mennecke, B.E. (2016). Collaboration, Connectedness, and Community: An examination of the factors Influencing Student Persistence in Virtual Communities. Supply Chain and Information Systems Publications, Iowa State University Digital Repository.

Laux, D., Jackson, A., and Mentzer, N. (2016). Impact of Collaborative Learning on Student Persistence in First Year Design Course. 123rd ASEE Annual Conference & Exposition, New Orleans, LA, June 26-29, 2016

Lee, S.,Bonk, C., Magjuka, R., Su, B., & Liu, X. (2006). Understanding the dimensions of virtual teams. *International Journal on ELearning, 5*(4), 507-523.

Mabrito, M. (2006). A study of synchronous versus asynchronous collaboration in an online business writing class. *American Journal of Distance Education*, *20*(2), pp.93–107.

McNamara, Judith and Brown, Catherine (2008). Assessment of collaborative learning in online discussions. In Proceedings ATN Assessment Conference 2008, Engaging Students in Assessment, University of South Australia, Adelaide.

Morsi, W.K., and Assem, H. M. (2021). Online versus Face-to-face Collaborative Learning: Perceptions of Students and Instructors of Technical Writing for Engineers. 2021 IEEE Global Engineering Education Conference (EDUCON), pp. 1571-1581.

Murphy, E., Rodríguez-Manzanares, M. A., & Barbour, M. (2011). Asynchronous and synchronous online teaching: Perspectives of Canadian high school distance education teachers. *British Journal of Educational Technology, 42*(4), 583–591.

Palloff, Rena M., and Pratt K. (2005). Collaborating Online: Learning Together in Community. San Francisco: Jossey-Bass.

Perveen, A. (2016). Synchronous and Asynchronous E-Language Learning: A Case Study of Virtual University of Pakistan. *Open Praxis, 8*, 21-39.

Scager, K., Boonstra, J., & Peeters, T., Vulperhorst, J., & Wiegant, F. (2016). Collaborative Learning in Higher Education: Evoking Positive Interdependence. *CBE Life Sciences Education*. 15(10).

Sobko, S., Unadkat, D., Adams, J., and Hull, G., (2019). Learning through collaboration: A networked approach to online pedagogy. *E-Learning and Digital Media*, 17(1), pp. 36-55.

Springer, L., Stanne, M.E. and Donovan, S.S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: a meta-analysis. *Review of Educational Research*, 69 (1), pp. 21-51.

Stump, G.S., Hilpert, J.C., Husman, J., Chung, W.T. and Kim, W. (2011). Collaborative learning in engineering students: gender and achievement. *Journal of Engineering Education*, 100 (3), pp. 475-497.

Visschers-Pleijers A.J., Dolmans D.H., De Leng B.A., Wolfhagen I.H., Van Der Vleuten C.P. (2006). Analysis of verbal interactions in tutorial groups: a process study. *Medical Education.* 40(2):129-37.

Zheng, W., Yan, J., Allison, J.R., Zhang, Z., and Shih, H. (2018). Effects of Online Collaborative Learning with Scaffolding in Multiple STEM Courses Based on Results from Three Consecutive-Year Implementation. 2018 ASEE Annual Conference & Exposition, June 24-27, 2018, Salt Lake City, UT

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Effectiveness of the Synchronous Online Flipped Classroom on Students' Learning During the COVID-19 Pandemic

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The flipped classroom approach is a pedagogical method for active learning and engagement in learning activities. Many Construction Management (CM) educators have adopted this pedagogical method and confirmed its benefits in classroom teaching. However, the effectiveness of the flipped classroom model on students' learning in 100% synchronous online courses, specifically for CM education, is not reported. CM educators need to understand the feasibility and effectiveness of flipped classrooms for online courses during the pandemic. This paper initially presents the technologies and methods adopted in this study to transform two online CM courses into a flipped approach. Later, the flipped classroom model's effectiveness is assessed through student feedback. The results indicated a mixed response from the students regarding the effectiveness of the flipped classroom model over traditional teaching. Although around two-thirds of the students recommend the flipped classroom model over conventional education, they now prefer conventional face-to-face teaching over the online flipped classroom.

Key Words: Pedagogy, Flipped Classroom, Synchronous Online Teaching

Introduction

The flipped classroom pedagogical model is a relatively new alternative to the typical lecture-based teaching approach. In conventional teaching, the students are taught course contents during class time, and they apply the learned concepts through homework, projects, etc., independently at home. This conventional approach is reversed in the flipped approach, where the direct instruction moves from the group learning space (e.g., classroom) to the individual learning space. The resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students to apply concepts and engage creatively in the subject matter. In simple terms, students must learn course contents before the lecture, and they apply the learned concepts in the classroom through diverse activities such as discussion, problem-solving, group projects, etc. Thus, students can expand their knowledge with active learning opportunities, apply it to real-world problems, and experience a better education (Mihai 2016).

The flipped model's benefit in enhancing students' learning experience has attracted many teachers to implement the flipped approach. Furthermore, this approach is practical for different modes of instruction such as traditional teaching (face-to-face), online format, or in a hybrid mode which is a mix of online and face-to-face instruction. While the success of flipped classroom model for face-to-face instruction which is the predominant teaching mode, is widely reported, there is limited reporting about the effectiveness of the flipped classroom model in an online format. However, there has been a sudden surge towards online education for the last two years due to the Covid-19 pandemic, and this trend of virtual education may continue in the future (Diederich et al., 2020). Hence, it is essential to understand whether the flipped classroom model, which proved to be an effective pedagogical method in conventional teaching, holds the same benefit in online education.

Implementing flipped model for online CM education may pose various challenges. First, the CM educators desire to facilitate an active peer learning environment in the classroom through hands-on and group activities (David and Cline, 2009; Hegazy et al., 2013). Online education may hamper such learning opportunities. Second, there is not exiting literature on which components of the course can be flipped and how strategically those components are planned for CM education. Third, does students' individual academic performance have an influence on how they perceive flipped approach? In this regard, this study aims to assess the effectiveness of flipped classroom model in online CM education.

Literature Review

Benefits of the Flipped Classroom Method

Mojtahedi et al. (2020) described that the flipped classroom model for Construction Education improves students' learning experience through collaborations and interaction between students. Lee and Kim (2016) argued that CM students' performance in a flipped classroom outperformed the traditional classroom model. Zapper et al. (2009) and Bishop and Verleger (2013) reported that students generally reacted positively to the flipped classroom model. Similarly, Mihai (2016) stated that the students acknowledged better education in the flipped classroom due to the more profound learning opportunities. Swithenbank and DeNucci (2014) showed the positive outcomes of the reversed pedagogical approach. Other reported benefits of the flipped classroom approach were: effectiveness in helping students apply fundamental concepts in solving cost engineering problems for Civil Engineering students (Ling and Gan, 2020), flexibility in the Civil Engineering class lecture time (Swartz et al., 2013), among others. Despite many researchers' reporting a wide range of benefits offered by flipped classrooms, most of the research was performed in face-to-face instruction mode. Does the flipped model hold the same benefit in online CM education is questionable?

Flipped Classroom in Online Synchronous Classes

The use of online formats for learning and teaching has become more prevalent in recent years due to the advancement of technology. Advanced technology allowed students access to instructional materials and lower costs associated with education (Taplin et al., 2013). Despite the emergence of cutting-edge online teaching technology, its usage was limited as the predominant teaching mode is face-to-face. Nevertheless, in the middle of Spring 2020, the Covid-19 pandemic forced all the instruction to shift online. This abrupt shift to online affected both the teaching and learning, such as less engagement in collaborative learning, student-faculty interactions, peer learning by interacting with fellow students, and easy distractions in online format (Dumford and Miller, 2018 and Hiranrithikorn 2019). As the online mode of instruction was the optimal choice for many universities globally during the Covid-19, faculty need to contemplate ways to promote student engagement in online education.

In general, there are two significant ways of online instruction asynchronous and synchronous. In asynchronous mode, the faculty records the class lectures and makes them accessible to students. Students can access the recorded lectures through faculty-selected paths such as institutions learning management systems (LMS) like Blackboard ™, sharing the videos through YouTube ™, etc. This mode offers more flexibility to students as they review the lectures on their schedules. However, in this mode, students miss the interaction with faculty and fellow students, which may impact their learning ability.

In synchronous mode, the faculty and students meet online at the scheduled time using the communication platforms like Microsoft Teams ®, Zoom, Webex, etc. Thus, synchronous online learning involves a real-time, instructor-led learning environment where students can simultaneously engage with instructors and other students. The instructor has control over the interaction in the class. Therefore, research indicates that synchronous online learning allows students to keep focused on the contents or tasks, promotes students' participation, and could lead to better performance (Chen and You, 2007; Hrastinski, 2010). Considering the possibility of interactions between the faculty and students in synchronous online teaching, many teaching faculty across different degree programs anticipated that the Flipped classroom may suit the synchronous mode of online instruction.

Research Objective and Questions

This study aims to examine the effectiveness of the flipped classroom model in synchronous online CM courses. The efficiency in this study means that the students had a positive experience in flipped approach compared with conventional ones. Besides the effectiveness, this study is also interested to understand if there is any influence of the student's performance on how they perceive the benefits of the flipped approach. For example, diligent students adapt to different learning approaches comfortably compared with underperforming students. Hence, this study aims to determine whether all divisions of the student body feel that the flipped classroom model is effective or only the well-performing students. Therefore, this study aimed to achieve the research objective by addressing the following two research questions:

1. How effective is the flipped classroom model on students' learning in students' perception? This question is addressed by examining the effectiveness of the flipped approach on students' learning from students' perspectives.
2. Is the effectiveness of the flipped classroom in students’ perception affected by their academic performance?
   The hypothesis for this question is that students with different academic performances differently perceive the effectiveness of the flipped classroom model.

Methodology

Design of the Flipped Classroom

In this study, three CM courses taught by one of the authors were redesigned to a flipped classroom model for 100% synchronous online classes. The courses were one section of the "Cost Estimating" and two sections of the "Construction Scheduling" courses. For these two courses, the student learning outcomes (SLO) were to 'create' construction project cost estimates and construction project schedules, respectively. According to Bloom's taxonomy creating is the highest level of learning outcomes. The courses include learning activities with problem-solving and the application of problem-solving skills into real-world problems. The three classes had been taught in the conventional learning method in 100% face-to-face format with lecture by the instructor, instructor-guided problem solving (or application), student-lead work example problems, and homework assignment before the COVID-19 pandemic. Before the Covid-19 pandemic, the instructor employed multiple methods like online quizzes, discussions, and problem-solving in the convention teaching setup. Moreover, students could work together on numerical example problems during class time, and grades were assigned for their classwork to encourage them to participate. However, when the instructor designed courses in the flipped classroom model for Fall 2020, the course contents were like the conventional teaching, except the activities were reversed. The differences between conventional and flipped classroom models are presented in Table 1.

Table 1

Comparison of the flipped classroom model with conventional teaching model

Teaching Method	Before class	Activities During class			Activities After class
Prior to the pandemic	N/A	Lecture	Instructor-guided problem solving (*Problem A*)	Student-led work example problem (*Problem B*)	Application to another problem in a homework (*Problem C*)
Flipped Classroom Model	• Lecture videos (including instructor-guided problem solving (*Problem A*)) • Online quiz	• Review of the contents • Feedback on online quiz	Instructor – guided problem solving (*Problem B*)	Student-led work example problem (*Problem C*)	Faculty provides feedback on the student's work performed during the class.

The significant difference between both methods was that students needed to review the lecture videos and other course materials before the online synchronous class in the Flipped model. Also, the students must take a quiz before the online course. Mojtahedi et al. (2020) recommended pre-class activity like quiz for active engagement in independent learning. The quiz coerces students to review the material and ensures that students studied the material. Typically, the lecture video(s) introduces a new topic and includes simple examples relevant to the subject to help students apply basic knowledge and develop problem-solving skills. To minimize the distractions, the instructor ensured that the lecture videos were typically 10-15 minutes long. During the synchronous online session, the faculty reviews the topic and provides feedback on pre-class activities. These steps support the students to refresh their memory as well as summarize the concepts. Later, the faculty demonstrates the field application of the concepts through a numerical example or case study. Subsequently, the students either work individually or as a group apply their knowledge in solving a problem and submit their work. By the end of the class, students submit their work to faculty, who assess them. No separate after-class activities were required in the flipped instruction. The course elements were reformatted and used for different purposes regarding students learning activities. The Problem A, B, and C in the Table 1 are just for illustration to show how differently the work problems were delivered in the flipped classroom model compared with conventional instruction method.

Tools for the Flipped Synchronous Online Classes

Since this study is applying the flipped classroom model for the 100% synchronous online courses, integrating different course elements with suitable technology is paramount. The selected technology shall support easy interaction and engage students in learning activities without any hindrances. Hence, the following list of technologies were used for the courses in this study:

- Sakai, a learning management system, was used for posting lecture videos, classwork problems, online quizzes, feedback to students, and their grades.
- The Zoom was a virtual space to facilitate interaction between students and instructors. The instructor also used the Breakout Room function for group work as needed.
- Microsoft Class Notebook was used for instant feedback of students' in-class work.
- An online whiteboard application (for example, Mural) was used to present solutions to problems such as network diagrams for construction schedule.
- Microsoft Stream was utilized to save lecture videos and to share them with students.
- Edpuzzle was used for adding interactive content such as quizzes in the lecture videos.
- Students' licenses for cost estimating computer software (OnScreen Takeoff, QuickBid, and Bluebeam Revu) were provided for installation on their computers.
- Citrix Remote Desktop and Virtual Apps were used to access the scheduling software.
- Microsoft Forms ® was used for collecting the feedback from the students.

Online Survey for Student's Perception on the Effectiveness of Flipped Classroom

This study addressed the research objective and questions by collecting and examining the students' responses through a questionnaire which focuses on addressing research question 1 (How effective is the flipped classroom model on students' learning in students' perception?). Students were provided the questionnaire through *Microsoft Forms* and the responses are analyzed in *Microsoft Excel.*

1. Which of the followings do you prefer for your classes?
   a) Traditional (non-flipped classroom) approach: class topics are introduced in the class, and in-class learning activities are performed
   b) Flipped classroom approach: class topics are introduced through pre-recorded lecture notes before class, more in-class learning activities during the class, and no additional homework is assigned.
2. How do you agree to the following statement? *The Flipped Classroom approach in this class has helped me learn in this class significantly.*
   - *Strongly agree, Somewhat agree, Neutral, Somewhat disagree*, and *Strongly disagree*
3. How do you agree to the following statement? *The Flipped Classroom approach in this class is more efficient learning module for me than the traditional (non-flipped classroom) approach*.
   - Strongly agree, Somewhat agree, Neutral, Somewhat disagree, and Strongly disagree
4. How would you recommend Flipped Classroom approach?
   a) I would NOT recommend the flipped classroom approach in any format of classes.
   b) I would recommend the flipped classroom approach both in the online class and in the in-person class.
   c) I would recommend the flipped classroom approach only in the online class.
   d) I would recommend the flipped classroom approach only in an in-person class.

In addition to students' responses to the survey questions, students' test scores were used to answer the second research question in this study. Is *the effectiveness of the flipped classroom in students' perception affected by their academic performance?* The courses (Construction Estimating and Construction Scheduling courses) for this study include one examination. The weight of the test is 20% toward the student's final grade in the Cost Estimating class and 25% in the Construction Scheduling class, respectively.

Data Collection

The students in the courses were asked the survey questions in an online *Zoom* class session toward the end of the Fall 2020 semester. The number of responses in each course is 19 responses out of 25 students in Cost Estimating class, 25 responses out of 26 students in Section 01, and 22 responses out of 23 students in Section 02 in Construction Scheduling class.

Results

Students' Perception of Flipped Classroom

Figure 1 shows the students' responses to the first and second questions of the questionnaire survey question on preference between the flipped classroom and traditional approaches. Out of the total 66 responses, 42 students (63.6%) preferred the conventional approach to the flipped classroom approach. In contrast to the first question response, in the second question, 50% of the students strongly agree or somewhat agree that the Flipped classroom approach helped them learn significantly. Like the second question, 56% of students responded positively to the third question (Figure 2), indicating that the Flipped classroom approach is a more efficient learning method than the conventional one. Similarly, two-thirds of the class recommends using the Flipped classroom approach either online or in in-person courses.

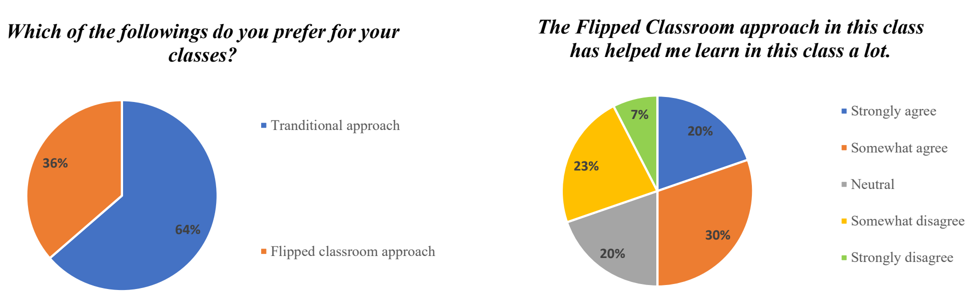

Figure 1: Responses to the Survey Question 1and 2

To address the second research question, we compared the students' test scores with their responses to question #3 of the questionnaire. In this analysis, this study categorized the students into various groups based on their responses to question #3. For example, all the students who responded strongly agree that the Flipped classroom approach is more efficient than the conventional method were considered one group. Later, each student's test score in that group was collected, and the mean and standard deviation of the group test score was calculated. Similarly, the scores of other groups were recorded.

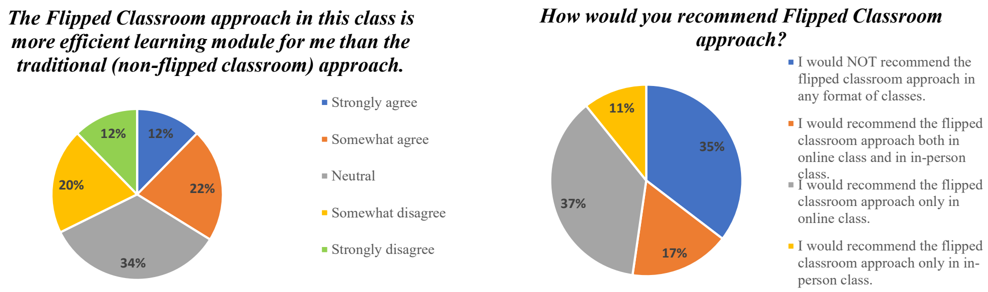

Figure 2: Response to the Survey Question 3 and 4

Relationship between Students' Perception and Academic Performance

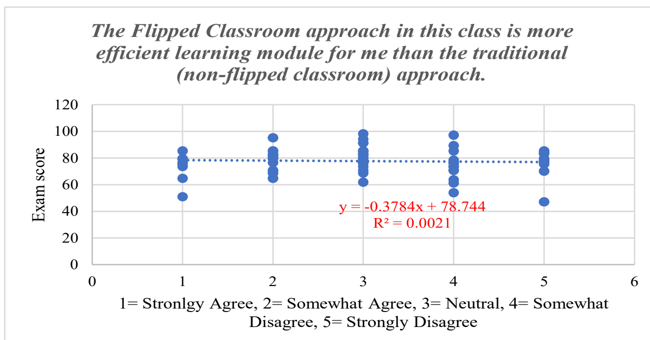

Figure 3: Response to the Question #3 vs. Exam Score.

Figure 3 shows the distribution of test scores for the students in the three courses. From a linear regression analysis as displayed in Figure 3, there is no strong relationship between the students' responses to question 3 and their test scores. Thus, the null hypothesis, 'The effectiveness of the flipped classroom model is differently perceived by students' academic performance.' should be rejected. Therefore, it is determined that students' perception of the effectiveness of the flipped classroom model was not related to their academic performance.

Discussion

The authors observed a mixed response from the students regarding the effectiveness of the flipped classroom model over traditional teaching. For instance, question 1 of the survey indicated that only one in every three students (~34%) preferred flipped classroom approach compared with the conventional one. However, a positive response to the remaining survey questions indicates that at least one in two students (>50%) liked the flipped classroom over the traditional approach and 64% of the recommended flipped approach over the conventional method.
The authors of the current study believe that the flipped classroom approach can help students learn and provide a better learning experience in a remote learning environment.

The authors believe one of the reasons for the mixed response is the timing of the study. This study was conducted in Fall 2020, where almost every course was offered online due to Covid-19. Based on the feedback received by the authors from students, most of the students indicated that they were saturated with online teaching and desperate for in-person classes. Several students in the courses in this study reported that they got tired of working in front of computer screen all day. Also, several students in the courses reported technology issues such as unreliable internet connection, downtime for the LMS tool, and crashed computer software. Nevertheless, the authors firmly believe that flipping classroom is effective for online education. However, certain factors outside the school (like covid-19 induced circumstances) might influence this study, resulting in mixed responses. Future research on flipped online education is required to clarify its benefits over conventional classes when the current covid-19 induced uncertainties ease. As Mojtahedi et al. (2020) recognized, the flipped portion of students' learning, pre-class self-learning, is one of the critical success factors for the flipped classroom approach. While students in the courses in this study were encouraged to study the contents in advance by watching lecture videos and taking online quizzes, it was observed that some students took pre-class online quizzes without watching the related lecture videos. Coffey and Clarke (2021) identified that this is an ongoing issue with some students, specifically in the online teaching approach. Instructors need to motivate students better to finish required homework assignments to enhance students' learning.

The findings from this study are limited to relatively small data sample with 66 students in one semester. Thus, it is required that more data need to be collected from flipped online courses in the future. Also, the authors believe that future studies on what level of 'flipping' format is the most beneficial for CM education is needed.

Conclusions

- The flipped classroom approach is a relatively new pedagogical approach for active learning, students' engagement, and a better education experience. By reversing listening to lecture in the classroom to a self-learning assignment before class, more class time can be used for a more active learning experience.
- This study's findings based on students' perception reveal a mixed response on the effectiveness of the flipped classroom model for online education over the conventional method.
- Most of the students agreed that the flipped model is adequate. However, they preferred traditional teaching over flipped classroom model possibly due to the lethargy caused by the complete remote learning during Covid-19 in 2020.
- One of the key findings of this study is that the student's perception of the flipped classroom model is not based on their academic performance (Figure 3).

References

Bishop, J. L. & Verleger, M. A. (2013). "The Flipped Classroom: A Survey of the Research." ASEE Annual Conference & Exhibition.

Chen, W., & You, M. (2007). The differences between the influences of synchronous and asynchronous modes on collaborative learning project of industrial design. In D. Schuler (Ed.), *Online communities and social computing* (pp. 275–283). Berlin Heidelberg : Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-3-540-73257-0_31

Coffey, R. and Clarke, S. (2021). Construction Management Teaching Methods and Assignments: Perception versus Reality. Proceedings for the 57th Associated Schools of Construction (ASC) Annual International Conference. Volume 2, page 377-386

Diederich, J., Wang, X., Dayyala, N., Inti, S., & Luo, Y. (2020, October). USB Linux: An IT Lab Instruction Tool During COVID-19. In *Proceedings of the 21st Annual Conference on Information Technology Education* (pp. 273-278).

Davis, K. A. & Cline, R. C. (2009). "Improving Course Comprehension through Experiential Learning." Construction Research Congress 2009.

Dumford, A.D., and Miller, A.L. (2018) Online learning in higher education: exploring advantages and disadvantages for engagement, *Journal of Computing in Higher Education*, 30, 452-465.

Flipped Learning Network (FLN). (2014) The Four Pillars of F-L-I-P™, https://flippedlearning.org/definition-of-flipped-learning/

Hegazy, T., Abdel-Monem, M., Saad, D., & Rashedi, R. (2013). "Hands-On Exercise for Enhancing Students' Construction Management Skills." J. Constr. Eng. Manage., 139(9), 1135-1143.

Hotle, S. L. & Garrow, L. A. (2016). Case Studies Effects of the Traditional and Flipped Classrooms on Undergraduate Student Opinions and Success. Journal of Professional Issues in Engineering Education and Practice, 142(1), ASCE

Hiranrithikorn, P. (2019) Advantages and disadvantages of online learning, International Academic Multidisciplinary Research Conference Proceedings, Berlin, 2019

Hrastinski, S. (2010). How do e-learners participate in synchronous online discussions? Evolutionary and social psychological perspectives. In N. Kock (Ed.), *Evolutionary psychology and information systems research* (pp. 119–147).

Lee, N. (2014). "A Conceptual Framework for Technology-Enhanced Problem-Based Learning in Construction Engineering and Management Education." American Society for Engineering Education.

Lee, N., and Kim, S.J. (2021). Exploring the Flipped Classroom Model in Construction Engineering and management Education: A Case Study, Proceedings for the 57th Associated Schools of Construction (ASC) Annual International Conference. Volume 2, page 414-422

Ling, F. Y. Y. and Gan, M. J. S. (2020). Mastery of Fundamental Concepts Based on Students' Learning Approach in Flipped Classrooms. Journal of Civil Engineering Education, 146(2), ASCE.

Mihai, L. (2016) 8 Flipped Classroom Benefits for Students and Teachers, https://elearningindustry.com/8-flipped-classroom-benefits-students-teachers

Mojtahedi, M., Kamardeen, I., Rahmat, H., & Ryan, C. (2020). Flipped Classroom Model for Enhancing Student Learning in Construction Education. Journal of Civil Engineering Education, 146(2), ASCE.

Swartz, B., Butler Velegol, S. and Laman, J. A. (2013) Three Approaches to Flipping CE Courses: Faculty Perspectives and Suggestions, 2013 ASEE Annual Conference Proceedings, Atlanta, GA, 2013.

Swithenbank, S. B. and DeNucci, T. W. (2014) Using a "Flipped Classroom" Model in Undergraduate Newtonian Dynamics," 2014 ASEE Annual Conference Proceedings, Indianapolis, IN, 2014.

Taplin, R. H., Kerr, R., & Brown, A. M. (2013). Who pays for blended learning? A cost–benefit analysis. *The Internet and Higher Education*, *18*, 61–68. doi:10.1016/j.iheduc.2012.09.002

Zappe, S., Leicht, R., Messner, J., Litzginer, T. & Lee, H. W. (2009). "Flipping the Classroom to Explore Active Learning in a Large Undergraduate Course." ASEE Annual Conference & Exhibition

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Analysis of Learning Outcomes of a Baccalaureate Degree Program in Construction Management

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This paper presents an analysis of the learning outcomes of a four-year baccalaureate degree program in construction management. The learning outcomes usually contain an action verb, a statement of the content to be learned and a description of the context of the learning. A textual analysis is performed to assess the distribution and frequency of occurrence of action verbs and to find most frequently occurring key words in the courses. The action verbs used in the learning outcome statements are tabulated in the schema of a revised Bloom's taxonomy. The analysis shows that although the action verbs can describe different cognition levels of the learners as they progress from 1st year to 4th year, the frequency of occurrence and distribution of the action verbs are not sufficient descriptors of the depth and breadth of the content covered. The analysis presents an approach that can be used to map learning outcomes of different courses and their correspondence with general learning outcomes of the program and to compare and standardize programs in construction management. The level of cognition and the content of cognition both are equally important when mapping courses within a program or using learning outcomes in benchmarking and standardizing two different programs.

Key Words: Learning outcomes, Bloom's Taxonomy, Action Verbs, Content, Construction Education

Introduction

Learning outcomes are used in education and training programs to outline the depth and breadth of the learning individuals are expected to achieve at the completion of the programs. A learning outcome is a statement that describes "the knowledge or skills students should acquire by the end of a particular assignment, class, course, or program" (Greenleaf, 2008, p. 3) and it refers to "the change in the learner's knowledge as a result of instruction" (Mayer, 2008, p.762). In other words, learning outcomes describe a knowledge or skill that learners acquire as a result of completion of the program which they did not possess previously (Watson, 2002). Moreover, a good learning outcome statement should describe, and help students understand why that knowledge and those skills will be useful to them. The learning outcome should guide the learners to interact efficiently with the content and should be stated in such a way that the degree of intended behavior achieved by the learners can be measured objectively.

Learning outcomes can be stated at the program level to “clarify the internal and lasting changes following program of instruction” (Richard, 2016, p. 9) and at the course level. Learning outcomes at the course level can be general learning outcomes which provide direction with respect to what is to be learned in a specific course or they can be specific learning outcomes which state what the learners should acquire at the completion of a topic, task, or assignment within the course. A learning outcome statement usually has three components – an action verb, a statement of the content to be learned and a description of the context of the learning.

One of the most widely discussed and applied frameworks in writing learning outcomes is Bloom’s taxonomy of educational objectives. In a seminal work published in 1956, Bloom classified students’ learning into various categories according to the level of cognition and grouped a range of action verbs in each cognition level (Bloom, 1956). One of the assumptions of Bloom’s taxonomy is that the same classes of behavior are demonstrated by learners at various levels of education and in the context of a range of subjects and their contents. This universal applicability of the taxonomy has increased its popularity among the education developers and teachers at all levels of education from elementary school to higher studies and in a range of subjects from the liberal arts to applied education.

The origin of learning outcomes in education programs can be traced to the psychological school of behaviorism. Merriam and Bierema (2013) argue that “what has become known as evidence-based practice where in quantifiable, systematic, and observable “outcomes” are used as markers of learning and in turn used to structure learning activities is a behaviorist-oriented model” (p.27). Learning outcomes not only provide a framework for structured and student-centered learning, but they are also “a practical device and represent a methodological approach that has been adopted to improve the competitiveness, transparency, recognition and mobility” (Adam, 2006 p. 3). In addition to shifting the focus from input to output, Maher (2004) argues that learning outcomes-based curriculum development enhances employability, increases quality and accountability, and facilitates accreditation of learning. Because of globalization and mobility of the workforce, there is a growing need for education providers and accreditation bodies to evaluate and standardize courses and programs. Adam (2006) also argues that the outcome-based approach has applicability at national and international level for wider recognition and transparency of the programs and courses.

However, the applicability of learning outcomes and outcome-based approach in curriculum maintenance, mapping of course outcomes to program level outcomes and comparing different programs for accreditation and mobility purposes requires a deeper focus on the overall content of the learning outcomes rather than only on the action verbs. Bloom’s taxonomy is intended to provide a classification of the cognition level but not the content that is cognized. As Bloom (1956) states “we are not attempting to classify the particular subject matter or content. What we are classifying is the intended behavior of students-the ways in which individuals are to act, think, or feel as the result of participating in some unit of instruction” (p.12). Although there have been extensive studies on the classification of the cognition level and associated action verbs, to the extent of author’s knowledge there has been no study to associate the content vis-à-vis the cognition level especially in construction education. The purpose of this paper is to classify the action verbs used in the learning outcomes and to assess significance of the content in the learning outcomes in recognizing the level of cognition.

As such, this study has three specific objectives:

- Analyze the action verbs used in the learning outcomes of a 4-year construction project management program
- Map action verbs used in the learning outcomes according to Bloom’s taxonomy
- Identify the importance of the learning content vis-a-vis the action verbs used in the learning outcome statements.

As a pilot study, this paper analyzes learning outcomes of an undergraduate program in construction management. Based on the outcome of this study, a comprehensive study of the course outlines of similar programs across North America is proposed as the next step.

Methodology

The course outlines used in this study are from a four-year baccalaureate degree program in Construction Project Management from a North American university. The program requires a total of123 credits to graduate. A student needs to complete 39 course works for 117 credits, a 600-hr internship of three credits and a capstone project of three credits. Out of the 39 course works, six are elective courses.

All the course outlines start with a brief description which outlines the general learning outcome of the course. The outlines usually list 10-12 learning outcomes each covering a distinct module or topic within the scope of the general learning outcome of the course. The learning outcomes are further divided into subtopics which are expressed as learning objectives. Each learning objective covers a unit or an activity which is stated with an action verb, a statement of the content to be learned and a description of the context of the learning as in the learning outcome statements. It should be noted here that although the distinction between learning objectives and learning outcomes is not universally recognized, literatures usually use learning objectives in the sense to describe the general learning outcome of a course (for example in Greenleaf, 2008) unlike in this case. Both learning outcomes and learning objectives are considered as learning outcomes in this study. A sample of a typical structure of a learning outcome statement and associated learning objective statements is presented in Figure 1.

Course Learning Outcome(s):

1. Identify civil, landscape, architectural, structural, mechanical, electrical and fabrication drawings in a set of construction drawings.

Objectives

1.1 List drawing views associated with each subset of construction drawings, such as plans, elevations and sections.
1.2 Discuss the purpose of various drawings.
1.3 Review phases of drawings which precede construction drawings.
1.4 Assemble a complete set of construction drawings in standard order.
1.5 Illustrate the relationships between various drawings, e.g., plans and sections, sections and elevations.
1.6 Locate a specified building element on all drawings which has information relevant to that element.

Figure 1. A sample learning outcome and associated learning objectives from a typical course outline

A regular student takes 41 courses out of which six are elective courses, one is an Internship and one is a Capstone project. Although students have a choice in which elective they take from a pool of few electives, only one elective from each pool is included in this analysis. Internship is included as a 3rd-year course although students take Internship in between 3rd and 4th year. An open-source data mining tool Orange (Demsar et al., 2013) is used to perform text analysis of the 41 course outlines. Text analysis is used to create a structured data set from a corpus of text materials to analyze the patterns and trends. Text analysis is gaining popularity as an automated process to structure, visualize and comprehend the vast amount of textual data. Researchers in the field of education have also used text analysis in the past, for example, to assess students' motivation in online classes (Reich et al., 2014), to assess online discussion (Bettinger, Liu, & Loeb, 2016) and to analyze difference in responses to male and female students in online discussions in MOOC (massive open online courses) courses (Fesler et al., 2019).

The purpose of the text analysis in this study is to analyze learning outcome statements used in the course outlines. The output from the analysis is used to generate plots of commonly used words and phrases and to identify action verbs used in the course outlines.

Results from the Analysis of the Course Outlines

Word cloud diagrams of the frequently occurring works in the course outlines are presented in Figure 2a for each year and in Figure 2b for all the years (1^{st}-4^{th} year) combined. Few commonly occurring words such as objective(s), outcome(s), and capitalized words such as “Construction”, “Project” and “Management” are filtered from the results as they are used in the name of the courses and name of the program too. However, the words construction, project and management starting with a small letter are retained as they form a part of the learning outcome statements as can be seen in Figure 1. Stop words and frequently occurring numbers have also been filtered from the output. Although words, such as explain, can be easily identified as an action verb, some words, such as research and design, can be a verb or a non-verb word. As the course outlines use a verb at the beginning of an outcome or an objective statement with a capital letter as seen in Figure 1, only words beginning with a capital letter are treated as an action verb.

Figure 2a. Frequently occurring words in the course outlines of 1st-year (top left), 2^{nd} -year (top right), 3^{rd} -year (bottom left) and 4^{th}-year.

Figure 2b. Frequently occurring words in 1st to 4th-year courses

World cloud of 1st -year (Figure 2a) shows that “construction”, “Calculate”, “using”, “Discuss”, “project”, “Identify” and “Describe” are the most frequently occurring words. Word cloud of the 2nd-year courses also shows similar words as in the 1st-year courses but there are few additional words such as “structural”, “design”, “soil” which are related to civil engineering subjects. In 3rd and 4th-year course outlines, “project”, “management”, “Explain” and “research” start appearing more frequently. “Identify”, “project”, “construction”, “Explain”, “Describe”, “management”, “Discuss” and “systems” are some of the words that occur frequently in course outlines from 1st-year to 4th-year (Figure 2b).

Table 1

List of top ten most frequently occurring verbs in learning outcomes

1st Year	Frequency	2nd Year	Frequency	3rd Year	Frequency	4th Year	Frequency
Calculate	70	Explain	86	Explain	82	Explain	89
Describe	63	Identify	79	Describe	71	Identify	69
Identify	57	Describe	60	Identify	67	Discuss	53
Discuss	48	Determine	40	Define	51	Recognize	33
Explain	39	Discuss	35	Review	39	Define	31
Outline	37	Calculate	32	Discuss	36	Analyze	30
Determine	35	Recognize	27	Develop	33	Examine	28
Solve	33	Define	26	Examine	32	Apply	27
Analyze	32	Apply	22	Analyze	31	Review	26
Define	31	Estimate	20	Outline	30	Describe	24

The plots show that the concept of “management” starts to occur more frequently in the course outlines after 2nd year whereas “construction” is present in the outlines from 1st-year. A separate list of ten most frequently occurring action verbs is shown in Table 1. The action verbs “Calculate” and “Solve” in 1st-year indicate that the focus of 1st-year courses is on foundational subjects of mathematics and physics. Furthermore, 2nd-year courses have more focus on technical subjects related with the field of civil engineering as demonstrated by the presence of words such as “structural”, “design”, “surveying”, and “soils”. The course outlines have more prominent presence of words “safety”, “risk” and “health” in 3rd-year courses. Fourth-year courses start to show the presence of the words “industry”, “research”, and “quality”.

The action verbs and their normalized occurrence frequency are plotted in Figure 3. Normalized frequencies are plotted on the horizontal axis and vertical axis shows different years. Normalization for each year is done using total number of courses in that particular year. A verb appearing on the right side is more frequently occurring than one on the left side. The program has ten courses in each year except in the 3rd-year which has 11 courses as Internship is included as a 3rd-year course in this study. For example, the normalized frequency of action verb "Calculate" in 1st-year is 70/10 (=7.0) and in 2nd Year is 32/10 (=3.2) which are shown in Figure 3 in the line of 1st-year and 2nd-year, respectively. Normalization of the plot for "All Years" shown in Figure 4 is done by dividing the sum by 41. For example, as the action verb "Explain" occurs 296 in total, the normalized frequency for "Explain" in the category of "All Years" is 296/41 (=7.2).

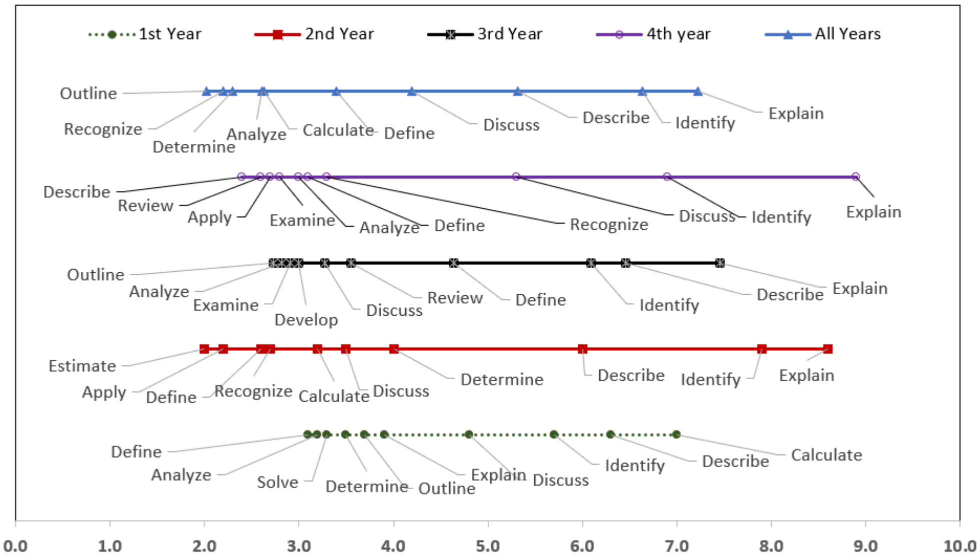

Figure 3. Plot of the top 10 frequently occurring action verbs in course outlines normalized with number of courses

The plot shows that action verbs "Explain", "Describe", and "Identify" are most commonly occurring action verbs in the course outlines with each verb occurring in each course outline at an average frequency of 7.2, 6.6 and 5.3, respectively.

Action Verbs and Bloom's Taxonomy

Education and trainings are concerned with bringing about changes in individuals and learning outcome are used to define the changes (Maher, 2004). As Bloom's taxonomy is the most widely used framework for classifying learning in cognitive terms and is the framework used to design outcome-based courses globally (Maher, 2004; Coates, 2000), this study uses revised Bloom's taxonomy as a framework to map the action verbs used in the learning outcomes. The verbs used in learning outcomes are action words that "describe the cognitive processes by which thinkers encounter and work with knowledge" (Armstrong, 2010). Bloom's taxonomy, a framework developed by Bloom and his colleagues in 1956, is widely used to categorize the action verbs into a continuum from simple to complex and concrete to abstract. The original taxonomy has been critiqued, revised, and updated by many scholars. For this study, a revision suggested by Patricia Armstrong from the Center for Teaching, Vanderbilt University (Armstrong, 2010) is used (Figure 4). The revised taxonomy has six categories – remember, understand, apply, analyze, evaluate, and create. Remember is the lowest cognition level which involves recalling of facts and basic concepts and create is the highest cognition level which involves producing an original work.

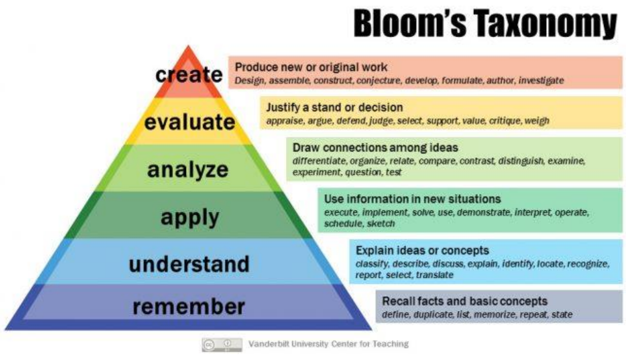

Figure 4. Revised Bloom's taxonomy from Armstrong (2010)

The top ten most frequently occurring action verbs used in the course outlines are tabulated in Table 2 along with revised Bloom's classification. It can be observed a large number of frequently occurring verbs in the course outlines fall under the category of "Understand" which is the second level of cognition in the revised Bloom's taxonomy (Figure 4). "Apply" is a category of higher order of cognition in Bloom's taxonomy and 1^{st}-year and 2^{nd}-year courses have many verbs in this category too. "Analyze" and "evaluate" are next higher order categories and 3^{rd}-year and 4^{th}-year courses have many verbs from this category.

Table 2

Categorization of the top ten frequently occurring verbs according to Bloom's taxonomy

Bloom's category	1st Year	2nd Year	3rd Year	4th Year	All Years
Remember	Define	Define	Define	Define	Define
Understand	Describe, Discuss, Identify, Explain, Outline	Describe, Discuss, Explain, Identify, Recognize	Describe, Discuss, Explain, Identify, Outline	Describe, Discuss, Explain, Identify, Recognize	Describe, Discuss, Explain, Identify, Outline, Recognize
Apply	Calculate, Determine, Solve	Apply, Calculate, Determine, Estimate		Apply	Calculate, Determine
Analyze	Analyze		Analyze, Review	Analyze, Review	Analyze
Evaluate			Examine	Examine	
Create			Develop		

"Create" is the highest order cognition in Bloom's taxonomy which includes verbs with the connotation of producing new or original work. Only one verb "Develop" appears as one of the top 10 frequently used verbs from this category. "Develop" is the 7^{th} most frequently used verb in 3^{rd}-year course outlines which is used 33 times in 11 courses with an average of three occurrences in each course (Figure 3).

To analyze the lack of higher cognitive level verbs in the course outlines, particularly in the senior year courses, occurrence of the verbs in this category is tabulated separately in Table 3. Numbers in parentheses indicate the number of occurrences of the verb in the course outlines. As these verbs are not among the top 10 frequently occurring verbs, they do not appear in Table 1.

Table 3

Tabulation of action verbs in "Create" category. Number in parenthesis is frequency of the verb.

Bloom's category	1st Year	2nd Year	3rd Year	4th Year
Create	Design (1), Develop (1), Investigate (1), Formulate (1)	Design (15), Develop (6)	Develop (33), Design (12)	Develop (10)

Although verbs in the "Create" category do not appear among the list of ten most frequently occurring verbs in 1st, 2nd and 4th year courses, the tabulated results show that verbs in this category are present in the course outlines in all years (Table 3). First-year courses use "Design", "Develop", "Investigate", and "Formulate" once each. Second-year and 3rd-year courses use "Design" 27 times and "Develop" 39 times in total. Fourth-year courses use "Develop" 10 times and "Investigate" and "Construct" twice and once, respectively. The results show that the number of verbs in the "Create" category increases from 1st to 3rd-year but the number decreases in the 4th-year courses.

To investigate the reason for the less frequent occurrence of higher cognition level verbs in the 4th-year course outlines, the learning outcome statements are further investigated. Instead of looking at the action verbs only, complete statements with action verbs, content and context are reviewed. Although two courses may use the same action verb, the depth and breadth of the learning may be different depending upon the content and condition that follow the action verb. Following two learning outcome statements are used as an example to illustrate this argument.

- Learning objective from a 1st-year course - Develop solutions to problems of inaccuracies in drawings.
- Learning objective from a 4th-year course - Develop the final project report [of a construction research project].

Although both learning objectives have "Develop" as an action verb, 1st-year students are "Developing" solutions for eliminating errors in drawings but 4th-year students are "Developing'" a report based on an actual research project. The content of the latter is obviously more complex and expects a higher level of sophistication from the learners. Therefore, it can be argued that the action verbs are necessary but not sufficient to represent the depth and breadth of the intended learning. In mapping course learning outcomes with program learning outcomes and in comparing two different programs, a complete analysis of the laddering of the action verbs from first year to final year should be accompanied by the analysis of the content and context associated with the action verbs. The level of cognition and the content of cognition both are equally important when mapping courses within a program or using learning outcomes in benchmarking and standardizing two different programs.

Conclusion

Learning outcomes focus on outputs as measured by changes in skills or knowledge rather than on inputs such as number of hours taught and amount of the course covered. Because of their focus on the learners, learning outcomes represent "a more realistic and genuine measure of the value of education than measures of teaching input" (Maher, 2004 p. 47). Using textual analysis of the learning outcomes of the courses in a typical baccalaureate degree in construction management in North America, this study shows that mapping of distribution and frequency of occurrence of the action verbs can be used to assess expected progression from lower to higher cognition level in the Bloom's taxonomy. Moreover, the results show that action verbs are necessary but not sufficient indicators to assess the level of learning expected from the learning outcome statement. Learning outcomes usually have three parts – an action verb, content of learning and context of learning. Although level of cognition is determined by the action verb, the analysis shows that the content and the context of a learning are equally important components to map the extent of the expected learning.

References

Adam, S. (2006), "An introduction to learning outcomes", in Froment, E., Kohler, J., Purser, L. and Wilson, L. (Eds), EUA Bologna Handbook, Raabe, Berlin, p. B2.3-1.

Armstrong, P. (2010). Bloom's Taxonomy. Vanderbilt University Center for Teaching. Retrieved Oct 12, 2021 from https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/.

Bettinger, E., Liu, J., & Loeb, S. (2016). Connections matter: How interactive peers affect students in online college courses. *Journal of Policy Analysis and Management*, *35*(4), 932-954.

Bloom, B. S. (1956). Taxonomy of educational objectives. Vol. 1: Cognitive domain. New York: McKay.

Coates, M. (2000). Compliance or creativity?: Using learning Outcomes to enhance learner autonomy. *In Academic Development–Challenges and Changes International Conference, South Africa, December.*

Demsar J, Curk T, Erjavec A, Gorup C, Hocevar T, Milutinovic M, Mozina M, Polajnar M, Toplak M, Staric A, Stajdohar M, Umek L, Zagar L, Zbontar J, Zitnik M, Zupan B (2013). Orange: Data Mining Toolbox in Python. *Journal of Machine Learning Research* 14(Aug): 2349−2353. https://orange.biolab.si

Fesler, L., Dee, T., Baker, R., & Evans, B. (2019). Text as Data Methods for Education Research. CEPA Working Paper No. 19-04. *Stanford Center for Education Policy Analysis*.

Greenleaf, E. (2008). Developing learning outcomes: A guide for University of Toronto faculty. University of Toronto: Centre for Teaching Support & Innovation. Retrieved Oct 12, 2021 from http://teaching.utoronto.ca/wp-content/uploads/2015/08/Developing-Learning-Outcomes-Guide-Aug-2014.pdf

Maher, A. (2004). Learning outcomes in higher education: Implications for curriculum design and student learning. *Journal of Hospitality, Leisure, Sport and Tourism Education*, *3*(2), 46-54.

Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. *American psychologist*, *63*(8), 760-769.

Merriam, S. B., & Bierema, L. L. (2013). *Adult learning: Linking theory and practice*. John Wiley & Sons.

Reich, J., Tingley, D. H., Leder-Luis, J., Roberts, M., & Stewart, B. (2014). Computer-assisted reading and discovery for student generated text in massive open online courses.

Richard, J. F. (2016). Writing Learning Outcomes: Principles, Considerations, and Examples. *Université de Moncton A resource document published by the Maritime Provinces Higher Education Commission January*.

Watson, P. (2002). The role and integration of learning outcomes into the educational process. *Active learning in higher education*, *3*(3), 205-219.

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Virtual Collaborative Spaces for Online Site Visits: A Plan-Reading Pilot Study

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Site visits or field trips are widely recognized by construction educators to engage students in active learning, supplement traditional lessons, and achieve better student learning experiences. However, site visits pose significant logistical and accessibility challenges for educational institutions and teachers, limiting the number of students who can benefit from them. Moreover, the restrictions on site visits have widened recently, as the reality of COVID-19 public health concerns have compelled instructors to fast-transition to online course delivery, canceling most site visits. The purpose of this study is to present construction students with online site visits to supplement contextualized learning in risky, unsafe, or impossible-to-achieve situations. In this project, Mozilla Hubs® was used to establish a virtual collaborative environment that resembled a real-world site visit to a building facility. A pilot study (i.e., a plan-reading assessment) was employed within the virtual environment that provided affordances involving an in-depth learning experience through collaborative communication. The findings demonstrate that virtual collaborative site visits give unique chances to deliver spatiotemporal contexts of sites online and provide an effective remote alternative when these learning opportunities are unavailable.

Key Words: Online site visits; Plan-reading activity; Virtual collaborative environment; Construction education; Virtual reality

Introduction

Direct observation of complicated and sensitive concepts is required in the Architecture, Engineering, and Construction (AEC) academic disciplines to deliver information and exchange ideas between scientists and students, resulting in collaborative learning experiences in real-world spaces (McGrath et al., 2015). AEC educators have used site visits or field trips to engage students in active learning, supplement traditional lessons, and achieve richer and deeper learning experiences (Ashford & Mills, 2006). Furthermore, Furthermore, site visits effectively allow students to speak and cooperate with their peers and other professionals in the real world. It improves students' understanding and exposes them to different real-world concepts introduced theoretically in class settings (Adedokun et al., 2011). Nevertheless, STEM site visits pose significant logistical and accessibility issues for educational institutions and teachers. For example, educational institutions are frequently hindered by a lack of financial resources, administrative responsibilities, safety concerns, and legal dangers in performing site visits. Teachers are under severe time limitations since they must follow strict instructional curricula. Students face additional stress during site visits since they are obliged to travel to remote areas, which conflicts with their attendance in other classes and other personal commitments (Zhang et al., 2017). Students with health issues frequently do not participate in these learning opportunities since it may be counterproductive for their health (Palaigeorgiou et al., 2017). As the reality of the COVID-19 public health issues has compelled schools to swiftly migrate to online course delivery methods, performing real-world site visits has become a challenge that impacted both students and instructors. Traditional online-based platforms for distanced education involve video-conferencing software (e.g., Zoom® and Microsoft Skype®), learning management systems (e.g., Canvas®), and emails (Denis McQuail, 2010). Since the online delivery approach is entirely different from face-to-face instruction, this rapid transition poses challenges for students, instructors, and institutions. For students who got used to face-to-face instruction, traditional online tools create a stronger sense of isolation and lack of contact (Fauville et al., 2021). These challenges further amplify the existing limitations of site visits, reducing STEM students' hands-on learning opportunities to enhance their knowledge understanding, information retention, creativity, and critical thinking in real-world spatiotemporal contexts(D. S. Anderson & Miskimins, 2006).

This paper aims to address this challenge by creating a fully online device-agnostic experience where groups of students can easily and repeatedly experience site visits that were previously impossible, dangerous, or expensive to visit. This paper focuses on illustrating the development of such an online site visit environment and exploring students' learning experience and the system's usability by conducting a pilot study (i.e., construction-related plan-reading activity). Construction management students were recruited to participate in a plan-reading activity as pairs within the online site visit. The contribution of this study to academia is to have a better understanding of the effectiveness of online site visits in construction-related education.

Background

A virtual site visit is a multimedia simulation of a distant location that enables students to observe and interact with site-specific information using electronic devices (Klemm & Tuthill, 2003). Virtual site visits provide a learning environment that allows students to avoid being physically present on site while overcoming spatial-,temporal-, and logistics-related challenges associated with traditional real-world site visits (Wen & Gheisari, 2020). Therefore, the virtual site visit is a promising educational method to supplement traditional site visits and serve as an alternative when traditional site visits are impractical, inaccessible, or dangerous. Due to these technological benefits, virtual site visits have been applied to experience AEC fields, including familiarizing students with the built environment disciplines, assisting students realize the complexity of the construction sites, and improving students' comprehension of building structures (Crawford et al., 2015; Zhang et al., 2017). To effectively achieve these applications, multiple technologies have been explored to represent jobsites digitally. These included reality-capturing techniques using 360-degree images or videos (Eiris et al., 2020) and virtual reality (VR) using computer-generated simulation of reality (Le et al., 2015). Reality-capturing technology simulates a real-world field trip with high levels of realism, which allows students to visit the actual construction sites. In comparison, virtual reality technology enables students to freely explore anywhere on the construction sites and reach out to particular construction activities.

Virtual site visits offer spatiotemporal contexts of sites properly, allowing students to observe and understand construction projects; however, many students struggle to collaborate and communicate contextual information on such virtual site visits. Due to such collaboration and communication barriers, virtual collaborative spaces have been explored to present digital construction jobsites with synchronous and asynchronous collaborative affordance to enhance students' education quality (Le & Park, 2012). These digital spaces have been used to empower students' hands-on exploration and creativity (Van, 2007), environment visualization, verbal and non-verbal communication (Le & Park, 2012), and ultimately, information transfer and learning (A. Anderson & Dossick, 2014). Nevertheless, one of the main barriers to using virtual collaborative spaces is the hardware and software requirements that hinder their accessibility and wide user reachability. For example, complex and large models may result in rendering issues (low frames-per-second rates) due to hardware limitations (Du et al., 2018). In addition, several software compatibility-related issues might arise, for example, when using game engines for development purposes that are different from the platforms used to create models (Du et al., 2018). An alternative that can potentially resolve many of these challenges would be to develop web-based virtual collaborative spaces that are device-agnostic and easily accessible online. Such web-based virtual collaborative spaces have been previously applied in remote education (Yoshimura & Borst, 2020) in other domains, but this paper provides the first effort to integrate it for a construction-related application.

Research Methodology

The research goal of this study is to present construction students with opportunities to enable online location-independent site visits where contextualized learning is dangerous, unsafe, or impossible to achieve. It leads to the following objectives: providing a clear workflow of design and implementation of online site visit; exploring effectiveness of virtual collaborative spaces in construction education; and testing the system's usability. Two steps were accomplished to achieve this goal. First, a virtual collaborative environment was created using Mozilla Hubs® (*Hubs by Mozilla*, 2021) to provide an in-depth learning experience through collaborative communication in a virtual space that resembles a real-world site visit to a building facility. Then, a plan-reading activity was conducted to understand students' learning outcomes within the virtual site visit and test the system's usability.

Online Site Visit Development

The virtual experience was designed using Mozilla Hubs® because of its device-agnostic characteristics and minimum hardware and software requirements, allowing access to the virtual site visit experience through a web browser (Yoshimura & Borst, 2020). Various collaboration and communication affordances in Mozilla Hubs® was used (e.g., embodied interaction through avatars and virtual pointers, shared virtual spatiotemporal context of site visits, voice and text chat, desktop and camera sharing) to facilitate remote collaborative tasks in the virtual site visit (Sun & Gheisari, 2021). In this study, the virtual site visit was developed using a real-world educational facility at the University of Florida as a real-world building context. This facility consists of classrooms, laboratories, offices, and mechanical rooms, unavailable to the students due to COVID-19-related restrictions imposed by the CDC and the University of Florida. Figure 1 shows the technical development process of the online site visit. First, the 3D model of the building facility was developed in Autodesk® Revit. The generated 3D model in .rvt format was then exported into a .glb format using the SimLab® GLTF exporter (*Simlab Soft - Enabling Interactive VR*, 2021). Then the .glb file of the building model was imported to the Mozilla Spoke® (*Spoke by Mozilla*, 2021) to edit the 3D model and add other contents into the scenes before publishing it into Mozilla Hubs® (https://hubs.mozilla.com/odLEL5N/virtual-site-visit-plan-reading).

Students were allowed to use specific tools within Mozilla Hubs® that would assist in their collaborative work. For example, students could communicate and collaborate with their peers via voice and text chat, as well as other drawing tools (Figure 2-a). Students were also allowed to share 2D drawings with their peers in real-time via uploading files (Figure 2-b).

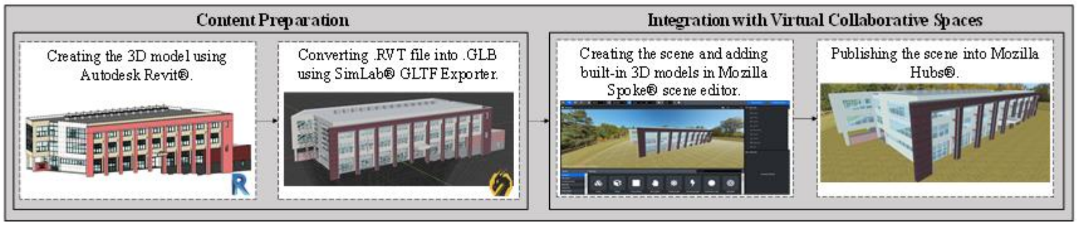
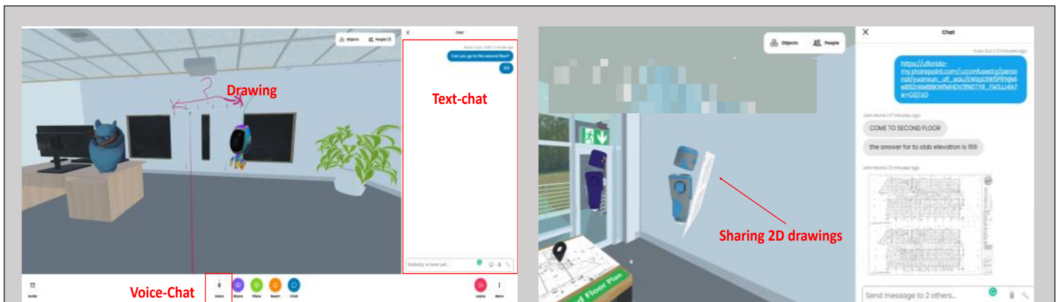


Figure 1. The technical development process of the online site visit



(a) Student-student interaction and communication in the virtual site visit (b) Sharing 2D drawings in the virtual site visit

Figure 2. Collaboration and communication affordances in the virtual site visit condition

Pilot Study – A Plan-Reading Activity

The purpose of this virtual site visit was to create a similar experience for students to walk inside a building facility and examine common plan reading tasks and interpret 2D drawings on the site. 2D drawings (e.g., plan views, elevations, detailed sections) are the only legally recognized design documents that depict buildings' spatial relationships, dimensions, details, and components (Sweany et al., 2016). These 2D drawings are commonly referred to on the sites by different project team members to comprehend and communicate the design and construction of building elements (Foroughi Sabzevar et al., 2021). Therefore, there is a need for educational programs to train better AEC students on how to effectively and adequately read plans while enhancing their interpretation and comprehension skills. Such plan-reading training commonly employs site visits to establish cognition, perception, and visualization of objects in both 2D and 3D (Chen et al., 2011). However, physical site visits were canceled due to COVID-19 and logistics-/safety-related challenges. This study developed an online site visit using Mozilla Hubs® to perform an actual plan-reading activity in an educational facility. Such environments not only enable students to communicate, interact, and collaborate within the same virtual space but also allow them to explore an interactive 3D building facility virtually, look at specific building components (e.g., walls, ceilings, doors, windows) on the building site, while having access to the 2D drawings associated with that building.

Experimental Methodology

The plan-reading study was performed to explore how online site visits could provide construction students with opportunities to collaborate on construction-related activities within a digital jobsite. The online site visit experiment was specifically designed and conducted for a construction management course. An educational building facility was selected for the online site visit in this project. This class was chosen due to its course modules on how to effectively read, understand, and use construction documents to facilitate communication. As a part of this course module, students are typically required to walk in a building facility and use the building 2D plans to perform a plan-reading activity. However, due to safety and health restrictions imposed by COVID-19, this class was only offered online, and students were not able to do the on-site plan-reading activity. First, all students participated in an online two-hour session focusing on plan-reading importance and techniques. Then, students were randomly assigned as pairs to complete a plan-reading activity within the online site visit. In addition to the plan-reading activity, students were required to respond to an online demographics and a system usability survey afterward. All online questionnaires were created and distributed through Qualtrics® (*Qualtrics XM*, 2021). The experiment protocol to collect the data for this activity was approved by the University of Florida Institutional Review Board (IRB# 202100453).

Study Metrics

The study had two primary metrics: plan-reading performance and system usability. Students worked in pairs to complete a plan-reading assessment that required answering a series of plan-reading questions. The course instructor and the graduate teaching assistants designed, discussed, and approved the questions to ensure that they met the module's plan-reading learning objective. The rate of correct responses (i.e., the percentage of correct responses out of all possible answers on the nine questions) and task completion duration (i.e., the time difference between when students started the plan-reading assessment and submitted it) were used to evaluate students' plan reading performance. System Usability Scale (SUS) was also used to understand users' experience within the virtual environment. SUS is a validated 5-point Likert-scale unidimensional questionnaire that assesses users' perceived usability of a system (Brooke, 1996). The SUS has been widely applied across various disciplines and fields. Numerous researchers have established its reliability, validity, and sensitivity to a variety of independent variables (Pedroli et al., 2018). The SUS was used in this study to assess the quality of the user experience by determining the: (1) effectiveness (i.e., users' ability to complete tasks using the system); (2) efficiency (i.e., users' resource consumption level while performing tasks); and (3) satisfaction (i.e., users' reactions to the system's performance). Additionally, student demographic information (i.e., age, gender, educational level, and their familiarity with plan-reading and virtual collaborative environment) was collected to understand the background of the participants. The study outcomes were analyzed using descriptive statistics.

Results and Discussion

A total of 18 students (9 pairs) participated in the online site visit study. Table 1 shows their demographic information.

Table 1
Online site visit participant demographic information

Parameters		**Responses Number** (Percentage)
Gender	Females	2 (11%)
	Males	16 (89%)

Educational Level	Undergraduates	15 (83%)
	Graduates	3 (17%)
Educational Background	Construction Management	14 (78%)
	Other (e.g., Architectural and Civil Eng.)	4 (22%)
Familiarity with Mozilla Hubs®	None	12 (67%)
	Some knowledge of	3 (17%)
	Fair	3 (17%)
	Competent	0 (0%)
Familiarity with Plan Reading	None	0 (0%)
	Some knowledge of	5 (28%)
	Fair	9 (50%)
	Competent	4 (22%)

Plan-Reading Performance and System Usability

The objective of the plan-reading assessment was to use the number of correct answers and task completion duration to evaluate students' plan-reading performances (Table 2). The number of correct answers followed a mean of 76% ± 1.5%. The observed students' text feedback indicated that the online site visit helped students' understanding of plan-reading. For example, one of the users indicated that "*the system could help me figure out architecture objects.*" The task completion duration (min: secs) displayed a mean of 21:05 ± 09:21. It should be noted that the task completion duration might have been longer because of some technical challenges (e.g., unstable network connection) encountered by several students. For example, a user experienced such technical difficulties and indicated that *"I have to take a while to load into rooms and sometimes I was kicked out room."*

Table 2

Results for plan-reading performance

Variables	Mean (SD)
Rate of Correct Responses	76% (1.5%)
Time (Mins: Secs)	21:05 (09:21)

Table 3 shows the *System Usability Scale (SUS)* results. Based on the obtained results, the overall usability score of this system was 62.65 out of 100. The obtained score seems acceptable based on Bangor et al. (2009) 's overall platform usability scoring system. The outcome shows that the usability of this developed system is between "Good" and "OK," and the acceptability range is low marginal. Nevertheless, the score (62.65) of virtual site visit is comparable with other studies exploring the effect of virtual collaborative environment in the education field (Granić et al., 2017). Despite showing low-marginal acceptability of overall usability in online site visits, some students' feedback acknowledged the potentials of such site visits to improve students' learning motivation. For example, one student indicated that "*the system was fun to use*," and another one stated that "*it could help me actually see the building better*."

Table 3

System usability scale (SUS) results

Questions **Scale:** Strongly Disagree (1) – (5) Strongly Agree	**Responses** Mean (SD)

Q1: I think that I would like to use this system frequently	3.67 (1.029)
Q2: I found the system unnecessarily complex.	2.56 (1.247)
Q3: I thought the system was easy to use.	3.67 (0.907)
Q4: I think that I would need the support of a technical person to be able to use this system.	2.78 (1.396)
Q5: I found that the various functions in the system were well integrated.	3.78 (1.003)
Q6: I thought there was too much inconsistency in this system.	2.72 (1.227)
Q7: I would imagine that most people would learn to use this system very quickly	4.00 (0.840)
Q8: I found the system very awkward to use.	2.83 (1.098)
Q9: I felt very confident using the system	3.50 (1.043)
Q10: I needed to learn a lot of things before I could get going with this system.	2.67 (0.907)
Overall Usability Score (Bangor et al., 2009) :	62.65 (3.114)

Conclusion and Future Work

This project utilizes collaborative spaces for conducting online site visits to overcome barriers associated with current learning and teaching approaches where contextualized learning is risky, unsafe, or impossible. For this purpose, an online site visit was developed in a virtual collaborative space. A pilot study for a plan-reading activity was conducted within the online site visit to understand students' learning experience within the online site visit and the virtual environment's usability. Results showed that the online site visit effectively helped students learn 2D drawings interpretation. Moreover, the system displayed low marginal acceptability, which illustrates a slightly unnecessarily complex system with technical issues that might not be easy to use. The observed results within the online site visit indicated that students could interact with the virtual environment and collaborate within the shared virtual spatiotemporal contexts. Additionally, the web-based virtual collaborative space was easily accessible online, allowing student access with any device. Moreover, the technical development process to create such an online site visit is not complex. Mozilla Hubs® and other new virtual collaborative platforms eliminate the need for computer programming and reduce the time investment for course instructors to develop the digital spaces. Overall, the study findings contributed to improving the existing online site visit in AEC education by creating a clear workflow of design and implementation of online delivery of spatiotemporal contexts of sites and offering an effective device-agnostic alternative when these learning opportunities are not available. However, there were specific research and technical challenges in implementing such online visits in this study that should be noted

This study also had a few research and technical limitations. First, the sample size of students was small (i.e., only 18 participants). Future research should collect a larger group of students from multiple AEC backgrounds. Moreover, this study only applied a plan-reading activity to evaluate the learning outcome in the virtual site visit. Additional studies should be conducted to understand the effects of virtual site visits on other construction-related educational activities. The low quality of the building texture diminished the sense of being on a real-world construction site, which could have been caused by the material texture settings used to export the 3D model. Additionally, Mozilla Hubs®' limitations on content file size degraded the quality of submitted 2D drawings within the environment, which might have impaired students' plan-reading abilities. Applying real-world construction materials textures and modifying the sizes of 3D components, text, images, and 2D drawings to achieve an appropriate quality might improve usability outcomes of the virtual environment. Finally, the students reported technical challenges (e.g., audio inconsistencies, low-resolution visual contents, fluctuating bandwidth, internet connection issues) that might have ultimately led to longer activity completion duration. Using students' computers and relying on their personal internet connections might have led to several technical difficulties. Future research should explore laboratory-controlled settings better to explore the benefits of such online site visits.

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References

Adedokun, O. A., Hetzel, K., Loran, •, Parker, C., Loizzo, J., Burgess, W. D., & Robinson, • J Paul. (2011). *Using Virtual Field Trips to Connect Students with University Scientists: Core Elements and Evaluation of zipTrips TM*. https://doi.org/10.1007/s10956-011-9350-z

Anderson, A., & Dossick, C. S. (2014). Avatar-Model Interaction in Virtual Worlds Improves Distributed Team Collaboration through Issue Discovery. *Computing in Civil and Building Engineering - Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering*, 793–800. https://doi.org/10.1061/9780784413616.099

Anderson, D. S., & Miskimins, J. L. (2006). Using Field-Camp Experiences to Develop a Multidisciplinary Foundation for Petroleum Engineering Students. *Https://Doi.Org/10.5408/1089-9995-54.2.172*, *54*(2), 172–178. https://doi.org/10.5408/1089-9995-54.2.172

Ashford, P., & Mills, A. (2006). *Evaluating the effectiveness of construction site visits as a learning experience for undergraduate students enrolled in a built environment course*. http://hdl.handle.net/10536/DRO/DU:30037045

Bangor, A., Kortum, P., studies, J. M.-J. of usability, & 2009, undefined. (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. *Citeseer*, *4*, 114–123. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.177.1240&rep=rep1&type=pdf

Brooke, J. (1996). *SUS-A quick and dirty usability scale*.

Chen, Y.-C., Chi, H.-L., Hung, W.-H., & Kang, S.-C. (2011). Use of Tangible and Augmented Reality Models in Engineering Graphics Courses. *Journal of Professional Issues in Engineering Education & Practice*, *137*(4), 267–276. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000078

Crawford, R. H., Stephan, A., Landorf, C., Brewer, G., Maund, K., & Ward, S. (2015). *Onsite and online: a 4-dimensional multi-disciplinary learning environment for construction industry professionals*. 987–996.

Denis McQuail. (2010). *McQuail's mass communication*. https://scholar.google.com/scholar?hl=zh-CN&as_sdt=0%2C5&q=Denis+McQuail.+%282010%29.+McQuail's+mass+communication+theory.&btnG=

Du, J., Shi, Y., Zou, Z., & Zhao, D. (2018). CoVR: Cloud-Based Multiuser Virtual Reality Headset System for Project Communication of Remote Users. *Journal of Construction Engineering and Management*, *144*(2), 04017109. https://doi.org/10.1061/(asce)co.1943-7862.0001426

Eiris, R., Jain, A., Gheisari, M., & Wehle, A. (2020). Safety immersive storytelling using narrated 360-degree panoramas: A fall hazard training within the electrical trade context. *Safety Science*, *127*. https://doi.org/10.1016/J.SSCI.2020.104703

Fauville, G., Luo, M., Queiroz, A. C. M., Bailenson, J. N., & Hancock, J. (2021). Zoom Exhaustion & Fatigue Scale. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3786329

Foroughi Sabzevar, M., Gheisari, M., & Lo, L. J. (2021). Improving Access to Design Information of Paper-Based Floor Plans Using Augmented Reality. *International Journal of Construction Education and Research*, *17*(2), 178–198. https://doi.org/10.1080/15578771.2020.1717682

Granić, A., Nakić, J., & Ćukušić, M. (2017). Preliminary Evaluation of a 3D Serious Game in the Context of Entrepreneurship Education. *28th CECIIS*. http://projectsymphony.eu

Hubs by Mozilla. (2021). https://hubs.mozilla.com/

Klemm, E. B., & Tuthill, G. (2003). Virtual field trips: Best practices. *International Journal of Instructional Media*, *30*(2), 177–193. https://login.lp.hscl.ufl.edu/login?url=https://www.proquest.com/scholarly-journals/virtual-field-trips-best-practices/docview/204262556/se-2?accountid=10920

Le, Q. T., & Park, C. S. (2012). Construction safety education model based on second life. *Proceedings of IEEE International Conference on Teaching, Assessment, and Learning for Engineering, TALE 2012*. https://doi.org/10.1109/TALE.2012.6360336

Le, Q. T., Pedro, A., & Park, C. S. (2015). A Social Virtual Reality Based Construction Safety Education System for Experiential Learning. *Journal of Intelligent and Robotic Systems: Theory and Applications*, *79*(3–4), 487–506. https://doi.org/10.1007/s10846-014-0112-z

McGrath, M., And, J. B.-I. C. G., & 2005, U. (2015). Visual learning for science and engineering. *Ieeexplore.Ieee.Org*. https://ieeexplore.ieee.org/abstract/document/1510540/

Palaigeorgiou, G., Malandrakis, G., & Tsolopani, C. (2017). Learning with Drones: Flying Windows for Classroom Virtual Field Trips. *Proceedings - IEEE 17th International Conference on Advanced Learning Technologies, ICALT 2017*, 338–342. https://doi.org/10.1109/ICALT.2017.116

Pedroli, E., Greci, L., Colombo, D., Serino, S., Cipresso, P., Arlati, S., Mondellini, M., Boilini, L., Giussani, V., Goulene, K., Agostoni, M., Sacco, M., Stramba-Badiale, M., Riva, G., & Gaggioli, A. (2018). Characteristics, usability, and users experience of a system combining cognitive and physical therapy in a virtual environment: Positive bike. *Sensors (Switzerland)*, *18*(7), 2343. https://doi.org/10.3390/s18072343

Qualtrics XM. (2021). https://www.qualtrics.com/

Simlab Soft - Enabling Interactive VR. (2021). https://www.simlab-soft.com/

Spoke by Mozilla. (2021). https://hubs.mozilla.com/spoke

Sun, Y., & Gheisari, M. (2021). *Potentials of Virtual Social Spaces for Construction Education*. *2*, 469–459. https://doi.org/10.29007/sdsj

Sweany, J., Goodrum, P., & Miller, J. (2016). Analysis of empirical data on the effects of the format of engineering deliverables on craft performance. *Automation in Construction*, *69*, 59–67. https://doi.org/10.1016/J.AUTCON.2016.05.017

Van, N. (2007). *Collaborative design in second life* . Proceedings of the Second International Conference World of Construction Project Management. https://research.tudelft.nl/en/publications/collaborative-design-in-second-life

Wen, J., & Gheisari, M. (2020). A Review of Virtual Field Trip Applications in Construction Education. *Construction Research Congress 2020: Safety, Workforce, and Education - Selected Papers from the Construction Research Congress 2020*, 782–790. https://doi.org/10.1061/9780784482872.085

Yoshimura, A., & Borst, C. W. (2020). *Remote Instruction in Virtual Reality: A Study of Students Attending Class Remotely from Home with VR Headsets*. https://doi.org/10.18420/muc2020-ws122-355

Zhang, C., Lu, Y., Xu, R., Ye, X., Shi, Y., & Lu, P. (2017). An Educational Tool based on Virtual Construction Site Visit Game. *Modern Applied Science*, *11*(8). https://doi.org/10.5539/mas.v11n8p47

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Integrating Technology Adoption Theories into the Construction Management Education: A Pilot Study

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Technology adoption and innovation play important roles in maintaining a competitive advantage for construction companies and are known to have considerable influences on the performance of construction projects. However, the construction industry is very slow in technology adoption because of a wide range of cultural and organizational barriers. More importantly, one of the main barriers that have merely been discussed is the industry readiness for implementing new technologies. To prepare the next generation of professionals to adopt and diffuse new construction technologies, construction education needs to "set the pace" by understanding current and future construction industry challenges and potential technological developments solutions. With the notion that there are disparities of current construction education regarding adopting new construction technologies, this pilot study aimed to examine the undergraduate engineering student learning outcomes through an active and interactive-learning activity about technology adoption theory with the industry professionals. The feedback obtained from students demonstrated that their understandings of new construction technologies, teamwork skills, and intellectual and critical thinking skills were improved through the activity. The results will contribute to a larger-scale study that aims to identify the areas that need improvements and realignments to the construction management curriculum for both academia and practice.

Key Words: Technology Adoption and Diffusion, Construction Management, Construction Education, Learning Outcomes, Industrial Collaborations

Introduction

The construction industry contributes greatly to GDP in the United States, increasing to 690.70 USD Billion in the second quarter of 2021. Over the last decades, the construction industry has undergone major changes. And the shortcoming of current systems has been discussed in the literature (Straub 2017), emphasizing the critical need for enormous technological transformation and embracing new modes of information sharing and communication (Becerik-Gerber et al. 2011). "Technology" in construction refers to machines, tools, modifications to the process to solve day-to-day problems and achieve project goals from design to demolition in a more efficient way (Skibniewski and Zavadskas

2013). While adopting technology and innovation play important roles in maintaining a competitive advantage for construction firms and are known to have considerable effects on overall performance, safety, and efficiency (Sepasgozar et al. 2016, Goodrum and Haas 2004), the construction industry is very slow in technology adoption (Harty 2008, Sepasgozar et al. 2016). Loosemore (2014) argued that the low innovation rate in the construction industry is due to the industry approach toward innovations: innovation in the construction industry is incremental and will be adopted in response to problems rather than being proactive and planned in advance.

The decision to deploy new technologies is affected by many constructs like "intention to use (Bhattacherjee and Hikmet 2007) and "resistance toward use" (Hsieh et al. 2014). In addition, many reasons for this low adoption rate were identified in previous literature: a wide range of cultural and organizational barriers (Mitropoulos and Tatum 2000). These barriers can be exacerbated because of the uniqueness of projects, the dynamic nature of the industry, and, more importantly, the companies' culture and expertise with technologies (e.g., Ozorhon and Oral 2017).

Furthermore, one of the main barriers that have merely been discussed in the literature is the industry readiness for this change and whether the current workforce or future ones are ready to implement these changes (Becerik-Gerber et al., 2011). Since the innovation adoption process is different for various construction technologies (Sepasgozar and Davis 2018), students need to learn how to tailor the adoption approach based on project characteristics, technology type, and customer requirements. Today's engineering graduates also need to know how to work in multidisciplinary teams, promote engineering science and computer skills, and have a broader understanding of social science and economics, so they will be better prepared for adopting and diffusing new technologies in the construction industry.

To better prepare the next generation of workforce and professionals to adopt and diffuse new construction technologies, engineering education must "not keep the pace" with industry and need to "set the pace" by understanding current and future construction industry challenges and potential technological developments solutions. With the notion that there are disparities and insufficiencies of current engineering education regarding adopting new construction technologies, this pilot study aimed to examine the engineering student learning outcomes based on the Associations of American Colleges and Universities (AACU) guidelines through an active-learning activity about technology adoption theory. This pilot study, is a part of a larger study that, in the long-term, will contribute to academia and practice by identifying the areas that need improvements and realignments to the construction engineering and management curriculum.

Background

Adoption and Diffusion of Construction Technologies

In order to incorporate innovations or technologies in the construction industry, there are two primary constructs to be taken care of: (1) adoption, (2) diffusion of the technology. Adoption theories focused on micro-perspective on change by mainly examining individuals' decisions to accept or reject any innovation. However, diffusion theories focused on macro-perspective and how the community adopts, accepts, or rejects any innovation (Straub 2009). In other words, diffusion is a cumulative frequency of individual adoptions (Roger 2010) consisting of five steps: awareness, persuasion, decision, implementation, and confirmation (these steps are further discussed in the methodology section). Therefore, Roger (2010) primarily described the technology spread in the social system (i.e., knowing as a socio-economic viewpoint). Thus, while the adoption is not a single event (e.g., Kale and Arditi 2010), the first step toward it is the knowledge and openness of individuals.

Furthermore, some studies investigated the adoption from a psychological viewpoint based on the technology acceptance model (TAM) developed by Davis et al. (1989). This theory is based on individuals' perceptions of technology/innovation and how this perception eventually affects the use of technology. Davis identified two perceived characteristics about an innovation: perceived ease of use, which is the degree to a person believes that using this system requires minimum efforts, and perceived usefulness, which is the degree a person believes that incorporating that system will enhance his/her job performance. Park and his colleagues (2021) revised and utilized TAM to predict information technology adoption in the construction industry. Later in 2003, Venkatesh and his colleagues proposed the "united theory of acceptance and use of technology" (UTAUT) based on several social cognitive theories and theory of reasoned behavior (by Ajzen 1991). This theory suggested that performance expectancy, effort expectancy (influence by perceived ease of use), and social influence (based on subjective norms from the theory of reasoned behavior) can predict individuals' behavioral intention for using technologies. According to these adoption and diffusion theories, various factors may affect whether an individual (or a company)will decide to adopt a technology.

Previous literature in the area of construction innovation showed that established general adoption theories discussed above are mainly being used in the construction industry. These theories are designed based on knowledge outside of the construction industry, so they lack the construction-specific constructs such as supply factors, demands, skills, and technology costs (e.g., Mitropoulos and Tatum 2000). Very few studies studied the adoption process in construction projects (e.g., Mitropoulos and Tatum 2000; Peansupap and Walker 2005a) and often focused on information systems adoption (3D, 4D, and BIM). In this study, since the focus is on the general aspect of technology adoption, we applied UTAUT to illustrate the key determinants of the technology adoption process.

Methodology

The activity was offered in a junior-level class named Construction Management and Engineering. This course introduces the planning, administration, management, and cost of construction projects and methodologies utilized in executing specified designs. The activity was conducted in three steps: first, the instructor gave a lecture about technology adoption theories and assigned topics to student teams; second, students had one week to do research and prepare presentations; third, students gave presentations to the client from the industry and evaluated the learning outcomes of the activity. Meanwhile, the client evaluated students' presentations to select the technology s/he would like to adopt for her/his company. The details of each step are discussed in the following session.

Description of the Activity

The instructor gave a lecture about Technology Adoption. The lecture consisted of three parts. The first part is about the current situation of technology adoption in the construction industry. As shown in Figure 1 below, the construction industry has the largest difference between expected and actual investments in emerging technologies. The instructor initiated a discussion with students by using

Figure 1. The purpose was to give students opportunities to think about the phenomenon based on their own observations and experience in the industry critically. The instructor also was able to understand students' perceptions of technology adoption in the construction industry.

The instructor summarized students' answers and guided students to the technology adoption theory, which was the second part of the lecture. The emphasis of this part is explanations of cognitive processes and critical determinants of technology adoption. The adoption decision process describes five stages that individuals go through during their evaluation of innovation.

- Stage one is when an individual realizes an innovation.
- Stage two, persuasion, is when an individual accumulates a certain amount of knowledge about the innovation's features to make a personal judgment, which could determine the result will be positive or negative.
- Stage three, decision, has an outcome of an individual's choice to adopt or reject an innovation.
- Stage four, implementation, is when an individual act on his or her decision.
- Stage five, confirmation, an individual re-evaluates whether to continue or discontinue with the innovation adoption (Straub, 2009).

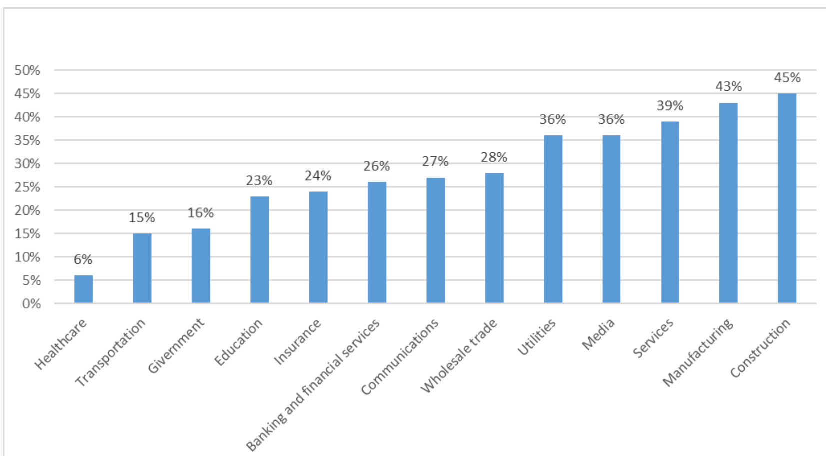

Figure 1. Average Difference between Expected and Actual Investments in Emerging Technology by Industry (adopted from Adam, 2019)

After, the instructor used the model (see Figure 2) to illustrate the key determinants of the technology adoption process. First, performance expectancy is reflected by the degree to which an individual believes that technology will assist them in performing job duties. Second, effort expectancy is reflected by the degree to which an individual perceives a particular technology to be easy to use. Third, social influence means the degree to which an individual feels social influence pressure to use a specific technology. Lastly, facilitating conditions are about the degree to which an individual believes conditions that his or her organization is supporting the change.

The last part of the lecture was the introduction of the client and the assignment of technology for students. In this activity, the instructor invited a project manager from a mid-sized construction contractor as the client, whose company did not adopt any technologies that will be presented by students later. The instructor introduced the basic background information of the client's position and company, such as job descriptions and services of companies. The instructor divided the class into three groups. Each group picked one technology that they would like to study for the presentation. The three technologies are Unmanned Aerial Systems (UAS), Virtual Reality (VR), and Building Information Modeling (BIM). The objective was to convince the client to adopt the technology by applying the technology adoption theories. Students used one week to prepare the presentation. They did research on the technology and its application. They also further studied the company about the ongoing projects and services. On the presentation day, each team gave a 15-20 minutes presentation to the client. The evaluation sheet (See Table 1) for the client was designed based on the key determinants of technology adoption (Im et al., 2011).

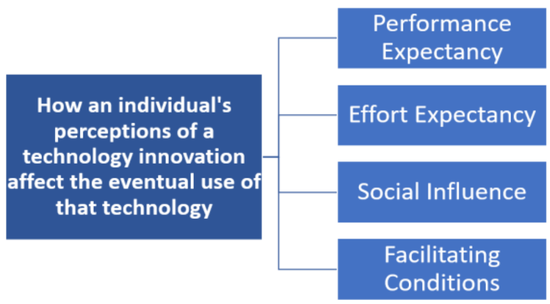

Figure 2. Key determinants of the technology adoption process (Venkatesh et al., 2003).

Table 1. Evaluation Form for the Client		
Measurement items (name of the technology): On a scale from 1 to 7, 1 being “Very Little” and 7 being “Very Much		
Performance expectancy	I would find this technology useful in my job	1 2 3 4 5 6 7
	Using this technology enables me to accomplish tasks more quickly	1 2 3 4 5 6 7
	Using this technology increases my productivity	1 2 3 4 5 6 7
Effort expectancy	It would be easy for me to become skillful at using this technology	1 2 3 4 5 6 7
	I would find this technology easy to use	1 2 3 4 5 6 7
	Learning to operate this technology is easy for me	1 2 3 4 5 6 7
Social influence	People who influence my behavior think that I should use this technology	1 2 3 4 5 6 7
	People who are important to me think that I should use this technology	1 2 3 4 5 6 7
	The senior management of my company may be helpful in the use of this technology	1 2 3 4 5 6 7
Facilitating conditions	My company have the resources necessary to use this technology	1 2 3 4 5 6 7
	My company have the knowledge necessary to use this technology	1 2 3 4 5 6 7
	My company intend to use this technology in the next 12 months	1 2 3 4 5 6 7

Assessment

Student surveys were filled out on paper after presentations in class. The student's survey consisted of a series of questions and their evaluations of learning outcomes of this activity. The learning outcomes measured for this activity were created based on the Associations of American Colleges and Universities (AACU) guidelines on important learning outcomes for engineering students (Hood et al., 2019). The learning outcomes of this activity include: 1) enhancing the knowledge of the construction industry; 2) developing intellectual skills (e.g., critical or creative thinking, quantitative reasoning, problem-solving, etc.); 3) developing professional skills (e.g., written or oral communication, teamwork, etc.) 4) enhancing the sense of social responsibility. Each learning outcome was evaluated on a 7-point Likert-type scale, with 1 being "very little" and 7 being "very much." The survey is shown in Table 2.

Table 2. Learning Outcomes Evaluation Survey for Students

Construction Engineering and Management Technology Adoption Activity Evaluation		
No.	On a scale from 1 to 7, 1 being "Very Little" and 7 being "Very Much	
1	This activity helped me develop intellectual and critical thinking skills	1 2 3 4 5 6 7
2	This activity helped me argue effectively.	1 2 3 4 5 6 7
3	My understanding of the construction industry has increased.	1 2 3 4 5 6 7
4	I am capable of locating, evaluating, and using the information in the literature.	1 2 3 4 5 6 7
5	I am confident in my ability to communicate construction management knowledge effectively.	1 2 3 4 5 6 7
6	I understand professional responsibility related to technology adoption in construction.	1 2 3 4 5 6 7
7	Will this activity be helpful for the growth of my career?	1 2 3 4 5 6 7
8	The activity helped me further develop my writing ability.	1 2 3 4 5 6 7
9	The activity improved my verbal communication skills	1 2 3 4 5 6 7
10	The activity increased my ability to collaborate and work in teams.	1 2 3 4 5 6 7

Results

As described earlier, each learning outcome was evaluated on a 7-point Likert-type scale. A total of 12 students filled out the survey in this class. The authors calculate the average evaluation score for each learning outcome (See Figure 3). The score can reflect how the activity addressed a learning outcome. The higher score indicated a learning outcome was addressed better than others in this activity. As shown in Figure 3, first, the overall result is positive because the score of every learning outcome is above 4.00, which is higher than the mean value of 7; second, the learning outcome 4, which is "I am capable of locating, evaluating, and using the information in the literature," has the highest score; the learning outcome 8, "The activity helped me further develop my writing ability," has the lowest score. Learning outcome 3, "My understanding of the construction industry has increased," has the second-highest score, and learning outcome 10, "The activity increased my ability to collaborate and work in teams," has the third-highest score. Most students have heard of technologies mentioned, but they barely know their exact applications in professional fields. During their presentation preparation, they spent the most time searching and studying these technologies regarding their functions, limitation, current market. In this process, they found many case studies related to the application in the construction industry. In the meanwhile, students have limited time and a tight schedule to prepare the presentation, which challenges their teamwork and coordination skills. These reasons may explain why learning outcomes 4, 3, and 10 were ranked in the top three.

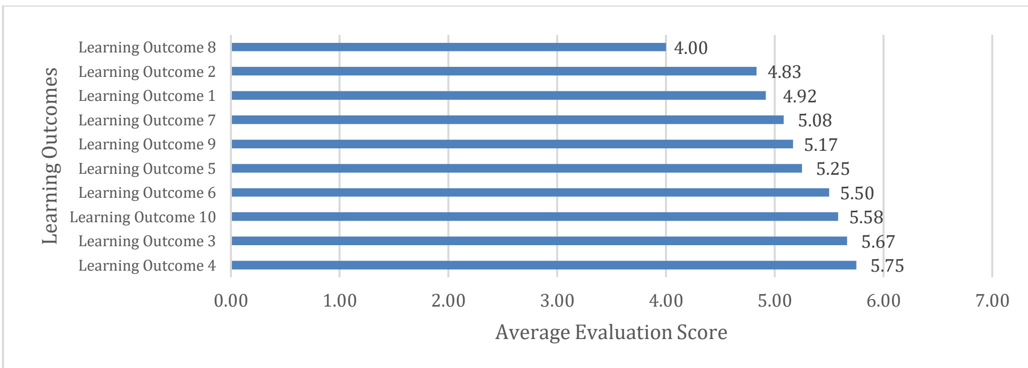

Figure 3. The average scores of learning outcomes evaluated by students

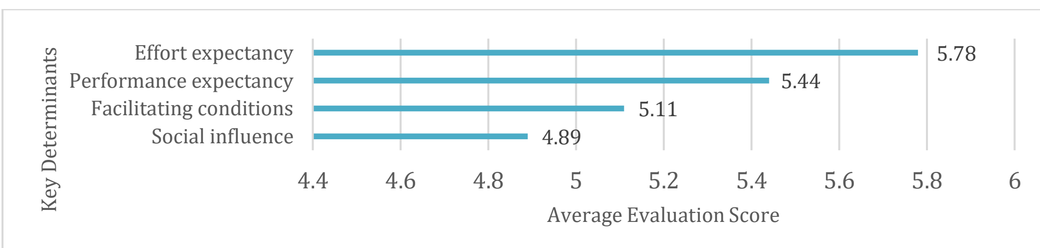

Figure 4. Average scores of key determinants of technology adoptions evaluated by the client

Figure 4 shows the average score for each evaluation item given by the client. The client filled out a paper evaluation form for each group based on how well the presentation addressed each key determinant of the technology adoption process. Each key factor had three evaluation items. Each evaluation item was also evaluated on a 7-point Likert-type scale. As shown in Figure 4, students obtained the highest score in ''Effort Expectancy.", which is about convincing an individual believes that technology will assist them in performing job duties. Among the three sub-evaluation items, students were more successful in demonstrating the easiness of technology operations. Students obtained the lowest score in "Social Influence.", which explains the degree to which an individual feels social influence pressure to use a particular technology, especially the evaluation item related to senior management influence. The overall result is also positive because the score of every learning outcome is above 4.00.

Discussion

The pilot study findings provided insights on the effectiveness of the activity about technology adoption in the construction management class. Students reported that the activity helped them understand the construction industry better and improve their professional skills such as communication and teamwork. During presentation preparations, students were able to study the technologies and came up with a strategy to link the technologies with actual projects. By communicating with clients from the industry, students would gain a practical understanding of technology applications. Instead of focusing only on technical information, students learned to study and understand a subject from multidisciplinary perspectives.

The findings of the pilot study should also be interpreted within its limitations. First, the data were collected from students from only one university in the United States. A much larger nationwide sample of students is needed. Second, only one client was invited to participate in the activity. There could be potential bias related to the perceptions of technology adoptions. Many personal traits such as age, past experience, and educational background could largely influence the degree to which an individual accepts a particular technology. For future study, multiple companies should be invited and generate a discussion panel with students.

Conclusion

Construction technologies have triggered the demands for (civil and construction) engineering graduates who have sufficient knowledge and skills to enhance industry operations through successful identification, adoption, and dissemination of technologies and sensors. This study utilized an active-learning approach to improving undergraduate students' skills and competencies as game-changers in the construction industry. The feedback obtained from students demonstrated that their understandings of new construction technologies, teamwork skills, and intellectual and critical thinking skills were improved through this activity. This pilot study calls for further research to integrate more active learning and problem-based learning activities in the construction management curriculum to ensure future engineering graduates have emerging competencies to foster construction transformations.

References

Adam Rosenthal, “How to Use Technology Adoption Rates to Market Emerging Tech”, https://blog.capterra.com/use-technology-adoption-rates-to-market-emergent-tech/

Becerik-Gerber, B., Gerber, D. J., & Ku, K. (2011). The pace of technological innovation in architecture, engineering, and construction education: integrating recent trends into the curricula. *Journal of Information Technology in Construction*.

Bhattacherjee, A., & Hikmet, N. (2007). Physicians' resistance toward healthcare information technology: a theoretical model and empirical test. *European Journal of Information Systems*, *16*(6), 725-737.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management science*, *35*(8), 982-1003.

Goodrum, P. M., & Haas, C. T. (2004). Long-term impact of equipment technology on labor productivity in the US construction industry at the activity level. *Journal of construction engineering and management*, *130*(1), 124-133.

Harty, C. (2008), "*Implementing innovation in construction: contexts, relative boundedness and actor-network theory*", *Construction Management and Economics*, Vol. 26 No. 10, pp. 1029-104

Hood, C. L., Holtzman, D. M., & Abbott, J. I. (2019). Essential learning outcomes (ELOs): Forming a bridge between college and the workplace. *Journal of Higher Education Theory and Practice*, 19(1), 73-79.

Hsieh, P. J., Lai, H. M., & Ye, Y. S. (2014). PATIENTS'ACCEPTANCE AND RESISTANCE TOWARD THE HEALTH CLOUD: AN INTEGRATION OF TECHNOLOGY ACCEPTANCE AND STATUS QUO BIAS PERSPECTIVES.

Im, I., Hong, S., & Kang, M. S. (2011). An international comparison of technology adoption: Testing the UTAUT model. *Information & management*, 48(1), 1-8.

Kale, S., & Arditi, D. (2010). Innovation diffusion modeling in the construction industry. *Journal of construction engineering and management*, *136*(3), 329-340.

Loosemore, M. (2014, April). Innovate or perish? Exploring some of the myths of construction innovation. In *Australasian Journal of Construction Economics and Building-Conference Series* (Vol. 2, No. 2, pp. 44-55).

Mitropoulos, P., & Tatum, C. B. (2000). Forces driving adoption of new information technologies. *Journal of construction engineering and management*, *126*(5), 340-348.

Ozorhon, B., & Oral, K. (2017). Drivers of innovation in construction projects. *Journal of construction engineering and management*, *143*(4), 04016118.

Park, Y., Son, H., & Kim, C. (2012). Investigating the determinants of construction professionals' acceptance of web-based training: An extension of the technology acceptance model. *Automation in construction*, *22*, 377-386.

Rogers, E. M. (2010). *Diffusion of innovations*. Simon and Schuster.

Sepasgozar, S. M., & Davis, S. (2018). Construction technology adoption cube: An investigation on process, factors, barriers, drivers and decision makers using NVivo and AHP analysis. *Buildings*, *8*(6), 74.

Sepasgozar, S. M., Loosemore, M., & Davis, S. R. (2016). Conceptualising information and equipment technology adoption in construction: A critical review of existing research. *Engineering, Construction and Architectural Management.*

Skibniewski, M. J., & Zavadskas, E. K. (2013). Technology development in construction: a continuum from distant past into the future. *Journal of Civil Engineering and Management*, *19*(1), 136-147.

Straub, E. T. (2009). Understanding technology adoption: Theory and future directions for informal learning. *Review of educational research*, 79(2), 625-649.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 425-478.

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Relationship between Undergraduate GPA and Associate Constructor (AC) Exam Scores of Construction Management Students

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Construction industry needs skilled workers, and professional certification is a way to get them. Senior level construction management (CM) students can take Associate Constructor (AC) exam as one of the first certifications as they transition into the industry. However, fewer graduating students are AC certified. The value of certifications and increasing popularity of the AC exam can motivate students to take the exam to gain professional credential and recognition. Also, the exam being reflective of the CM curriculum can motivate students to get certified. Therefore, this research assessed the correlation between undergraduate GPA (UGPA) and AC exam scores of CM seniors. The hypothesis was that there would be a positive relationship between UGPA and AC exam scores. The independent variable was UGPA while the dependent variable was the AC exam score. SAS studio facilitated the statistical analysis of the data obtained from an accredited CM undergraduate program in the south eastern part of the USA. The result showed a strong positive correlation between the scores thereby supporting the hypothesis. It was concluded that CM students needed to consider AC exam as one of the certifications as they go into the construction industry especially when their academic performances are good.

Key Words: Associate Constructor (AC) Exam, Construction Management, GPA

Introduction

Construction industry is one of the industries contributing to the national economy. It is estimated to be about 9% of the gross domestic product (Bureau of Economic Analysis, 2021). With this contribution, it is also one that experience lack of skilled or professional workers. Barrows et al. (2020) states that there is a growing need for skilled and proficient construction professionals to ensure that project goals are met and delivered within budget, safety, and on time. The 2020 Construction Outlook Survey by the Associated General Contractors of America (AGC) found out that about 80% of construction firms have trouble filling both salaried and hourly craft positions, and about 70% foresee labor shortages to be the biggest problem in the next coming years. This will result in overstretched skilled workers, delays in project completion and increased project costs.

Continuous training and professional certifications are possible ways to ensure that those transitioning into the construction industry have the skills and ability to meet the demands of the growing field. Coglianese (2018) posits that the industry has established certifications that verify knowledge, ethics and expertise of those who acquire them and that these certifications are varied in such a way that students entering the industry become overwhelmed on which certifications to spend their money and time on. Associate Constructor (AC) by the American Institute of Constructors (AIC) is one of the certifications available to students with training argued to be mainly from the 4-year CM curriculum.

AIC was formed in 1971 to advance professionalism and ethics of the constructional professionals (AIC, 2022a; Burgett, 2018; Sylvester, 2012). In 1993, the AIC formed the Constructor Certification Commission to administer the beginning level of professionalism through AC examination-also called level 1 certification, and advanced level of professionalism called the Certified Professional Constructor (CPC) examination-also called level 2 certification. The commission started giving the exams in 1996 and has certified more than 25,000 people in either AC or CPC since then (Burgett, 2018). Those wishing to take the exam must qualify by either having 4 years of CM degree or 4 years of construction industry field experience and then become certified after passing the exam (AIC, 2022a). Credentialed ACs are individuals with skills and knowledge in managing the construction process and they bring value to projects as they have verified skills and knowledge level that is based on a nearly 26-year-old body of knowledge that continues to develop (AIC, 2022b). CPCs are those with the highest level of certification in the constructor certification program. They are more experienced in managing projects and give the project owners the peace of mind that their projects are being managed efficiently and effectively (AIC, 2022b).

The benefits of these certifications to the construction industry, employers and construction professionals are driving the growth and popularity of the CPC and AC exams (Ford et al., 2012; Bruce et al., 2008). To the constructor, it enhances individual's image, increases self confidence that they have met a national standard of professional practice and provides a recognized professional credential indicating a high level of skill and knowledge of the construction process. To the employer, these credentials provide the company with a competitive marketing edge by showing the employer's dedication to the professionalism of its employees. To project owners, it provides a higher assurance that the project is being managed efficiently by a skilled, ethical and professional team (AIC, 2022a).

This current research focused on the employee's side especially the senior level CM undergraduates who would like to transition into the construction industry after graduating successfully. Usually, students are to take the AC exam in their senior year after completing the CM curriculum. This is because the exam is taken to be reflective of the curriculum content of most CM education programs. The American Council for Construction Education (ACCE) as an accrediting body for CM educational programs ensures that the quality of a construction program is high through extensive evaluation and award of accreditation, and this can be used to standardize the curriculum which leads to standardized AC exam items that reflect the needs of the industry.

As noted by Coglianese (2018) and Bruce et al. (2010), there are many reasons someone can choose to get certifications, e.g., desirable position, salary boost, or prestige. These reasons can also serve as motivating avenues for CM seniors to take AC certification. Completion of CM curriculum can motivate students towards AC certification since the exam is aligned with the curriculum. For example, senior students may be inclined to pursue the certification if their academic performance are good as shown by cumulative GPA at or above 3.0 showing good mastery of the CM curriculum. This approach may increase the motivation level which culminates in seeing more young credentialed professionals getting into the construction field thereby improving the overall image of the industry.

Therefore, this research investigated the relationship between academic performance of CM students and their AC exam scores. The outcome of this study was expected to encourage students to pursue AC certification as they get into the construction industry. Literature review section follows to discuss value of certifications, correlation studies and motivation of students towards AC certification.

Literature Review

Value of Certifications in the Construction Industry

According to AIC (2022b), certification is a voluntary third-party organization process to recognize the education or experience of an individual who meets certain criteria. These certifications continue to increase in number with the evolvement of the construction industry (Barrows et al. 2020). Noteworthy, certification need to be distinguished from licensure. According to Coglianese (2018) and Barrows et al. (2020), professional licenses are usually needed to practice in certain professions such as law, architecture or engineering where the professionals must meet the required standards of care while certification is not required to practice a profession but shows competence and provides a high level of assurance that the professional will fully complete the project. The value of certification is seen when the profession and public accept and benefit through better salaries and improved image or better quality of projects delivered by those certified (Barrows et al., 2020; Clevenger et al., 2017).

El Debs et al. (2016) on the importance of certifications to recent graduates found out that safety certifications (OSHA-10hr and OSHA-30hr) and sustainability certifications were ranked highest by industry personnel surveyed. Barrows et al. (2020) focused on the value of certifications in seeking employment where it showed that PMP certification was most valued in senior project management levels followed by LEED AP. OSHA trainings were most valuable to project engineers and project managers. Even though AC certification did not feature in the valued list, it was the second cheapest considering the total cost incurred to obtain and maintain certifications. Coglianese (2018) also investigated the value of certifications through survey of newly graduated CM students and found out that safety with OSHA training displayed highest value. AC certification showed neutral to little value. Noteworthy is that these studies relied on opinion surveys to determine certification value.

AC Examination and Correlational Studies

According to AIC (2022b), AC exam is an 8-hour exam administered in late fall and spring semesters annually, and comprises of 300 multiple choice questions which are weighted in 10 content areas of the AC exam study guide:1. Communication skills, 2. Engineering concepts, 3. Management concepts, 4. Materials, methods, and project modeling and visualization, 5. Bidding and estimating, 6. Budgeting, costs, and cost control, 7. Planning, scheduling, and schedule control, 8. Construction safety, 9. Construction geomatics(surveying), and 10. Project administration. These content areas mimic the CM curriculum in many ways and so students who take and pass AC exam are assumed to have knowledge and mastery of CM education curriculum content. For assurance of quality and standardization, the exam is accredited by the American National Standards Institute (ANSI) and also includes the industry professionals in the team to assess the exam questions (submitted by educators) for relevance before they are integrated in the final exam packet for students to take (Burgett, 2018; AIC, 2022a). The passing score is 70% or higher which is equivalent to a score of 210 or more in the exam (AIC, 2022a). The exam is either paper based or computer-based at an approved exam site.

Correlational research about the UGPA and AC exam are rare. Ford et al. (2012) conducted a study measuring educational program's effectiveness using the AC exam. In actuality, the study predicted AC exam using SAT scores (combined math/verbal scores) of 160 CM students at Western Carolina University. The results showed a correlation of 0.60. Another correlational study by Sylvester (2012) at Western Kentucky University investigated student's grade point average (GPA) success in passing the AC exam from the year 2004 to 2009. The study divided the 81-student cohort into four GPA range categories and mapped GPA to the AC exam. The results showed the higher (3.5-3.9) GPA grouping led to a higher pass rate at 67% with no linear correlation with GPA (Sylvester, 2012; Bradford et al., 2019). With these, the current study explores AC certification using the latest dataset.

Performance and Motivation

Performance refers to a behavior towards a goal. It is always assumed that those who excel are very serious and complete their work in high standing. They accomplish their full academic tasks, earn excellent grades, and are able to graduate successfully. Their performance mirrors the three types of knowledge: declarative knowledge, procedural knowledge, and motivation (Kuncel et al., 2001; Wao et al., 2016). Declarative knowledge refers to realizing what to do when faced with a problem and finding a solution while procedural knowledge refers to ability to complete a task. Motivation is the drive to complete the task. That is, the persistence to act in a way to ensure excellence (Kuncel et al., 2001; Wao et al., 2016). Performance in the undergraduate level as measured by UGPA needs the two types of knowledge but motivation component may need strengthening especially for the AC exam.

Overall, no current study (within the last 2 years) has investigated the association of AC exams and undergraduate students' performance as measured from their GPAs. This gap has motivated conducting a correlational study to help bridge this gap with a relatively current dataset.

Research Methods

The study investigated the relationship between the AC certification exam performance and undergraduate academic performance of CM students. The data were conveniently sourced from an ACCE accredited CM undergraduate program in the south eastern part of the USA. Data analysis using SAS studio employed descriptive statistics, correlation analysis and trend analysis. Descriptive statistics comprising of mean, mode, median, standard deviation, maximum and minimum, and distribution plot showed the nature of the distributions and variations of the AC exam and UGPA scores. Correlation analysis determined the nature and strength of the relationship between the scores. Trend analysis assessed the existence of upward mobility or downward trend in the correlation indices over the semesters the AC exam was taken. Specifically, increasing trend would imply a better relationship while a decrease implies lower level of relationship between the scores. It was hypothesized that a positive relationship existed between the scores where those who scored high GPAs would be expected to perform well in the AC exam.

The original dataset before data screening consisted of 260 CM seniors who took the AC exam. The dataset showed 5 zero (0) scores on the AC exam and these were then removed. One of the reasons for such scores was that a student went into the exam room and left without attempting the test, or some missed the test. After data screening, the sample size was 255 which were used in the analysis. The data comprised of AC and GPA scores of those who graduated from Fall 2015 to Spring 2019. Usually, the AC exam score is 300 as the maximum score with 210 as the passing score (70%). For this data, AC exam scores ranged from 144 to 274. The highest GPA score was 3.93 with 2.15 as the lowest score. CM students were encouraged over their academic career to maintain a 3.0 cumulative GPA in order to graduate in good academic standing. Also, the students were required to pay for the AC exam and would be reimbursed their registration fees if they passed. The independent variable was the cumulative UGPA at graduation. The dependent variable was the AC exam score. UGPA was used because it gives the academic performance of a student and AC exam score reflects level of mastery of the CM curriculum which mimics construction industry requirements and proficiency.

Results

Descriptive Statistics

Descriptive statistics comprising of mean, mode, median, standard deviation, kurtosis, skewness, and minimum and maximum values were calculated for the variables and shown in table 1.

Table 1

Descriptive statistics of UGPA and AC certification exam scores

Var.	N	Mean	Median	Mode	Std	Skew	Kurt	Min	Max	Distribution plot
UGPA	255	3.29	3.35	3.47	0.37	-0.68	0.07	2.15	3.93	Negatively skewed with 3 outliers
AC	255	234	237	252	22.40	-1.02	1.49	144	274	Negatively skewed with 6 outliers

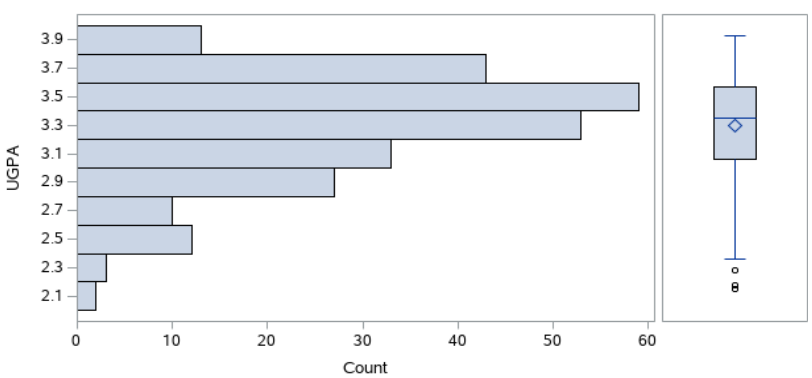

Figure 1. Distribution plot for UGPA scores.

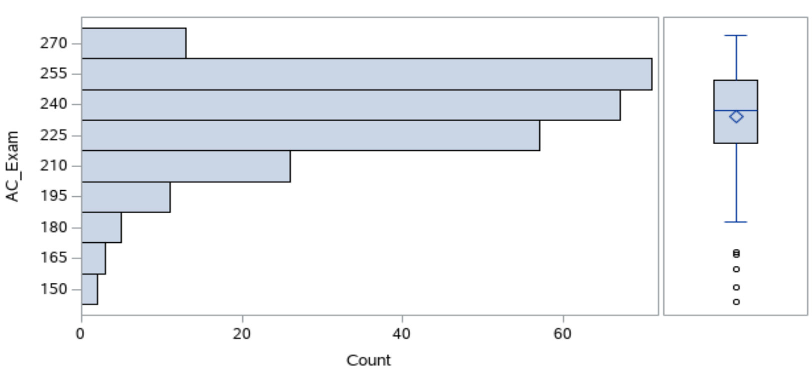

Figure 2. Distribution plot for AC certification exam scores.

In Table 1, Figure 1 and Figure 2, the distribution of UGPA and AC exam scores for all the students were negatively skewed implying that students tended to perform well with most of their scores clumping up on the upper side of the test score scale. Noteworthy is that there were some outliers which tended to fall way down below the passing score. Table 2 also gives the statistics by semesters.

Table 2

Descriptive statistics of UGPA and AC exam scores as differentiated by semester

Semester	Variable	N	Mean	Median	Mode	Std Dev	Minimum	Maximum
Fall 2015	UGPA	17	3.08	3.23	3.24	0.32	2.28	3.48
Spring 2016	UGPA	35	3.32	3.41	3.19	0.33	2.54	3.87
Fall 2016	UGPA	27	3.27	3.29	3.45	0.36	2.50	3.81
Spring 2017	UGPA	36	3.14	3.18	3.05	0.35	2.37	3.74
Fall 2017	UGPA	21	3.36	3.53	3.25	0.43	2.18	3.92
Spring 2018	UGPA	47	3.28	3.38	3.47	0.43	2.15	3.90
Fall 2018	UGPA	31	3.39	3.34	3.19	0.25	2.83	3.92
Spring 2019	UGPA	41	3.42	3.53	3.60	0.38	2.36	3.93
Fall 2015	AC Exam	17	231.35	230.00	219.00	19.80	184.00	262.00
Spring 2016	AC Exam	35	237.57	247.00	252.00	25.37	144.00	268.00
Fall 2016	AC Exam	27	237.33	237.00	207.00	20.98	197.00	274.00
Spring 2017	AC Exam	36	232.78	234.50	220.00	22.86	167.00	264.00
Fall 2017	AC Exam	21	227.76	228.00	222.00	17.49	196.00	259.00
Spring 2018	AC Exam	47	230.47	240.00	229.00	27.86	151.00	270.00
Fall 2018	AC Exam	31	231.16	236.00	236.00	16.82	183.00	257.00
Spring 2019	AC Exam	41	240.83	244.00	221.00	19.15	188.00	167.00

Table 2 shows that most students were taking the exam in the spring. Of the 255 who took the exam, 35 failed, about 14% (35/255*100%) failing rate. This implies that about 86% passed on average.

Correlation between AC Exam Scores and UGPA Scores

Correlation analysis investigated the nature and strength of the relationship between UGPA and AC exam scores for those students who completed their undergraduate CM degree and also took AC exam. Using the modified Pearson correlation coefficients guide from Wao et al. (2017), the interpretation of correlation indices are; +/- 0.7 and higher = very strong positive/negative relationship, +/- 0.4 to 0.69 = strong positive/negative relationship, +/-0.3 to 0.39 = moderate positive/negative relationship, +/-0.2 to 0.29 = weak positive/negative relationship, +/-0.1 to 0.19 = very weak relationship and +/-0.01 to 0.09 = negligible relationship. This implies that the results ranged from moderate positive to strong positive relationships. Figure 3 shows the trend of the correlation indices assessed over the semesters. The sample size for each semester is also shown.

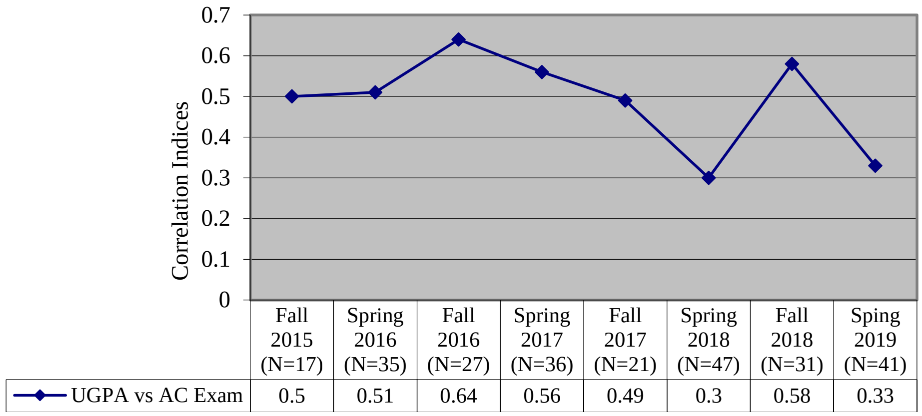

Figure 3. Correlation coefficients of UGPA and AC exam score of the students.

The graphical trend plot in Figure 3 shows the relationship between UGPA and AC exam as relatively modest/strong positive correlation indices. Noteworthy, it would be useful to assess the overall correlation coefficient that aggregates all the scores of the two variables for all the students over the duration. Thus, a correlational of 0.436 (r = 0.436) was found to exist between the scores at a *p*-value ($p<0.0001$) for the 255 students over the 4-year duration of the study. Figure 4 shows the scatter plot.

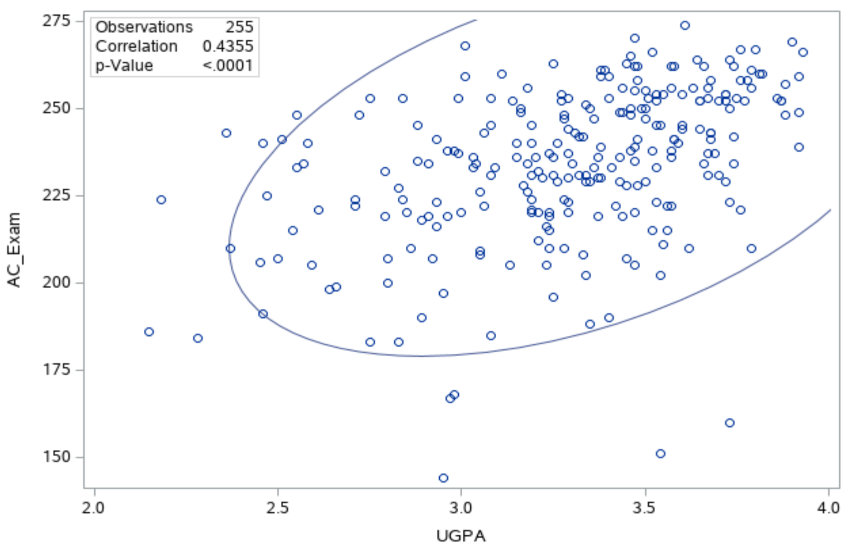

Figure 4. Scatter plot of AC exam scores and UGPA scores of the students.

Somewhat similar *p*-values were seen for the correlation values over the semesters in Figure 3 (Fall 2015, p = 0.0397; Fall 2016, p = 0.0003; Fall 2017, p = 0.0228; Fall 2018, p = 0.006; Spring 2016, p = 0.0018; Spring 2017, p = 0.0004; Spring 2018, p = 0.0387; Spring 2019, p = 0.0368). These *p*-values (including one for the total number of students) were statistically significant at p = 0.05. Interpretation of the *p-value* is to reject the null hypothesis when *p-value* is less than 0.05 implying a statistically significant difference in the result or fail to reject the null hypothesis if *p-value* is greater than 0.05 suggesting insufficient information to reject the null hypothesis. Therefore, it is clear from the statistically significant correlational results that the performance in AC exam relates well with UGPA.

Discussion and Conclusion

Review of literature has shown that professional certifications have been on the rise to meet the growing need for skilled workers and also that qualified people are needed in projects. Value of certifications to students has been documented, e.g., better salaries, professional image, etc. AC certification has been identified to be available to CM students which they can use to demonstrate that they have the basic professional knowledge and competence needed to handle projects when they pass the exam. Students need the knowledge gathered over their 4-year CM education career as a prerequisite to take the exam. The knowledge as depicted from academic performances, which is measured by their GPAs, can be used as a motivating factor to pursue certification before going into the construction field. Relative cheapness of the AC exam compared to other certifications can also be a source of motivation. Passing it would imply that an individual is ready for the construction field.

Therefore, this research explored the relationship between the cumulative GPA and the AC exam of CM seniors. The idea was that those who excelled in the exam by achieving the passing score of 70% and above would be construed to have mastered the CM curriculum which is reflective of the industry needs with regard to the skills needed for the growing workforce. Statistical results were reported.

The performance in the AC exam was found to be relatively high as depicted by the negatively skewed distributions of the scores. Similar result was seen in the UGPAs. With the 35 students failing the AC exam, it was deduced that the success rate was at 86%. This is higher when compared with the study by Braford et al. (2019) and Sylvester (2012) where 67% pass rate was recorded in AC exam but surprisingly with no linear correlation with GPA. This 86% success rate in the exam was a clear sign that students were getting highly motivated to take and pass the exam. This result showed a statistically significant strong correlation with UGPA which implied that if students performed well academically in the CM curriculum, there was a higher likelihood that they would perform equally well in the AC exam and have the AC credential when they transition into the construction industry especially when motivated. However, there could be limitations with this deduction and a need to interpret it with caution as other things can influence this outcome especially when applied to a wider population of CM students. There could be some institutional motivational approaches to help students prepare and be encouraged to take and pass the exam which can vary across programs and universities. Some CM programs may be providing revision incentives to students while others leave students to study alone. Others may be paying the exam fee for students as incentive to excel or students pay and get reimbursed by university/program if they pass the exam, etc. These may have differing levels of motivation that affect passing rates whether with high or low GPAs.

In conclusion, this research showed that the performance of students in undergraduate CM curriculum has a positive relationship with the AC exam scores and so this could be a decent indicator of their abilities to pass AC exam before getting in the construction industry. The correlations semesterwise and for the whole sample were statistically significant to warrant a conclusion of reliable relationship across the variables examined. The outcome of this study aligns with Ford et al. (2012) where this current study has correlation of 0.436 between AC and GPA scores while Ford et al. (2012) had 0.60 between AC and SAT scores. Thus, the hypothesis of the existence of positive correlation between AC exams scores and UGPAs was supported. Noteworthy, it would be logical to argue that other factors such as emotional stability and motivation to take the exam could also impact success, and so this positive correlation should not be construed to mean causation, and generalizability of the outcome to the whole CM students' population should therefore be done with caution. This research contributes to the correlation studies and its outcome could provide useful information to CM students wishing to pursue AC certifications. Further research may involve predictive research on the subject.

Reference

American Institute of Constructors (AIC), (2022a). Retrieved from https://www.aic-builds.org/ on February 25 2022.

American Institute of Constructors (AIC), (2022b). Retrieved from https://www.aic-builds.org/about-certification on February 25 2022.

Barrows, M., Clevenger, C., Abdalla, M. & Wu, W. Value of certifications when seeking construction employment. Relationship between admission GRE scores and graduation GPA scores of construction management graduate students. *International Journal of Construction Education and Research,* 16 (1) 61-79.

Bradford, C., Larson, K. & Naganathan, H. (2019). Determinants for students success on the associate constructor exam. In Proceedings of the International 55th ASC Conference.

Bruce, R. D., Sauer, A. D., & McCandless, D. W. (2008). Comparing the impact of the Certified Professional Constructor (CPC) credential on the careers of construction educators and industry practitioners. In *Proceedings of the International 44th Annual Conference Associated Schools of Construction, Auburn, Alabama*.

Bruce, R. D., Gebken, R., Shawn, S. (2010). Comparing credentials in the building design and construction community: CPC, LEED AP, and DBIA. 46th ASC Annual Conference.

Burgett, J. M. (2018). Perception of the AC exam by pass or fail status. 54th ASC Annual Conference.

Clevenger, C. M., Abdallah, M., & Wu, W. (2017). Advisory board feedback on construction education learning outcomes. *Proceedings of the Associated Schools of Construction 53rd Annual International Conference, Seattle, Washington.*

Coglianese, C. (2018). Value analysis of CM professional certifications for the newly graduated CM students. Retrieved from https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1133&context=cmsp on February 25 2022.

El Debs, L. C., Shaurette, M., & Benhart, B. L. (2016). Professional certifications in construction industry: A comparative view from students and companies. 52nd ASC Annual International Conference Proceedings, Provo, UT.

Ford, K., Kinard, D & Sims, B. (2012). Measuring educational program effectiveness using the associate constructor exam. Journal of Technology, Management & Applied Eng., 2-8.

Gross Domestic Product (GDP) by Industries, United States Bureau of Economic Analysis. Retrieved from https://www.bea.gov/data/gdp/gdp-industry on February 25 2022.

Kuncel, N., Hezlett, S., & Denize, O. (2001). A comprehensive meta-analysis of the predictive validity of the graduate record examinations: Implications for graduate students selection and performance. Psychological Bulletin, 127(1), 162–181.

Sylvester, K. E. (2012). Assessing student learning using the constructor qualification examination in us accredited programs. Journal of Civil Engineering and Architecture, 1473-1481.

Wao, J.O., Ries, R., Flood, I., Lavy, S. & Ozbek, M. (2016). Relationship between admission GRE scores and graduation GPA scores of construction management graduate students. *International Journal of Construction Education and Research*, 12. (1)37-53.

Wao, J. O., Bivins, K. B., Hunt, R., Ries, R., & Schattner, S. (2017). SAT and ACT scores as predictors of undergraduate GPA scores of construction science and management students. Proceedings of the 53rd ASC Annual Conference, Seattle, USA, April 5-8, 2017.

2020 Construction Outlook: Associated General Contractors (AGC). Retrieved from https://www.agc.org/sites/default/files/Files/Communications/2020_Outlook_Survey_National.pdf on February 25 2022.

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Influence of Pedagogical Agent Deictic Gestures on Construction Management Students Learning within a 360-Degree Virtual Field Trip

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Field trips are widely recognized as an essential educational component to connect classrooms with the real world. When students don't have access to real field trips, virtual ones have been developed by educators and researchers. Pedagogical agents have been applied to serve as a tour guide and educational tool that facilitate students learning in a virtual learning environment. Such agents are computer software generated and controlled entities that replicate or emulate humans. Previous studies have found that adding anthropomorphic traits to pedagogical agents in learning environments has significantly improved students' learning experience; however, this area has yet been explored in the context of a virtual construction field trip. In this study, a virtual field trip to a complex mechanical room was developed using 360-degree panoramas and a pedagogical agent was employed to lead the tour. This study focuses on one single anthropomorphic trait - deictic gestures, which are pointing gestures used to refer to specific objects – and explores how such trait affects students' quantitative learning outcomes and feedbacks on four aspects of the agent, including facilitating learning, credibility, human-like, and engaging. It was found that deictic gestures can improve students' learning performance and attitudes on multiple aspects of the agent.

Key Words: Construction Education, Virtual Field Trip, Pedagogical Agent, Anthropomorphic Traits, Deictic Gesture

Introduction

A construction field trip is an interactive and essential component of construction education that connects classrooms with the real world, where students are traditionally transported to real construction jobsites to meet personnel and observe the dynamic construction working procedures (Eiris Pereira & Gheisari, 2017; Murray & Tennant, 2016). The field trip has been actively implemented within multiple construction curriculums such as mechanical, electrical, and plumbing system, facility operation, and maintenance, and construction materials (Eiris Pereira & Gheisari, 2017). Field trips help students build a spatiotemporal awareness and provide students opportunities to obtain technical and practical knowledge onsite to reinforce the core concepts they learn in class

(Arslan, 2004; Eiris Pereira & Gheisari, 2019; Mills, Ashford, & McLaughlin, 2006). However, there are a great amount of logistic and spatiotemporal challenges associated with the implementation of field trips, such as safety concerns, travel expenses, time conflict with other classes, large class sizes, and not being able to see or hear in a crowed or noisy environment (Wen & Gheisari, 2020). The COVID-19 pandemic that has been lasted for two years further prevents educators to plan and implement such trips, resulting in fewer opportunities for students to observe complex and dynamic construction activities in a real-world setting.

To overcome barriers of traditional field trips, researchers and educators have explored virtual learning environments that support an experience of observing the physical conditions of a construction project via the Internet or other technologies (i.e., virtual field trip applications) and such environments can be assessed anytime anywhere by students (Eiris & Gheisari, 2017; Finch & Wing, 1996; Jaselskis et al., 2011; Wen & Gheisari, 2020). For instance, Eiris, Wen, and Gheisari (2020) developed a masonry materials' field trip using 360-degree panoramas, and students perceived this platform as easy to use and highly realistic. Among these virtual field trip applications, pedagogical agents have been applied to serve as a tour guide and educational tool that facilitate students learning in a virtual learning environment (Eiris et al., 2020; Eiris, Wen, & Gheisari, 2021a, 2021b). Such agents are computer software-generated and controlled entities that replicate or emulate humans (Eiris & Gheisari, 2017). Anthropomorphism is defined as the attribution of human traits, emotions, or intentions to non-human entities. Previous studies have found that adding anthropomorphic traits to pedagogical agents in learning environments has significantly improved students' learning experience (Lester et al., 1997; Lester, Zettlemoyer, Grégoire, & Bares, 1999; Mayer, 2014; Mayer & DaPra, 2012). However, this area has yet been explored in the context of a virtual construction field trip. This study focused on one single anthropomorphic trait: deictic gesture. Deictic gestures are pointing gestures used to refer to specific objects. In this study, deictic gestures were incorporated into the pedagogical agent to refer objects in the 360-degree learning environment. A virtual field trip, namely *iVisit*, to a complex mechanical room was developed using 360-degree panoramas and a pedagogical agent was employed to lead the tour. This study contributes to the body of knowledge by understanding how deictic gestures affect students' quantitative learning outcomes and feedbacks on four aspects of the pedagogical agent, including facilitating learning, credibility, human-like, and engaging.

Relevant Studies

Pedagogical agents are lifelike characters presented on a computer screen that guide users through multimedia learning environments and they have been widely used in such environments (Seel, 2011). Previous research shows that the inclusion of pedagogical agents in the learning environment improves students' learning and overall learning experience (Lester et al., 1997, 1999). For example, a study conducted by Lester et al. (1999) showed that merely the presence of lifelike character in the learning environment had a positive effect on students learning experience. Due to the positive effect of the pedagogical agent in the learning environment, there has been significant research in designing pedagogical agents to bring the most out of pedagogical agents to assist learning. Previous research shows that the addition of anthropomorphic traits to pedagogical agents can significantly improve learning in students. For example, a study conducted by Lester et al. (1997) involved a pedagogical agent with five different levels of expressiveness with respect to hand gestures and speech. The study found that students who learned from fully expressive agents performed significantly better than students who learned from other agents. Another study showed that the addition of anthropomorphic attributes like facial expressions and deictic gestures also significantly improved learning in students

(A. L. Baylor & Kim, 2009). Although anthropomorphic traits, in general, improve learning, there is evidence in previous research suggesting that certain anthropomorphic traits influence more in specific learning topics (A. L. Baylor & Kim, 2009; Bergmann & Macedonia, 2013). For example, iconic gestures were found to be positively affecting learning new foreign languages (Bergmann & Macedonia, 2013), deictic gestures were found to be positively affecting learning in procedural modules, and facial expressions were found to be positively affecting learning in attitudinal modules (A. L. Baylor & Kim, 2009). Therefore, it is necessary to find out the effects of anthropomorphic traits in different learning topics. This study investigates the effects of gestures (specifically deictic gestures) in the field of construction management where a pedagogical agent leads a virtual field trip.

Methodology

In this section, the platform development for the virtual field trip (iVisit) and the experimental design are discussed. To develop the iVisit platform, a 360-degree virtual learning environment would be created to provide background contexts for a complex mechanical room. Meanwhile, pedagogical agents were models, and deictic gestures were carefully designed for iVisit contents. Then, a between-subject study was conducted, and two experimental conditions were applied. Condition 1 employed a pedagogical agent with no deictic gesture while Condition 2 employed a pedagogical agent with deictic gestures. The 360-degree virtual learning environment of a mechanical room and the learning contents that were covered during the field trip was exactly the same in both conditions. The study measures would also be introduced in this section.

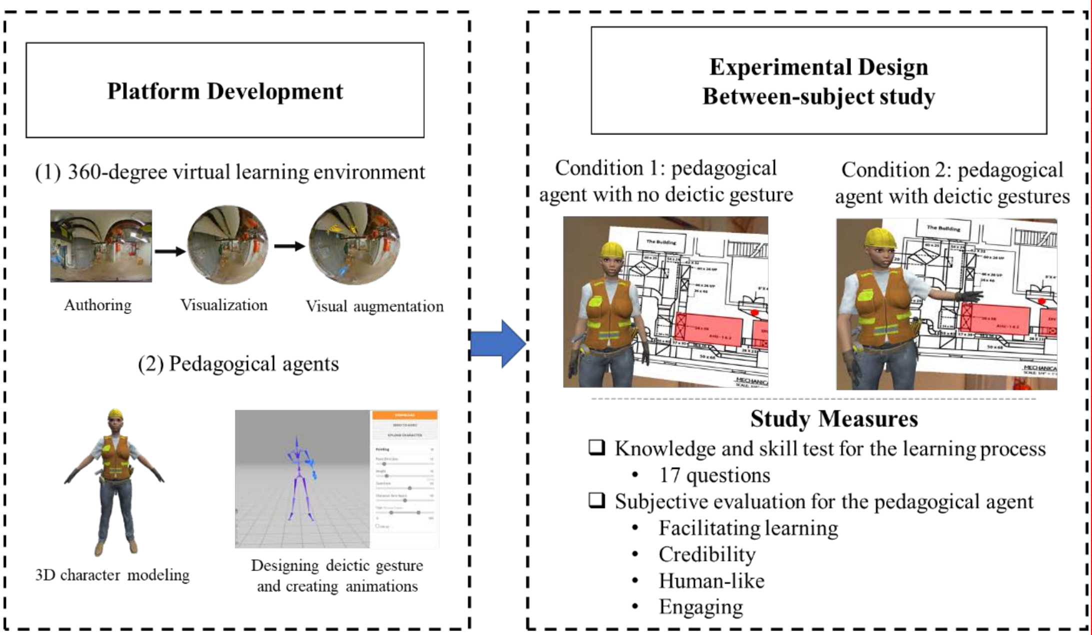

Figure 1. Research Methodology

Platform Development

In this process, the development of the iVisit platform is introduced: the creation of component (1) 360-degree virtual learning environment, and generation of component (2) pedagogical agents (Figure 1). For component (1), 360-degree panoramic images of selected locations in the mechanical room were captured using the 360-degree cameras and authored into equirectangular scenes using computer software. Then, game engines (i.e., Unity) that support 3D graphics were used to render the 360-degree panoramic environment. The equirectangular scenes imported to the game engine were projected into spherical visualization of the mechanical room, where the user's perspective is in the middle of the sphere. Finally, visual augmentations were superimposed over the 360-degree environment to provide users with more detailed information or visual highlights for designated locations or equipment in the mechanical room.

The pedagogical agent used for purpose of this study was developed using Daz3D. The Pedagogical agent was designed whose clothing matches with a construction worker's attire, which matched the context of the construction background and lead to persuasion and credibility (Chaiken, 1979; Eiris et al., 2020, 2021a). A female pedagogical agent was chosen because previous research says that female instructors motivated learners, increased interest in engineering fields, and self-efficacy in students (Plant, Baylor, Doerr, & Rosenberg-Kima, 2009). The pedagogical agent model was then exported to Unity as an FBX file. Animations for the pedagogical agent were imported from Mixamo, which provides a wide of animation for humanoid animated characters. For this study, we used deictic gestures in which the direction of pointing can be adjusted to the required direction. To point to different objects in the 360-degree environment, deictic gestures were configured based on the direction requirements in Mixamo. The resulting animations were imported to Unity and configured to humanoid animation. The humanoid animation was then applied to the pedagogical agent to refer to different objects in the 360-degree environment.

Experimental Design

Study Procedure

To understand the effects of deictic gestures on students' learning in the 360-degree environment, a between-subjects study was conducted with two conditions: agent with no deictic gesture (i.e., No-Gesture group) and agent with gestures (i.e., With-Gesture group). For the study, we recruited participants from two undergraduate classes in construction management. Students were provided extra credits as compensation to participate in the study (IRB202100669).
The study was conducted using Qualtrics. During the study, participants went through four stages, informed consent, pre-survey, iVisit interaction, and post-survey. After the consent form, participants were assigned to one of the two conditions evenly. After finishing the pre-survey, students were asked to download the iVisit platform. iVisit platform was pre-uploaded to the cloud, and a shareable link was generated and embedded in the Qualtrics for students to download the iVisit platform. iVisit contained two sessions: a learning session and an assessment session. The learning session included three scenes that explained the working of the heating, ventilation, and air conditioning system in a building. The assessment session consists of 17 questions based on the contents students studied in the learning session. After the iVisit experience, students were asked to complete a post-survey to subjectively evaluate the pedagogical agent in iVisit.

Study Measures

To evaluate the impact of the deictic gestures on students' learning, 17 knowledge and skill questions were embedded in iVisit to quantitatively evaluate students learning outcomes. These 17 questions were specifically developed based on the learning contents that were covered in the mechanical room trip. Some questions were location-sensitive (i.e., asking students to identify certain locations) to make sure students understood not only what the equipment or device was and how did it work, but also understood the spatial arrangement in the mechanical room. These questions were validated by the class instructor as well as the expert in the associated area. Furthermore, this study used an Agent Persona Instrument (API) survey questionnaire for students to evaluate the persona of the pedagogical agent. API has been used in multiple studies to understand the effectiveness of the pedagogical agent in learning considering four aspects: facilitating learning, credibility, human-like, and engaging (A. Baylor & Ryu, 2003). API considers two important constructs, (1) Informational usefulness and (2) Affective Interaction. Facilitating learning and credibility reflects on the Informational Usefulness construct, while human-like and Engaging reflect on the Affective Interaction construct of the pedagogical agent. The four aspects would be assessed by multiple statements on a 5-point Likert scale where one indicates strongly disagree and five means strongly agree. The responses for each aspect were aggregated and normalized from a 0 to 100 range. The detailed descriptions for each aspect were as follows:

- Facilitating learning aspect refers to how the agent facilitates learning and reflection. Higher scores indicated students are more likely to positively rate the agent as a learning facilitator.
- The credibility aspect refers to the value of the advice or instruction from the agent. A higher score indicated students' higher level of recognition of the agent's credibility.
- The human-like aspect refers to the naturalness of the agent's nonverbal communication with respect to personality and emotional expression. A higher score indicated students' higher level of recognition of the agent's human-like feeling.
- The engaging aspect refers to the level of motivation provided by the agent. A higher score indicated the pedagogical agent supported a higher level of engagement.

Data Collection and Analysis

Twenty-six students were participating in the experiment and were randomly assigned to No-Gesture and With-Gesture groups. Both groups had thirteen participants where ten of them were male and three of them were female students. The average ages for the two groups were very similar (No-Gesture: 21 vs With-Gesture: 20). Overall, participants in the two conditions shared very similar demographic backgrounds; besides, as they were recruited from the same classes, their academic backgrounds were also considered similar. An analysis was performed using descriptive statistics. It was found that students in the With-Gesture group gained a higher score (Mean: 61.09%; STD: 3.78%) for the knowledge and skill test than students in the No-Gesture group (Mean: 56.33%; STD: 5.64%). Overall, students in the With-Gesture group rated the pedagogical agent more positively from all aspects (facilitating learning, credibility, and human-like) except the engaging aspect (Table 1). Additionally, the independent samples t-tests were performed for four measures; however, there was no significant difference detected (Table 1).

Table 1: Results of the Descriptive Analysis and Independent Samples T-Tests

Measure	**Group**	**Mean**	**SD**	**Independent Samples T-Test**	
				W	**p**
Facilitating Learning	No-Gesture	63.93%	3.72%	80.50	0.313
	With-Gesture	66.15%	4.72%		

Credibility	No-Gesture	75.90%	5.04%	76.00	0.237
	With-Gesture	81.54%	3.47%		
Human-like	No-Gesture	37.80%	5.41%	77.00	0.254
	With-Gesture	39.08%	3.36%		
Engaging	No-Gesture	57.85%	3.50%	98.50	0.652
	With-Gesture	54.46%	5.61%		

Discussion and Conclusion

Generally speaking, students in both conditions presented somewhat positive attitudes on the credibility aspect of the pedagogical agent, as *'(the) agent was smart and credible, I didn't doubt any of the words or knowledge it said'*. Students also presented slightly positive attitudes on facilitating learning and engaging aspects of the agent. Nevertheless, a somewhat negative attitude on the human-like aspect of the pedagogical agent was observed in both conditions. Noticeably, the majority of students (21 out of 26) commented on the monotone and robotic voice and suggested applying a real human's voice for the agent may help with the engaging and human-like aspect of the agent. The results of the independent samples t-test suggest that deictic gestures did not influence students' perception of the pedagogical agent. Given the significant amount of students who provided negative comments regarding the voice, it is potential that the robotic voice dramatically distracted students; therefore the actual conditions (with or without deictic gestures) may not be allocated with proper attention from students. This aligned with students comment *'The voice was very monotone and sometimes it was hard to pay attention.'*

Therefore, in the future applications of the pedagogical agents in the learning environment, specific significance should be attached to the application of the natural or real human voices. This study also found pedagogical agents implementing deictic gestures can improve students' learning performance and result in higher knowledge and skill scores. However, such findings are only limited to the current participants and need careful considerations for generalization. Moreover, future researchers and educators need to carefully consider and balance the benefit of the deictic gestures and their effort investment in the implementation of the gesture. In the future, more participants will be recruited in the construction management classes in the following semesters, and their demographics (such as age, gender, year in school) would be also investigated to find if any of the demographics affect the research outcomes. Statistical analysis will be conducted to detect the correlations between students' demographics, learning performance, and the pedagogical agent's informational usefulness and affective interaction in the virtual learning environment.

References

Arslan, G. (2004). Design of a Web-Based Virtual Construction Site Visit for Education of Civil Engineering Student (Part I). In *Towards a Vision for Information Technology in Civil Engineering* (pp. 1–8).

Baylor, A. L., & Kim, S. (2009). Designing nonverbal communication for pedagogical agents: When less is more. *Computers in Human Behavior*, *25*(2), 450–457.

Baylor, A., & Ryu, J. (2003). The API (Agent Persona Instrument) for assessing pedagogical agent persona. *EdMedia+ Innovate Learning*, 448–451. Association for the Advancement of Computing in Education (AACE).

Bergmann, K., & Macedonia, M. (2013). A virtual agent as vocabulary trainer: Iconic gestures help to improve learners' memory performance. *International Workshop on Intelligent Virtual Agents*, 139–148. Springer.

Chaiken, S. (1979). Communicator physical attractiveness and persuasion. *Journal of Personality and Social Psychology*, *37*(8), 1387.

Eiris Pereira, R., & Gheisari, M. (2017). Site Visit Application in Construction Education: A Descriptive Study of Faculty Members. *International Journal of Construction Education and Research*, 1–17. https://doi.org/10.1080/15578771.2017.1375050

Eiris Pereira, R., & Gheisari, M. (2019). Site visit application in construction education: A descriptive study of faculty members. *International Journal of Construction Education and Research*, *15*(2), 83–99.

Eiris, R., & Gheisari, M. (2017). RESEARCH TRENDS OF VIRTUAL HUMAN APPLICATIONS IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION. *Journal of Information Technology in Construction (ITcon)*, *22*(9), 168–184.

Eiris, R., Wen, J., & Gheisari, M. (2020). *iVisit: Digital Interactive Construction Site Visits Using 360-Degree Panoramas and Virtual Humans*. 1106–1116. https://doi.org/10.1061/9780784482865.117

Eiris, R., Wen, J., & Gheisari, M. (2021a). iVisit-Collaborate: Collaborative problem-solving in multiuser 360-degree panoramic site visits. *Computers & Education*, 104365.

Eiris, R., Wen, J., & Gheisari, M. (2021b). IVisit–Practicing problem-solving in 360-degree panoramic site visits led by virtual humans. *Automation in Construction*, *128*, 103754.

Finch, E., & Wing, R. D. (1996). A navigable walkthrough simulator for built environment education: Archiwalk. *Facilities*.

Jaselskis, E., Ruwanpura, J., Becker, T., Silva, L., Jewell, P., & Floyd, E. (2011). Innovation in construction engineering education using two applications of internet-based information technology to provide real-time project observations. *Journal of Construction Engineering and Management*, *137*(10), 829–835.

Lester, J. C., Converse, S. A., Kahler, S. E., Barlow, S. T., Stone, B. A., & Bhogal, R. S. (1997). The persona effect: Affective impact of animated pedagogical agents. *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, 359–366.

Lester, J. C., Zettlemoyer, L. S., Grégoire, J. P., & Bares, W. H. (1999). Explanatory lifelike avatars: Performing user-centered tasks in 3D learning environments. *Proceedings of the Third Annual Conference on Autonomous Agents*, 24–31.

Mayer, R. E. (2014). Principles based on social cues in multimedia learning: Personalization, voice, image, and embodiment principles. *The Cambridge Handbook of Multimedia Learning*, *16*, 345–370.

Mayer, R. E., & DaPra, C. S. (2012). An embodiment effect in computer-based learning with animated pedagogical agents. *Journal of Experimental Psychology: Applied*, *18*(3), 239.

Mills, A., Ashford, P., & McLaughlin, P. (2006). The value of experiential learning for providing a contextual understanding of the construction process. *AUBEA 2006: Proceedings of the 31st Australasian University Building Educators Association Conference*, 1–13. University of Technology Sydney.

Murray, M., & Tennant, S. (2016). " Off-piste pedagogy": Construction site visits for undergraduate civil engineers. *Sixth International Symposium of Engineering Education*, 165–172.

Plant, E. A., Baylor, A. L., Doerr, C. E., & Rosenberg-Kima, R. B. (2009). Changing middle-school students' attitudes and performance regarding engineering with computer-based social models. *Computers & Education*, *53*(2), 209–215.

Wen, J., & Gheisari, M. (2020). A Review of Virtual Field Trip Applications in Construction Education. *Construction Research Congress 2020: Safety, Workforce, and Education*, 782–790. American Society of Civil Engineers Reston, VA.

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Barrier to the use of Sandbag Material Technologies as a Sustainable Affordable Housing Solution: Perspectives from South Africa

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Abstracts: over 12.5 million families in South Africa live in slums without access to adequate housing. Previous studies projected that meeting housing demand in South Africa will take hundreds of years with the available resources and technologies. Therefore, achieving sustainable and affordable housing solutions remain a pressing goal. This study assessed the perception of experts and end-users on the barriers to the use of sandbag material technology as a Sustainable Affordable Housing Solution in South Africa. The study draws on focus group discussions held with 12 leading experts on alternative technologies and local South African end-users to obtain data to address the research objective. It emerged that lack of social acceptance, lack of support from the government, limited Professional Expertise, and Access to finance are barriers to the use of sandbag material technology in South Africa. The study concludes with some recommendations and adds significantly to the limited knowledge on alternative building material technologies such as Sandbag technology.

Key Words: Affordability, Alternative Building Technologies (ABTs), Building Materials, Housing, Sandbags, Sustainability

Introduction

Housing is a fundamental need of humans. Housing provides essential security, safety, and shelter needs. However, approximately 1.6 billion people – more than 20% of the world's population lack adequate housing, and an estimated 100 million people are homeless (Adabre et al., 2020). About 12.5 million families don't have access to adequate housing (Grady et al., 2019). This suggests that the existing construction methods and materials are incapable of solving the problems of inadequate housing and a need for alternative building materials. Sandbags (typically known as earthbags or soil bags) are polypropylene bags or polymer materials filled with granular materials. The sandbag has been proposed as an affordable, sustainable, recyclable, and alternative building material capable of providing access to housing (Cataldo-Born et al., 2016).

Despite the advantages of Sandbag Building Technology (SBT) and its potential to bridge the housing deficit in South Africa, its adoption in housing construction is low. Botes (2013) and Salzer et al. (2016) found that conventional brick, concrete, and steel houses are most preferred and considered modern by an average person. South Africans perceived that houses constructed with sandbags were only meant for the poor. They expressed their preference to live in a house built with conventional materials; brick, concrete blocks, and mortar (Grady et al., 2019). This is evident as the preponderance of the South African built fabric comprises traditional material, including bricks, concrete blocks, and mortar (Dlamini 2020). Therefore, to enhance the comprehensive implementation of sandbag technologies in housing delivery in South Africa, it is crucial to determine the local experts' and end-users' perceptions of the barriers to the use of sandbag technologies as a sustainable and affordable housing solution in South Africa.

In the light of the above background, this study evaluates the level of use and perception of the local experts and end-users on the barriers to the use of Alternative Building Technology (ABT) such as sandbag building technologies as a sustainable and affordable housing solution in South Africa.

The Concept of Sustainable Affordable Housing (SAH) and Use of Sandbag Material Technology

According to Pullen et al. (2010) a sustainable, affordable housing concept (SAH) is "housing that meets the needs and demands of the present generation without compromising the ability of future generations to meet their housing needs and demand." Sustainable Affordable Housing (SAH) provides an economic benefit, improved occupant health, comfort, energy, and water efficiency while also reducing cost (Golubchikov and Badyina, 2012). Sustainable Affordable Housing (SAH) provides an 80% reduction in energy (Adabre et al., 2020). Affordable housing is when a household spends less than 30% of its income on housing (Friedman and Rosen, 2018). A house is sustainable when it is of good quality, in a good location for a lower-middle-income household, and the cost is reasonable to allow a household to meet other basic living costs on a sustainable basis (National Summit on Housing Affordable, 2006).

Sandbag building technology (SBT) provides economic and environmental advantages to affordable houses in many developed and developing countries. It is an earthen architecture that uses locally available soil placed in woven bags filled and stacked to form a building (Rincon, 2019). Castaldo-Born et al. (2016) found that houses constructed with SBT consume less energy during construction and operations. It also regulates the internal temperature of the building by absorbing excess heat during the day and releasing it at night, thereby providing a relaxed internal environment in hot and warm weather (Rincón et al., 2019; Shaker et al., 2017). More so, economically, SBT is relatively cheaper than conventional technologies. The approximate cost per square meter of a sandbag house in India and South Africa is 7.55 and 242 US dollars, respectively (Ecobuilder, 2019). Despite the benefit of SBTs, their adoption is low in South Africa.

Even though researchers and manufacturers view that adopting SBTs is crucial to solving the housing deficit in South Africa by delivering sustainable and affordable housing. Little or no recent research has been done on evaluating the barriers to adopting SBTs as alternative methods of construction in South Africa.

Research Methods

This research adopted a qualitative research approach that employed focus group interviews as the primary method of data collection for this study. The qualitative descriptive study was guided by Cresswell and Clark's explanation of qualitative descriptive studies (Cresswell and Clark, 2004). Consistent with qualitative descriptive research, this research wasn't carried out based on any prior theoretical or philosophical orientation. It follows an inductive content analysis approach, where codes were directly derived from text data. Hence, the research employed a purposive sampling technique to gain in-depth information of both the experts' and end-users' perceptions of the barriers to adopting sandbag technologies in South Africa. Focus group participants for the present study comprised of SBT experts and end-users in South Africa. Table 1 shows the demographic profile of the focus group participants and their expertise.

Data Collection

Cape Town was selected as the appropriate location for the focus groups discussion. A range of experts across the South African construction industry was present physically, while others joined online. Two focus group discussions with 6 participants each were held in Cape Town, thus within the acceptable range of 6 to 15 as Morgan (1997) advised. Previous research demands at least two focus group sessions for research methods relying on focus groups data (Guest et al., 2017). The two focus group sessions addressed two general questions which sought the perspectives and opinions of the experts and end-users regarding the objectives of the present study. The general question is; what are the barriers to adopting ABTs such as sandbag materials in South Africa?

The primary aim of the focus group discussion is to generate data from the discussion of the participants, not to impose consensus, and the two sessions were managed to achieve this aim. The discussion was recorded with a video camera, and it lasted for 2 hours. Also, some of the participants made formal presentations to clarify their arguments and point. The video recording and other output generated during the focus group discussion were transcribed.

ID	**Involvement in sandbag technologies**	**Experience with SBTs (Years)**
C1	An SBT expert and the CEO of a sandbag construction company	25
C2	United Nations researcher on infrastructural investment, green building and biomimicry	20
C3	A doctoral researcher on sustainable and affordable housing in South Africa.	15
C4	A quality assessor inspector at the Centre for Research in housing innovation	25
C5	A researcher on alternative construction	8
C6	An occupant of an SBT house in South Africa	3
D1	A leading researcher on Alternative Building Technologies	25
D2	A leading researcher on Alternative Building Technologies	30
D3	A researcher on sustainable and affordable housing in South Africa.	5

D4	An SBT expert and the CEO of a sandbag manufacturing company	25
D5	An Associate Professor and an expert researcher on sustainable construction	13
D6	An occupant of an SBT house in South Africa	3

Table 1: Profile of the focus group member

Data Analysis

The audio-recorded data were transcribed verbatim and analyzed using NVivo 11 software packages. Open coding was conducted, which entails a line-by-line or verbatim examination of data where qualitative data were selected into the unit of meaning. Furthermore, the various codes emanated from the selected data were used to mark the critical point, and these were grouped into various concepts. Then, this concept was further divided into codes and subcodes. The number of references to each code was used as a basis for accessing the relative importance of each code. According to Chileshe et al. (2016), in analyzing qualitative data in construction research, several references to codes are treated to indicate their weight and relative importance. Bazeley (2007), notes that "people repeat ideas that are of significance for them."

Code (references)	**Subcodes**
1. Social acceptance (17)	• Poor-quality house. • Burnt down houses • Poverty
2. Government support (11)	• Building codes and regulation • Scarcity of sand in South Africa
3. Professional expertise (9)	• Ego • Limited life span
4. Preference for brick(7)	• Lack of knowledge • Awareness
5. Access to finance (4)	

Table 2: NVivo thematic classification

Validity and Reliability

The study follows the recommendation of Rosenthal (2016) that direct quotations of the respondent should be presented to demonstrate the reliability and validity of the data. Hence, the themes were accompanied by direct quotations of responses attributed to the participants in the focus group discussion. More so, it is subjected to an NVivo word frequency analysis to check for word consistency, as shown in Figure 1.

Figure 1: NVivo word frequency analysis

Figure 2: NVivo Thematic classification

Data Analysis and Finding

Five themes were classified into nine sub-themes that emerged from the dataset. The summary of barriers to using sandbag technology as a sustainable, affordable housing solution in South Africa is shown in Figures 2 and Table 2.

Expert and End-user's perception on the barriers to the use of Sandbag Technologies in South Africa.

This study explores the experts' and end-users' perceptions of the significant barriers to using SBTs in housing construction in South Africa. The perception was coded into five subcategories, with 48 references, as shown in Figure 2 and discussed in the following sub-sections.

Social Acceptance

The experts agreed that the lack of social acceptance of sandbags is a significant problem in the South African context despite its advantage and potential to resolve housing challenges (17 references as shown in Figure 2). Most South Africans naturally prefer houses constructed with brick and concrete. "*social acceptance is a big problem. People think that because I'm getting a sandbag house, I'm getting a poor-quality house. I'm getting an inferior house, and there is a perception that a brick house is what I need to aspire towards, I must have a brick house.*" *(Participant D6)*. This is bolstered by the research of Kulshreshtha et al. (2020) and Rincon et al. (2019), who concluded that the population associated sandbag houses with poverty and felt ashamed to live in a sandbag house in India and sub-Sahara Africa.

The experts interviewed noted that the people burned down most alternative building technology houses built in the informal settlement because the community does not accept and approve it. "*People have burnt down houses that were built for them in Frieda. We built 600 houses in Frieda, they were built with polystyrene, and when the contractors started, they were burnt down. When the community doesn't accept and approve a house made of sandbag*" - *(Participant C2)*.

More so, experts noted that the community threaten their lives. The project team was stoned and forced to leave the townships due to people's lack of acceptance and approval of this technology. "*What would it entail because we have tried building the houses in Townships like Khayelitsha, and we were stoned and told to get out. If I had stayed there for five more minutes, I probably would have been killed*" *(Participant D4)*. This finding is consistent with extant studies that have linked the low adoption of earth technology to end-users lack of social acceptance (Kulshreshtha et al., 2019; Lyamuya et al., 2013).

Social acceptability emerged as an essential factor that needs to be addressed in adopting SBT in affordable housing in South Africa; when people do not accept a concept, implementing it may be difficult. According to research by Wustenhagen et al. (2007), for a technology to be widely adopted, it has to be accepted by the end-users, professionals, investors, and the Government.

Preferences for Conventional Material

It emerged from the expert discussion that preference for conventional materials among community members plays a massive role in the non-acceptance of ABTs (seven references as shown in Figure 2). South Africans have a preference for houses built with brick and concrete. Most especially in the informal settlement of South Africa, they believe an alternative building technology house such as sandbag is meant only for the poor. "*One of the issues is South Africans have a natural likeness for houses constructed with bricks and concrete, and they believe an alternative building house will tag them as poor. And there is the issue of people often saying; we don't want to be seen as poor people*" - *(Participant D3)*

There was a consensus among the experts that most people believe houses constructed with alternative building technology are of poor quality and have limited life spans. The experts agree that if the community does not accept this technology, it may never be implemented. "*People believe that because a house is built of sand, it is of poor quality and has a limited life span. When the community does not accept a concept, it will never be implemented*" *(Participant C3)*. This agrees with the study of Reddy and Mani (2007). They concluded that increased adoption of energy-intensive conventional construction led to a steep decline in the uptake of sandbag construction.

Government support

It emerged from the discussion of experts that there is no support from the Government in terms of established building regulation codes and policy on alternative building technologies such as sandbags in South Africa. *"However, as much as we've tried in South Africa, we've never been able to achieve this because the perception is not good, and I don't think there's a will from government to accept it"* *(Participant M9)* shown in Figure 2. Government support was seen as a significant barrier with 11 references, compared with professional expertise (9 references), preference for brick and block (7 references), and access to finance (4 references). Experts attributed this to the lack of adequate published research on the performance of alternative building technologies such as sandbags. "*Government can* *only have confidence when there are published results on the performance of sandbag housing" (Participant D1)*. This is consistent with Rincon et al.'s (2019) research, where he observed an absence of general recommendations by the government and building codes for sandbag technologies

Professional Expertise

Professional expertise was predominantly seen as a barrier with nine references, as illustrated in Figure 2. It emerged from the expert discussion that construction professionals' perception of sandbag technology plays a significant role in implementing SBTs in South Africa. Experts argue that construction professionals do not understand the sandbag construction process. Hence, a practical understanding of the specifications of sandbag construction limits the successful implementation of this method of construction. *Participant C5 notes that "construction professionals ought to understand the process of constructing using sandbags and what needs to be done to prevent issues like cracking and using multiple materials*." This is consistent with Grady et al.'s (2019) and Ugochukwu's (2015) research, where they observed that most professionals prefer to use conventional building materials and technologies than alternative building technologies because they are more familiar with the latter.

Access to finance

The respondents discussed finance access, the least rated barrier with four references illustrated in Figure 2. Based on the experts' argument, it emerged that banks refused to offer bonds/mortgages for sandbag houses. Without this type of investment, it is hard to own a sandbag house or get enough funding to build one. According to *Participant C1 "banks will not finance it, and this is probably the biggest problem*". Leverage (2017) noted that many investors are unfamiliar with the technology and efficiency of ABTs. Therefore, accessing housing credit and insurance from financial institutions is almost impossible. (Zami and Lee, 2011). However, some experts argued that the financial institution's support depends on the Government's approval. "*Banks don't have a problem as long as the Government has approved the system; I don't think there will be any problem since the sandbag system has been there for some time*" *(Participant C5)*

This study has contributed to the limited body of knowledge of barriers hindering the use of SBTs in South Africa through a focus group discussion with experts and end-users in South Africa. It is expected that when the barriers are overcome, the stakeholders will be keen to adopt ABTs instead of conventional building materials in housing construction in South Africa.

Conclusion and Recommendations

Achieving sustainable and affordable housing solution remain a pressing goal. This study assessed the perception of experts and end-users on the barriers to the use of alternative building technologies (ABTs) such as sandbag material technology as a sustainable affordable housing solution in South Africa. This study found that the perceived barriers to the use of ABTs such as sandbag material technology comprise of social acceptance (17 references), lack of support from the Government (11 references), limited Professional Expertise (9 references), and Access to finance (4 references). The social acceptance of sandbag houses was perceived as the most significant barrier to the use of SBTs in South Africa. This study revealed that South Africans do not accept or approve the SBTs on housing projects. Due to end-users' lack of acceptance and approval of this technology project teams implementing SBTs have been stoned and forced to leave project sites. This study established that South Africans view that houses built with alternative building technology are inferior and associate them with poverty and therefore prefer to stay in a brick and blockhouse.

Based on these findings, the study concludes that achieving a sustainable and affordable housing solution in South Africa through the use of alternative building technologies such as SBTs is hindered by the lack of social acceptance of the technologies by the end-users, professionals, and investors, lack of support from the Government, preferences for conventional building technologies, lack of professional expert knowledge and access to finance

The study recommends that workshops and seminars be held by the promoters of SBTs to create awareness of the benefits of sandbags by the stakeholders. Scholars view that multiple and continuous educative outreach efforts of the economic and environmental benefits could improve the perceptions of ABTs among citizens. The study also recommends that promoters should build SBT demonstration projects across all provinces in South Africa because People become more accepting of ABTs once they physically experience a house made from the technology. Also, community members should be trained and involved in the construction process.

This research extends the knowledge of SBTs beyond intelligent guesses and arguments to capture the view of the local expert and end-users on barriers to the use of ABTs such as Sandbag material technology as a sustainable, affordable housing solution in South Africa. Thus, this study adds significantly to the limited body of knowledge on alternative building technologies, focusing on SBT houses. Consequently, the findings provide policymakers with information on the barriers to the use of ABTs in housing construction. It also provides policymakers with strategies for overcoming the barriers identified. Further studies on the barriers to the use of alternative building technologies barriers in different locations are recommended.

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References

Adabre M.A., Albert P.C, Amos D., Robert O. Rotimi A. and Theophilus A. 2020. Critical barriers to sustainability attainment in affordable housing: International construction professionals' perspective. Journal of Cleaner Production 253 119995

Bazeley, P., 2007. Qualitative Data Analysis with NVivo. SAGE, London.

Botes, A. W. (2013). *A feasibility study of utilizing shipping containers to address the housing backlog in South Africa*. Doctoral dissertation, University of Stellenbosch.

Cataldo-Born, M., Araya-Letelier, G. & Pabón, C. 2016. Obstacles and motivations for earthbag social housing in Chile: energy, environment, economic and codes implications. *Revista de la Construcción. Journal of Construction,* 15(3): 17-26.

Chileshe, N., Rameezdeen, R., Hosseini, M.R., 2016. Drivers for adopting reverse logistics in the construction industry: a qualitative study. Eng. Construct. Architect. Manag. 23 (2), 134e157.

Creswell, J. W., & Clark, V. L. P. (2004). Principles of qualitative research: Designing a qualitative study. *Office of Qualitative & Mixed Methods Research, University of Nebraska, Lincoln*.

Dlamini, T. U. 2020. *The feasibility of wood-plastic composites as a building material for RDP houses in South Africa.* Ph D dissertation, Stellenbosch University.

Friedman, R., Rosen, G., 2018. The challenge of conceptualizing affordable housing: definitions and their underlying agendas in Israel. Hous. Stud. 1e23

Golubchikov. O. and Badyina. A. Sustainable Housing for Sustainable Cities: A Policy Framework for Developing Countries, (2012).

Grady, B., Muzila, D., O'Neill, K., Tanner, A., Belz, M., Tshiguvho, T. & Gumede, D. 2019. *Alternative Building Technologies for Low-Income Housing in Cape Town, South Africa.* Doctoral dissertation, Ph. D. Thesis. Worcester Polytechnic Institute, Worcester, MA, USA.

Guest, G., Namey, E., Taylor, J., Eley, N., & McKenna, K. 2017. Comparing focus groups and individual interviews: findings from a randomized study. *International Journal of Social Research Methodology*, *20*(6), 693-708.

Hadjri, K., Osmani, M., Baiche, B., & Chifunda, C. 2007, September. Attitudes towards earth building for Zambian housing provision. In *Proceedings of the Institution of Civil EngineersEngineering Sustainability.* 160(3): 141-149. Thomas Telford Ltd.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.

Kulshreshtha, Y., Mota, N. J., Jagadish, K. S., Bredenoord, J., Vardon, P. J., van Loosdrecht, M. C. & Jonkers, H. M. 2020. The potential and current status of earthen material for low-cost housing in rural India. *Construction and Building Materials*. 247, 118615.

Lyamuya, P. & Alam, K. 2013. Earth Construction in Botswana: Reviving and Improving the Tradition. *CAA DHAKA 20th General Assembly and Conference*. 2 Macêdo dos Santos, D. & Beirão, J. N. D. C. 2017. Generative tool to support architectural design decision of earthbag building domes.

Morgan, D.L., 1997. Focus Groups as Qualitative Research. SAGE Publications, Inc, Thousand Oaks, California.

National Summit on Housing Affordable, 2006. Achieving a national affordable housing agreement: background paper 2: key terminology and indicators. In: National summit on housing affordability

Reddy, B. V., and Mani, M. (2007). Preface: Proceedings, International Symposium on Earthen Structures, Indian Institute of Science, Bangalore, 22-24 August. Interline Publishing, India.

Rincón, L., Carrobé, A., Martorell, I. & Medrano, M. 2019. Improving thermal comfort of earthen dwellings in sub-Saharan Africa with passive design. *Journal of Building Engineering.* 24: 100732.

Rosenthal, M.: Qualitative research methods: why, when, and how to conduct interviews and focus groups in pharmacy research. Curr. Pharm. Teach. Learn. 8(4), 509–516 (2016)

Salzer, C., Wallbaum, H., Lopez, L. F. & Kouyoumji, J. L. 2016. Sustainability of social housing in Asia: a holistic multi-perspective development process for bamboo-based construction in the Philippines. *Sustainability*. 8(2): 151.

Shaker, A., Medhat, H., Abou-elgheit, M., Nassar, M., Mahmoud, Y., Hamza, A. S. and Abou-Zeid, M. 2017. A proposed sandbag housing unit for poor and disadvantaged Areas. Conference proceeding: *Leadership in Sustainable Infrastructure*. Vancouver, Canada. May 31 – June 3.

Ugochukwu, I. B. & Chioma, M. I. B. 2015. Local building materials: an affordable strategy for housing the urban poor in Nigeria. *Procedia Engineering*. 118:. 42-49.

Zami, M. S. & Lee, A. 2011. Inhibitors of adopting stabilized earth construction to address the urban low-cost housing crisis: An understanding by construction professionals. *Journal of Building Appraisal*. 6(3):227-240.

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Energy and Cost Comparison of Building Cooling Systems

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Cooling a building can be approached with several different methods but determining which method to pursue can be a matter of operator preference. This study examines four equipment systems of building cooling (Variable Refrigerant Flow, Rooftop Units, Hydronic Chiller, and Split Systems) and their capacities, abilities, and inabilities. These systems are then compared against one another for efficiency and operating cost in a one-year timeframe. Yearly operating cost, energy usage, and system operating time were analyzed from each unit's performance and then compared against one another. The efficiencies, energy usage, and cost are compared to find the most efficient and cost-effective system for various owner needs and applications. Depending on the performance of the individual systems, it may be more suited to a specific application. Variable Refrigerant Flow was the most efficient due to its method of heat rejection and higher efficiency components. The chiller was also an efficient option, with the heat rejection through water being an efficient method. Rooftop units and split systems were less efficient but lowered initial capital cost. Overall, capital cost and operating expense priority determine the best method for an individual application.

Key Words: HVAC, Energy, Cooling, Efficiency, Cost, Building Cooling Systems

Introduction and Background

The conditioning of indoor spaces has been one of the more significant advances of comfort in the last 100 years. However, the method in which spaces and buildings are cooled, heated, and ventilated is a varied and widely studied field that is advancing daily. There are many independent and combinations of possibilities in accomplishing the same goal, from variable refrigerant flow systems to closed-loop chilled water systems. While other factors differentiate all the cooling methods, the most significant factor in the balance of energy efficiency is the yearly operating cost and the initial capital investment (Medjugorac et al., 2020). The owner often decides which direction to take, assisted by a life-cycle cost analysis. This energy analysis exposes future costs operating costs and maintenance, and upkeep.

The importance of energy analysis is driven by the increase of energy consumption by modern building systems (Kumar et al., 2017). As the density of building construction increases, especially in urban centers, conventional energy sources are becoming depleted. (Kumar et al., 2017). This has led building owners to be more aware of their energy usage and selected equipment. In conjunction with the awareness of an owner's energy usage, conditioning equipment manufacturers have installed options with their equipment, which have reduced energy consumption through different methods. Heat Recovery devices, such as thermal wheels or air-to-air fixed-plate heat exchangers, have been shown to reduce energy consumption by reusing waste heat from a system (Papakostas et al., 2018). Energy savings are not just used for an owner's energy savings but are mandated by various code authorities. ASHRAE 90.1 has been used to take advantage of outdoor air conditions for cooling a space using an airside economizer in specific cooling equipment capacities (Quirk, 2011).

In addition to specialty equipment accessories, there are also aspects of building design that are inherently passive and help with energy conservation. Energy management in building design is not solely the engineer's obligation but can also be looked at from an architect’s perspective. An architect's inputs to a reduced energy load include green building aspects, including double-skin façades, green roofs, and window blinds (Randelovic et al., 2020). Sensible building controls are another method to balance a building’s energy usage. Using specific temperature setpoints for a building’s intended usage while also balancing the comfort of the building’s occupants has also been shown to be a practical approach for energy conservation (Kwak et al., 2019). Overall, there are many ways to manage a building’s energy usage for its conditioning, but this study will focus on the several types of equipment used to achieve that end.

An older approach to cooling space is a Roof Top Unit (RTU). RTU’s, also known as packaged units, or DX (Direct Exchange) units. Compared to other methods, they have a low initial capital cost and straightforward installation (Silhol, 2021). Silhol also shows that since all the cooling and heating coils and fan sections are contained within the unit, RTU’s are a good option for projects with limited interior mechanical space. While RTU’s are commonplace, they may sometimes sacrifice efficiency for ease of use and low cost. This is often due to the continued manufacture of RTU’s with single-speed components, regardless of new requirements for multi-speed supply fan operation (Cai et al., 2018). However, this has been addressed by retrofitting variable speed components to existing units (Wang et al., 2019). With variable speed components, Wang was able to show a 31% improvement in cooling efficiency. Li et al. (2015) mentioned in their research that manufacturers have begun to see the long-term benefit of using these variable speed drives, making them standard in their packaged units. These package units are combined with new power modeling approaches for these variable speed drives in RTU’s (Li et al., 2015), bringing a traditional RTU approach closer to the higher efficiencies of other cooling technologies.

One of the other cooling methods is using water as a heat transfer medium, which is most often utilized with a water-cooled chiller using a cooling tower. Heat is taken from the conditioned space and transferred to the water. Water is run through a cooling tower, rejecting the heat into the atmosphere, and the water returns into the system. While this method is simple to understand and operate, it has noticeably lower efficiencies than other cooling methods (Li et al., 2021). While efficiencies are still low compared to other methods like variable refrigerant flow, chilled water systems have improved. Chilled water systems with an energy efficiency ratio (EER) less than 3.8 have begun to be phased out (Hua et al., 2010). Chilled water systems are still in use because of their larger cooling capacity compared to other methods. Chillers are readily available (not custom built) for up to 500 tons of cooling (6,000 MBH) by most major manufacturers. The use of chillers is most often seen in large-scale commercial buildings such as office buildings, and the choice to use them is often a balance of energy efficiency and overall capacity (Suamir et al., 2018).

While commercial approaches to cooling are widely varied, most residential applications use a similar method of a split system. A dedicated outdoor heat pump or condenser is connected by refrigerant line sets to an indoor air handler (or furnace). This system is commonplace in most homes but can be commercialized for smaller building applications. The benefit of a split system can be seen in its versatility of applications, use of various refrigerants, and versatility in installation location (Elgendy et al., 2017). The most significant benefit is their low cost, as demonstrated by their use in most homes. However, once the system size increases, it may not be feasible to use split systems. A Variable Refrigerant flow system can be up to 12% more energy efficient with the same capacity (Li et al., 2017). Li explains this by showing that most split systems use single-speed fans and variable capacity units, like VRF (Variable Refrigerant Flow), to reduce stop-start energy waste. Regardless of these findings, split systems continue to be commonplace and will remain, so unit other small capacity options are available at comparable prices.

As mentioned previously, one of the most competitive systems available today in building HVAC systems is Variable Refrigerant Flow or VRF. Invented by Daiken as VRV© (Variable Refrigerant Volume) in the 1980s, VRF is just now becoming commonplace in most new building designs. It works on taking heat rejected from the parts of a building that need cooling and using it to heat other areas of the building that need heating. This system has improved with the improvement of refrigerants for the cooling and heat cycles and the introduction of variable speed components (Saab et al., 2018). It differs from other systems in its heat reuse and can save up to 47% compared to traditional methods like an RTU (Lee et al., 2018). Energy and subsequently money savings like this have taken the attention of many building owners. They can explain why half of the new medium-sized commercial buildings and a third of new large commercial buildings use VRF today (Aliehyaei, 2020). They are considered first in energy-efficient design due to their very operation being efficient with heat rejection. Using VRF and other building design options has allowed the construction of buildings with a net-zero or net-negative energy impact (Kim et al., 2019). The efficient nature of the system, its interchangeability of components, and more accurate modeling techniques (Kim et al., 2020) have allowed design engineers to layout a building's lifecycle energy consumption more accurately. This has increased importance as the focus shifts more towards overall lifecycle impact than initial capital cost.

As there are many different options in conditioning space, it is essential to consider each system's benefits. Selection depends entirely on the end user's needs, and it is necessary to see how each system will perform given the same circumstance. Capital cost may be valued over energy efficiency, or the opposite may take priority. In either case, a comparison of all options is helpful for engineering analysis. This study will take the known abilities of the given systems and compare them against one another to find what system is ideal for a given circumstance.

Methodology

Rooftop units, hydronic systems, split systems, and variable refrigerant flow have unique capabilities and disadvantages. To compare these four cooling systems to one another accurately, a comparison including all four methods needed to be run at once. Systems in each of the four categories were selected from Carrier's lineup of products to control the information supplied for the performance of each system. As Carrier makes each system, the product information provided was similar across all systems and made the comparison more practical. These four systems and their performance in the baseline environment were the focus of this study.

For the baseline environment, a basic test building was modeled to map the energy use of each system given the same parameters. Using Carrier's Hourly Analysis Program (HAP), each system was run simultaneously in the identical test building, with the same building envelope parameters. Fenestration, wall and floor composition, and roof composition were all modeled to see how energy was used and directed within this building. This level of modeling allowed for the simulation of not only instantaneous use of electricity in each system but power usage throughout the year as demand for cooling increased and declined. The efficiencies of each system were mapped and simultaneously compared to one another, showing how each system performs in varying climatic conditions throughout the year. A complete comparison of the energy usage and efficiency of the four systems was collected and then subsequently compared against one another.

Before the four cooling systems could be analyzed, the test conditions needed to be established to ensure a consistent comparison baseline. The first step in creating a baseline test environment was to select weather data that would allow for an accurate analysis of system performance over the course of a year. ASHRAE weather conditions from the Atlanta Hartsfield International Airport measuring station were used for this project. A sample of the data recorded from the Atlanta measuring station is shown in Figure 1. All temperatures shown are in degrees Fahrenheit. A number of weather stations are in the area, but the Atlanta airport readings, shown as selection D, are some of the oldest, most accurate, and well-kept conditions in the area and provided excellent data points to input into the Carrier HAP software for comparison. Among the data collected in the report were the average dry bulb and wet bulb temperatures of each month and the extremes in the hottest month of the year. Also included were the average dewpoints for dehumidification calculations and the extreme design conditions for 5, 10, 20, and 50-year averages. All of this data was incorporated into the weather information of the HAP program to show the energy usage of each system throughout the year.

D ATLANTA HARTSFIELD INTL AP, GA, USA (WMO: 722190)

Lat:33.64N Long:84.43W Elev:1027 StdP: 14.16 Time zone:-5.00 Period:82-06

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
1	20.7	25.8	3.5	6.8	27.4	8.8	9.0	32.2	25.5	37.3	24.0	38.1	11.8	320

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	17.1	93.8	74.3	91.5	74.0	89.3	73.4	77.2	88.2	76.2	86.5	75.3	84.9	8.9	300

Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 and 55/69
0.4%			1%			2%			0.4%		1%		2%		
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
74.2	132.7	81.2	73.3	128.4	80.1	72.4	124.8	79.4	41.2	88.3	40.2	86.6	39.3	85.4	813

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
22.0	19.2	17.3	82.4	11.8	96.5	7.6	3.3	6.4	98.9	2.0	100.8	-2.3	102.6	-7.8	105.0

Figure 1: ASHRAE Weather Conditions

In addition to the weather data used, a test building needed to be designed so that these systems could show realistic performance in a building, not just their hypothetical performance or performance metrics from the manufacturer. A model building, shown in Figure 2, was created using Autodesk's Revit software to the model square footage of different spaces. In addition, this allowed window convection rates and wall, roof, and floor transmission rates. These values added parameters that allowed for a higher level of accuracy in modeling the performance of each of these cooling systems. When run over a year, the peak loads for each building component were calculated and added to the entire system performance. Window and skylight solar loads were 8,390 BTU/h at peak, window transmission from convection was 3,206 BTU/h, wall transmission was 3,946 BTU/h, floor transmission was 586 BTU/h, door transmission was 467 BTU/h, and roof transmission was 10,831 BTU/h. In addition, overhead lighting added 4,178 BTU/h of load, and miscellaneous electrical loads added 3,908 BTU/h. This adds to a total of 35,512 BTU/h, or roughly 3.55 MBH. While this would typically require a system with around 3 tons of cooling capacity, each system was sized to an entire 10-ton unit.

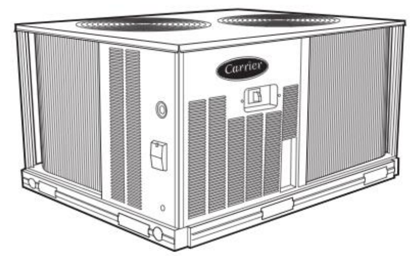
Figure 2 : Building used to Cooling System

For the systems to be analyzed, their parameters and performance capabilities had to be input into HAP. This included their net and gross cooling capacities, electrical data, heat gain from fans and other accessories, as well as their efficiencies. In addition to these different parameters, standard parameters such as the cooling setpoint were also set. For this study, the cooling setpoint was established at 75°F. This allowed the program to simulate when cooling systems would run based on outdoor conditions as well as how the indoor conditions held and rejected heat. Another aspect of putting this data into HAP was the simultaneous simulation of all the systems. If a parameter needed to be changed, it could update all systems at once, once they had been modeled. Additionally, system psychometrics for each system were generated, mainly to check when the highest load occurred and to match it to the hottest month for ASHRAE weather conditions.

a. 10 Ton WeatherMaker RTU

b. Carrier VRF Heat Pump

c. AquaSnap Air-Cooled Liquid Chiller



d. Gemini Split System – 10 Ton Split System

Figure 3: Four different Cooling Systems

Once the test building was established and input into HAP, each system and its performance needed to be input, tested, and analyzed, all systems tested were made by Carrier, which allowed for the same parameters to be explored across all four different systems, namely: a) 10 Ton WeatherMaker RTU, b) Carrier VRF Heat Pump, c) AquaSnap Air-Cooled Liquid Chiller, and d) Gemini Split System – 10 Ton Split System. The four units are shown below in Figure 3.

Data Analysis and Results

When modeled with the test building, the WeatherMaker RTU used over half of the building's energy in cooling. The distribution of energy is shown in Figure 4, with 20.2% of the energy going to other electric equipment and 23% going to the building lighting. The total cost of energy for the RTU over one year was $1,119, calculated by an 8,760-hour simulation. The energy distribution of the building when using the variable refrigerant flow system is shown in Figure 4. Only 43.5% of the building's energy went towards cooling, with 26.4% in electrical equipment and the final 30% towards building lighting. As explained previously, this efficiency is from the heat pump's ability to redistribute waste heat. The annual cost of the heat pump in cooling mode only was $749 but had a higher cooling cost in the winter months at $22 and $16 in January and December, respectively. Again, this is due to the cooling mode constantly running even in seasons that require the most heat. Overall, this system's efficient process and components had a low cost for cooling relative to the rest of the building cost.

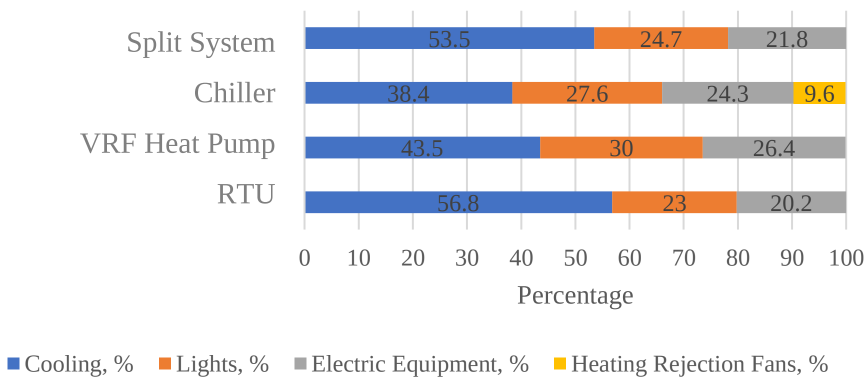


Figure 4: Four different Cooling System Energy Usage

While this unit did have more components needing to be powered, the overall percentage of building electricity to operate this chiller is 48%. This is split between 38.4% of the energy going towards the chiller operation and 9.6% going towards the heat rejection fans on this chiller. While this is a higher energy usage than purely refrigerant-based solutions, it should be noted that hydronic chillers such as this one are more efficient at distributing and dissipating heat from a system. The additional load of this building includes 24.3% of the building's energy going towards electrical equipment and 27.6% going to building lighting, shown in the distribution in Figure 4. The cooling cost in this system is $901 for the year, mainly during the cooling months. The highest cost of running this chiller is in the hottest month of the year, July, at the cost of $171. Virtually no cost was incurred in the winter months as the chiller would not be running. The split system cooling method for this building net 53.5% of building energy being used on cooling. While all components for cooling are in one package, it still had the disadvantage of a refrigerant line set connecting to indoor distribution units. 21.8% of electricity was used for electrical equipment, and 24.7% was used for building lighting, shown in Figure 4. The cooling cost for this system over the year was $1,279, having the highest costs

in July and August at $229 and $213, respectively. While this is higher than other systems, no cooling cost was incurred in the winter, as heating could only run if cooling was not.
After all of the systems were analyzed, their relative performance was then measured. Using the Cobb county energy rate of $0.10 per kWh, the energy cost for each system was calculated over the course of a year, broken into 12 months. This fluctuation in cost is shown in Figure 5. The highest cooling cost is in the summer when outdoor air temperatures are highest, with the rooftop unit having the highest cost at $229. It should be noted that the rooftop unit also has the lowest cost in the wintertime. The variable refrigerant flow had the lowest energy cost in the summer, at $112, due to its reuse of waste heat but had the lowest change in cost between winter heating and summer cooling seasons. It is clear to see the differences in the cost of the monthly operation of each system in this breakdown, given a constant energy rate.

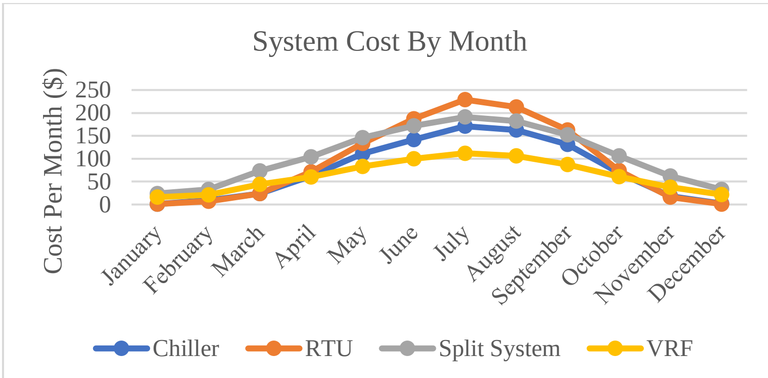


Figure 5: Energy Cost of the Four Systems by Month

Another cost breakdown can be shown with the amount of money given to each category. As the same building test parameters were held constant in this study, a baseline cost of $974 across all systems accounts for building lighting and other electrical loads. This distribution, shown in Figure 6, shows that the split system has the highest yearly cost at $2,253 for building operation over 12 months. The rooftop unit had the following highest cost, at $2,093. While using both electricity for water circulation and heat rejection, the chiller system had the second-lowest yearly cost at $1,875. The lowest summer cost shows that variable refrigerant flow also had the lowest annual operation cost at $1,723. VRF has the lowest operation cost over a year in this scenario from an operation standpoint. Since this was only looking at cooling over a year, this ordering could shift with the introduction of measuring heating costs.

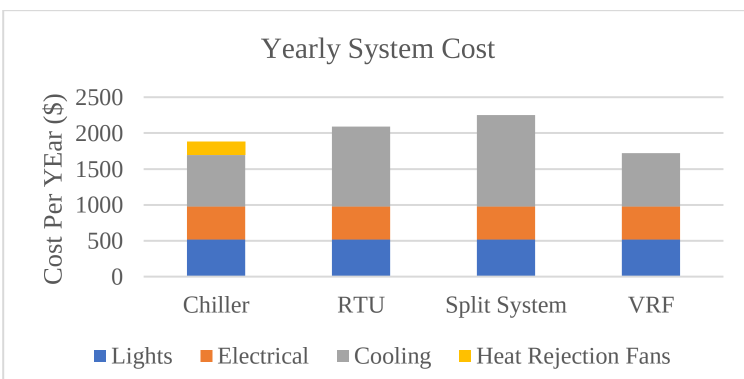


Figure 6: Distribution of Energy Usage of the Four Systems

The final aspect of the system's performance that was analyzed was the usage per month of each unit. This study found that the unit's more efficient, the less it ran over any given month. The unit's energy usage was measured against the capacity required from the space and climatic conditions over the course of one year. The VRF unit ran the least, only running 44% of the time in the highest load month of July. The rooftop unit ran 83% of the time in this same month. Higher efficiency units were able to cool the same space, with less energy in less time. This allowed the unit to cycle down or even shut off in lower loads (night or winter). The distribution of the runtimes as a percentage of the time in the month is shown below in Figure 7.

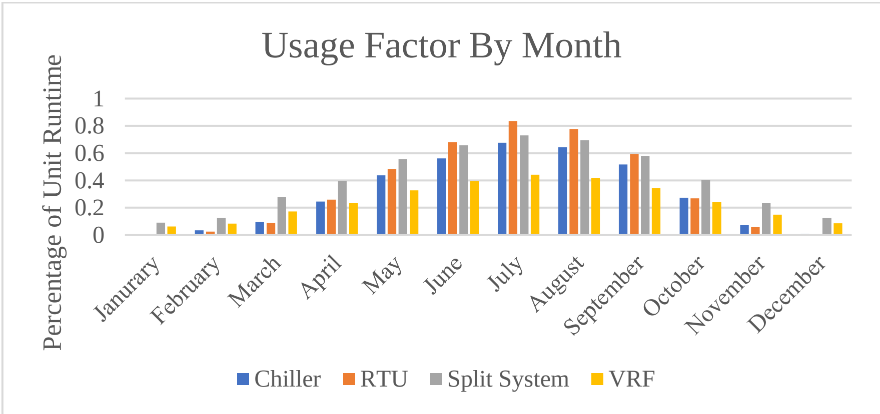


Figure 7: Monthly Usage of the Four Systems

Conclusion

Individual performances of each system were analyzed and compared. It was clear that the variable refrigerant flow system had the highest efficiency and subsequently lowest operating cost. While it is inherently efficient due to the fundamentally different handling of heat rejection, it is also efficient from the components used, such as digital scroll compressors or brushless direct-drive fans. Overall, this technology's higher initial capital investment pays off in the cost savings seen over the unit's lifespan. The next most efficient and cost-sensitive system was the chiller. While less efficient than the VRF system, chillers are also very efficient in handling heat. As the chiller system size increases, the cost-benefit of having a hydronic system also increases. Since this system was limited to only 10 tons, its efficiency was hampered. On the lower end of the performance was the rooftop unit. While this system did not perform as efficiently as others, it is offset by its lower cost and simpler design. These rooftop units are often easier to install and operate, which may be attractive for some consumers. The least efficient system in this study was the split system. This had a number of disadvantages, including less efficient components, a refrigerant line set, and low tonnage capability. However, it should be noted that this system is one of the most commonly sold, especially in the residential market. This is because they are often the most simple to operate as well as some of the lowest initial capital costs. To determine the best system, each building needs to be analyzed, and the owner's needs need to be met. If the owner is initially looking for lower capital cost, they may settle for a less efficient system. If they pursue energy efficiency or an energy rating, they may need to set aside additional funding for a more efficient unit. Each system's application is unique and depends entirely on the circumstances. However, this study's variety of mechanical cooling equipment shows a system for every application.

References

Cai, J. (1), & Braun, J. E. (2). (2018). Assessments of variable-speed equipment for packaged rooftop units (RTUs) in the United States. Energy and Buildings, 164, 203-218. 10.1016/j.enbuild.2018.01.007

Elgendy, E. (1,2), Melike, M. (1), & Fatouh, M. (1). (2018). Experimental assessment of a split air conditioner working with R-417A under different indoor and outdoor conditions. International Journal of Refrigeration, 85, 268-281. 10.1016/j.ijrefrig.2017.10.005

Hua, T., Yitai, M., Minxia, L., Chuntao, L., & Li, Z. (2010). The Status and Development Trend of the Water Chiller Energy Efficiency Standard in China. Energy Policy, 38(11), 7497-7503. https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=eoh&AN=1247739&site=eds-live&scope=site&custid=ken1

Kim, D. (1), Cho, H. (1), Koh, J. (2), & Im, P. (3). (2020). Net-zero energy building design and life-cycle cost analysis with air-source variable refrigerant flow and distributed photovoltaic systems. Renewable and Sustainable Energy Reviews, 11810.1016/j.rser.2019.109508

Kim, W., Han, Y., Kyoung, J. K., & Kwan-Woo Song. (2020). Electricity load forecasting using advanced feature selection and optimal deep learning model for the variable refrigerant flow systems. Energy Reports, 6, 2604-2618. 10.1016/j.egyr.2020.09.019

Kumar, D., Rizwan, A. M., & Abdul, G. M. (2017). Energy Analysis of Selected Air Distribution System of Heating, Ventilation and Air Conditioning System: A Case Study of a Pharmaceutical Company. Mehran University Research Journal of Engineering and Technology, 36(3), 745-756. https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=edsdoj&AN=edsdoj.0f968d9d4a34238bea6b38825f3e0bc&site=eds-live&scope=site&custid=ken1

Kwak, Y., & Huh, J. (2019). Management of cooling energy through building controls for thermal comfort and relative performance in an office building. Science & Technology for the Built Environment, 25(2), 139-148. 10.1080/23744731.2018.1503033

Lee, J., Im, P., Munk, J. D., Malhotra, M., Kim, M., & Song, Y. (2018). Comparison Evaluations of VRF and RTU Systems Performance on Flexible Research Platform. Advances in Civil Engineering, , 1-16. https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=edb&AN=128894119&site=eds-live&scope=site&custid=ken1

Li, J., Wang, X., & Ji, Y. (2021a). Energy Consumption Evaluation of Water Chiller in Cooling Station. 2021 11th International Conference on Power, Energy and Electrical Engineering (CPEEE), Power, Energy and Electrical Engineering (CPEEE), 2021 11th International Conference On, , 170-174. 10.1109/CPEEE51686.2021.9383335

Li, Y. (1), Liu, M. (1), & Lau, J. (2). (2015). Development of a variable speed compressor power model for single-stage packaged DX rooftop units. Applied Thermal Engineering, 78, 110-117. 10.1016/j.applthermaleng.2014.12.038

Li, Z., Wang, B., Li, X., Shi, W., Zhang, S., & Liu, Y. (2017). Simulation of recombined household multi-split variable refrigerant flow system with split-type air conditioners. Applied Thermal Engineering, 117, 343. 10.1016/j.applthermaleng.2017.02.003

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CO2eq Comparison Between a Light Gauge Steel Framing Structure and a CMU Structure for Single-Family Residential Projects in Costa Rica

The challenges posed by the degradation of the planet's environment are of increasing importance. The United Nations have called for a substantial reduction of climate change pollutants such as carbon dioxide equivalents (CO2eq) within the next decade. The construction industry and building operations contribute an estimated 39% of the worldwide CO2eq, with 28% attributed to operational emissions and the remaining 11% to embodied emissions. This case study analyzes the embodied CO2eq by the structural portion of three residential construction projects in Costa Rica using two building systems. One building system is widely used locally, consisting of load-bearing concrete masonry unit walls and concrete elements. The other building system is a recently introduced alternative based on light gauge steel framing and paneling. The analysis shows that the light gauge steel frame alternative is more efficient in terms of embodied CO2eq by 33% averaging the three models which translates to 52.4 kgCO2eq saving per square meter of living space built. The research is limited to the three models examined, which were representative of low income, middle complexity, and higher-end types of local housing units. Construction time, cost, and other factors were not considered in this study.

Keywords: Embodied Carbon Dioxide Equivalent, Light Gauge Steel Framing, Concrete Masonry Construction, Costa Rica Construction Industry

Introduction

The degradation of the planet's environment is a subject of growing concern. One of the major causes of this is global warming, caused by the greenhouse effect resulting from the increasing volume of gases harmful to the environment generated by natural gases and by-products of human activities (Gopi, Senior, van de Lindt, Strong, & Valdes , 2015). These Green House Gases warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space. Global Warming Potential (GWP) is a concept developed to allow comparisons of the Global warming impacts of different gases. GWP is in itself a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period, usually 100 years, relative to the emissions of 1 ton of carbon dioxide (CO2) over the same period (United States Environmetal Protection Agency, n.d.). For practicality, CO2 equivalent emissions (CO2 emissions or CO2 eq) are used as a common unit of measure of GWP that considers CO2 and the combined effect of gases influencing the greenhouse effect (Athena Sustainable Materials Institute, 2019).

Building operation and construction are estimated to be responsible for 39% of CO_2 emissions in the world, with 28% percent of this proportion being related to operations emissions necessary for the cooling, heating and power consumption of buildings, and 11% is due to the embodied CO_2 emissions associated with materials and construction processes throughout the whole building lifecycle (World Green Building Council , 2020). An estimated 6% of the total emissions attributed to buildings and construction are considered direct, upfront CO_2 emissions from materials and construction processes to build residential projects (UN Environment Programme, 2020). The United Nations is currently promoting that by 2030, all new buildings, infrastructure, and renovations will have at least 40% less embodied CO_2, with significant upfront carbon reduction (United Nations Department of Economic and Social Affairs, 2015). Embodied construction CO2eq is defined as the amount of CO2eq released during the manufacturing, transportation, construction, and end-of-life phases of all building materials. Therefore, there is a need to focus on the key sources of embodied CO_2, namely the structural elements such as foundations, frames, and other forms of superstructures, which often represent the most prominent contributors (UK Green Building Council, 2017). Sustainability performance in terms of GWP has been considered as influential as the traditional factors when choosing a structural system, namely code, cost, construction schedule, and site constraints (Griffin, Reed, & Hsu, 2006).

The construction industry in Costa Rica has had a recent long period of decelaration, accompanied by an increase in the cost of materials caused by international market pressures (Camara Costarricense de la Construccion (CCC), 2021). The fierce competition created by this environment has forced the market to open the doors to non traditional structural systems to compete with long standing traditional mainly concrete based systems. The objective of this study was to quantify and contrast the embodied CO2eq of two structural systems available in Costa Rica for three typical local residential housing designs. The relative competitiveness of each system was not considered in this study for factors other than their embodied CO2eq. Costa Rica's economy is strongly tied to its projection as a beacon of sustainability, and is internationally recognized as a pioneer nation that holds sustainability at its core of societal and economial policies (Government of Costa Rica , 2019), making the factors analyzed in this study relevant as part of the national vision for a sustainable future.

Literature Review

A case to use Carbon Dioxide equivalency as a sustainable criterion for Bridge design was made by performing a systematic assessment of the embodied CO2eq by the superstructures of trunkline bridges in the State of Colorado, U.S.A. and creating a sustainability ranking scale based CO2eq of each bridge, thus providing a simple approach to facilitate efficient decision making when choosing a design approach of similar systems (Gopi, Senior, van de Lindt, Strong, & Valdes , 2015). The study emphasizes on the need for sustainable construction and that sustainability criteria should play a significant role in such design decisions.

An analysis was done to compare the cost and embodied energy of the same house located in two different seismic zones built on masonry, with embodied anergy calculated by quantifying the materials in terms of weight and using the ICE database (Cobirzan, et al., 2017) The conclusion is that the embodied energy is lower in the house located in the low seismic zone in comparison to the house of same architectural distribution located in a high seismic zone, caused by the increased amount of concrete and reinforcement steel used in the latter. These results highlight the necessity of evaluating embodied energy at a design level to make sustainable design decisions, which becomes of higher importance in high seismic areas. For reference, the computed result of embodied CO_2 found in this study for confined masonry is approximately 134 kgCO2 eq per square meter.

A life Cycle Environmental Assessment of Light Steel framed systems was done featuring cement-based walls and floors (Abouhamad & Abu-Hamd, 2020). The case study was a building built in Cairo University, used for administration occupancy, with a floor plan of 256 square meters and five floor of 3.5 meters in height. To calculate the embodied energy of the building the Athena Impact Estimator for Buildings was used. The author concludes that Light Steel Framing systems have lower embodied energy than conventional systems and that the construction system selection process taken early on in the design stage affect the expected environmental impacts of the building over its service life. For reference, the computed result for embodied CO2 including foundations, wall shells and steel framing was computed at 140 kgCO2eq / sqm.

Most of the literature reviewed analyses the embodied carbon of a building in one single system, but none was found to compare a same building using the two alternatives. This research contributes to the body of knowledge by analyzing different models in each alternative.

Structural System for Residential Construction in Costa Rica

The most common structural system for residential construction used in the country consists of load-bearing concrete masonry unit (CMU) walls and reinforced concrete foundations and slabs. However, this approach has been challenged in recent years by a light gauge steel framing and paneling system. The two structural systems analyzed in this investigation were the Light Gauge Steel Framing and the CMU System.

The light gauge steel framing system is manufactured from cold-formed steel and is emerging in the international markets as an innovative and cost-efficient solution, with its basic building elements being cold-formed C or U sections that are fabricated off-site into panels and then transported to the site ready for erection (Abouhamad & Abu-Hamd, 2020). Load-bearing walls consist of galvanized steel profiles designed to form structures complying with seismic regulations while providing cladding and interior wall face coverings. The foundation system considered for all cases consisted of concrete mat foundations. In addition, they included a reinforced concrete slab and additional reinforcement beneath the walls in the form of integrated strip footings.

The CMU system considered for this study consisted of structurally confined load bearing masonry. CMUs are installed and reinforced as required and then structurally confined with a network of onsite poured concrete beams and columns. Walls are supported by strip footing foundations that are independent of the concrete slab used for floors. Structural concrete elements such as beams, columns, and footing are poured with a minimum strength of 210 kg/cm^2.

Case Study Models

Three residential models were analyzed, varying in area and complexity. The most basic unit had an area of 42 m^2, one story, and a relatively high wall density. An intermediate model also had one story, but a higher area of 209 m^2, thicker walls, and larger living spaces. Finally, the most complex and higher income-oriented model had two stories and an area of 167 m^2, requiring a more elaborate and thicker structural system. The deliberate use of these models allowed a deeper observation of the behavior of the competing systems, as discussed later in this paper. All three models are located in Playas del Coco, in the Guanacaste province of Costa Rica. The location is relevant as this directly affects the results when using different tools and software to calculate embodied carbon of materials.

Figures 1 to 3 show the floor plans of each model, and Table 1 shows the details of the models used in the study

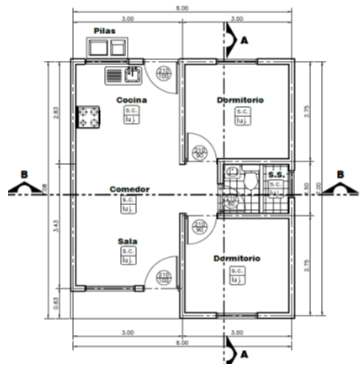

Figure 1. Floor plan low-income house model

Figure 2. Floor plan one story house model

Figure 3. Floor plan, two-story house model

Table 1

General Information for Case Studies

Model	Area (sqm)	Wall density (m^2 wall/m^2 floor)	Masonry System		Light Gauge Steel Framing System			
			Wall thickness	Strip foundation	Section Width	Gauge	Stud Spacing	Nog Spacing
Low-Income	42	2.65	12 cm	50 x 20 cm	3 ½”	22	60 cm	120 cm
One Story	209	1.49	15 cm	40 x 20 cm	3 ½”	18 and 20	40 cm	90 cm
Two Story	167	2.29	15 cm	60 x 20 cm	3 ½”	18 and 20	40 cm	90 cm

Methodology

This case study included the following steps:

1. Investigate previous research about the analyzed structural systems including other studies that use embodied carbon to determine their environmental performance.
2. Research the availability and capabilities of existing software tools and choose the most appropriate one for this investigation.
3. Quantify areas and volumes for each of the researched models.
4. Estimate the embodied CO2eq for each model in each of the two alternative systems.

Analyze the results.

Building components

Only differentiating elements were analyzed for each system; that is, common elements were not considered such as structure of second floor slabs which can be built using the same slab system in both systems, roof decking, roof cladding, finishes, electrical, mechanical, plumbing, heating, ventilation, and air conditioning systems Elements for the CMU system consisted of foundations, slabs on grade, confined masonry walls. For the light gauge steel framing system, elements were framing, including fiber glass insulation, fiber cement cladding, and regular gypsum walls for interior faces.

Variables and Software Input

Two software packages and databases were considered for this investigation. The Inventory of Carbon and Energy (ICE) (Hammond & Jones, 2008) consists of a database developed in Bath, England, for embodied carbon in commonly used materials in construction. The second software package was the Impact Estimator Software published by the Athena Sustainable Materials Institute in Canada and the United States, which contains a wide variety of options to choose from when computing information both in generalities for the project and specific materials. While ICE has a limited selection in materials when choosing drywall and cladding, the Impact Estimator Software has a balanced array for selection in all materials needed for this calculation. In addition, the geographic location and weather characteristics for the Impact Estimator Software fit more to the Costa Rican conditions than the ICE. Another advantage of the Impact Estimator software package is that the results include a life cycle assessment comprising product stage, construction process stage, use stage, end of life stage, and benefits and loads beyond the Building Life Cycle stage. This information is relevant for the study as

the alternatives analyzed consist of building components with different life spans and end-of-life benefits due to their recycling and reuse capabilities (Athena Sustainable Materials Institute, 2019). Therefore, the Impact Estimator Software was chosen as the main tool to estimate CO2eq quantities.
When using the Impact Estimator, the first step is to input general information, specifically important: a) life span of the structure: 50 years for model 1 and 70 years for models 2 and 3. b) location: Orlando, Florida for its similarities in weather characteristics in the area as compared to the location of the case study, and for its relative proximity to Costa Rica when compared to other locations available.
Table 2 shows the items included in the analysis when inputting specific material quantities into the software. For clarity and as an example, Tables 3 and 4 show the bill of materials used for each alternative on the low-income house model. The remaining models follow the same form.

Table 2
Structural Elements considered for the analysis

Item	**Description**	**Type analyzed**
1	Concrete for footings, floors, beams, and columns	ID436 Concrete Benchmark CAN 25 MPa.
2	Concrete to fill concrete blocks	ID435 Concrete Benchmark CAN 15 MPa.
3	Masonry walls, model 1	ID059 4-inch normal weight CMU
4	Masonry walls, models 2 and 3	ID389 6-inch normal weight CMU
5	Reinforcing Steel	ID024 Rebar, Rod, Light sections.
6	Light Gauge Steel Framing wall structure	ID031 Galvanized Studs.
7	Interior walls one face for Light Gauge Steel Framing Option	ID050 ½" Regular gypsum Boards
8	Insulation in all walls for Gauge Steel framing options	ID041 Fiber Glass Batt R11-15
9	Exterior cladding for Light Gauge Steel Framing Option	ID125 Fiber Cement

Table 3
Bill of materials for concrete alternative on low – income house model

Material	Unit	Total	Foundations	Walls	Mass Value	Mass Unit
4" Normal Weight CMU	Blocks	1047.64	0.00	1047.64	11.47	Tons
Concrete CAN 15 MPa	m3	3.11	1.04	2.07	7.12	Tons
Concrete CAN 25 MPa	m3	10.50	7.23	3.27	24.45	Tons
Mortar	m3	0.82	0.00	0.82	1.54	Tons
Rebar, Rod, Light Sections	Tons	0.74	0.32	0.43	0.74	Tons

Table 4
Bill of materials for light gauge steel framing alternative on low – income house model

Material	Unit	Total	Foundations	Walls	Mass Value	Mass Unit
1/2" Regular Gypsum Board	m2	169.60	0.00	169.60	1.37	Tons
Concrete CAN 25 MPa	m3	7.74	7.74	0.00	18.02	Tons
FG Batt R11-15	m2 (25mm)	111.30	0.00	111.30	0.03	Tons
Fiber Cement	m2	29.72	0.00	29.72	0.42	Tons
Galvanized Studs	Tons	0.55	0.00	0.55	0.55	Tons
Rebar, Rod, Light Sections	Tons	0.37	0.37	0.00	0.37	Tons

Results and Discussion

Table 5 summarizes the result of each model on each alternative system. The results were consistent with previous research, as discussed in this section, especially compared to the one-story model analyzed by Corbizan et al. and the two-story model studies by Aboumad & Abu-Hamd. The higher figure for the five-story building is also consistent with the fact that a multistory project will inherently have a more robust wall system and foundation than a typical single-family house. Tables 5 summarizes the quantities embodied for each analyzed structural system in each house model.

Table 5.
CO2 results for all models

Structural Masonry Option				**Light Gauge Steel Framing Option**			
Low- Income model							
Component	kgCO2eq	kgCO2eq/sqm	%	Component	KgCO2eq	KgCO2eq/sqm	%
Foundations	3130.00	74.52	42	Foundations	3060.00	72.86	68
Walls	4309.55	102.61	58	Walls	1431.07	34.07	58
Total	**7439.55**	**177.13**	**100**	**Total**	**4491.07**	**106.93**	**100**
One Story Model							
Component	kgCO2eq	kgCO2eq/m^2	%	Component	KgCO2eq	KgCO2eq/m^2	%
Foundations	12477.89	59.70	44	Foundations	12879.63	61.63	63
Walls	15793.07	75.56	56	Walls	7550.00	36.12	37
Total	**28270.96**	**135.27**	**100**	**Total**	**20429.62**	**97.75**	**100**
Two Story model							
Component	kgCO2eq	kgCO2eq/m^2	%	Component	KgCO2eq	KgCO2eq/m^2	%
Foundations	8499.62	50.90	32	Foundations	8059.98	48.26	44
Walls	18063.66	108.17	68	Walls	10242.89	61.33	56
Total	**26563.28**	**159.06**	**100**	**Total**	**18302.87**	**109.60**	**100**

The model with the biggest embodied CO2eq per square meter was the low-income housing unit. Probable factors for this result are the model's wall density and its structural system's useful life. Given that it is a compact design with a higher density of walls per square meter of floor, the total embodied CO2eq for the concrete block option for this model was 177 KgCO2eq/sqm, which is 12% higher than the average of the three models. In contrast, the lightweight gauge steel alternative had 106

KgCO2/sqm, only 2% above the three-model average. Moreover, the expected useful life of the low-income house model was estimated at 50 years, compared to 70 years for the larger one and two-story models (Organo de Normalizacion Tecnica, 2020). This difference in expected useful life influences the results. There is no need to replace any part of the structure in either of the two structural systems analyzed for the low-income unit. In contrast, the larger houses need to replace certain parts of the light gauge steel framing system between years 50 and 70, resulting in a more significant difference in KgCO2eq/sqm between the two structural systems for the two larger units. The results for total kgCO2eq per alternative per lifecycle stage can be seen in Figure 5.

Table 6 shows the average KgCO2/sqm for key structural elements across the three house models. The light gauge steel framing system performed better in every case considered. The average embodied energy per square meter of the light gauge steel framing alternative was computed at 104.75 $kgCO_2$/sqm, which is 33% less than the average concrete block house at 157.15 $kgCO_2$/sqm as the reference. The walls are the differentiators in the results found, as the difference in foundations is of only 1% as compared to the 54% difference found in walls.

Table 1

Average kgCO2eq/m^2 per alternative

Component	Concrete Block KgCO2/m^2	Light Gauge Steel Framing GgCO2/m^2	Difference %	Difference kgCO2/sqm
Foundations	61.7	60.9	-1%	-0.8
Walls	95.5	43.9	-54%	-51.6
Total	157.2	104.8	-33%	-52.4

Conclusion

In this case study project, located in the Guanacaste province of Costa Rica, three houses were compared in terms of kgCO2eq/sqm. The study focused on using two structural alternatives: the concrete block system, specifically confined masonry, widely used and a traditional way of building in the country, and the other an up-and-coming system in the local market, the light gauge steel framing system. Foundations, concrete slab on grade, and walls were compared by calculating the embodied carbon of one and the other. The light gauge steel framing system performs better in every case with a considerably lesser embodied CO2 per square meter than the concrete counterpart. In addition, four factors that directly affect the embodied carbon of each system were: a) wall thickness, b) density of walls, c) repairs and replacement of parts, and d) recycling and reusing potential. Foundations were not found to have a significant differentiating effect on the results.

The results found in this study are limited to single-family residential projects with similar floor plans and wall density as the three samples, built on a geographic location similar to Playas del Coco, Guanacaste in terms of weather and geographic location. However, the results found show a tendency worth exploring by adding more case studies with different characteristics to validate if the results found apply to other regions in terms of weather characteristics and seismic activity and other types of projects in terms of use and size.

Of particular importance are the results found on the low-income housing sample, as this floor plan is widely used and is the benchmark for this type of project in the country. Given this condition, the results apply to most low-income housing projects in Costa Rica, as all the regions are seismic and have similar weather conditions. In Costa Rica, low-income housing is state-sponsored and is built not in single units, taking advantage of the economy of scale by building several units at a time. Further research can analyze the cost and schedule factors of the two alternatives by using a multi-unit project as a case study to determine if the light gauge steel framing alternative is the better performer in terms of embodied carbon and be less costly and faster to build. If this is the case, this system might prove to be the most sustainable way of building state-sponsored low-income projects. Operations emissions were not considered in this study, which is an important factor that can be considered in determining the most alternative environmental overall in terms of CO2eq from operations and embodied emissions.

References

Abouhamad, M., & Abu-Hamd, M. (2020). Life Cycle Assessment of Light Steel Framing Buildings with Cement-Based Walls and Floors. MDPI.

Athena Sustainable Materials Institute. (2019). User Manual and Transparency Document, Impact Estimator for Buildings. Ontario.

Athena Sustainable Materials Institute. (n.d.). Impact Estimator for Buildings software. Ontario, Canada: www.athenasmi.org.

Camara Costarricense de la Construccion (CCC). (2021). Informe Economico del Sector Construccion. San Jose, Costa Rica.

Cobirzan, N., Voinea, M., Kopenetz, L., Munteanu, C., Balog, A.-A., & Tamas, F. (2017). Assessment of Cost and Embodied Carbon for Masonry Structures Located in Low and High Seismic Zones. Brasov, Romania.

Gopi, V., Senior, B., van de Lindt, J., Strong, K., & Valdes-Vasquez, R. (2015). Carbon Dioxide Equivalency as a Sustainability Criterion for Bridge Design Alternatives. Fort Collins, Colorado: Colorado State University.

Government of Costa Rica . (2019). Gobierno de Costa Rica. Available at www.presidencia.go.cr/comunicados/2019/09/costa-rica-named-champion-of-the-earth-for-pioneering-role-in-fighting-climate-change/

Griffin, C., Reed, B., & Hsu, S. (2006). Comparing the Embodied Energy of Structural Systems in buildings. Portland, Oregon.

Hammond, G., & Jones, C. (2008). Embodied Energy and Carbon in Construction Materials. Bath, UK: University of Bath.

Organo de Normalizacion Tecnica. (2020). Manual de Valores Base Unitarios por Tipologia Constructiva. San Jose, Costa Rica.

UK Green Building Council. (2017). Embodied Carbon: Developing a Client Brief. London.

UN Environment Programme. (2020). 2020 Global Status Report for Buildings and Construction. Nairobi, Kenya.

United Nations Department of Economic and Social Affairs. (2015). United Nations. Available at http://sustainabledevelopment.un.org

United States Environmental Protection Agency. (n.d.). epa.gov. Available at https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

World Green Building Council. (2020). Bringing Embodied Carbon Upfront: Coordinated action for the building and construction sector to tackle embodied carbon. London.

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A Comparative Life Cycle Assessment Study of Wood and Steel Materials on a Virtual Office Building at the Project End-of-Life Stage

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The disposal of construction and demolition waste has an impact on the environment. This study focuses on the end-of-life stage to assess a virtual office building, by applying a comparative life cycle assessment (LCA) and used Athena software. The study determined LCA methods, and software tools based on a thorough literature review and then assessed the environmental impact of steel versus wood materials on a virtual office building model that was created from an actual construction project. The study quantifies the environmental impact of steel and wood materials into nine categories, including Global Warming Potential, Acidification Potential, etc., by using life cycle inventory (LCI) and life cycle impact assessment (LCIA) analyses. The results of this study show that the wood structure building has greater impact on environment than the steel structure building at the end-of-life stage in four categories of (1) Acidification Potential, (2) Eutrophication Potential, (3) Ozone Depletion Potential, and (4) Smog Potential, but has less impact on other five categories with actually a positive environmental impact in the Global Warming potential. The results of this study can provide valuable information about the environmental impact of different materials to reduce the environmental impact at the end-of-life stage.

Key Words: Life Cycle Assessment, End of Life Stage, Environmental Impact, Global Warming

Introduction

The construction industry is one of the largest resource consumers and waste producers in the United States and in the world. It uses 40% of the world's raw materials and produces 35% of the world's waste (Yuan et al. 2012). In 2017, 569 million tons of construction and demolition debris was generated in the United States, which is more than twice the amount of generated municipal solid waste, and demolition represents more than 90 percent of total construction and demolition debris generation (EPA 2019). In 2018, the construction and demolition debris were increased to 600 million tons, of which 188.8 million tons were generated by building demolition (EPA 2020). All of these

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debris disposal processes result in environmental impact to some degree, such as pollution, and requires actions to reduce such impact.

In order to reduce the environmental impact of the construction and demolition, it is necessary to assess the degree of such impact. By much previous research, such environmental impact is commonly studied by using life cycle assessment (LCA) method, which assesses the life cycle stages of building products, include (1) production stage, (2) construction stage, (3) use stage, and (4) end-of-life stage (ISO 2017). The first stage mainly focuses on the process from raw materials to building products, while the second stage focuses on the installation process during construction. The third stage assesses the use and operation of building after the construction is completed, and finally the last stage focuses on demolition of building when it reaches it's the end of service life. Resource consumption is involved in each of the stages described above, such as raw material collection, raw material processing, transportation, and waste disposal (Huang et al. 2018). Existing research results were focusing on the first three stages but only a few were focusing the end-of-life stage, which were mainly on improving the rate of recycling and reuse and on optimize recycling scheme for the waste generated (Yazdani et al. 2020; Akhtar and Sarmah 2018; Gálvez-Martos et al. 2018; Di Maria, Eyckmans, and Van Acker 2018). However, the end-of-life stage has more scope of work than just recycling and requires further investigation on its impact. Therefore, this study has explored a comparative LCA case study of building materials at the project end-of-life stage. This study will have a contribution to the effort of reducing environmental impact in the construction industry and to the body of knowledge of building LCA.

Methodology

The methodology includes two main parts: (A) Determine the study method, software and scope, and (B) Conduct a case study on a virtual office building model. Literature review has been conducted about in four areas: (1) the LCA method; (2) environmental impact of construction includes four life cycle stages: production, construction, use, and end-of-life stage; (3) impact of steel and wood as a structural building material on the environment; and (4) LCA software tools. Through the review of the literature, the research method, research scope and software use of this article are determined. Then a case study project, a two-story office building was chosen to be used to create a virtual model for assessment. The complete schematic explanation of the methodology is showed in Figure 1.

The total area of the building is 15,700 square feet, in which the original beam and column system of the building was made of steel. Additionally, the study chose to use wood structural materials to compare with steel structure materials. As the office building has only one design scheme that uses steel as the structural material, the wood structural design only uses wood materials to replace the steel materials of the beam and column system in the original structural drawing. The scope of this case study is limited to the impact of steel material and wood material on the environment at the end-of-life stage. The steel structure model is established using the software of Revit based on the original structure drawings (Figure 2). As a comparison, a new wood structure model is established by replacing steel material with wood material in the steel structure model. In those two models, glulam is used for columns and beams of wood structure, wide flange is used for columns and beams of steel structure. Some other details about this case study project can be found in Table 1.

There are three steps to the assessment of the project. The first step is life cycle inventory (LCI) analysis, Athena Impact Estimator for Buildings (IE4B) is used in this part as LCA software. When users input relevant building data into the IE4B, the IE4B provides a cradle-to-grave LCI profile to

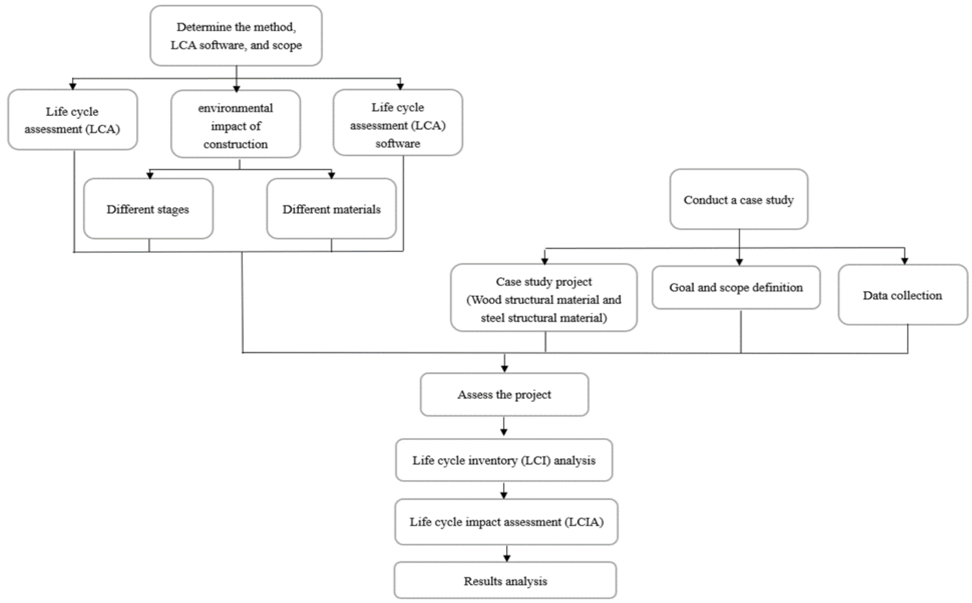

Figure 1. Study methodology

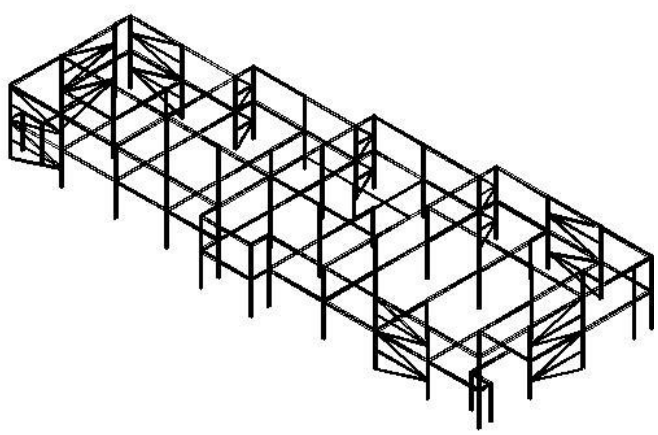

Figure 2. Revit structure model

Table 1. Case study project description.

Item	Specification
Building type	Office Rental
Project location	Minneapolis*
Building life expectancy	60 years
Building Height	33.4 ft
Gross floor area	15,700 ft^2

* The nearest city of Minneapolis is selected here.

assess a building's environmental impact. The LCI results include raw materials input; emission to air, water, and land; and energy consumption. The second step is life cycle impact assessment (LCIA), The LCA results data obtained by IE4B conform to the ISO 14040/14044 standard, and the life cycle impacts were evaluated with the TRACI v2.1. The last step is comparison and analysis of the results from the LCIA. The required data about the office building are from the structural drawings of the office building. The software processing data is from three database: Scenario database, Athena LCI database, and TRACI v2.1 database.

Table 2 summarizes the input data that need to be entered to assess the building. The difference between the input of steel structure building materials and wood structure materials only lies in the types of beams and columns, and the others are the same. Then the software will adjust the algorithm by applying the size of the input material type, load, and geometric conditions, and calculate the amount of structural materials required in the column and beam system. By inputting the data into the software, the life cycle inventory (LCI) and life cycle impact assessment (LCIA) of the end-of-life stage can be obtained. However, this paper only reports the LCIA results.

Table 2. Beams and columns input data.

	Item	Area 1	Area 2	Area3	Area4	Area5	Area6
Steel and Wood structure model	No. of columns	23	31	4	21	26	4
	No. of beams	43	46	3	39	35	3
	Bay size	24 ft	24 ft	22.8 ft	24 ft	24 ft	22.8 ft
	Supported span	8 ft	23.5 ft	8 ft	8 ft	23.5 ft	8 ft
	Supported area	4,801 ft^2	10,596 ft^2	211 ft^2	4,801 ft^2	10,596 ft^2	221 ft^2
	Column height	15.25 ft	15.25 ft	15.25 ft	14 ft	14 ft	14 ft
	Supported element	Floor	Floor	Floor	Roof	Roof	Roof
	Live load	100 psf	100 psf	100 psf	50 psf	50 psf	50 psf
Steel structure model	Column type	WF	WF	WF	WF	WF	WF
	Beam type	WF	WF	WF	WF	WF	WF
Wood structure model	Column type	Glulam	Glulam	Glulam	Glulam	Glulam	Glulam
	Beam type	Glulam	Glulam	Glulam	Glulam	Glulam	Glulam

Key findings

The data from Table 1 and 2 was input into the Athena Impact Estimator for Buildings software, the LCIA results were obtained for the end-of-life stage and are show in Table 3 and 4, which include three parts: (1) de-construction demolition (C1) & disposal (C4), (2) transport (C2), and (3) benefits and loads beyond the system boundary (BBL) (D), for steel and wood structural materials, separately.

The LCIA results of the steel structure building

Table 3 and Figure 3 show the results of LCIA for the steel structure building. Among those nine categories, three are related to energy consumption.

Table 3. The results of LCIA for the steel structure building.

LCA Measures	Unit	De-construction, Demolition, Disposal (C1 & C4)	Transport (C2)	BBL material (D)
Global Warming Potential	kg CO2 eq	3.84E+03	2.87E+01	8.97E+03
Acidification Potential	kg SO2 eq	3.70E+01	2.76E-01	2.06E+01
HH Particulate	kg PM2.5 eq	1.23E+01	1.53E-02	9.02E+00
Eutrophication Potential	kg N eq	2.26E+00	1.72E-02	1.06E+00
Ozone Depletion Potential	kg CFC-11 eq	1.66E-07	1.00E-09	0.00E+00
Smog Potential	kg O3 eq	1.17E+03	8.72E+00	2.08E+02
Total Primary Energy	MJ	5.59E+04	4.19E+02	4.12E+04
Non-Renewable Energy	MJ	5.58E+04	4.18E+02	4.12E+04
Fossil Fuel Consumption	MJ	5.58E+04	4.18E+02	8.26E+04

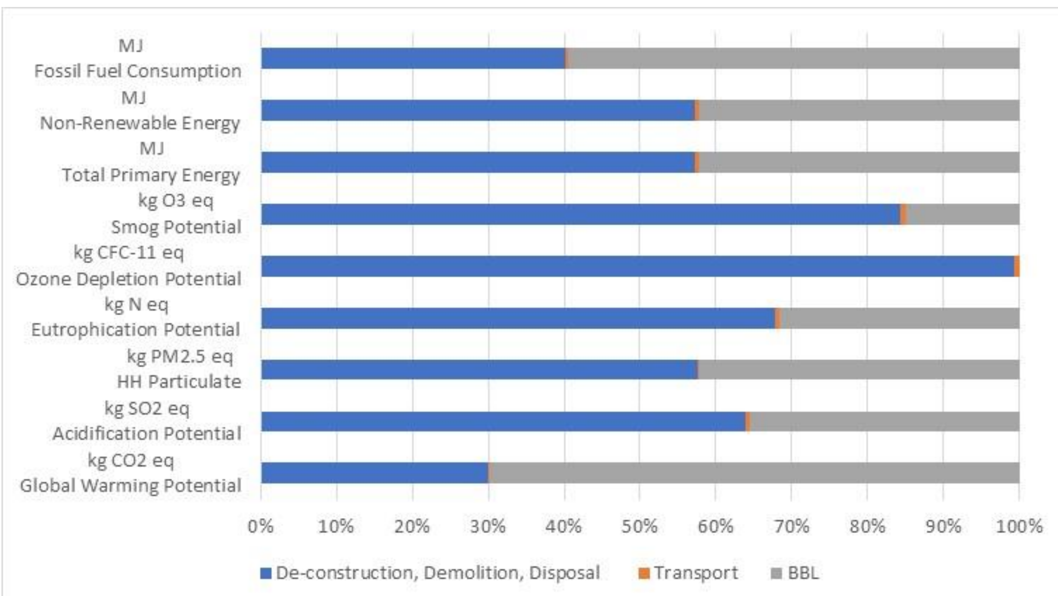

Figure 3. The results of LCIA for the steel structure building.
Note: De-construction, Demolition, Disposal (C1 & C4), Transport (C2), and BBL (D).

In the Total Primary Energy Consumption, module C4 consumes the least energy, followed by module D, and module C1 & C4 consume the most energy. Fossil Fuel Consumption is a subset of Total Primary Energy, meaning the data of Fossil Fuel Consumption should be smaller than Total Primary Energy. However, the Fossil Fuel Consumption of BBL is greater than the Total Primary Energy of BBL, which is abnormal and needs further investigation.

For the rest of (six) categories, Module C1&C4 has the highest proportion of Ozone Depletion Potential and the lowest proportion of Global Warming Potential (GWP). Module C2 has the highest proportion of Smog Potential and the lowest proportion in Human Health Particulate. The highest proportion of module D is GWP, and its lowest proportion is Ozone Depletion Potential. In general, module C2 accounts for the lowest proportion of environmental impact in all nine categories, and module C1 & C4 accounts for the highest proportion of environmental impact in seven categories (except for GWP and Fossil Fuel Consumption categories).

The LCIA results of the wood structure building

The results of the LCIA for the wood structure building shown as Table 4 and Figure 4. Except for GWP, the proportion of module C1 & C4 is greater than module C2 in the other eight environmental impact categories. Among them, module C1 & C4 accounts for the largest proportion of Acidification Potential, while human health particular accounts for the least. However, module D is very different, only showing GWP's value and the value is negative; the other eight environmental impact categories are showing zero (0). When forests grow again, after they have been cut down for making wood structural material, they will absorb carbon dioxide in the air, thus making the GWP value negative. The premise is that the forest is completely regenerated after logging. The forest regeneration after felling not only produce new wood materials, but also absorb carbon dioxide from the air, so as to reduce the environmental impact. Overall, wood is a good structural material to reduce environmental pollution.

The Comparison of LCIA results

Nine categories of LCIA results between steel structure building and wood structure building are compared, respectively. As an example, Figure 5 shows the results of GWP between the steel structure building and the wood structure building. The GWP of the two buildings in module C1 & C4 are similar. In module C2, the GWP's value of the wood structure building is more than the steel structure building. For module D, the GWP's value of the steel structure building is greater than the wood structure building, because the GWP of the wood structure building is negative. Overall, the GWP of the wood structure is negative, and GWP of the steel structure is positive. Therefore, the steel structure building has more environmental impact than the wood structure building.

Acidification Potential of module C1 & C4 and Module C2 for the wood structure building is greater than that for the steel structure building. However, Acidification Potential of module D for the steel structure building is greater than that for the wood structure building. For the total value of Acidification Potential, the wood structure building is greater than the steel structure building. Except for the result of module C2 in Human Health Particulate for the wood structure building is a little bit greater than that for the steel structure building, the results of other modules in Human Health Particulate for the steel structure building are greater than those for the wood structure building. Additionally, the total value of Human Health Particulate for the steel structure building are greater than that for the wood structure building. Eutrophication Potential of module C1 & C4 and module C2 shows that the wood structure building is greater than the steel structure building. However, Eutrophication Potential of module D shows that the steel structure building is greater than the wood structure building. For the total value of Eutrophication Potential, the wood structure is greater than the steel structure building. The steel structure building of Ozone Depletion Potential in module C1 & C4 is similar to the total value of the steel structure building, and the total value of Ozone Depletion Potential for the steel structure building is similar to the value of module C1 & C4 for the wood structure building. Overall, the total value of Ozone Depletion Potential for the wood structure building is greater than the steel structure building. Not only the total value of Smog Potential for the wood structure building is greater than the steel structure building, but also the Smog Potential of module C1 & C4 for the wood structure building is greater than the steel structure building. For the results of Total Primary Energy Consumption, Non-Renewable Energy Consumption, and Fossil Fuel Consumption, the wood structure building use more energy than the steel structure building in module C1 & C4 and module C2. However, the energy consumption of module D for the steel structure building are greater than the wood structure building. The total value of energy consumption includes Total Primary Energy Consumption, Non-Renewable Energy Consumption, and Fossil Fuel Consumption for the steel structure building are greater than wood structure building.

Additionally, the results from the software of the sensitivity analysis for changing project location and changing building life expectancy are the same as the original results from the software. But the reasons for getting the same results are different. The reason why the LCIA results of the sensitivity analysis in changing project location have not changed is that the location of Minneapolis and the location of USA use the same database. And the reason why the LCIA results of the sensitivity analysis in changing building life expectancy have not changed is that changing the building life expectancy will not change the environmental impact. The changing column types of sensitivity analysis shows the results of Acidification Potential, Eutrophication Potential, Ozone Depletion Potential, and Smog Potential for the wood structure building are greater than those in the steel structure building. In addition, the wood structure building at the end-of-life stage of GWP has the positive environmental impact.

Table 4. The results of LCIA for the wood structure building.

LCA Measures	Unit	De-construction, Demolition, Disposal (C1 & C4)	Transport (C2)	BBL (D)
Global Warming Potential	kg CO2 eq	3.87E+03	8.28E+02	-1.23E+05
Acidification Potential	kg SO2 eq	5.54E+01	7.97E+00	0.00E+00
HH Particulate	kg PM2.5 eq	1.36E+00	4.41E-01	0.00E+00
Eutrophication Potential	kg N eq	3.46E+00	4.95E-01	0.00E+00
Ozone Depletion Potential	kg CFC-11 eq	1.69E-07	2.89E-08	0.00E+00
Smog Potential	kg O3 eq	1.84E+03	2.51E+02	0.00E+00
Total Primary Energy	MJ	5.77E+04	1.21E+04	0.00E+00
Non-Renewable Energy	MJ	5.76E+04	1.21E+04	0.00E+00
Fossil Fuel Consumption	MJ	5.76E+04	1.21E+04	0.00E+00

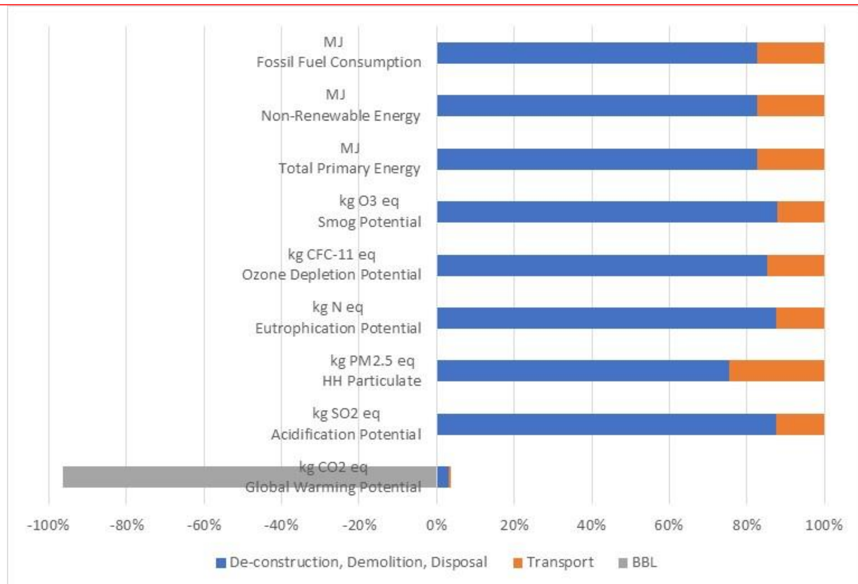

Figure 4. The results of LCIA for the wood structure building.
Note: De-construction, Demolition, Disposal (C1 & C4), Transport (C2), and BBL (D)

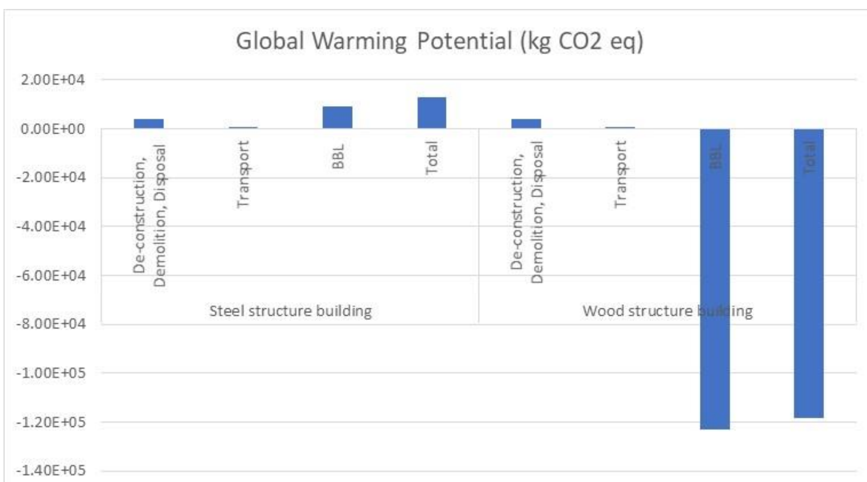

Figure 5. The results of GWP for both buildings.
Note: De-construction, Demolition, Disposal (C1 & C4), Transport (C2), and BBL (D).

Conclusion

This case study is focused on the environmental impact at the end-of-life stage between a wood structure building and a steel structure building. Life cycle assessment and Athena Impact Estimator for Building software are used in this study. The environmental impact is quantified into nine categories: Global Warming Potential (GWP), Acidification Potential, Human Health Particulate, Eutrophication Potential, Ozone Depletion Potential, Smog Potential, Total Primary Energy Consumption, Non-Renewable Energy Consumption, and Fossil Fuel Consumption. The comparison of LCIA results between the wood structure building and the steel structure building shown that Acidification Potential, Eutrophication Potential, Ozone Depletion Potential, and Smog Potential in the wood structure building are greater than those in the steel structure building. Conversely, the comparison also shown the wood structure building performed worse in GWP, Human Health Particulate, Total Primary Consumption, Non-Renewable Energy Consumption and Fossil Fuel Consumption than the steel structure building. The interesting result is the GWP of the wood structure building, because that result is negative. It means wood structure building at the end-of-life stage for the GWP has a positive environmental impact. Finally, it is concluded that the steel structure building has more environmental impact than the wood structure building at the end-of-life stage. This study's results can help decision-makers choose the structural material better to reduce the environmental impact and energy consumption of buildings at the end-of-life stage.

Due to the difficulty caused by COVID-19 pandemic, some limitations still exist in this study and are listed here: (1) There was only one type of frame design for each type of materials, i.e., the wood structure building design is obtained by replacing steel with wood materials. A future study should choose a building with two or more types of frame design for different structural materials; (2) The project location of Fargo is not provided in the database; therefore, Minneapolis was used, but these two cities are so different. For future study, the researcher should find a case study project in which location is provided in the software or more locations should be added to the software.

References

Akhtar, Ali, and Ajit K Sarmah. 2018. "Construction and demolition waste generation and properties of recycled aggregate concrete: a global perspective." Journal of Cleaner Production 186: 262-281.

Di Maria, Andrea, Johan Eyckmans, and Karel Van Acker. 2018. "Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making." Waste management 75: 3-21.

EPA, U. 2019. Advancing sustainable materials management: 2017 fact sheet.

EPA, U. 2020. Advancing sustainable materials management: 2018 fact sheet.

Gálvez-Martos, José-Luis, David Styles, Harald Schoenberger, and Barbara Zeschmar-Lahl. 2018. "Construction and demolition waste best management practice in Europe." Resources, Conservation and Recycling 136: 166-178.

Huang, Beijia, Xiangyu Wang, Harnwei Kua, Yong Geng, Raimund Bleischwitz, and Jingzheng Ren. 2018. "Construction and demolition waste management in China through the 3R principle." Resources, Conservation and Recycling 129: 36-44.

ISO, ISO. 2017. "21930: 2017-Sustainability in buildings and civil engineering works–Core rules for environmental product declarations of construction products and services." Geneva (Switzerland): International Organization for Standardization.

Yazdani, Maziar, Kamyar Kabirifar, Boadu Elijah Frimpong, Mahdi Shariati, Mirpouya Mirmozaffari, and Azam Boskabadi. 2020. "Improving construction and demolition waste collection service in an urban area using a simheuristic approach: A case study in Sydney, Australia." Journal of Cleaner Production 280: 124138.

Yuan, Hongping, Abdol R Chini, Yujie Lu, and Liyin Shen. 2012. "A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste." Waste management 32 (3): 521-531.

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A Post-Construction Evaluation of Long-term Success in LEED-certified Residential Communities

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In this study, a post-construction evaluation model was developed to identify the determinants of the long-term success of sustainable residential projects from users' points of view. To do this, a primary model was developed based on the existing theories and models including measures adopted from LEED standards and UC Berkeley's Center for the Built Environment (CBE) tool. The model included four predictor variables investigating the perceived performance of buildings, infrastructure, neighborhood, and economic aspects. The response variable was residential satisfaction as the determinant of long-term success. The data was collected through an online survey from the residents of LEED-certified residential communities in the USA (n=192). After validating the model through confirmatory factor analysis (CFA), the relationships between the independent and dependent variables were evaluated through structural equation modeling (SEM). The results showed that the perceived building performance was the most influential factor in determining satisfaction followed by the perceived neighborhood design while perceived infrastructure performance and perceived cost performance did not show any significant effect in determining satisfaction. The findings benefit researchers by providing a model for the evaluation of the long-term performance of green buildings and providing opportunities for practitioners to determine priorities for future sustainable residential development projects.

Key Words: Green Building, Satisfaction, Perceived Performance, Confirmatory Factor Analysis, Structural Equation Modeling

Introduction

Project success has been the focus of several studies and traditionally, the iron triangle factors (time, cost, and scope) have been the focus in evaluating project success. However recently, the importance of the long-term evaluation of project success has been highlighted, which evaluates the successful performance of the projects at the post-construction stage with a focus on three main aspects of sustainability, satisfaction, and life cycle cost performance (Adabre & Chan, 2019; Dvir et al., 2003). This is even more important when it comes to sustainable residential projects as one of the main focuses of sustainable construction is the long-term performance of the buildings. Therefore, besides technical aspects, a comprehensive assessment of project success in sustainable development projects must include long-term successful performance (Adabre & Chan, 2019).

One factor that is of high importance in determining the long-term successful performance of a project is its accordance with human needs and expectations (Williams et al., 2015). This is even more important in residential projects as the end-users are residents who spend a significant amount of their time in their homes. Therefore, it is crucial to investigate the feedback of users about their living environment to find if it is performing successfully. Perceived project performance compared to the expected performance is an important factor indicating the success of a project (Toor & Ogunlana, 2010). This highlights the role of users' judgments and satisfaction in determining the success of sustainability practices as several experts have suggested that customer satisfaction is a critical dimension of project success (e.g. Heravi & Ilbeigi, 2012; Davis, 2014).

Considering the residents' judgments and perceptions can provide essential ideas for successful housing development and the improvement of design and construction practices (Aliyu & Muhammad, 2016). This can be important both by providing lessons for architects and contractors and by providing a benchmark and a pool of research on the building industry to indicate how the end product meets the expectations and needs of its end users (Enright, 2002). By ensuring that the feedback of users is considered throughout the building design and construction processes, the quality of the built project is protected both during the construction process and later in the operation phase (Preiser & Vischer, 2006).

Although users' satisfaction can be collected in surveys, the analysis of this variable can be challenging. This becomes even more highlighted in evaluating the satisfaction with sustainable residential communities as it depends on the time, place, and evaluation system of the assessors. Reviewing the literature and looking at the factors that have been considered as variables to evaluate the satisfaction of users with residential buildings and communities, satisfaction appears to be a complex and multifaceted subject that demands much more research to provide a better understanding of the relations between the factors. Therefore, it is important to understand the theoretical and empirical aspects of the evaluation of users' satisfaction to determine the variables and successfully develop an evaluation model. This research is an attempt to develop and validate a model to evaluate the associations between the perceived performance and satisfaction of sustainable residential communities and identify the key determinants of satisfaction in sustainable communities.

Developing a conceptual Model

Reviewing the relevant theories regarding users' satisfaction with housing projects (e.g., Housing Needs Theory, Housing Adjustment Theory, and Psychological Construct theory) as well as the developed model for evaluation of user's satisfaction (e.g., Weidemann & Anderson, 1985), an a-priori model for evaluating the relationships between the long-term success factors of sustainable residential projects was developed. The model consists of several components that are measured through one or a few indicators or variables (Figure 1). The model indicates the effect of the perceived performance of the building, neighborhood design, infrastructure, and cost performance on the level of satisfaction of residents with their home and community. Furthermore, the model pictures the way that satisfaction can be evaluated directly by asking a question about satisfaction and indirectly based on the intention of residents to behave in response to their home and neighborhood conditions. The mutual interaction between sustainability and satisfaction is also pictured in this model.

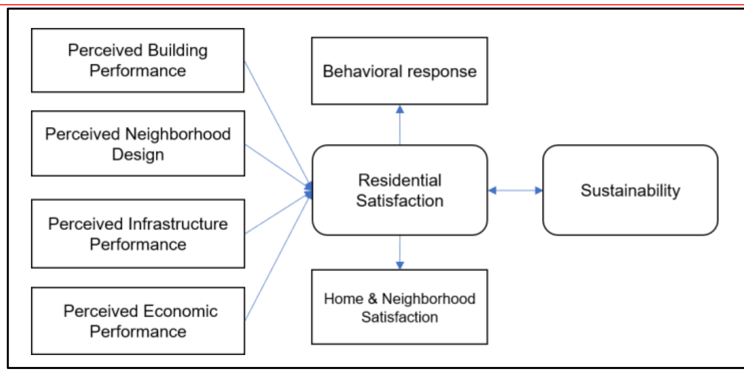

Figure 1. Conceptual model of long-term success factor interactions

Method

Data Collection

To evaluate the long-term success of sustainable residential projects from users' points of view, the data was collected from residents of LEED-certified residential communities, in the USA, through an online survey using a structured questionnaire. Multi-stage sampling was adopted as the sampling method in this research; in the first step, among all of the LEED-ND certified projects (101 projects), 40 projects were selected randomly to survey the residents. Individuals were then randomly sent an email that included a link to the survey. After asking some eligibility questions on the first page of the survey including age, and the duration of the stay in the neighborhood, eligible respondents were directed to the main survey question (those whoe lived in the neighborhood for at least six months and had more than 18 years old).

Research Variables

The attributes of the physical environment that were considered as the predictor variables consisted of three main groups of building features, infrastructure, neighborhood aspects. Building features were features that are mentioned as the criteria for determining individual building sustainability according to LEED certification such as energy efficiency, insulation, water efficiency, etc. Infrastructure attributes were the elements of the built environment that provide a context for the entire neighborhood and are considered as green infrastructure in the LEED certification system. Finally, neighborhood aspects were aspects that were related to the pattern and design of the neighborhood such as density, walkability, the mix of the land use, etc. As the focus of this study was evaluating the successful performance of sustainable residential projects from the users' point of view, only features specific to sustainable communities were considered. A seven-point Likert scale was employed to evaluate the perceived performance of each attribute with 1 being "very poor" and 7 being "very well". The sustainability-specific attributes adopted from LEED-BD+C Multifamily Midrise and LEED-ND standards as well as the UC Berkeley Center for the Built Environment survey tool were considered as measures to evaluate the performance of the physical environment. A set of economic measures was also developed from the literature in order to evaluate the cost performance of the residential communities.

Overall satisfaction with the residential built environment was considered as the dependent variable. Two sets of questions were asked to measure the overall satisfaction. The first set of questions asked the level of satisfaction of the residents with their home and neighborhood and the second set of questions measured the intentions of residents to behave in response to the current condition of their residential built environment (Weidemann & Anderson, 1985). Both measurements used a 7_point Likert scale to evaluate the responses.

Data Analysis

Respondents' Profile

A total of 192 responses was collected including 49% female, 49.5% males, and 1.5% others. The summary of respondents' profiles is presented in Table 1.

Table 1

Summary of sample characteristics

Variable	Number	Percentage	Variable	Number	Percentage
Gender			Education level		
Female	94	49	High school graduate or less	8	4.2
Male	95	49.5	Some College or two-year degree	36	18.8
Other	3	1.5	Four-year degree	59	30.7
			Graduate degree	89	46.4
Age			Income		
18-34	75	39.1	Less than $59,999	30	15.8
35-54	104	54.2	$60,000 - $119,999	101	52.6
55 or above	11	5.7	$120,000 or more	60	31.3
Undefined	2	1	Undefined	1	0.5

Reliability Test

The internal consistency of the entire survey data was tested by conducting a Cronbach's alpha test. The alpha value for the survey data was above 0.7 showing a high internal consistency of the data.

Confirmatory Factor Analysis

In order to validate the model for the data, confirmatory factor analysis (CFA) was conducted. Testing the assumptions for conducting confirmatory factor analysis, the data did not meet the assumption of multivariate normality. Therefore, the maximum likelihood (ML) method, which is the most commonly used method used for this analysis, could not be used (Table 2). As the substitute method, the "robust" ML estimation (Satorra and Bentler, 2001) was used as it is the most appropriate approach to deal with the non-normality of the data. The data was analyzed using JASP version 14.1, which uses Lavaan syntax for the data analysis.

Table 2

Mardia's multivariate skewness and kurtosis

Test	B	z	p-value
Skewness	141.0779	4514.49211	<0.0001
Kurtosis	799.9258	13.05944	<0.0001

Conducting CFA the model was validated and the fittest model representing the variables was achieved. Multicollinearity among the indicators was also addressed using CFA. As shown in Table 3, overall fit indices show that the overall model fits the data and can provide a valid and reliable structural equation model to evaluate the relationships between the latent independent and dependent variables.

Table **Error! No text of specified style in document.**3

Results of final CFA

Variable/Indicator	Estimate	p	Std. Est. (all)
Factor 1: Perceived Infrastructure Performance			
GI1-Outdoor Lighting	1.176	< .001	0.645
GI2-Recycling Facilities	0.863	< .001	0.522
GI3-Rainwater Collection System	0.851	< .001	0.519
GI4-Public Transit Infrastructure	0.956	< .001	0.571
GI5-Biking Infrastructure	0.897	< .001	0.548
GI6-Road Quality	1.001	< .001	0.578
Factor 2: Perceived Neighborhood Design			
ND1-Walking Infrastructure	1.035	< .001	0.719
ND2-Neighborhood Density	0.712	< .001	0.577
ND3-Mixed Use Neighborhood	1.052	< .001	0.716
ND4-Housing Diversity	0.802	< .001	0.53
ND5-Access to Public Space	0.879	< .001	0.628
Factor3: Perceived Building Performance			
BP1-Thermal Comfort	0.949	< .001	0.726
BP2-Availability of Daylight	0.999	< .001	0.717
BP3-Indoor Water Efficiency	0.90	< .001	0.671
BP4-Quality Views from Window	0.907	< .001	0.601
BP5-Indoor Materials Used	0.96	< .001	0.704
BP6-Building Energy Efficiency	0.901	< .001	0.665
Factor 4: Perceived Cost performance			
EP1-Value/Rent	0.972	< .001	0.73
EP2-Utility Bills	0.918	< .001	0.656
EP3-Travel and Transportation Costs	1.084	< .001	0.723
EP4-Other Fees (HOA/Condo fees, tax, etc.,)	0.811	< .001	0.579
Factor 5: Residential satisfaction			
S1-Plan to Live permanently	1.264	< .001	0.836
S2-Recommend to others	1.18	< .001	0.825
S3-If look back, would move here again	1.02	< .001	0.744
S4-Overall Neighborhood Satisfaction	1.002	< .001	0.702
S5-Overall Home Satisfaction	0.972	< .001	0.77

Fit indices: X^2/df= 1.3, p-value= <.001; CFI= 0.956; RMSEA= .040; SRMR= 0.051

Structural Equation Modeling

After validating the model through conducting CFA, a structural equation modeling (SEM) was performed to provide an understanding of the relationships between the perceived performance of the built environment in residential projects and the level of satisfaction of the users as the determinant of the long-term success of these projects. The results of the SEM are presented graphically in Figure 2 and the key findings are summarized in Table 4. The darker color of the lines in the model shows a stronger relationship between the factors. The relationship between the item with the highest factor loading and the corresponding factor is shown as a dashed line for each factor. The positive relationships in this model are shown by the green color while the negative relationship is shown in red.

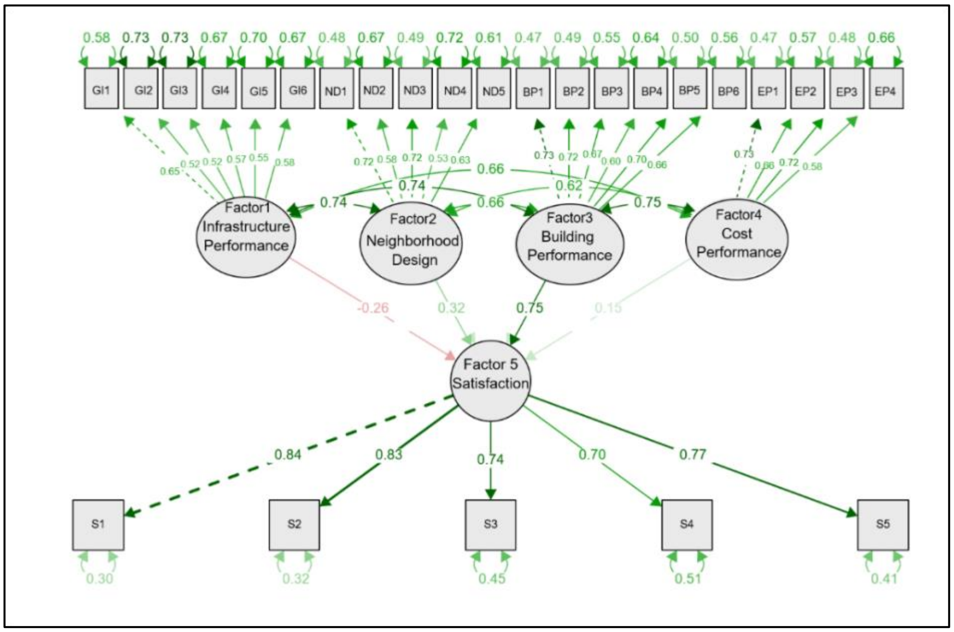

Figure 2. Modeling the effects of the perceived performance on satisfaction; Fit indices: X^2/df= 1.30, p-value < .001: CFI= 0.956; RMSEA= 0.040; SRMR= 0.51

Table 4

Summary of SEM key results: the relationships between IVs and the DV

Latent variables (IVs)	estimate	Std. error	z	p	Standardized estimate
Perceived Infrastructure Performance	-0.281	0.149	-1.883	0.06	-0.261
Perceived Neighborhood Design	0.394	0.157	2.512	**0.012**	0.322
Perceived Building Performance	1	0.203	4.918	**< .001**	0.751
Perceived Cost performance	0.199	0.176	1.132	0.258	0.153

*Dependent Variable: Residential Satisfaction

Results

Figure 2 and Table 4 show that perceived building performance and perceived neighborhood design have significant relationships with satisfaction. Among the two independent variables, perceived building performance is the most influential (coefficient=0.0.751, $p<.001$) followed by perceived neighborhood design (coefficient= 0.322, $p=0.012$). Other independent variables including perceived infrastructure performance ($p=0.06$) and perceived cost performance ($p= 0.15$) do not bring significant information to explain the influence on satisfaction score meaning these independent variables do not show a statistically significant relationship with residential satisfaction.

Discussion

This study evaluated the long-term success of these projects from the users' points of view by finding the relationship between the perceived performance of the built environment and the satisfaction of the users. The results of the evaluation showed that perceived building performance has the highest influence on overall satisfaction with the residential communities followed by perceived neighborhood pattern and design. On the other hand, cost performance and neighborhood infrastructure did not show any significant relationship with residential satisfaction.

The perceived building performance having the highest influence on residential satisfaction was expected as people spend several hours of their days in their homes, and a positive perception about their immediate living environment will create higher satisfaction. Satisfaction with home can affect the residents' opinions about their neighborhood and provide overall satisfaction as Bonaiuto (2004) suggests that perceived quality of the residential units is a prerequisite of obtaining an environmental and psychological picture of the living environment. Moreover, Ibem et al. (2015) suggested that residents' evaluation of their living environment is mainly influenced by the perceived quality of housing characteristics along with the actual quality of the housing environment.

Furthermore, the influence of perceived neighborhood pattern and design on providing residential satisfaction was also expected as the design factors are tangible factors for people, and they can easily evaluate them visually. The effect of perceived performance of the neighborhood built environment on place attachment and residential satisfaction has been demonstrated by Noriza et al. (2013) highlighting that neighborhood design factors are among the factors that have very important effects on determining residential satisfaction. Factors such as compactness, housing diversity, access to the public spaces, walkability, and land use mix could easily be understood and if the residents are satisfied with these factors, they usually perceive their neighborhood as a satisfactory community.

On the other hand, the relationship between perceived infrastructure performance and residential satisfaction was not found to be significant in this study. This finding was not expected as the infrastructure features that are considered in this study, namely outdoor lighting, rainwater collection systems, recycling facility, public transit, and road quality, are demonstrated to directly affect the quality of life of the people in their living environment. The finding of this research is inconsistent with Bonaiuto (2004) indicating that infrastructure features are influential in determining the satisfaction of residents. However, the findings of Adriaanse (2007) showed that neighborhood infrastructure is not among the most important influential factors in determining residential satisfaction. It is worth mentioning that each of the evaluated infrastructure attributes can potentially be significantly associated with satisfaction but when we look at them as a group, their perceived performances do not have any association with overall satisfaction. This highlights the importance of evaluating the relationship between each infrastructure attribute and the overall satisfaction to understand the influence of each individual infrastructure in predicting residential satisfaction.

This study has another finding that was not expected based on the existing literature. The cost performance of the built environment was found not to have any significant relationship with residential satisfaction while research has demonstrated the economic aspects of the neighborhood as an important predictor of satisfaction (Sirgy & Cornwell, 2002). As the most tangible criteria by residents, perceived cost performance was expected to be a significant predictor of residential satisfaction in this research. This finding can be due to two reasons: first, it may come from the overall high cost of living in the LEED-certified buildings and communities. If this is the case, one of the most highlighted aspects of living in a sustainable community, which is lower post-construction costs would be in doubt. The other possible reason for this finding could be the lower importance of the cost of living in sustainable communities when it comes to comparison with the quality that it is providing for residents. Even if this is the reason for the insignificant relationship between satisfaction and cost performance, still one of the main aspects that are highlighted in LEED-certification and green buildings is not working well in practice.

Conclusion

With an increasing emphasis on the role of users in evaluating the long-term success of sustainable residential projects, it is important to recognize the key factors contributing to users' satisfaction in green residential buildings. This research employed an SEM in order to investigate the relationships between the perceived performance of the built environment in sustainable residential projects and the level of satisfaction of the users with these projects in order to provide an understanding of the long-term success of these projects. The results showed that the perceived performance of the building is the most important factor determining the satisfaction of residents with their residential communities. The second important factor that affected the satisfaction of residents was neighborhood pattern and design while other aspects such as economic aspects and neighborhood infrastructure did not show any impact on providing satisfaction. The findings of this study determined the aspects that could potentially be considered for improving future sustainable community development projects that best meet residents' needs and expectations.

Despite being unique research by addressing one of the most important aspects of long-term project success of sustainable residential projects, this research has some limitations. The small number of responses for conducting CFA is one of the important limitations of this study. Although the minimum requirement for conducting such analysis was met by the number of respondents, the findings were more generalizable if the number of responses was more. Therefore, future research can improve the generalizability of the findings by surveying a higher number of LEED-certified community residents. The findings of this study can benefit researchers by providing a model for the evaluation of the long-term performance of green buildings and providing opportunities for practitioners to determine priorities for future sustainable residential development projects.

References

Adabre, M. A., & Chan, A. P. C. (2019). Critical success factors (CSFs) for sustainable affordable housing. *Building and Environment*, *156*(April), 203–214. https://doi.org/10.1016/j.buildenv.2019.04.030

Adriaanse, C. C. M. (2007). Measuring residential satisfaction: A residential environmental satisfaction scale (RESS). *Journal of Housing and the Built Environment*, *22*(3), 287–304. https://doi.org/10.1007/s10901-007-9082-9

Aliyu, A. A., & Muhammad, M. S. (2016). A review of post-occupancy evaluation as a tool and criteria for assessing building performance. In *Proceedings of the Academic Conference on Agenda for Sub-Sahara Africa*.

Bonaiuto, M. (2004). Residential satisfaction and perceived urban quality. In *Encyclopedia of Applied*

Psychology, Three-Volume Set (pp. 267–272). https://doi.org/10.1016/B0-12-657410-3/00698-X

Davis, K. (2014). Different stakeholder groups and their perceptions of project success. *International Journal of Project Management*, *32*(2), 189–201. https://doi.org/10.1016/J.IJPROMAN.2013.02.006

Dvir, D., Raz, T., & Shenhar, A. J. (2003). An empirical analysis of the relationship between project planning and project success. *International Journal of Project Management*, *21*(2), 89–95. https://doi.org/10.1016/S0263-7863(02)00012-1

Enright, S. (2002). Post-occupancy evaluation of UK library building projects: some examples of current activity. *LIBER Quarterly*, *12*(1), 26. https://doi.org/10.18352/lq.7665

Heravi, G., & Ilbeigi, M. (2012). Development of a comprehensive model for construction project success evaluation by contractors. *Engineering, Construction and Architectural Management*, *19*(5), 526–542. https://doi.org/10.1108/09699981211259603

Ibem, E. O., Adeboye, A. B., & Alagbe, O. A. (2015). Similarities and differences in residents' perception of housing adequacy and residential satisfaction. *Journal of Building Performance*, *6*(1), 1–14. Retrieved from http://spaj.ukm.my/jsb/index.php/jbp/index

Noriza, R., Ariffin, R., & Khairi Zahari, R. (2013). Selection and peer-review under responsibility of Centre for Environment-Behaviour Studies (cE-Bs), Faculty of Architecture, Planning & Surveying ScienceDirect Perceptions of the Urban Walking Environments. *Procedia-Social and Behavioral Sciences*, *105*, 589–597. https://doi.org/10.1016/j.sbspro.2013.11.062

Preiser, W. F. E., & Vischer, J. C. (2006). The evolution of building performance evaluation: an introduction. In *Assessing Building Performance* (pp. 25–36). Routledge. https://doi.org/10.4324/9780080455228-9

Satorra, A., & Bentler, P. M. (2001). A scaled difference chi-square test statistic for moment structure analysis. *Psychometrika*, *66*(4), 507–514. https://doi.org/10.1007/BF02296192

Sirgy, M. J., & Cornwell, T. (2002). How neighborhood features affect quality of life. *Social Indicators Research*, *59*(1), 79–114. https://doi.org/10.1023/A:1016021108513

Toor, S.-R., & Ogunlana, S. O. (2010). Beyond the 'iron triangle': Stakeholder perception of key performance indicators (KPIs) for large-scale public sector development projects. *International Journal of Project Management*, *28*(3), 228–236. https://doi.org/10.1016/J.IJPROMAN.2009.05.005

Weidemann, S., & Anderson, J. R. (1985). A conceptual framework for residential satisfaction. In *Home Environments* (pp. 153–182). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4899-2266-3_7

Williams, P., Ashill, N. J., Naumann, E., & Jackson, E. (2015). Relationship between quality and satisfaction: Customer-perceived success factors for on-time projects. *International Journal of Project Management*, *33*(8), 1836–1850. https://doi.org/10.1016/j.ijproman.2015.07.009

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Roof Design Efficiency for Energy Consumption in Residential Units

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This project investigates roof efficiency designs in the southeastern United States homes by creating a workflow for efficient roofing design. For this purpose, multiple 3D models are generated with different floorplan sizes and lower roof heights from the original pitch. This is done to find the most effective pitch in cost and performance, while still satisfying codes and local regulations. A Building Information Modeling (BIM) software package from Autodesk (Revit) is employed in this process along with an add-on, Metal-Wood-Framer (MWF), to create detailed models of the involved structures. Then, due to its compatibility with Revit and its parametric energy analysis, the Autodesk Insight platform was selected to further analyze the models. Results from Autodesk Insight provided information on Energy Use Intensity (EUI) and cost mean while comparing against Architecture 2030 and ASHRAE 90.1 standards. The RS Means catalog was employed to estimate the cost of roof construction. In the modified models, the cost of roof construction is lower than in the original models because less material is needed. However, findings indicate that, in the modified models, the EUI and cost mean is higher than in the original models, which may be due to heat gain/losses and lack of ventilation.

Key Words: design, roof, geometry, energy efficiency, cost analysis

Introduction, Objective and Literature Review

Roof design is an important factor to consider when designing residential structures. With the cost of construction rising, there is a new demand for cost-effective design/construction assemblies. The use of 3D BIM can assist with this task. Varying the roof pitch could lower its costs and also modify the energy performance of the associated building (Roof Replacement Cost, 2018). The purpose of this study was to analyze ten different residential buildings with different square footages, in order to see if lowering the roof pitch of their roofs would increase energy performance. This study focuses on homes in the southeast region of the USA. It analyzes their upfront costs and their solar efficiency versus more common roof designs. The way roofs are designed and constructed has not changed much overtime. So, it is conceivable that the current popular roof geometry may not be the most affordable or energy efficient. The selected roofs were geometrically similar because most roofs in the Southeast region have an average roof pitch of 9”/12”, or higher. This causes the quantity and cost of the involved materials to be relatively high. The average cost of a new roof, in the southeast region, is increasing (Roof Replacement Cost, 2018). Modern roofs, regardless of their geometrical shape, consist of five components which include structural framing, sheathing, underlayment, gutters, and finished surfaces (Vandervort, 2014). However, with some modifications applied to roof components, the price of a new roof construction can be lowered. This can be done by lowering the pitch of the roof in order to meet minimum code requirements and local regulations. High roof pitches are not required in most areas in the Southeast region. Another alternative to lower roof prices is to reconsider the materials used in new roof construction. Some of these materials may include different framing lumber sizes, different kinds of thermal protection, and/or different kinds of surface finishes. BIM software can be used to efficiently create new roof designs, t. Using BIM will facilitate a collaborative process in which multiple trades can be involved in planning, design, and construction (Lorek, 2018). Designers and contractors may use BIM services to generate 3D models that could assist owners in making informed decisions (Hergunsel, 2011). Some of the BIM-related software employed for this purpose may be Autodesk AutoCAD, Autodesk Revit, Revit add-on MWF, Rhinoceros, and Rhinoceros add-on Grasshopper. The use of BIM software can facilitate the process of designing a new roof. Additionally, it can make the roof more modular which, in return, can make it cheaper and its construction safer. For the purpose of this project, only two software programs were considered for design authoring, Autodesk Revit and the MWF add-on to Revit.

Since the construction industry is a heavy consumer of raw materials and one of the largest contributors to waste generation, i.e., about 40% of the materials that are dumped in landfills are construction waste (Yuan et. al., 2017), there is a strong public interest in reducing this waste. By using BIM/parametric software (e.g., Rhinoceros add-on Grasshopper, Autodesk Revit, etc.) there can be a reduction in construction waste (Yuan et. al., 2017). This may be achieved by predesigning the members in Autodesk Revit and then employing the quantity take-off function to extract the amounts of materials before the construction phase begins. Using Revit can benefit users with real-time quantity amounts that automatically adjust when design changes are made. This assists in cost-sensitivity analysis that could save time, money, and materials (Zhao et. al., 2015). In this study the Insight platform was used to investigate roof design efficacies for lower energy consumption, due to its compatibility with Revit and its parametric energy analysis capability. In order to get consistent results relative to the energy model outputs (and analysis in the cloud platform) other “variables” were maintained “constant” (i.e., envelope materials of the residential units) over the selected models.

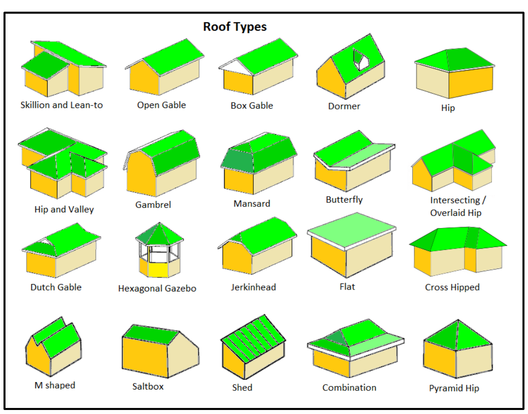

Figure 1. Roof Types (Roofing Calculator, 2019)

Most of the residential structures in southeastern cities have a similar roof design. As seen in figure 1, some of the most common roof structures in this region are a gable, open gable, hip, hip & valley, and cross-hipped. The advantages of the gable roof style is that it easily sheds water and snow, and due to the high pitch in gable roofs, they have large attic space, which is good for ventilation purposes (Roofing Calculator, 2019). However, a gable roof style is problematic in high winds and hurricane areas as some structural members of the roof may not be properly secured and, if the overhang of the roof is too large, the wind could cause uplift (Roofing Calculator, 2019). The advantages of the hip style roof is the strength inherit in the design for example hip roofs perform better in high wind environments (Roofing Calculator, 2019). However, a hip roof style is usually more costly to build compared to a simple gabled roof because it requires more material(Roofing Calculator, 2019).

The roofs of buildings include rafters, ridge board, ceiling joist, struts, and hangers as seen in figure 2 below. The ceiling joists span from the width of the building exterior wall to a center load-bearing wall. The rafters support the main assemblies and determine the roof pitch. The rafters meet at the top at the ridge board which is the highest line on a roof structure. The struts and the hangers are also known as the web, these parts structurally support the rafters and ceiling joists. The most common material used when building these structures is wood. However, the finishes on the roof may vary by owner's preference. The most common roof finishes materials used in the southeast region are asphalt shingles and/or metal panels.

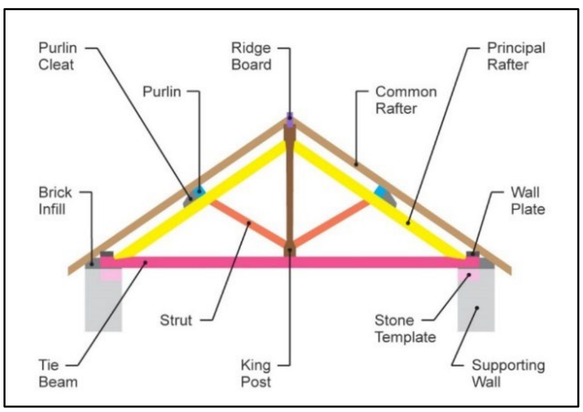

Figure 2. Roof Structure (Home Stratosphere, 2018)

A Cloud-Based Building Energy Analysis Tool

Autodesk Insight

There are several companies that produce software focusing on building performance analyses. One of these software applications is Autodesk Insight, a powerful cloud-based tool that assists users in improving the energy and environmental performance of any model that is parametrically authored in Autodesk Revit. Some of the features found on Insight are real-time feedback, BIM integrations, complete building energy analysis and several more (Introducing Autodesk Insight 360, 2015). To accomplish complete building energy analysis, Insight focuses on heating and cooling loads, day lighting analyses, and solar radiation analyses (Wagner, 2017). Once Insight finishes all analyses of the elements stated above, the results can be outputted as seen in figure 3 below. Figure 3 illustrates several Insight features, such as Benchmark Comparisons, EUI, and model history. To obtain the EUI, Autodesk Insight considers several different factors, such as HVAC systems, lighting power density, and glazing properties (Wagner, 2017). Once it gathers all the parameter that determine annual energy usage, it divides it by the total area of the building, to obtain a normalized quantity by square footage. The result shows maximum, mean, and minimum EUI.

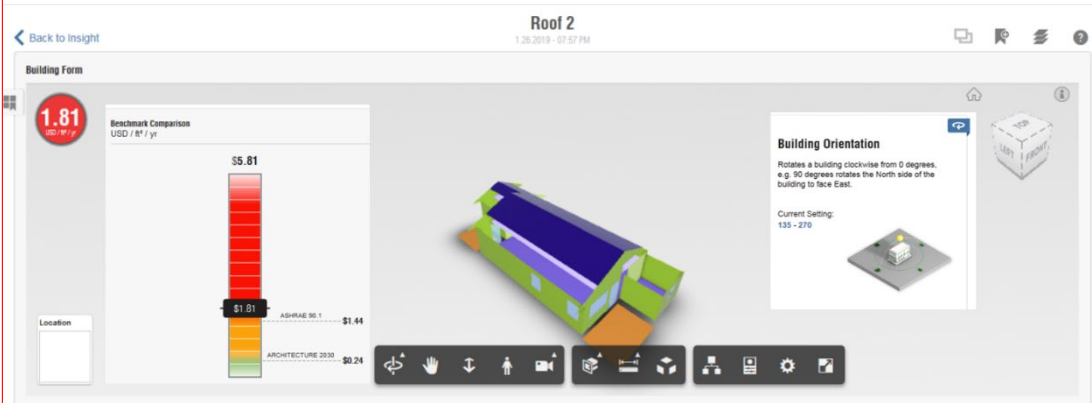

Figure 3. Autodesk Insight Output

The maximum is related to the highest amount of money in EUI dollars, the mean is the average, and the minimum is representing the least amount of money needed for a particular design which, in some instances, can be negative. Users receive results expressed in energy use per area and per year. The Insight computations also show comparisons of the current model's EUI with respect to ASHRAE 90.1 and Architecture 2030 benchmarks (Wagner, 2017). The first standard for comparison is ASHRAE 90.1 which is the energy standard for buildings, except for low-rise residential structures. Insight looks at four major factors, which are the building envelope, HVAC systems, power and lighting system, and complete building energy performance. All these components may vary by location. The building envelope requirements cover the thermal performance of the building envelope (roofs, walls, floors, and doors). For walls and roofs, the thermal requirements are given in terms of either the maximum allowable U-factor 4 or the minimum insulation R-value 5, and can vary on location (Crall, 2009). The HVAC systems requirement of the air ducts and pipes must have a minimum R-value of the building code location. They must also meet energy-efficiency ratios (EER). EER measures energy efficiency at peak loads while the integrated energy-efficiency ratio (IEER) measures annual load efficiencies. Residential equipment must meet seasonal energy-efficiency ratios (SEER) which rate efficiency over a range of outdoor air temperatures. All are expressed in Btu/W*hr., where 3.4 Btu/W*hr. = 1.0 COP (Coefficient of Performance) (Boldt and Rosenberg, 2018).

The second standard that Insight compare models against is Architecture 2030 which started in 2007 and is now adopted by 839 US cities. The goal of the Architecture 2030 challenge is to reduce 100% the world Greenhouse Gas (GHG) emissions by 2030. It states that all new construction must be designed to high-energy efficiency standards and by 2050 these sites must be carbon neutral as well. To receive the Architecture 2030 benchmark in Autodesk Insight, the software tracks the carbon footprint of the model in real-time (AIA 2030 Commitment, 2019). Architecture 2030 provides five steps that can help realize this. The first step is establishing a EUI baseline using Autodesk Insight (Architecture 2030, 2019). The second step is to apply low/no-cost passive design strategies to achieve maximum energy efficiency (Architecture 2030, 2019). These low/no-cost passive design strategies can be related to building orientation, optimizing daylight, solar heat gain, etc. The third step is integrating energy efficient technology and systems (Architecture 2030, 2019). This technology can be programmable thermostats, energy efficient air conditioners, LED lighting, etc. The fourth step will be to incorporate on-site/off-site renewable energy to meet the remaining energy demands such as solar panels (Architecture 2030, 2019). And the last step is to engage in iterative energy modeling throughout the entire design (Architecture 2030, 2019).

Energy Model Output

After the analysis is completed, Autodesk Insight displays the building performance output as seen in Figure 3 above. Some of the outputs include building orientation, daylight & occupancy control, HVAC, infiltration, light efficiency, operating schedule, plug load efficiency, PV (panel efficiency, payback limit, and surface coverage), wall construction, roof construction, window glass, window shades, and window wall ratio (WWR) for various asphalt shingles and metal panel roofs considered in this study.

- Building Orientation shows "the process of rotating the building from 0 to 90 degrees (north to face east)" for a more efficient EUI and cost mean; Daylight & Occupancy Control "shows the process of using a daylight dimming and occupancy sensor system" for a more efficient EUI and costs mean (Autodesk, 2015).
- HVAC shows "a range of HVAC system efficiency, which will vary, based on location and building size"; Infiltration shows "the unintentional leaking of air into or out of conditioned space; often due to gaps in the building envelope" (Autodesk, 2015).
- Light efficiency "shows the average internal heat gain and power consumption of electric lighting per unit floor area"; Operating Schedule shows "the typical hours of use by building occupants" (Autodesk, 2015).
- Plug Load Efficiency shows "the cost of power used by equipment (computers, small appliances, etc.) excluding lighting, heating and cooling equipment"; PV shows "the efficiency, surface coverage, and the payback period of the solar panels"; Wall construction shows "the overall ability of wall construction to resist head losses and gain"; Roof construction shows "overall ability of roof construction to resist heat losses and gain"; Window Glass show "glass properties controlling the amount of daylight, heat transfer and solar heat gain into the building along with other factors"; Window shades show "how to reduce HVAC energy use. The impact depends on the other factors, such as window size and solar heat gain properties"; Window Wall Ratio shows "the interaction with windows properties to impact daylight, heating, and cooling" (Autodesk, 2015).

Experimental Research Methodology

All models used in this research were authored through Autodesk Revit software. The energy analysis completed in this project was performed with Autodesk Insight cloud platform. The RS Means catalog was utilized to create a parallel real-time simulation on cost analysis. The add-on software (MWF) was used to create the actual structure of the roof. It was provided by StrucSoft Solution with a student free trial (https://strucsoftsolutions.com). The floor plans were gathered from local architectural styles to be fitted for the SE-region construction means and methods. Ten floor plans were selected. They all corresponded to residential structures, ranging from 868 Sq Ft (2 Bedrooms, 1 1/2 bathroom) to 4064 Sq Ft (4 Bedrooms, 3 1/2 bathrooms). The style of the residential floor plans was chosen to match the style seen in the SE region of the state. Therefore, some included styles are Craftsman, Coastal Beach, Traditional, and Acadian. Ten structures were created, all the walls, ceilings and floors of the residential units were modeled with predetermined uniform layers. Additionally, all the doors and windows were configured the same to maintain consistency throughout the project experimental models and analyses. When it came to roofing materials, two were used as top layers: metal sheets and asphalt shingles. For this project, five (5) asphalt shingle models and another five (5) metal panel models were configured.

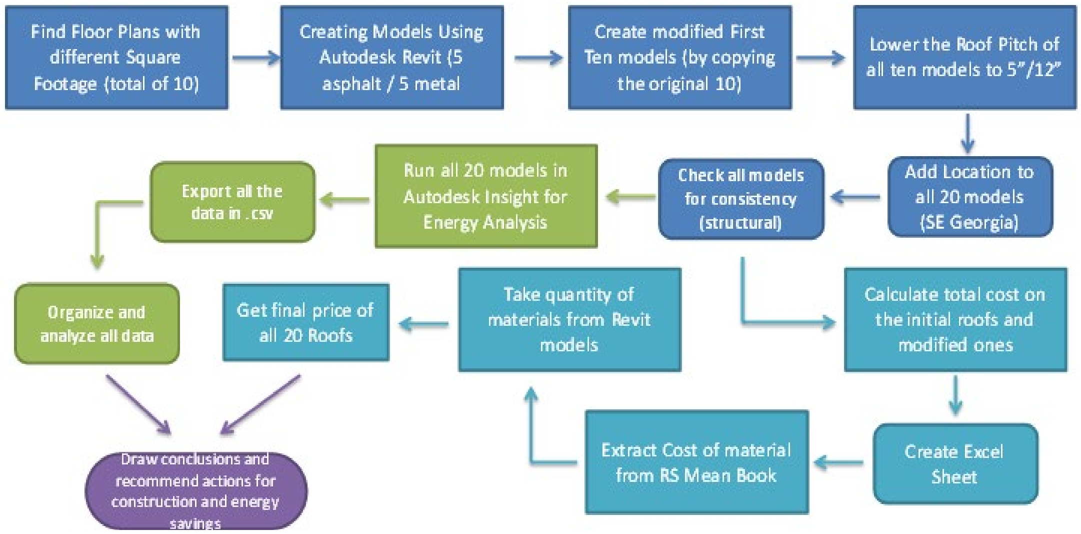

Figure 4. Research Methodology Flow Chart

According to the residential building codes and the local regulations where the project was situated, the minimum thickness of concrete slab on grade by code was 4" (on residential structures). However, in this study, a greater concrete thickness was selected for all the slabs used in the simulations. This preference was adopted to avoid affecting the building energy analysis relative to their thermal masses. After generating all models, the next step was to create the roof structures using MWF. Once these structures were incorporated into the models, the next task was to create the modified models. These models were an exact copy of the first ten (10) original models, with all the roofs lowered to 5"/12" pitch. This roof pitch was chosen because it was the lowest pitch allowed by the code in the SE region of the state. This pitch was also chosen for creating and testing a more efficient roof design. Then, the structure supporting the lowered roof was added by using MWF again (see flowchart in figure 4).

Models' Analysis for Energy Efficiency and Conclusions

Once all twenty (20) models were completed and checked for consistency, they were ready for analysis using Autodesk Insight. Locations were assigned to the models and the next step was to analyze them via the Insight cloud. All roof structures, previously generated via MWF, were included in the models during the analysis process. The energy optimization feature in Autodesk Revit was also used in this process. Once the analysis was completed, the end result showed Real-time feedback, BIM integrations, complete building energy analyses and several other parameters (introduced in Autodesk Insight 360, 2015), as seen at the following website: https://insight360.autodesk.com/oneenergy. Once all the analyses were done and availed for viewing in the cloud, the next step was to export the intermediate results to be further analyzed. All data was exported into a .csv file and then transferred to an MS Excel file for additional processing. In the Excel file, data obtained for each model was expressed as max., mean, and min. costs, in US dollars to power the building throughout the year. The cost mean represents the average cost to power the building throughout the year. The cost min meant the least cost to power the building throughout the year. It should be mentioned that, in some instances, the min cost could be a negative number. Even though in this project a cost analysis was performed to include the cost of all materials used in the roofs of all considered models, the main focus of this work was on the energy output and analysis/interpretation. This was done by generating ten (10) BIM models with their original roof pitches (provided by their actual designers), and by replicating them with lower roof pitches (5”/12”). Autodesk Insight was used only to analyze and compare the performance of the modified building against that of the original models and RS Means catalog was used to estimate the material costs of each model style. It was decided to exclude the cost of labor, equipment, and tools from the cost comparison analysis due to a high variation on prices. The results are summarily presented in figures 5 and 6 (where OG refers to the “original roofs” and Mod refers to the “modified roofs”). At the beginning of this project, it was assumed the modified models would be less expensive to build and they will attain a better energy performance than the original models on a yearly basis. However, after analyzing the data it was observed that the original models were often less costly when it came to energy performance than the modified models. There were 2 exceptions Model 1 and Model 5 required less energy in after design modification. In Model 1, the cost mean of the modified model and EUI was lower than the original, therefore the EUI and cost mean is found lower in the modified model. However, in Model 5 the costs mean of the modified and original models are both the same, and the EUI is also held at very close values. From all the case studies, only Model 1 meets/beats the Architecture 2030 and ASHRAE 90.1 requirements. Most floor plans and their models were very close to satisfying the ASHRAE 90.1 requirements, with some minor modifications to the building envelope and building orientation. Nevertheless, the other models met ASHRAE 90.1 thresholds. Regarding the cost of construction, the modified models are less expensive as less materials were required to build them (i.e., lower pitches resulted in less roof surface). However, when considering the prices per square foot (unit prices), the modified roof models were more expensive than the original models.

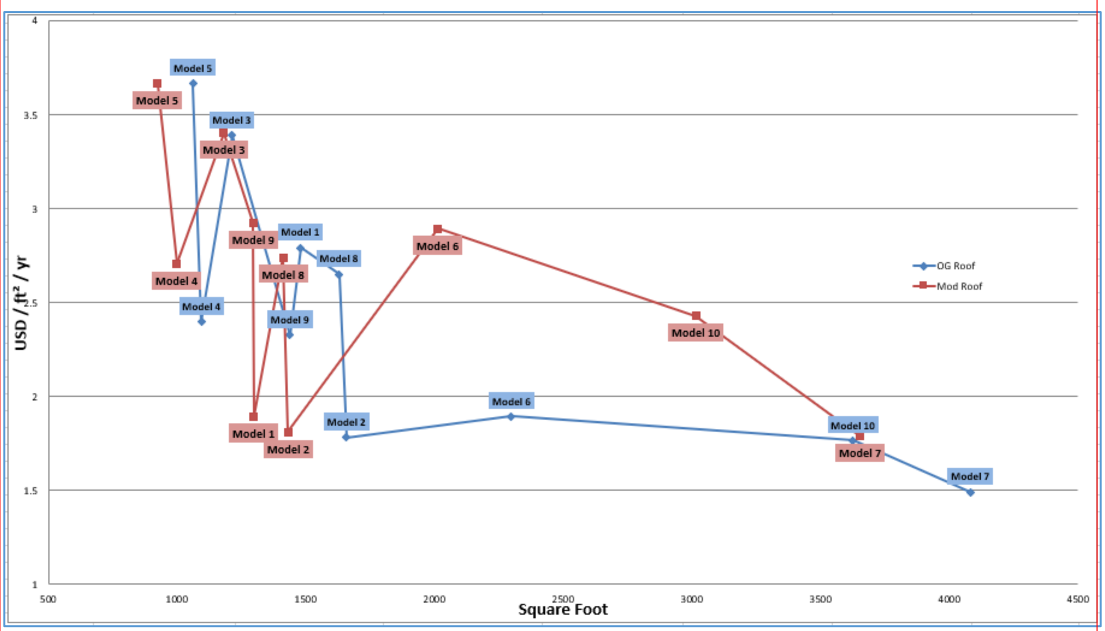

Figure 5. Cost Mean to Roof Square Footage Comparison

Adding to the body of knowledge, when further examining the data, it can be observed that the 5”/12” roof pitch is not the most effective roof when it comes to building performance. This result may have happened because of the reduced space for air circulation associated to the modified roofs. It may have also caused by the heat gain/loss which may increase on 5/12 pitch roofs. Once heat gain/loss increases in the building, the EUI will also increase with it due to the higher demand on the HVAC systems. Even though the low pitch would save the occupant of the building costs in the construction process, in the end, the occupant(s) would actually start losing money after the payback period is completed and therefore one conclusion would be to not recommend lower pitched for humid climate zones such as the southeast United States.

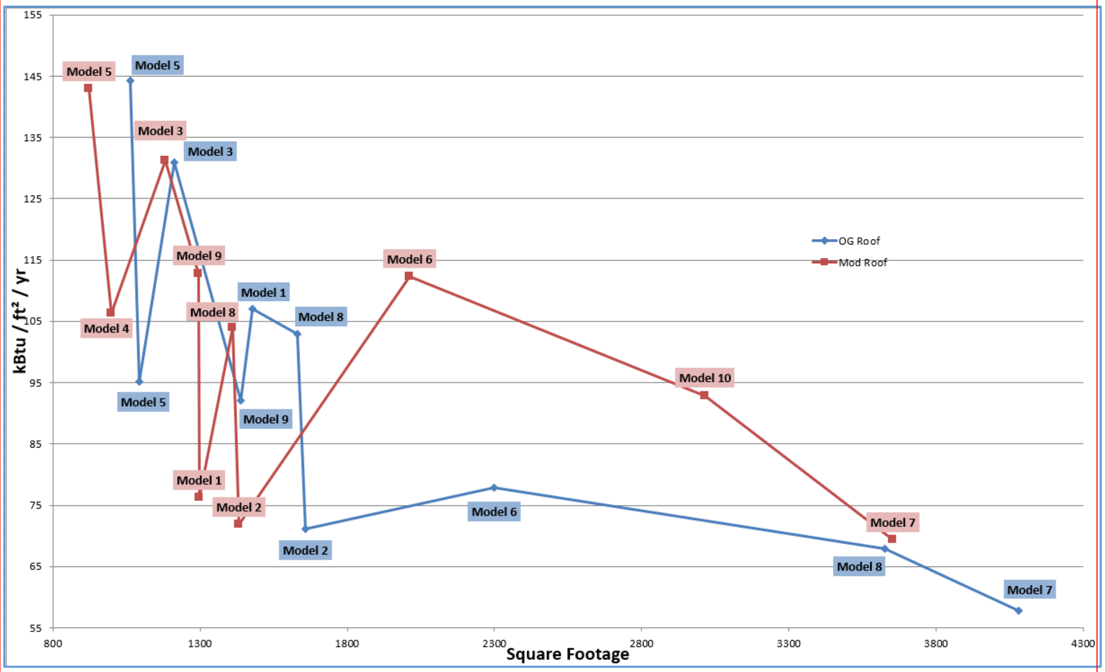

Figure 6. EUI Mean to Roof Square Footage Comparison

For future research another location, such as a city in the northeast region of the United States, could be investigated to determine if increasing or decreasing incrementally the pitch of the roof affects the building energy performance in severe cold winters with large amounts of snow. When choosing another location, the local building codes would need to be analyzed to make sure the future project complies with local/state related codes. Another aspect which is of interest to the authors is how variations in material might affect the performance of residential roof structures (another study limitation). In this project, the insulation analyzed was rigid insulation. In future projects, other types of insulation with a higher R-value and different sized lumber could be used in the models, as such factors could potentially provide better energy performances.

References

AIA 2030 Commitment. (2019). "AIA 2030 Commitment | Architecture 2030 Challenge." *Autodesk*, <https://www.autodesk.com/sustainability/architecture-2030> (Mar. 24, 2019).

Autodesk. (2015). "High performance and sustainable building design analysis." *Insight*, <https://insight360.autodesk.com/oneenergy> (Mar. 19, 2019).

Boldt, J., and Rosenberg, M. (2018). "Achieving compliance with ASHRAE 90.1." *Consulting-Specifying Engineer*, <https://www.csemag.com/articles/achieving-compliance-with-ASHRAE-90-1/> (Oct. 29, 2021).

Crall, C. (2009). “Codes and Standards Update: ASHRAE 90.1.” *Insulation Outlook*, <https://insulation.org/io/articles/codes-and-standards-update-ASHRAE-90-1/> (Oct. 29, 2021).

Hergunsel, M. F. (2011). “ Benefits of Building Information Modeling for Construction Managers and BIM Based Scheduling.” *Worcester Polytechnic Institute Digital WP*. MS Thesis.

Home Stratosphere.(2018). “39 Parts of a Roof Truss with Illustrated Diagrams & Definitions*“. Home Stratosphere*, Home Stratosphere webpage, <https://www.homestratosphere.com/parts-of-roof-truss/> (Oct. 25, 2021).

Introducing Autodesk Insight 360. (2015). *Insight Blog by S. Egger*, <https://blogs.autodesk.com/insight/introducing-autodesk-insight-360-2/> (Oct. 29, 2021).

Lorek , S. (2018). “What is BIM (Building Information Modeling)” *Constructible: Construction Industry Resources*. <https://constructible.trimble.com/construction-industry/what-is-bim-building-information-modeling> (Oct. 26, 2021).

Meeting the 2030 Challenge. (2019). *Architecture 2030*. <https://architecture2030.org/2030_challenges/2030-challenge/> (Mar. 10, 2021).

Plotner, S. C. (2019). Building Construction Costs with RSMeans data. *Gordian RSMeans Data*, *77th Annual Edition*. Rockland, MA.

Roofing Calculator (2019). “Top 15 Roof Types, Plus Their Pros & Cons - Read Before You Build!” *Roof Cost Estimator - Calculate Your Roof Replacement Costs*, < https://www.roofingcalc.com/top-15-roof-types-and-their-pros-cons/ > (Oct. 24, 2021).

Roof Replacement Cost (2018). *Roof Cost Estimator - Calculate Your Roof Replacement Costs*, < https://www.roofingcalc.com/roof-replacement-cost/> (Oct. 21, 2021).

Roof Replacement Cost in 2018: New Roof Prices. (2018). *Roof Cost Estimator - Calculate Your Roof Replacement Costs*, <https://www.roofcostestimator.com/roof-replacement-cost/> (Oct. 21, 2018).

Vandervort, D. (2014). “Roof Construction Basics.” *HomeTips*, <https://www.hometips.com/how-it-works/roof-construction.html> (Oct. 25, 2021)

Wagner, C. (2017). “Get Insights into Your Building's Energy Usage.” *Autodesk Support & Learning*, <https://knowledge.autodesk.com/support/revit-products/getting-started/caas/simplecontent/content/get-insights-your-building-E2-80-99s-energy-usage.html?st=how does insight calculate cost mean> (Oct. 29, 2020)

Yuan, Z., Sun, C., and Wang , Y. (2017). “Integration of parametric design into modular coordination: A construction waste reduction workflow.” Automation in Construction, 88, 1–12.

Zhao, Q., Li, Y., Hei, X., and Wang, X. (2015). “Toward Automatic Calculation of Construction Quantity Based on Building Information Modeling.” *11th International Conference on Computational Intelligence and Security (CIS)*. IEEE Xplore, 19-20 Dec. 2015. Shenzhen, China.

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Use of Pulverized Recycled Glass in Concrete

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The potential to use recycled products in building methods and materials is important to consider. A problem exists in the recycling process where many city municipalities have removed glass recycling from their recycled waste stream forcing consumers to waste glass into a common waste stream for all waste. At Central Washington University (CWU), use of pulverized glass in concrete was analyzed to determine the difference in strength of the concrete when reducing the amount of virgin concrete sand in concrete as a material. With an applied research methodology, the researcher studied the effects of reducing virgin sand and replacing it with locally sourced pulverized glass. A control was used for a typical 3,000 psi concrete mix commonly found in structural concrete applications on roads, bridges, buildings, and foundations. Reductions in virgin sand were made at 25% and 50% and replaced with pulverized glass at the same percentage within the concrete mixture. Concrete compression tests were performed on three concrete 6-inch by 12-inch cylinder samples at the specified virgin sand and sand reduction levels using the American Society of Testing Materials (ASTM) standards. Results showed an eleven percent (11%) and twelve percent (12%) reduction in concrete strength using pulverized glass for sand.

Key Words: Pulverized Glass Sand, Virgin Sand, Recycled Glass, Concrete, Sustainability

Introduction

There are many consumer products that are recyclable. As Jacoby (2019) states, glass is a 100% recyclable material, nearly 10 million metric tons of glass is disposed of every year in the U.S., and 33% of waste glass gets recycled in the U.S. This compared to several European nations where 90% of glass gets recycled on average each year is quite low. Glass is made from readily available domestic materials such as sand, soda ash, limestone, and “cullet.” It is also known that some glass products cannot be used in the manufacturing of new glass storage containers because the glass may be contaminated, or the recycled glass particles are too small to meet manufacturing standards to be reused. Glass that cannot be recovered for the creation of new containers can then be used for non-container use or “secondary” uses include tile, water filtration, sandblasting, concrete pavements, and parking lots (www.gpi.org/glass-recycling-facts).

There are many municipalities where residents could take their used glass to be deposited to a common location to be processed and recycled. In some locations, the collection and movement of the glass to be recycled provides the consumer or individual depositing the glass to be paid a certain amount of money based on collections made in the initial purchase the glass product. About ten (10) states have laws established for consumers who get paid to recycle glass, these states include California, Connecticut, Hawaii, Iowa, Massachusetts, Maine, Michigan, New York, Oregon, and Vermont (Williams, 2019).

While some states have laws established for consumers to be paid for recycling glass and other materials, other states may have drop off locations for recyclables using a multi-stream or single stream collection point. In the state of Washington, there are some site locations consumers can drop their recyclables that will be transferred to a different location to be processed into a usable material. There are costs associated with the transfer of the recycled material to each individual processing location. In some cases, especially in rural areas, the material will be handled multiple times until it is processed, this creates an additional cost associated with the processing effort that some entity must absorb. Glass may be collected at a single transfer station but will ultimately be trucked to additional locations to be sorted and processed to become a usable material. In 2019, the City of Ellensburg, Washington eliminated the collection of glass at the local transfer facility. Within Washington state there were several other locations where collection points were eliminated to collect and process recycled glass due the cost of transportation. This forces consumers to find alternative locations or methods to either recycle glass or dump glass into the landfill.

The City of Ellensburg, Washington eliminated the recycling and transportation of glass due to the costs, market use of recycled glass, and cross contamination of glass that make it difficult to process. Other cities and states like Sarasota County, Florida, and Mecklenburg County, North Carolina were also forced to rethink their glass recycling efforts due to costs associated with the production and processing of recycled glass (Rogoff & Gardner, 2016). Once glass is recycled there are the challenges associated with the collection, transportation, and processing and recycling of glass. In other areas around the country the challenge of collecting and transporting consumer glass has been either eliminated or redirected to a different waste stream. Some recycling centers have a focused waste stream for different recycled materials to include paper, glass, cardboard, tin, steel, and various plastics. Other locations will have a multi-stream system that allows the consumer to dispose of their recycled material in one place to be either picked up curbside or dropped at a transfer center to be processed. When these materials are collected, in many cases the bulk recycled materials must be transported to a different location to be processed into a material that can be re-used as another material for different product applications. A prime example of this is the use of plastic bottles that are collected and recycled to be used in clothing applications (Bastone, 2022).

The use of recycled glass has been around for many years in the production of new products and different building applications. Glass has been found to be utilized as subgrade material for pipe installation, coarse aggregate, hot mixed asphalt, structural and architectural concrete, mortars, and precast concrete (Afshinnia, 2019; Dehghanpour & Yılmaz 2019; Meyer & Xi, 1999). These secondary uses provide an additional use for recycled glass that would normally be placed in the landfill and increase demand for the use of recycled glass.

Literature Review

The recycling effort from consumer to the processing of recycled glass to be utilized in new materials and construction means and methods has been researched. There have also been advantages and disadvantages associated with the application of recycled glass in concrete. As Afshinnia (2019) has identified the fact that most mixed glass usually cannot be recycled into some building materials due to its chemical properties that can have a reaction with other materials in the material mixing process. To properly recycle glass, it is advisable to separate the different colors of glass due to the chemical composition of the colored glass which consist of sand, soda ash, limestone, and cullet. This is especially true when using concrete for household counter tops. When converting used glass to a building material there are challenges associated with recycled glass to be considered so the material can be used with other material applications. A challenge when recycling glass into concrete is a chemical reaction that is created known as an alkali-silica reaction (ASR). In concrete applications, this must be neutralized in the mixture to assist with the quality of the final product (Afshinnia, 2019 & https://www.concrete.org/).

An ASR reaction creates a siliceous gel in the cement paste and swells at different times either during the mix of fresh concrete or during the curing process. The ultimate physical reaction comes in the form of cracking in the final concrete product (Klemenc, 2011). As Afshinnia (2019) has identified, the way to treat ASR is to neutralize the reaction using low alkali Portland cement, supplementary cementitious materials (SCMs) to include silica flume, fly ash, slag, and metakaolin, and pozzolans. Afshinnia (2019) also cites the fact that using recycled glass show a reduction in the strength of the concrete can be 10% to 20% less than when using virgin aggregate materials. This effect has been mapped to show the variability of cracking that can occur through ASR with the different colors of glass. It was also found through this research that green glass exhibits less distress due to the presence of chromium used to produce the glass.

Using pozzolans helps reduce the reactivity of ASR in concrete. The American Concrete Institute (ACI) specifically defines the use of pozzolans to "combine with calcium hydroxide in the concrete to calcium silicate hydrate where the use of pozzolan may increase or decrease water demand depending on the particle shape, surface texture, and fineness." Product manufacturers also cite the use of pozzolans reduce the concrete permeability, decreases efflorescence & controls ASR, improves mix rheology, color, and appearance, reduces drying shrinkage, increases the density and tightness of concrete, and improves surface characteristics of the concrete (concretecountertopsupply.com). ACI also states that this will reduce bleeding due to the fineness of the pozzolan material and reduce the maximum rise in temperature when used in large amounts by slowing the rate of the chemical reactions (https://www.concrete.org/).

Other studies have been conducted on replacing virgin sand with recycled waste glass. Nafisa, Rabin, & Nagaratnam (2020) researched the utilization of waste glass as a partial replacement for sand in concrete. Their study relied on a control and three samples reducing natural river sand in concrete at 20%, 40%, and 60%. They maintained a control sample which met its design concrete strength within twenty-eight (28) days of cure. Additionally, from their control group there was a slight reduction in strength in replacement of glass for sand, yet the compressive strength still met the design strength required for the concrete mixture. Therefore, their tests showed only about a 2% reduction strength at twenty-eight (28) days when sand was replaced with up to 60% recycled waste glass sand. There was also a slight ASR reaction, but little effect on the overall concrete strength.

Methodology

The purpose of this applied exploratory research was to determine if there was an effect on concrete strength when pulverized glass is introduced in place of virgin sand aggregate. This applied exploratory research design tested three different concrete mix designs to identify the strength relationship associated with the use of virgin sand and locally sourced pulverized glass to replace a portion of virgin sand in the concrete mix. A limitation of this study included a small sample size due to limited material resources. The basic procedure to perform the tests included research into the types of materials that could properly be used to avoid the ASR and the use of standardized concrete testing procedures. A simple procedure was used and followed to create nine (9) cylinders is identified below:

1. Acquire materials
2. Weigh ingredients based on a water cement ratio of 0.50
3. Cast three (3) cylinders each representing the control of virgin sand and the reduction of sand being replaced by pulverized glass as listed:
    a. Standard mix with virgin sand
    b. -25% Reduction of sand replaced with pulverized glass
    c. -50% Reduction of sand replaced with pulverized glass
4. Let cylinders cure for 24hrs
5. Release cylinders and place in PH temperature-controlled water bath at 73°F
6. Let cylinders cure for 28 days per American Society for Testing Materials (ASTM) standards
7. Cap cylinder
8. Perform compression test

Concrete Standards

To perform the test, the procedures used to make the concrete followed the ASTM standards for concrete aggregate and sand moisture content testing, concrete sand gradation analysis (ASTM C33) and making, curing, capping, and testing 6-inch by 12-inch concrete cylinders (ASTM C31, C192, C511, C617, C39) (Kosmata & Wilson, 2011). The standards are shown in table 1 below:

Table 1

ASTM Standards for Making, Curing, Capping, and Testing Concrete

Standard	**Title**
C31	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C33	Concrete aggregate and sand moisture content testing, concrete sand gradation analysis
C192	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C511	Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C617	Standard Practice for Capping Cylindrical Concrete Specimens
C39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

Concrete Mix Designs

While all the above standards were followed, researchers used a standard mix design with a water to cement ratio (W/C) of 0.50 with no reduction in sand as the control measure to perform the study. This mixture utilized a 100% virgin sand mix with the ingredients as shown below in Table 2:

Table 2

Standard Concrete Mix Design (100% Virgin Sand)

Mix Ingredients	Standard Mix Design (Lbs)	Absorption	Moisture Content
Coarse Aggregate	22.00	1.80%	1.91%
Fine Aggregate	12.00	1.50%	5.29%
Cement	6.50		
Water	2.78		
Total Weight	43.28		

Note: W/C Ratio = 0.50

Once the standard mix design was identified, mix designs were created with the reduction of virgin sand to be replaced with locally sourced pulverized glass. The following mix design in Table 3 was created for a concrete mixture that would reduce the virgin sand by twenty-five (25%) and percent 50% and replace it with pulverized glass respectively. The mix design is shown below with all weights shown in pounds (Lbs).

Table 3

Concrete with Sand Reduction Replaced with Pulverized Glass

Mix Ingredients	-25% Sand Reduction (Lbs)	-50% Sand Reduction (Lbs)	Absorption	Moisture Content
Coarse Aggregate	22.00	22.00	1.80%	1.91%
Fine Aggregate	9.00	6.00	1.50%	5.29%
Pulverized Glass	3.00	6.00	0.00%	0.00%
Cement	5.36	5.36		
Bottle Poz	1.14	1.14		
Water	2.89	3.00		
Total Weight	43.39	43.50		

Note: W/C = 0.50. *A standard value of 17.5% of the cement weight was reduced and replaced with pozzolan to reduce the Alkali Silica Reaction in the concrete mixture.*

As identified by Afshinnia (2019) to prevent ASR, it was recommended to use a supplementary cementitious material to neutralize the reaction caused by the recycled glass. To prevent ASR researchers used a Fishstone Bottle Pozzolan in place of Portland cement. Manufacturer’s recommendations identified the amount of pozzolan that could be used can range between fifteen (15%) to twenty (20%) percent. For this project, researchers used a value of 17.5% pozzolan by weight as the best amount to replace cement and reduce the potential for ASR. Figure 1 below shows the physical mixture components which include course and fine aggregate (sand), cement, pulverized glass, and the pozzolan additive.

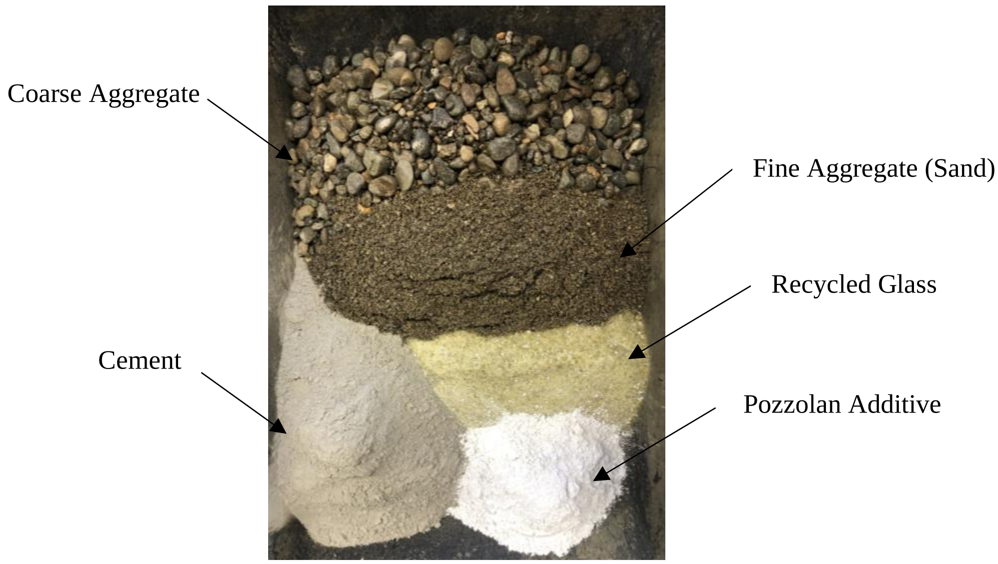

Figure 1. Concrete mix components

Results

The researcher's goal with this project was to test the feasibility of using pulverized glass in concrete. Other researchers have performed similar research with processed recycled pulverized glass (Nafisa, Rabin, & Nagaratnam, 2020). The difference in this study was that all the pulverized glass was locally sourced, cleaned for impurities, and then placed in the concrete mixture. Ultimately, the researcher's wanted to determine if there was a strength relationship when the amount of virgin sand was reduced and replaced. Compression tests were performed on the six (6) inch by twelve (12) inch concrete cylinders. By removing virgin sand by weight at -25% and -50% then replacing sand with pulverized glass, there were a total of three concrete cylinders casted for each test variable with a total of nine (9) compression tests performed. Shown below in Table 4 are the results of the compression tests for each of the cylinders in pounds per square inch (psi) with the reductions in virgin sand content.

Table 4

Compression Test Results

Cylinder Test	**Standard 100% Virgin Sand (psi)**	**-25% Sand Reduction and Replacement (psi)**	**-50% Sand Reduction and Replacement (psi)**
1	6203	5630	5255
2	4993	5389	5333
3	7193	5340	5545
Average	6163	5452	5377

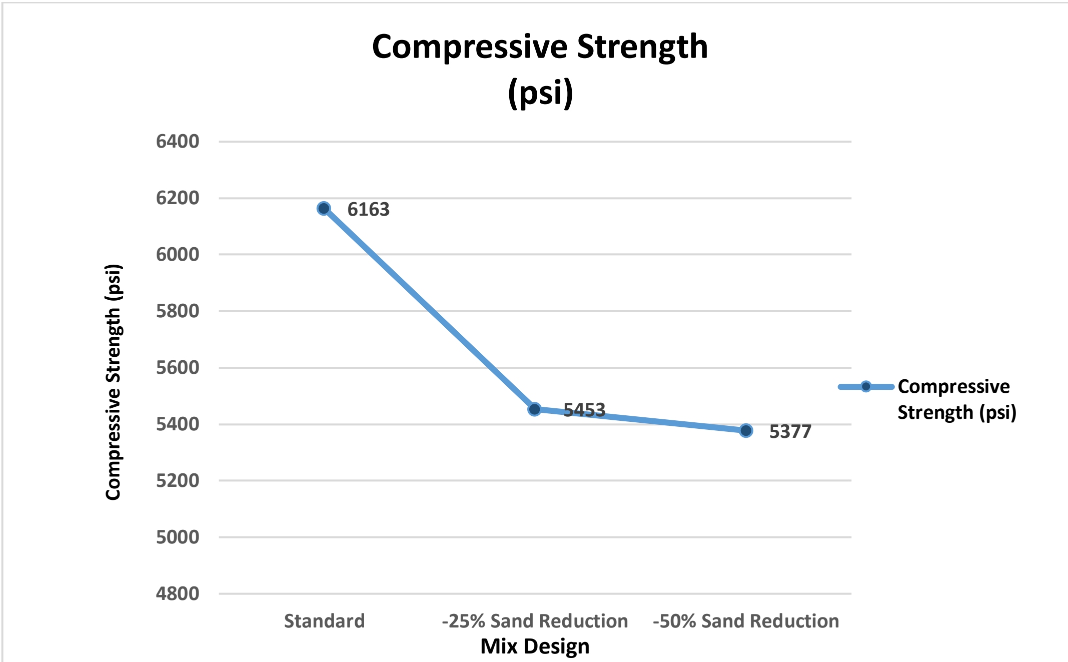

Figure 2. Compressive strength of concrete cylinders from 0% to 50% sand reduction

While a limitation to this study was a small sample size, the results suggested that there was a reduction in strength when pulverized glass is added to the concrete mixture. Similar to the findings by Nafisa, Rabin, & Nagaratnam (2020), when reducing the amount of sand from the control cylinders there was slightly over eleven percent (11.5%) loss in strength when reducing the sand and replacing with twenty-five (25%) pulverized glass. And, by reducing the sand and replacing with fifty (50%) pulverized glass there was just over twelve percent (12.8%) loss in strength. With the reduction of virgin sand from the concrete mix, the compressive strengths of the samples still met or exceeded their design strength of 3,000 psi.

What should be observed is within the mix design, for the two test samples, as the fine aggregate was reduced by their respective amounts of 25% and 50%, this changed the total amount of water to be added to the mixture. Both the cement and pozzolan admixtures remained the same, this was due to the retained water that had to be accounted for in the aggregate to maintain the water cement ratio of W/C = 0.50.

Conclusion & Discussion

What this exploratory study provides is that recycled glass can be used as a material to replace virgin sand. Comparatively, when averaging the compression strengths at the 25% and 50% sand reduction levels it the average strength for these compression strengths is at 5,415 psi. This was surprising to the researchers because most high strength concrete for structural applications is specified at compression strengths above 5,000 psi.

Replacing sand with pulverized glass in concrete has shown that it can be a viable material for concrete applications but must be treated to attain the necessary outcomes. By using pozzolans, they do help by improving the concrete mechanical and durability properties associated with the use of pulverized glass in the final product. Use of pulverized glass with the reduction of virgin sand is also an environmentally conscious application to reuse a material that is readily available in many different locations, but has proven to be a costly operation when going from a consumer glass product to a usable recycled construction material. Although there was a decrease in concrete strength, there are many architectural and structural concrete applications where pulverized glass can be used. As seen in this study, the tests proved to hold concrete compressive values close to those needed for many structural applications, but further testing would be required if this practice could be used as a standard in highway or structural applications. What this study also shows, is the ability to use pulverized glass as sand to potentially reduce concrete production's impact on the carbon footprint for construction materials.

At Central Washington University and within the Ellensburg community this project started further discussion on the use of recycled pulverized glass in many different applications. Since the completion of this study local non-profits have created a glass recycling cooperative to collect and crush glass for use. Some uses have included crushed glass in plant growing operations to conserve water, fill in piping operations, outdoor architectural features, and farming. There have been several presentations made to bring the awareness of recycling efforts locally and around the state as well.

Future research on this subject would be to further expand on the use of pulverized recycled glass in building and industrial applications. Further studies would look at the use pulverized glass in a mass concrete application such as a sidewalk or concrete wall to determine the durability of the finished product in different environmental applications over several years. Additionally, there would be a strong interest to determine the actual carbon footprint that exists with the complete operation from consumer glass acquisition to the final reuse of recycled glass in building products. As many have mentioned, the operation of recycling glass is an expensive venture for any city or municipality to undertake. Researching the costs associated with glass recycling starting with the transportation of glass along with the processing operation would prove to be beneficial when considering deploying a glass recycling operation. In construction education, it would be interesting to have students investigate the recycling efforts needed to create the pulverized glass and process it to be ready for use in concrete applications by looking at the costs and impact on the carbon footprint to produce concrete. Studies like these would help to determine how environmentally sustainable the use of recycled glass would be in concrete or other materials. Overall, this research does show there is a potential for the application of recycled glass to be used in many areas of construction means and methods.

References

Afshinnia, K (2019). *Concrete Decore*. Vol 19, No 8 https://www.concretedecor.net/decorativeconcretearticles/vol-19-no-8-november-december-2019/waste-glass-in-concrete-has-advantages-and-disadvantages/

American Concrete Institute. Retrieved from: https://www.concrete.org/

Bastone, K (2022). *Patagonia Moving Swiftly Toward Recycled Materials*. Retrieved from: https://www.flyfisherman.com/editorial/patagonia-moves-toward-recycled-materials/455588

Concrete Countertop Supply. Retrieved from: https://concretecountertopsupply.com/

Dehghanpour, H & Yılmaz, K (2019). Evaluation and Investigation of Waste Glass Aggregates and Powders in Architectural Mortars. *Scientific Herald of the Voronezh State University of Architecture & Civil Engineering*. 2019, Vol. 44 Issue 4, p28-42. 15p. 7

Glass Packaging Institute. Retrieved from: https://www.gpi.org/glass-recycling-facts

International Solid Wastes and Public Cleansing Association, ISWA, 30(9), 917–921. https://doi-org.ezp.lib.cwu.edu/10.1177/0734242X12448512

Imteaz, M. A., Ali, M. M. Y., & Arulrajah, A. (2012). Possible environmental impacts of recycled glass used as a pavement base material. *Waste Management & Research: The Journal for a Sustainable Circular Economy*. Volume: 30 issue: 9, page(s): 917-921

Jacoby, M. (2019). Why Glass Recycling in the US is broken. February 11, 2019. *Chemical Engineering News*, Volume 97, Issue 6. https://cen.acs.org/materials/inorganic-chemistry/glass-recycling-US-broken/97/i6 .

Klemenc, S.E. (2011). What to Expect When Mixing Concrete with Glass. *Building With Concrete*, Vol. 11, No. 5, July 22. https://www.concretedecor.net/departments/building-with-concrete/when-concrete-meets-glass/?fbclid=IwAR33RcosI9-YyeNlhQEBudAL8zUWJ1zRQ1zbOOzA-bXNr6x6us9Eb4w9wl8

Kosmata, S.H. and Wilson, M.C (2011). *Design and Control of Concrete Mixtures: The guide to applications, methods, and materials* (15th Ed.). Farmington Hills, MI: Portland Cement Association, 421-426.

Rogoff, M.J. & Gardner, R.B. (2016). High Costs and Limited Markets Put a Crack in Glass Recycling. *MSW Management*. https://www.mswmanagement.com/recycling/article/13023949/high-costs-and-limited-markets-put-a-crack-in-glass-recycling

Meyer, C., & Xi, Y. (1999). Use of Recycled Glass and Fly Ash For Precast Concrete. *Journal of Materials in Civil Engineering*, 11(2), 89. https://doi-org.ezp.lib.cwu.edu/10.1061/(ASCE)0899-1561(1999)11:2(89)

Nafisa T, Rabin T, & Nagaratnam S. (2020). Performance of recycled waste glass sand as partial replacement of sand in concrete. *Construction and Building Materials*, Volume 239, 2020.

Williams, G (2019). How to Make Money Recycling. *US News and World Report*. https://money.usnews.com/money/personal-finance/saving-and-budgeting/articles/how-to-make-money-recycling

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Opportunities and Challenges

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Urbanization and the evolution of people's lifestyles have a significant impact on the quantity of waste that is generated and dumped each year. In addition, due to the emergence of the COVID-19 pandemic, the use of masks has increased significantly, and the amount of plastic waste generation worldwide has doubled. These wastes have had a negative impact on the environment and have attracted the attention of many departments. Faced with both increasing amounts of generated plastic wastes and the growing interest of sustainability, the construction sectors must take an advantage using recycled plastic wastes in construction applications to reduce the negative impacts of the generated plastic wastes, while meeting future infrastructure demand. This study conducts a comprehensive analysis of the opportunities and challenges of plastic waste application in the construction industry. In this context the objective of the study is to 1) explore the most used plastic wastes in construction industry, 2) identify potential application of plastic waste in construction industry, 3) identify potential application of COVID-19 plastic waste in construction industry, 4) outline challenges and opportunities involving the applications, and 5) Provide recommendations for advanced research required for plastic waste application in construction industry. It is concluded that the use of plastic waste in construction will significantly improve environmental sustainability, reduce the construction cost, improve the performance of construction, and serve as a reliable supply of construction materials. Finally, to overcome challenges areas for further research are also suggested.

Key Words: Plastic Waste, Construction, Construction Material, Recycling, Safety, Sustainability, Environment

Introduction

Urbanization and the evolution of people's lifestyles have a significant impact on the quantity of waste that is generated and dumped each year. Products are made and then discarded, resulting in waste. Most of these wastes are disposed at landfills. The high cost of landfilling, the inefficiency of non-specific locations, and the use of land space may hinder waste management. Although the output of solid waste is increasing year by year, only a small part of it is recycled or landfilled, and a large part of it is deposited directly or indirectly in the marine environment. Moreover, during COVID-19 pandemic, a large amount of face masks has been generated and littered in the parking lots, parks, and ocean, which result in an increased number of wastes (Saberian et al., 2021).

Plastic wastes are one of the big solid wastes that threaten our world's sustainability. Annually, almost 300 million tons of plastic waste are generated (Singh & Sharma, 2016). Plastic waste is produced globally due to its widespread use in industries including automotive, manufacturing, packaging, and healthcare (Rokdey et al., 2015). Due to the significant expense and energy involved with landfilling, these wastes have been dumped in aquatic bodies. When plastic waste enters in the oceans, it causes ecological, economic, and aesthetic harm (Jambeck et al., 2018). Plastic's limited biodegradability further limits its recyclability and environmental disposal. Finding uses for plastic wastes will help to manage it in a sustainable manner. Moreover, reuse and recycling of plastic waste outperform landfilling and incineration (Lazarevic et al., 2010).

Source reduction, reuse, and landfilling have all been used to limit the quantity of plastic waste that is produced each year to a manageable level. Plastic waste generation has steadily increased because of significant technological advancements. To preserve a sustainable ecosystem, it is important to develop new methods to recycle this plastic waste. In addition to protecting the environment, recycling plastic waste provides a way to absorb these materials into various industries, such as construction, where they may be used. Utilizing plastic waste in construction not only protects the environment, but it also lessens the environmental hazard that this plastic's manufacturer offers to the environment. Using plastic in the construction industry might also aid in the industry's environmental goals, as well. By reducing the quantity of new plastic processed and generated, reusing plastic waste results in significant reductions in energy use and carbon emissions. From an engineering perspective, plastics are very durable, cost-effective, long-lasting, easy to mold, and easy to maintain (Hopewell et al., 2009). As a result of these characteristics, as well as the growing awareness of the environmental impact of plastic waste, plastic has become an increasingly popular material for engineering and construction applications.

The most common plastic waste in the waste stream is polyethylene and polyethylene terephthalate (PET) have been used in concrete, building plaster, pavements, bock, mortar, to reinforce asphalt in road surfaces and create a stronger, more crack-resistant structures (Almeshal et al., 2020; Okunola A et al., 2019; Proshad et al., 2017; Siddique et al., 2008; da Silva et al., 2021). Although the potential of plastic waste in the construction industry is huge, its application and development are now severely limited. As plastic waste may be used in the construction industry, this study provides a comprehensive analysis of its opportunities and challenges. In this context, the objective of this study is to 1) explore the most used plastic wastes in construction industry, 2) identify potential application of plastic waste in construction industry, 3) identify potential application of COVID-19 plastic waste in construction industry, 4) outline challenges and opportunities involving the applications, and 5) provide recommendations for advanced research required for plastic waste application in construction industry.

Methodology

The methodology used was to search for the information present in this review through literature and articles in the academic databases: google scholar, science direct, springer, Elsevier, research gate, and academia, using a selection criterion based on the following keyword: Plastic Waste, Construction, Construction material, Recycling, Safety, Sustainability, Environment.

Literature Review

Major component of plastic waste and level of recyclability

Polyethylene terephthalates (PET), High density polyethylene (HDPE), Polyvinyl Chloride (PVC), Low density polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS) were the most used in Concrete, building plaster, Block, Mortar, Pavements, Base/Subbase of Pavement, hot mix asphalt (HMA) (Almeshal et al., 2020; Okunola A et al., 2019; Proshad et al., 2017; Siddique et al., 2008; da Silva et al., 2021).

Figure 1. shows construction applications of different plastics in different sectors (i.e., Concrete; building plaster, Block, Mortar, Pavements, Base/Subbase of Pavement, hot mix asphalt (HMA)). From Figure 1 it can be said that PET is the most popular plastic in construction application (i.e., concrete, mortar, building plaster, block, pavements). Where PVC is the least applied plastic in construction (i.e., concrete, mortar). Moreover, HDPE, LDPE, PS, PP are also used frequently in the construction industry. By comparing Figure 1 and Figure 2 it can be said that recyclability is one of the main factors which influences the application of plastic in construction industry. Since the recyclability level PVC in is difficult they are being least applied in the construction industry where other plastics with easier recyclability is the most applied in construction industry.

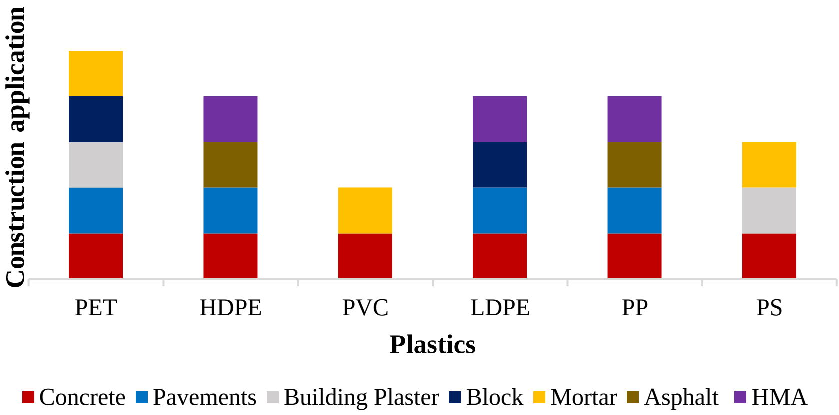

Figure 1. Construction application of different plastics

Figure 2 represents the recyclability levels of different plastics for construction application. Basically, recyclability depends on different factors (i.e., cost of processing, availability, collection procedure). In most cases, the plastic which recyclability level is easier have high levels of application and the plastic which recyclability is difficult have low levels of application as shown in the Figure 2. From Figure 2 it can be said that PET, HDPE, PP and LDPE could be recycled easily but recyclability of PVC and PS is difficult. Polystyrene (PS)) has a high level of application despite their recyclability is very difficult. The reason for that may be related to the wide availability, low cost of production, and PS is mostly used plastics in terms of packaging of different products.

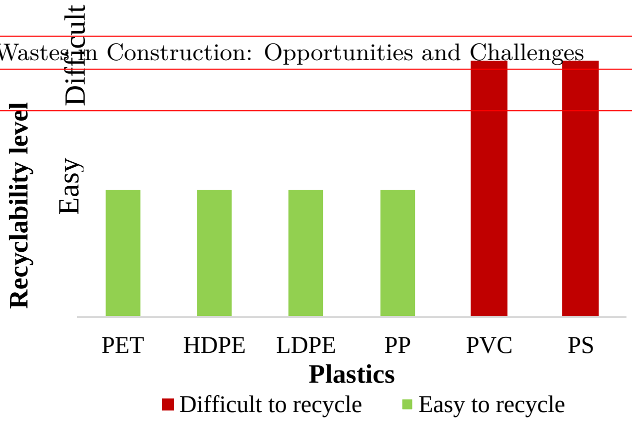

Figure 2. Recyclability level of different plastics.

Plastic waste application in construction industry

Mixing plastic waste into concrete, mortar, building plaster, asphalt, Hot mix asphalt (HMA) and pavement base/subbase modification is a better choice for plastic waste disposal. Table 1 describes the application of plastic waste in the construction industry. The review focuses on the challenges and opportunities of plastic waste as construction material. It can be said from Table 1, opportunities (improve performance, environment quality, reduce cost) and challenges (i.e., Functionality, recycling plan, collection, separation, processing, field performance) are quite similar for all plastic application in construction. Improvement of concrete overall quality, concrete cracking resistance, plaster tensile resistance and compressive strength of earth block is possible by using PET, PS and PVC (Ismail & AL-Hashmi, 2008; Batayneh et al., 2007; Hama & Hilal, 2017; Puri et al., 2013; Aciu et al., 2018). Besides, using HDPE, LDPE, PP, PET and PS it is possible to improve asphalt's mechanical properties, asphalt binder's viscosity, CBR and subgrade modulus (k_s) (Abu Abdo & Khater, 2018; Gibreil & Feng, 2017; Jha et al., 2014; Wang et al., 2022; Angelone et al., 2015; Arabani & Pedram, 2016). However, after all these opportunities researchers have found that the challenges have narrowed the scope of applications. The main challenges of using plastic waste are collection, separation and processing of the plastic waste. Though there are separate bins are provided for recycled plastic waste disposal, most often the bins are contaminated by other wastes. Moreover, people are not using the bins for the disposal of plastic waste. For this reason, collection & separation procedure get complex, operation cost of this process increases. Moreover, for using plastic waste in the construction it is required to process the material in smaller size by advanced process (i.e., grinding, pelleting, shredding), so expensive machines are required for this. Above all, researchers addressed environmental benefits and reduction of construction cost are the prime benefits of using plastic waste in the construction industry.

Table 1
Summary associated opportunities and challenges of plastic waste application in construction industry

Material	Application	Challenge	Opportunity	Author
PET	Concert, Building plaster Asphalt Block	Functionality, Recycling plan, collection, separation, processing	Improve performance, environment quality, reduce cost	Ismail & AL-Hashmi, (2008); Batayneh et al., (2007); Hama & Hilal, (2017);

				Khalid et al., (2018); Salim et al., (2019); Abu Abdo & Khater, (2018)
HDPE	HMA Asphalt Pavement	Processing, functionality	Improve performance, environment quality, reduce cost	Gibreil & Feng, (2017); Jha et al., (2014); Angelone et al., (2015); Arabani & Pedram (2016)
LDPE	Asphalt HMA Block	Processing Functionality	Improve performance, environment quality, reduce cost	Angelone et al., (2015); Suaryana et al., (2018); Kumi-Larbi et al., (2018)
PP	HMA Asphalt	Processing, functionality	Improve performance, environment quality, reduce cost	Wang et al., (2022); Angelone et al., (2015)
PVC	Concrete Mortar	Processing, recyclability, functionality	Improve performance, environment quality, reduce cost	Puri et al., (2013); Aciu et al., (2018);
PS	Concert Building plaster Pavement	Processing, Functionality, Field performance	Improve performance, environment quality, reduce cost	Ismail & AL-Hashmi, (2008); Hama & Hilal, (2017); Salim et al., (2019); Mohajerani et al., (2017

Applications of Plastic Wastes in Construction Industry During Covid-19

During the pandemic, masks have always been the most popular protective equipment. As a result, more people are using face masks for different purposes. It can protect people against COVID-19, but it is not good for the environment since the most often used single-use mask is not biodegradable (i.e., Plastic). The most common surgical mask is a disposable one. Most of the masks are made of polypropylene (Henneberry, 2020).

Saberian et al., (2021) performed a series of tests on shredded face mask blends at different percentages for highway base and subbase applications, including modified compaction and resilient modulus testing. The combination of recycled concrete aggregate (RCA) base with three different concentrations of shredded face mask (1%, 2%, and 3%) gave the necessary stiffness and strength for paving/foundation. The inclusion of shredded face mask increased the strength and pliability of the fibrous recycled concrete aggregate mixes. When 1% SFM and RCA were added, the strength remained totally unconfined at 216 kPa, but the modulus substantially increased (314.35 MP). Even when SFM was increased by more than 2%, stiffness and strength were decreased.

Kilmartin-Lynch et al., (2021) conducted some tests of concrete using face mask as a modifier. The masks have been inserted with volume at 0% (control), 0.10%, 0.15%, 0.20% and 0.25%, to test the overall quality of the concrete, with the test focus on pressure strength and indirect tensile strength, elasticity modulus and ultrasonic pulse velocity. With the addition of the single-use masks, the strength properties of the concrete settings were increased as well as the overall quality of the concrete increased. However, the trend of increasing force began to decline over 0.20 percent.

However, previous studies have shown that in terms of performance, there is an opportunity to use covid 19 masks in construction. The use of masks in the construction industry is environmentally beneficial and cost-effective, but the challenges of using covid 19 masks are huge. Due to safety issues, it is challenging to collect, separate and process of such masks during this pandemic. Throughout the process of using masks in construction, people may be affected by the covid-19 virus.

Challenges of Applying Plastic Wastes in Construction Industry

Although the use of plastic wastes for construction has several environmental and economic advantages, its widespread adoption still presents certain challenges. Based on the above reviewed studies, some of the main challenges and opportunities of using plastic wastes in construction industries. Challenges are categorized based on collection and processing, functionality, and field performance.

Collection & Processing:

1. One of the main challenges of plastic wastes is collecting and separating before recycling as these wastes are contaminated with other wastes as they are collected from different sources, as a result, these wastes are consisted hazardous and certain causation procedures are needed.
2. No separate collection and separation method is being used to collect the used facemasks during Covid-19 pandemic.
3. The complicated chemical composition of some plastics such as polystyrene makes traditional recycling techniques unsuitable, as a result, advanced technology is needed, which may result in added cost.
4. Plastic wastes need to be processed for using in construction in smaller size by grinding, pelleting, or shredding, as a result, advanced equipment is needed, which may require skilled manpower to operate and increase the cost of construction.

Functionality

1. Plastic has limited strength; therefore, it is not ideal for projects that need to withstand a lot of pressure. Moreover, the low surface energy of the plastic can lead to poor mechanical adhesion in composite material. Due to this insufficient combination, the overall mechanical properties of the composite material may be reduced.
2. Lack of standards for the use of plastic waste in the construction industry despite extensive research has been conducted on construction applications, these applications are still not well standardized commercially.
3. While there have been many field projects with recycled plastics constructed, a more thorough and comprehensive evaluation of how these are performing over the long-term is needed.

Field performance

1. Construction workers are not properly trained up in using plastic wastes in construction sectors as they are not familiar with this process. Moreover, proper safety measures and safety training is not available for the application of plastic waste in construction industry.

2. During Covid-19 pandemic using recycled face mask in construction is a threat for the construction workers, as there are no proper safety guidelines available regarding using covid 19 face mask in the construction.

Opportunities of Applying Plastic Wastes in Construction Industry

1. The use of plastic waste in construction applications will solve the problem of solid waste management and the consumption of raw materials of construction. For this reason, construction cost will be reduced because conventional construction materials are expensive. Moreover, Plastic waste in construction industry will be energy efficient because of replacing conventional raw materials which requires energy for production.
2. Using plastic wastes in construction application will bring a new horizon in the academic field of Construction Management and Engineering.
3. Using Covid-19 face mask in construction application will reduce the pandemic generated waste and construction cost. Moreover, facemask can improve the performance of construction.
4. Using plastic wastes in Construction Management will reduce the environmental pollution and make the world environment more sustainable.

Conclusions and Recommendations

Plastics are widespread in our modern world, and the waste they generate is unavoidable. Consequently, the use of plastic wastes in different construction applications is a viable option for managing these wastes and enhancing the sustainability of the environment, reducing the cost of construction, improving the performance of construction work, and serving as a reliable supply of construction materials. In this study, the opportunities, and challenges of the application of plastic waste in the construction industry have been thoroughly addressed. The conclusions and recommendations of the study are the following:

- The use of plastic wastes for construction applications is an efficient and sustainable waste management solution despite its applications is full of challenges, however, the advanced technology makes the application more possible.
- The use of Covid-19 pandemic plastic waste in transportation industry could improve the United states road network and reduce the future environmental threats from this plastic wastes.
- Proper safety guideline and separate collection procedure should be developed for the application of recycled Covid-19 face mask in construction industry.
- The use of recycled plastic waste should be included in academic curricula to familiarize future construction leaders with the use of plastics in construction.
- Appropriate training programs should be developed to train and understand construction workers on the application of plastic waste in construction.
- Further research work is required to determine the solutions for resisting chemical reaction occurs for using plastic waste in construction.

References

Abu Abdo, A. M., & Khater, M. E. (2018). Enhancing rutting resistance of asphalt binder by adding plastic waste. *Cogent Engineering*, *5*(1), 1452472. https://doi.org/10.1080/23311916.2018.1452472

Aciu, C., Ilutiu-Varvara, D.-A., Manea, D.-L., Orban, Y.-A., & Babota, F. (2018). Recycling of plastic waste materials in the composition of ecological mortars. *Procedia Manufacturing*, *22*, 274–279. https://doi.org/10.1016/j.promfg.2018.03.042

Angelone, S., Cauhapé Casaux, M., Borghi, M., & Martinez, F. O. (2015). Green pavements: Reuse of plastic waste in asphalt mixtures. *Materials and Structures*, *49*(5), 1655–1665. https://doi.org/10.1617/s11527-015-0602-x

Arabani, M., & Pedram, M. (2016). Laboratory investigation of rutting and fatigue in glassphalt containing waste plastic bottles. *Construction and Building Materials*, *116*, 378–383. https://doi.org/10.1016/j.conbuildmat.2016.04.105

Akinwumi, I. I., Domo-Spiff, A. H., & Salami, A. (2019). Marine plastic pollution and affordable housing challenge: Shredded waste plastic stabilized soil for producing compressed Earth bricks. *Case Studies in Construction Materials*, *11*. https://doi.org/10.1016/j.cscm.2019.e00241

Almeshal, I., Tayeh, B. A., Alyousef, R., Alabduljabbar, H., Mustafa Mohamed, A., & Alaskar, A. (2020). Use of recycled plastic as fine aggregate in cementitious composites: A review. *Construction and Building Materials*, *253*, 119146. https://doi.org/10.1016/j.conbuildmat.2020.119146

Awoyera, P. O., Akinmusuru, J. O., & Ndambuki, J. M. (2016). Green concrete production with ceramic wastes and laterite. *Construction and Building Materials*, *117*, 29–36. https://doi.org/10.1016/j.conbuildmat.2016.04.108

Batayneh, M., Marie, I., & Asi, I. (2007). Use of selected waste materials in concrete mixes. *Waste Management*, *27*(12), 1870–1876. https://doi.org/10.1016/j.wasman.2006.07.026

Benson, C. H., & Khire, M. V. (1994). Reinforcing sand with strips of reclaimed high-density polyethylene. *Journal of Geotechnical Engineering*, *120*(5), 838–855. https://doi.org/10.1061/(asce)0733-9410(1994)120:5(838)

da Silva, T. R., de Azevedo, A. R., Cecchin, D., Marvila, M. T., Amran, M., Fediuk, R., Vatin, N., Karelina, M., Klyuev, S., & Szelag, M. (2021). Application of plastic wastes in construction materials: A review using the concept of life-cycle assessment in the context of recent research for future perspectives. *Materials*, *14*(13), 3549. https://doi.org/10.3390/ma14133549

Gibreil, H. A. A., & Feng, C. P. (2017). Effects of high-density polyethylene and crumb rubber powder as modifiers on properties of hot mix asphalt. *Construction and Building Materials*, 142, 101–108. https://doi.org/10.1016/j.conbuildmat.2017.03.062

Garel, A., & Petit-Romec, A. (2020). Investor rewards to environmental responsibility: Evidence from the COVID-19 crisis. *Journal of Corporate Finance*, *68*, 101948.

Hahladakis, J. N., & Iacovidou, E. (2019). An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling. *Journal of Hazardous Materials*, *380*, 120887. https://doi.org/10.1016/j.jhazmat.2019.120887

Hama, S. M., & Hilal, N. N. (2017). Fresh properties of self-compacting concrete with plastic waste as partial replacement of sand. *International Journal of Sustainable Built Environment*, *6*(2), 299–308. https://doi.org/10.1016/j.ijsbe.2017.01.001

Henneberry, B. (2020). How Surgical Masks are Made, Tested and Used., Tested and Used. *https://www.thomasnet.com/articles/other/how-surgical-masks-are-made/*.

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1526), 2115–2126. https://doi.org/10.1098/rstb.2008.0311

Ilyas, S., Srivastava, R. R., & Kim, H. (2020). Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *Science of The Total Environment*, 749, 141652. https://doi.org/10.1016/j.scitotenv.2020.141652

Ismail, Z. Z., & AL-Hashmi, E. A. (2008). Use of waste plastic in concrete mixture as aggregate replacement. *Waste Management*, *28*(11), 2041–2047. https://doi.org/10.1016/j.wasman.2007.08.023

Jambeck, J., Hardesty, B. D., Brooks, A. L., Friend, T., Teleki, K., Fabres, J., Beaudoin, Y., Bamba, A., Francis, J., Ribbink, A. J., Baleta, T., Bouwman, H., Knox, J., & Wilcox, C. (2018). Challenges and emerging solutions to the land-based plastic waste issue in Africa. *Marine Policy*, *96*, 256–263. https://doi.org/10.1016/j.marpol.2017.10.041

Jha, J. N., Choudhary, A. K., Gill, K. S., & Shukla, S. K. (2014). Behavior of plastic waste fiber-reinforced industrial wastes in pavement applications. *International Journal of Geotechnical Engineering*, *8*(3), 277–286. https://doi.org/10.1179/1939787914y.0000000044

Khalid, F. S., Irwan, J. M., Ibrahim, M. H. W., Othman, N., & Shahidan, S. (2018). Performance of plastic wastes in fiber-reinforced concrete beams. *Construction and Building Materials*, *183*, 451–464. https://doi.org/10.1016/j.conbuildmat.2018.06.122

Kilmartin-Lynch, S., Saberian, M., Li, J., Roychand, R., & Zhang, G. (2021). Preliminary evaluation of the feasibility of using Polypropylene Fibres FROM COVID-19 single-use face masks to improve the mechanical properties of concrete. *Journal of Cleaner Production*, *296*, 126460. https://doi.org/10.1016/j.jclepro.2021.126460

Kumi-Larbi, A., Yunana, D., Kamsouloum, P., Webster, M., Wilson, D. C., & Cheeseman, C. (2018). Recycling waste plastics in developing countries: Use of low-density polyethylene water sachets to form plastic bonded sand blocks. *Waste Management*, *80*, 112–118. https://doi.org/10.1016/j.wasman.2018.09.003

Kwak, J. I., & An, Y.-J. (2021). Post covid-19 pandemic: Biofragmentation and soil ecotoxicological effects of microplastics derived from face masks. *Journal of Hazardous Materials*, 416, 126169. https://doi.org/10.1016/j.jhazmat.2021.126169

Lazarevic, D., Aoustin, E., Buclet, N., & Brandt, N. (2010). Plastic Waste Management in the context of a European Recycling Society: Comparing Results and uncertainties in a life cycle perspective. *Resources, Conservation and Recycling*, *55*(2), 246–259. https://doi.org/10.1016/j.resconrec.2010.09.014

Maderuelo-Sanz, R., Acedo-Fuentes, P., García-Cobos, F. J., Sánchez-Delgado, F. J., Mota-López, M. I., & Meneses-Rodríguez, J. M. (2021). The recycling of surgical face masks as sound porous absorbers: Preliminary evaluation. *Science of The Total Environment*, 786, 147461. https://doi.org/10.1016/j.scitotenv.2021.147461

Machsus, M., Chen, J. H., Hayati, D. W., Khoiri, M., Mawardi, A. F., & Basuki, R. (2021). Improvement for asphalt mixture performance using plastic bottle waste. *International Journal of GEOMATE*, *20*(79). https://doi.org/10.21660/2021.79.j2035

Proshad, R., Kormoker, T., Islam, M. S., Haque, M. A., Rahman, M. M., & Mithu, M. M. (2017). Toxic effects of plastic on human health and environment : A consequences of health risk assessment in Bangladesh. *International Journal of Health*, *6*(1), 1. https://doi.org/10.14419/ijh.v6i1.8655

Puri, N., Kumar, B., & Tyagi, H. (2013). Utilization of recycled wastes as ingredients in concrete mix. *International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN*, *22783075*.

Rajput, P. S., & Yadav, R. K. (2016). Use of plastic waste in bituminous road construction. *International Journal of Science and Technology & Engineering*, *2*(10), 509-513.

Rivas, K. (2020, November 25). Coronavirus face masks can be reused with 'dry heat,' FDA says. Fox News. https://www.foxnews.com/health/coronavirus-face-mask-reused-dry-heat-fda.

Rowan, N. J., & Laffey, J. G. (2021). Unlocking the surge in demand for personal and protective equipment (PPE) and improvised face coverings arising from coronavirus disease (covid-19) pandemic – implications for efficacy, re-use and sustainable waste management. *Science of The Total Environment*, 752, 142259. https://doi.org/10.1016/j.scitotenv.2020.142259

Royo-Bordonada, M.A., García-López, F.J., Cortés, F., & Zaragoza, G.A. (2020). Face masks in the general healthy population. *Scientific and ethical issues. Gaceta Sanitaria.* https://doi.org/10.1016/j.gaceta.2020.08.003

Rokdey, S. N., Naktode, P. L., & Nikhar, M. R. (2015). Use of plastic waste in road construction. *International Journal of Computer Applications*, *7*, 27-29.

Suaryana, N., Nirwan, E., & Ronny, Y. (2018). Plastic bag waste on hotmixture asphalt as modifier. *Key Engineering Materials*, *789*, 20–25. https://doi.org/10.4028/www.scientific.net/kem.789.20

Saberian, M., Li, J., Kilmartin-Lynch, S., & Boroujeni, M. (2021). Repurposing of COVID-19 single-use face masks FOR pavements base/subbase. *Science of The Total Environment*, *769*, 145527. https://doi.org/10.1016/j.scitotenv.2021.145527

Salim, K., Houssam, A., Belaid, A., & Brahim, H. (2019). Reinforcement of building plaster by waste plastic and glass. *Procedia Structural Integrity*, *17*, 170–176. https://doi.org/10.1016/j.prostr.2019.08.023

Shafiq, H., & Hamid, A. (2016). Plastic roads: A recent advancement in waste management. *International Journal of Engineering Research And*, *V5*(09). https://doi.org/10.17577/ijertv5is090574

Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. *Waste Management*, *28*(10), 1835–1852. https://doi.org/10.1016/j.wasman.2007.09.011

Singh, P., & Sharma, V. P. (2016). Integrated plastic Waste Management: Environmental and improved Health Approaches. *Procedia Environmental Sciences*, *35*, 692–700. https://doi.org/10.1016/j.proenv.2016.07.068

Wang, G., Li, J., Saberian, M., Rahat, M. H., Massarra, C., Buckhalter, C., Farrington, J., Collins, T., & Johnson, J. (2022). Use of COVID-19 single-use face masks to improve the rutting resistance of Asphalt Pavement. *Science of The Total Environment*, 154118. https://doi.org/10.1016/j.scitotenv.2022.154118

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Assessing the Structural properties of the Sandbag wall for alternative housing construction

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Abstracts: It is estimated that 1.6 billion people live in substandard housing, and more than 100 million people have no housing. In South Africa, about 12.7% of households lived in informal dwellings in 2019. This suggests that the existing conventional methods of construction and materials are incapable of solving the housing problems. The sandbag building material has been proposed as an affordable, sustainable, and recyclable alternative building material capable of accelerating housing provision in South Africa. However, previous studies show significant variations in filling materials used. There is also a lack of understanding of the sandbag wall based on the infill material. Therefore, this study examined the structural properties of the sandbag when filled with dune sand and crusher dust. Laboratory tests included compressive load on a three-bag stack, frictional shear strength between the interface of sandbags, and the structural stability of sandbag walls when subjected to vertical loading. A key finding was that although the displacement limits were reached before the bags failed, the bags of both fill materials could sustain compressive loads far beyond the ultimate design loads with large deflections in the bags. This suggests that the filled sandbags are not the determining factor in the design of sandbag structures.

Key Words: Building material, Compressive test, Crusher dust, Dune sand, Frictional shear, Housing, Sandbag wall, Stability

Introduction

According to United Nations (2019), about 1.6 billion people – more than 20% of the world's population lack adequate housing, and an estimated 100 million people are homeless. About 12.7% of households in South Africa lived in informal dwellings in 2019 (StatsSA, 2019). Slum-dwellers are described as a group of individuals living in a house that lacks structural quality or durability, among other conditions (United Nations, 2019). This suggests that the existing construction methods and materials are incapable of solving the problems of inadequate housing and a need to develop alternative building materials.

Sandbags (typically known as earthbags or soil bags) are polypropylene bags or polymer materials filled with granular materials. The sandbag has been proposed as an affordable, sustainable, recyclable, and alternative building material capable of providing access to housing (Ecobuilders, 2019), because of the high and increasing cost of modern materials.

Sandbags have been widely used since the 17th century for military defence and flood protection. They have also been used in soil retaining walls and embankments to increase the bearing capacity of footings (Cataldo-Born et al., 2016). The use of sandbags as a structural material for housing has gained interest over the years because of the advantages of being versatile and manageable and can be filled with any suitable granular material. However, no standardized guidelines exist on which materials to use or that specify the structural properties (Santos and Beirão 2016). Also, current project designs are based only on the experience of the builders or trial and error construction. Furthermore, studies reviewed (see Dunbar and Wipplinger, 2006 and Daigle, 2008) show significant variations in both materials and test methods used to evaluate the sandbags.

Therefore, this study investigates the behaviour of sandbags under uniaxial compression when filled with dune sand or crusher dust. The paper presents the review of recent research on the structural performance of sandbags based on the types of tests done and their purposes and the results obtained. After that, it presents the experimental test methods, including commentary on the preparation of sandbags and testing, the results obtained from the testing, and conclusions.

Literature review

The subject of sandbags has not been adequately explored in terms of research in the construction industry. Although there are no guidelines for sandbag construction nor testing, research has been conducted over the past decade to investigate the use of sandbags in housing and other construction purposes. For example, in Dunbar and Wipplinger (2006), no details on the material composition were provided, neither were the average bag deformation values provided, and the bag sizes were not specified. The study by Daigle (2008) used testing procedures in ASME 447 (now ASTM C1314), which was inadequate as it only relies on 3-unit stacks when testing compressive strength. This section briefly presents a review of previous studies and their findings related to the research objective. The performance of sandbags is governed by both the material properties and structural properties. Material properties relate to the fill, bags, and type of reinforcement used to construct the sandbag structures. In contrast, structural properties are associated with the behaviour of the sandbag structure when subjected to compression, flexural, shear, or impacts

Material properties of sandbags

The material properties of sandbags vary with changes in the composition of the fill. Previous studies such as Dunbar and Wipplinger (2006) did not investigate fill properties. The only tests carried out were the shear box tests done by Vadgama and Heath (2010) and Ralph (2009) on the builders' sand, of which it proved to have shear strength and friction angle of 76.60 kN/m2 and 26.5^0, respectively. Though soil particles are typically divided into clay, silt, and sand, sand fills are usually preferred due to their cohesion; hence, they have been the most used fill material. However, filling made up of clay particles is particularly important since clay acts as a binding agent. Because clay has a disadvantage of expanding when exposed to high moisture levels, an acceptable optimal range between 5% and 30% is typically used. Daigle (2008) confirmed this by having 37% and 27% of clay and silt in the topsoil and sandy soil fill, respectively. In addition, sandbag structures are more commonly constructed using a fill material with at least 10% fines to aid compaction. While only one study (Daigle, 2008) considered large-sized particles such as crushed granite, it was found that this material resulted in early cracking or tearing of the bags.

The widely used bags for the construction of sandbags are polypropylene bags. These bags come in different sizes, with 20 kg as the ideal bag weight to allow individual handling during construction. From the studies undertaken by Daigle (2008), Ralph (2009), and Vadgama and Heath (2010), the only parameter tested was the tensile strength of the bag material. The reasons for the variation in results between the different studies – about 19KN/m (Ralph, 2009; and Vadgama and Heath, 2010) and about 7KN/m (Daigle, 2008) is unknown but could be related to the bag thickness, size, and thread count, as well as differences in the test methods used to obtain results, all of which would need to be investigated further.

Compressive strength of sandbags

Compression tests on bag stacks, such as those carried out by Dunbar and Wipplinger (2006), Daigle (2008), Ralph (2009), and Vadgama and Heath (2010), allow the compressive strength of the sandbags to be determined. Dunbar and Wipplinger (2006) tested the soil dirt, sand, and rubble-filled sandbags in a 3-bag stack, while Daigle (2008) tested crushed granite, sandy soil, and topsoil-filled specimens on 3-bag, 6-bag, and 9-bag stacks, Ralph (2009), and Vadgama and Heath (2010) conducted tests on stack heights of 1, 3, 5 and 8, filled with builders' sand, in which the 8-bag stack fill material was also stabilized, and the three and 5-bag stacks were reinforced with 3-point barbwire.

The studies obtained different results for the 3-bag stacks, summarized in Table 1. The fine-soil fill type includes soil dirt and topsoil, medium-sand type includes sand, sandy soil, and builders' sand, and coarse-granular type includes rubble and crushed granite. It is to be noted that Ralph (2009) and Vadgama and Heath (2010) experienced initial bag tearing at 1.61 MPa; however, the ultimate strength of the stacks was considered invalid due to end-restraint effects. The soil dirt-filled bags in the study by Dunbar and Wipplinger (2006) were unable to be loaded to failure (i.e., bag tearing) due to the limited capacity of the testing equipment, meaning the bag strength at failure could not be obtained. This was also observed in the study by Daigle (2008), where the soil-filled (topsoil and sandy soil) bulged but did not fail by tearing. Failure by bag tearing was observed in both the studies by Dunbar and Wipplinger (2006) and Daigle (2008) of rubble and crushed granite-filled bags. This was attributed to the coarseness and angularity of the fill material that tore the bags at lower loads.

Authors	Ultimate strength of different fill material types (MPa)		
	Fine soil	Medium sand	Coarse granular
Dunbar and Wipplinger (2006)	2.14	0.30	0.40
Daigle (2008)	2.33 – 2.98	2.33 – 2.98	1.27 – 1.29
Ralph (2009) & Vadgama and Heath (2010)	-	1.61	-

Table 1: Compressive strength of 3-bag stacks, with different fill material types from various studies

The results by Daigle (2008) were also shown to be higher than those obtained by Dunbar and Wipplinger (2006), Ralph (2009), and Vadgama and Heath (2010). A possible reason for the higher strengths could be the different fill materials used, as they differed in composition. Also, for stacks greater than three bags, Daigle (2008) obtained lower loads than Ralph (2009) and Vadgama and Heath

(2010) with close-related stack heights. Like the three bag findings, the difference in results could be attributed to the different fill materials used, as Daigle (2008) used crushed granite fill and Ralph (2009) and Vadgama and Heath (2010) used builders' sand. Daigle (2008) also observed that the increase in stack height decreased the compressive strength of the sandbag stack, which was owed to the confinement caused by the loading plates, which was shown to be less impactful as the overall height of the stack increased. Ralph (2009) and Vadgama and Heath (2010) saw the same trend and considered the 8-bag stacks most relevant to minimize end-restraint effects caused by the loading plates.

Bag failure was observed as one of the failure mechanisms by different authors. Considering the 3-bag stacks, Dunbar and Wipplinger (2006) and Daigle (2008) expected the sandbags to fail by bag tearing, leading to a sudden drop in strength and compromising the integrity of the sandbag. Vadgama and Heath (2010) expected the sandbags to fail by loss in confinement or to tear the bag at the top and bottom faces due to the bags' tensile capacity being reached. In Dunbar and Wipplinger (2006)'s study, this was observed in the rubble-filled specimen, where tearing occurred in two parallel lines on the top and bottom faces of the middle bag. Daigle (2008)'s crushed granite-filled sandbags failed by bulging, tearing the bag material.

Furthermore, Vadgama and Heath (2010)'s sandbags failed by tearing longitudinally on the upper and lower faces of the sandbags. It is to be noted that Dunbar and Wipplinger's and, Vadgama and Heath's bags were tied the same way by twisting the open end and folding the tied end underneath the bag when stacking. Hence the same failure pattern was obtained. On the other hand, Daigle's bags were tied by folding the end and spiral screw with pins at the edges and centre of the fold.

Stability of sandbag walls under lateral load

The stability of sandbag walls was tested under lateral loads by Thiart (2008) and Croft and Heath (2011), who conducted flexural testing on constructed sandbag walls. Both walls were rendered with chicken wire mesh and cement plaster. Thiart's wall withstood a lateral load of 15.78 kN at failure, while Croft and Heath's wall withstood 7.32 kN. The difference between the two walls could be related to the wall size tested as Croft and Heath's wall was smaller (0.23 x 1.07 m) than Thiart's (4 x 2.5 m), which was also supported by return walls. The study by Croft and Heath (2011) also illustrated the benefit that plaster has on the wall's strength and stiffness, which were shown to be superior to those not plastered. However, the strength of the plaster might also have been contributed by the chicken wire mesh used, which would need to be explored further.

Locally in South Africa, the sandbag construction method was developed to solve the housing shortage experienced in the country due to its advantages of low energy consumption and affordability. However, there is limited research in South Africa on the structural performance of sandbags as a construction material. The studies done by Thiart (2008), Dlambulo (2009), and Herman (2009) were done to satisfy the Agrément standards in South Africa. The only similarity between these local studies and the studies reviewed is the performance of sandbag walls under lateral loads, which was done by Thiart (2008) and discussed earlier. As mentioned before, structural performances of sandbags walls were influenced by material and structural properties. However, in these studies, the material properties of the sandbags and fill material used were not reported on, which might impact the performance of the wall. Another aspect to consider is the chicken wire mesh and plaster, whose effects on the sandbag wall were not investigated.

There is still a need for more research as the current knowledge and understanding of sandbags as a construction material is still lacking. The tests carried out in the reviewed studies showed that sandbag walls do not behave the same as brick walls. Hence, guidelines for masonry wall construction do not apply to sandbag construction, and there is a need to develop standardized guidelines and test methods for sandbag wall construction.

Methods

This research conducted three tests: compressive loading (prism test), frictional shear strength at bags interface, and the stability of sandbag wall under vertical loading. The compressive load test looked further to understand the behaviour of sandbags under vertical load and attempt to quantify the compressive strength of sandbags, with variations in material content (fill). The sandbag shear strength test aimed to determine the shear strength between two sandbags, while the stability test was intended to assess the wall's stability when subjected to vertical loads. Dune sand and crusher dust were used as fill material for the experiment, as no preference was given to the material to be used. However, only the compressive strength test used both fill materials. Only dune sand was used for the wall stability and shear strength test. The dune sand particles are between 0.5 and 1 mm in size, while the crusher dust, on the other hand, shows that more than 55% of its particles are larger than 1mm. Figure 1 shows images of the bag empty and filled. The bags also have a foldable collar of 100mm used to retain material once filled.

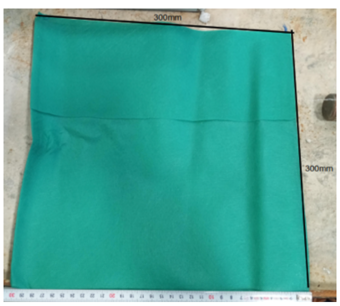

Figure 1. The polypropylene sandbags; empty (left) and filled (right)

The sandbags used measured 300 x 300 mm in size. These bags were made of double-stitched non-woven polypropylene fabric from recycled plastic. When filled, these bags measure approximately 290 x 290 x 60 - 75 mm.

Design loads

The design loads were used to compare what the bags would be expected to withstand in service and inform the vertical loads applied in the frictional shear strength and wall stability tests. In design, two limit states are considered. The first is the serviceability limit state (SLS), which looks to restrict deformations, displacements, and local damage of the structure during service. At the same time, the second is the ultimate limit state (ULS), which focuses on safety and corresponds to the maximum load-carrying capacity a structure is expected to take. The service and ultimate loads computed were based on a 75 m^2 single-storey house and determined as per SANS 10160-2, the South African National Standard used to determine the load imposed on a structure. For simplicity, the following assumptions were made in determining the weight and imposed loads: the roof was a free-draining 120 mm thick reinforced concrete slab, and only the longitudinal walls were load-bearing.

A breakdown of the serviceability and ultimate limit states are presented in Table 2, which are given as a line load and load per single sandbag. A bag length of 300 mm was assumed in determining the load on a single sandbag. It should be noted that the assumptions listed above were only made to get an indication of the loading magnitudes that can be expected in the field. As such, the design loads presented here only serve as an approximation and may not accurately reflect those obtained from a detailed structural design.

Load limit state	Line load (kN/m)	Load per single bag (kN)
Serviceability Limit State	20.6	6
Ultimate Limit State	26.9	8

Table 2: Serviceability and ultimate limit states, as per SAMS 10160-2

Bag filling preparation

The moisten dune sand was placed in the sandbags using a cylindrical PVC container for the wall construction, as illustrated in Figure 2. Before filling, the fill materials were brought to their optimum moisture content to aid in compaction. This moisture content was determined for each material during testing. Dune sand and crusher dust had a water content of ±10% and ±3%, respectively. The bags were filled to mass between 7 and 8 kg for both materials. Once filled, the bags were closed by flipping the foldable collar on the bag over the opposite side and flattened using a wooden paddle.


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Figure 2. Bag filling preparation; moisten the sand; fill the PVC cylindrical container, and fill the bag

Compressive loading (prism test)

Two different materials were considered for this test: dune sand and crusher dust. The test involved stacking three bags filled with the same material on top of one another and applying a vertical compressive load. The test was carried out using an Amsler compression testing machine. The bags were stacked, with the folded collar facing the same direction. A steel block of 2.5 kg was then used to flatten and compact the bags, and the width and height of each bag were recorded. A constant displacement of 12 ±2 mm/min was applied when loading the bag stack, and compressive loads were measured every 30 ±2 seconds. The load was applied until the bags could not take any more load or when the piston head had reached its displacement limit. The failure criterion was assumed to be the bag tearing. After testing, the load was removed, the bags were inspected for damage and its dimensions were recorded.
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Stability of sandbag wall under vertical loading

Two 12 bag high wall variations were considered in the test for the stability of a sandbag wall when vertically loaded. The first sandbag wall was encased in a frame that measured 1000 mm high and 750 mm long and stacked in a stack bond arrangement, where bags were laid directly on top of one another. The second wall type was a standalone sandbag wall measuring approximately 930 mm high and 675 mm long and stacked in a masonry bond arrangement. The sandbags filled with dune sand were stacked in the frame to form the sandbag wall. This frame was constructed using braced timber battens held in place using 4 x 75 mm chipboard smooth shank screws. The braced timber battens are typically referred to in the South African sandbag building industry as “EcoBeams". They comprise two 38 x 38mm timber battens braced together with a steel lattice, at 150 mm apart. Four EcoBeams were assembled to form the frame for the sandbags.

The wall was constructed below the loading plate, and a plumb bob was used to centralize the wall’s vertical alignment with the actuator. A wooden paddle was utilized to flatten and shape the individual bags during wall construction, a common approach used in sandbag wall construction in South Africa. To ensure the standalone wall remained straight during its construction, a frame was used in encasing the sandbag wall. Once constructed, a steel spreader beam was placed on the wall and vertically loaded. The steel spreader beam measured 350 (H) x 200 (W) x 750 (L) mm and weighed 87 kg. The vertical loads were applied incrementally using a 250 kN loading capacity actuator. The framed wall was first subjected to 20 kN, followed by increments of 5 kN, while the standalone wall was subjected to 5 kN first, followed by increments of 5 kN. The initial load of 20 kN on the framed wall was based on the ultimate design load discussed earlier. The initial load of 5 kN was selected for the standalone wall, as it was anticipated that the wall would not be capable of withstanding this magnitude of loading. A load rate of 0.2 kN/s was applied between each load increment where the vertical load was kept constant, and the wall's stability was assessed visually.

Result and Discussion

Effect of different fill material

The study found a significant difference in the structural performance of sandbags depending on the fill material. The sandbags filled with dune sand reached a peak load of 42 kN (0.5 MPa), while the crusher dust bags reached 65 kN (0.77 MPa). Similar findings were reported in Dunbar, and Wipplinger (2006), who found the sand-filled bags have lower compressive strengths of 0.30 MPa than rubble and soil-filled bags with 0.40 MPa and 2.14 MPa, respectively. Daigle (2008), however, found the opposite, with the granite bags only able to bear loads between 1.27 and 1.92 MPa before tearing, while the sandy and topsoil filled bags were able to withstand loads of 2.33 and 2.98 MPa, without any tearing.

The higher loads sustained by the crusher dust were due to differences in particle shape and size distribution, with a higher proportion of fine and coarse particles than the dune sand. This, combined with the sharpness and angularity of the courser particles, could have provided enough binder to hold the particles together within the bag, thus improving the bag's resistance to loading. Despite this benefit, the angularity and sharpness of the crusher dust particles also resulted in the bags fraying, unlike the dune sand-filled bags that showed no damage. Such cases were also reported in Daigle (2008) and Dunbar and Wipplinger (2006), who attributed the tearing of the dirt and rubble-filled bags to the coarseness and angularity of the material.

Compressive loading

The results obtained from the testing showed both the dune sand and crusher dust bags to remain intact throughout testing and that the displacement limits of the piston head had been reached. Similar findings were also reported in Dunbar and Wipplinger (2006) and Daigle (2008) for the bags filled with sand, both of whom commented that the compressive strength of the bag is not the determining factor when working with sandbag construction. The compressive loads resisted by the bags were well above those required by the ultimate and serviceable design loads. However, the large deflections observed in the bags are of significant concern from a serviceability point of view. If the ultimate limit state of 8 kN is considered, the dune sand and crusher dust had compressed by approximately 8 and 14 mm, respectively. Similarly, in the case of the standalone wall, displacements were observed immediately after the loads were applied, which continued until failure. It could be said then that while the compressive strength of the bags is not the determining factor in design structures made from sandbags, the serviceability limit state is, which is also what Ralph (2009) and Vadgama and Heath (2010) concluded from their study.

Wall stability under vertical load

The framed and standalone sandbag walls tested withstood a maximum load of 31 kN (41.3 kN/m) and 15 kN (20 kN/m), respectively. Although the standalone sandbag wall failed below the ultimate design load of 20 kN, the framed wall surpassed this value by 55% (26.9 kN). Furthermore, signs of damage in the framed wall were only detected once the applied load went past 25 kN (125% of the ultimate design load). A concern, though, is the sudden torsional failure the framed wall experienced at 31 kN, as such sudden failure types (such as shear failure) are avoided when it comes to structural design.

Displacements in the thickness of the bag were seen for the standalone sandbag wall throughout testing, which failed below the serviceability limit state of 15.5 kN. Approximately 15% of the wall's height had compressed before being deemed to have failed. Gaps between adjacent sandbags were also observed, and these gaps were highest in the upper middle section of the wall, with the bottom and top layers showing no gaps. Similar to the end restraint effects observed for the compressive loading test, this behaviour can be attributed to the limited frictional resistance between the bags, enabling the bags to slide horizontally and form gaps. The results suggest that the EcoBeams play a significant role in the wall's stability and load-bearing resistance. The EcoBeams provide most of the wall's load-bearing resistance and confine the sandbags to the frame, limiting horizontal displacements between the bags. As for the sandbags, their structural contribution is only complementary when used with the EcoBeams.

Conclusion

This study investigates the behaviour of sandbags under uniaxial compression when filled with dune sand or crusher dust. Emphasis was placed on the material and structural properties of the sandbag walls. Three experimental tests were conducted: the compressive testing of a 3-bag stack, frictional strength testing between bags, and wall stability when subject to vertical loading. Dune sand and crusher dust were the fill materials for the compressive load test, while only dune sand was considered for the frictional shear strength and wall stability tests. It emerged that the crusher dust exhibited a higher load-bearing resistance than the dune sand due to its particle shape and size, which enable better interlocking between particles. It was found that the bags of both fill materials could sustain compressive loads far beyond the ultimate design loads. However, the large deflections observed in the bags are of significant concern from a serviceability point of view.

End restraint effects were also seen during this test, suggesting that this test does not yield representative results in the field and that a new test method be developed to evaluate bag stacks. The results of the wall stability under vertical loading suggest that the frame (EcoBeam) plays a significant role in the stability and load-bearing resistance of the wall and that the contribution of the sandbags was only complementary. Significant improvement on the shear friction between the sandbags is required if the frame is not considered, as the frame was shown to confine the sandbags and prevent lateral displacements. Based on these findings, the study concludes that the compressive strength of sandbags is not the determining factor in the design of sandbag structures. Instead, more focus should lie on the serviceability aspects, which include the sandbags' deformations and displacements and the sandbag structure's stability. Further studies are recommended into the influence of the render on the stability of sandbag walls.

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References

1. Cataldo-Born, M., Araya-Letelier, G. & Pabón, C. 2016. Obstacles and motivations for earthbag social housing in Chile: energy, environment, economic and codes implications. *Revista de la Construcción. Journal of Construction,* 15(3): 17-26.
2. Croft, C. & Heath, A. (2011). Structural resistance of earthbag housing subject to horizontal loading. University of *Bath MEng dissertation*. Available: http://www.earthbagbuilding.com/pdf/croft.pdf.
3. Daigle, B. C. (2008). Earthbag Housing: Structural Behaviour and Applicability in Developing Countries.
4. Dlambulo, K. (2009). Fitting attachments and door slamming tests on non-conventional wall
5. systems. The Cape Peninsula University of Technology.
6. Dunbar, R. & Wipplinger, L. (2006). Prism Testing of Polypropylene Earthbags. *Unpublished report, West Point Military Academy. http://www. Earthbag building. com/Testing/prismtest. htm.*
7. Ecobuilders (2019) Sandbag Building Disclosure Document. Green Perspectives CC, Durban, South Africa.
8. Herman, A. (2009). Hardbody and soft body impact test conducted on a sandbag wall. Cape
9. Peninsula University of Technology.
10. Santos, D. M. & Beirão, J. N. D. C. 2016. Data collection and constructive classification of superadobe buildings. *Ciência e Sustentabilidade*. 2(2): 208-226.
11. Statistics South Africa's Household Survey. (2019). Key findings: P0318 – General Household Survey (GHS) Government Publishers, Pretoria. https://bit.ly/31HAU2F
12. Thiart, R.A. (2008). Stability of the Sandbag Wall System to Horizontal Load Specified by Agrement. The Cape Peninsula University of Technology.
13. United Nations (2019) Inclusive United Cities for All: Affordable Housing and Homelessness. Department of Economic and Social Affairs.

14. Vadgama, N. & Heath, A. (2010). Material and structural analysis of earthbag housing. *University of Bath, Somerset, United Kingdom, Department of Architecture and Civil Engineering*.

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The Early History of Undergraduate Construction Education in the United States

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The history of undergraduate construction education in the United States has garnered faint attention by academics and little is known about construction programs in existence before the formation of the Associated Schools of Construction (ASC) in 1965. This study uses contemporary historical documents to identify construction programs that existed before the second world war, and programs created during or shortly after the war. A total of nine programs with courses related to the "building industry" are identified as being in operation prior to 1941 and 23 programs are identified as existing by 1946, and 36 programs by 1953. The research also identifies, and analyzes a study conducted by Arthur A. Hood of the Johns-Manville Company who has a major influence on establishing programs during and after the war. Over half of the institutions represented at the inception meeting of the ASC were identified as being established as a result of this study and the actions of Arthur A. Hood. There is a strong case to be made for Arthur A. Hood being the founding father of construction education in the United States.

Key Words: Construction Education, History, Curriculum, Industry, Associated Schools of Construction

Introduction

The history of the conception and inception of the Associated Schools of Construction (ASC) in 1965 is well documented on the association's website. The fourteen representatives from nine universities that met at the University of Florida, on March 19 and 20, 1965 included representatives from Arizona State University, Auburn University, Clemson University, Colorado State University, University of Florida, Michigan State University, University of Minnesota, University of Nebraska and Virginia Polytechnic Institute. The discussion at that meeting suggests that the discipline of building construction had matured to a point where 4-year degree programs were justifiable and that a formal association was both desirable and necessary (The Associated Schools of Construction, 2019). The history of construction education in the United States has been paid little attention since the formation of the ASC in 1965. The author was unable to find any definitive study on the subject in the publications of the ASC nor in any other database. The subject has been partially addressed in previous research. Robson (1995) claimed the first identifiable construction program started at the University of Florida in 1936. In studying the evolution of construction education at two institutions, the authors identified the use of the college catalog as a tool for gathering information about the history of a program. The research identified the programs at Texas A&M University and Colorado State University as having their programmatic starts as a Bachelor of Science in Architectural Construction in 1948 at the Agricultural and Mechanical College of Texas and as the Light Construction and Management program in 1946 at the Colorado Agricultural and Mechanical College. Significantly the program at Colorado State was identified has having been developed "in response to a study conducted by Johns-Manville citing an industry need for more and better trained manpower" (Burt et. al, 2008). This claim suggests a significant industry involvement in establishment of at least one early program. There is a need therefore, to document the early history of construction education in the United States to better understand industry's involvement, as a means to guiding us in developing curriculum, accreditation etc. The previous research identified above shows programs were in existence prior to the second world war and some programs were established following the end of that conflict. Using contemporary historical documents this paper seeks to identify those construction programs existing before the second world war and programs created during or shortly after the war. The research also seeks to identify, and analyze the study conducted by Johns-Manville and determine its impact on the history of construction education in the United States.

Method

Identifying construction programs existing before the second world war or created during or shortly after the war

In order to identify the construction programs existing before the second world war or created shortly afterwards, the author analyzed college guides from the early 1950's. *Lovejoy's College Guide* is a reference guide to the colleges and universities of the United States. The 1953/54 edition references 2,049 colleges and universities. Individual degree programs are listed under various career tracks. The only career track found that is applicable to construction is called "Building Industry". This track identifies 36 institutions that offer 4-year degrees in this career track (Lovejoy, 1953).

The process began by identifying names of the 36 programs from the 1953/54 edition of the *Lovejoy College Guide*. Once the names of these programs were identified, the next step was to find, where possible, the date when the program was first offered. Analysis of each individual institutions annual college catalogs or bulletins were used to identify both the name and possible starting date of the program.

Identifying and analyzing the study conducted by Johns-Manville

Identifying the study by Johns-Manville mentioned in *Celebrating the Past, Building the Future," A Historical Perspective of Construction Education at Colorado State University from 1946 to 2006* was much more complex. Initial enquiries to the Corporate Records Management Specialist at the Johns Manville failed to identify this document. Searches of catalogs of schools identified in Lovejoy's guide also made no mention to the study. Eventually an article entitled *To Beat the Housing Crisis* in a November 1948 edition of the Wisconsin alumnus magazine provided the first connection between the Johns Manville company and a new construction curriculum. The article is about the first cohort of graduates from the University of Wisconsin's Light Building Industry program. The article states that "the curriculum in Light Building Industry at Wisconsin is a direct outgrowth of the efforts of Arthur A. Hood, formerly of the Johns Manville company, now editor of the *American Lumberman*. Mr. Hood visited many universities the country over to urge the administrative officers to install education facilities for the great industry which he represented" (Wisconsin Alumni Association, 1948, p.15).

With a name to associate to the study and Mr. Hood's association with the American Lumberman, searches using the *WorldCat* database and trade magazine indexes eventually identified the study mentioned in the Colorado State history. The study written by Arthur A. Hood and published by Johns-Manville is titled *New Career Opportunities in the Building Industry for High School Graduates Planning to enter College* and was published in 1942. The study makes a compelling case for the *Light Construction Industry* playing a major role in the post-war economy. It identifies the educational problem of the absence of a training program for the building industry and recommends curriculum be developed at colleges and universities to solve the problem. The study also identifies 11 universities having installed courses in "light construction engineering and marketing" (Hood, 1942).

Additional contemporary documents were identified and analyzed to determine the impact this study had on construction education. This involved analysis of university catalogs, journal articles and trade publications.

Results

Construction Programs operating prior to Second World War

From the 36 programs identified in the 1953/54 edition of *Lovejoy's College Guide*, it has been possible to identify at least nine programs in operation prior to 1941. Table 1 shows the nine programs together with the year they were established and the name of the program. The program names and the year of creation were identified mainly by analyzing university course catalogs and bulletins. The author identified the program within the catalog having the greatest alignment with the building industry.

Table 1
Construction programs in operation prior to 1941

Institution Name	Year	Program Name
University of Denver	1938	Building Industry and Real Estate Program
University of Florida	1936	Building Construction
Iowa State College	<1938?	Architectural Engineering
Kansas State College	1925	Architectural Engineering
University of Kansas	1913	Architectural Engineering
University of Kentucky	1934	Civil Engineering with Special Emphasis on Architectural Engineering
Massachusetts Inst. of Technology	1927	Building Construction
State Uni. of N.Y. Agri. & Tech. Inst. (Delhi)	1937	Building Construction
Penn State College	1922	Architectural Engineering

It is clear from the above table that programs teaching construction curriculum were offered under many different titles. The earliest program called Building Construction is at Massachusetts Institute of Technology (1927). This four-year course is listed in the catalog as preparing students to enter "the business of building". The curriculum is based on the Civil Engineering course with classes also taken in Architecture. The focused building construction classes cover building finance and management; cost accounting; professional and industrial relations; analysis, details and assembly of the materials of building; and construction methods and procedure.

The program at Kansas State Agricultural College (1926) in Architectural Engineering is located in the Division of Engineering. The curriculum is listed as being "for the student who wishes to specialize in the constructional side of the building profession". Some of the fields identified that the graduate could go into include "superintending of building construction, general contracting, and the estimating of costs for construction projects".

Construction Programs started during or shortly after the Second World War

From the 36 programs identified in the 1953/54 edition of *Lovejoy's College Guide*, it has been possible to identify at least 14 programs that started during or shortly after the end of the second world war. Table 2 shows the 14 programs together with the year they were established and the name of the program.

Table 2
Construction programs established after 1941

Institution Name	Year	Program Name
Alabama Poly. Inst.	1945	Building Construction
Colorado A & M College	1946	Light Construction and Marketing
Georgia Inst. Of Technology	1950	Building Construction
University of Illinois	1950	Architectural Engineering
University of Maine	1946	Civil Engineering: Light Building Construction Option
Michigan State College	1948	Light Construction and Lumber Marketing
University of Minnesota	1951	Forestry: Building Products Merchandising and Light-Construction
University of New Hampshire	1943	Building Construction and Marketing
State University of. L.I. Agri. & Tech. Inst. (Farmingdale)	<1947?	Building Construction
Syracuse	1942	Retail Merchandising & Light Construction
North Carolina State College	1949	Construction
Oregon State College	1953	Construction & Design
Texas A & M	1948	Bachelor of Science in Architectural Construction
University of Wisconsin	1945	Light Building Industry

Interestingly the majority of these programs include the word construction in the program name, with only one program using Architectural Engineering. The name "Light Construction", not seen in the pre-war programs is a common theme among the post war programs. The program at Alabama Polytechnic Institute (now Auburn University) is a good example of a program that was created during this period. A survey conducted by the American Society for Engineering Education (1941) identified courses being offered in both architecture and engineering. A total of three construction classes were offered in the School of Architecture and Applied Arts, the earliest of which was first offered in 1929. The annual bulletin for 1940/41 lists a "Construction Option" in the School of Architecture and Applied Arts. This 5-year program "is for the student who plans to engage particularly in the structural field of architectural practice, or who wishes to prepare himself for the business of contracting, the manufacture or sale of building materials, or other branches of construction" (Alabama Polytechnic Institute, 1941). By 1942 there was also a "Light Construction Option" being offered in the Division of Engineering. The curriculum for this option is listed as being "especially designed to meet the urgent need for trained engineers in the building trades industries" (Alabama Polytechnic Institute, 1942). By 1945 the two construction related options have been consolidated into a four-year degree in "Building Construction" in the School of Architecture and the Arts (Alabama Polytechnic Institute, 1945).

The Impact of the Arthur A. Hood and Johns-Manville Study

Prior to the publication of *New Career Opportunities in the Building Industry for High School Graduates Planning to enter College* published in 1942, Arthur A. Hood made a significant impact on both the lumber and construction industries. He was born in Sioux City, Iowa in 1891, and entered the lumber industry after graduating high school working in lumber yards. By 1914 he was the sales manager of James Lumber co. in St. Paul Minnesota (Building Materials Merchandiser, 1965). In 1930, he was serving as the President of the Associated Leaders of Lumber and Fuel Dealers of America. In this capacity he proposed establishing a mortgage company to support lumber dealers to compete with the mail-order home building industry (The Southern lumberman, 1930). By 1931, this proposal had resulted in the formation of the National Homes Finance Company with Hood as the temporary secretary (The Southern lumberman, 1931). Mr. Hood was the vice-president and general manager of this organization in 1933 (The Southern lumberman, 1933). By 1937 he was working for the Johns-Manville Sales Corporation of New York as Manager of the Housing Guild Division (Hood, 1937). The National Housing Guild was up and running by 1940 under the sponsorship of the Johns-Manville Company. Arthur Hood is credited as proposing the plan to make "the lumber and building materials dealer as the focal point for the building industry in every community in the country, coordinating the activities of all the various factors who contribute to furnish a complete home". He also proposed training programs for dealers to familiarize them with modern merchandising methods, correct estimating procedure, and other tools (Brown, 1940, p. 43). As part of establishment of the National Housing Guild, Hood (1940 p. 47) identified education as a key issue " to enable the dealer to train his executives, salesmen, employees, contractors, and other building industry factors on the parts they individually play in making this machinery work for the benefit of all members of the industry and the consumer."

The Johns-Manville company published *New career opportunities in the building industry for high school graduates planning to enter college* in 1942. However, it would appear that Hood had identified the need to include colleges and universities in his planning sometime beforehand as he had visited institutions prior to 1942 (Wisconsin Alumni Association, 1948). The study identifies the absence of a training program adequate for the needs of the industry. The heterogeneousness of the industry and the complexity of the process are cited as some of the major factors for this absence. The "Light Construction Industry" defined as including new homes, structural improvements and farm buildings is identified as a significant part of the post-war economy. In order to educate the men and women to produce these new homes, the study identifies 50 subjects as the knowledge needed for these individuals. A complete listing of these subjects is beyond the scope of this paper. The list however does include many of the topics required under the American Council for Construction Accreditation standards (2006) prior to its revisions in 2015. These are set out in table 3 below.

Table 3
Examples of subjects identified in "New career opportunities in the building industry for high school graduates planning to enter college"

Construction Supervision & Danger Points	Material Uses, Application, Fabrication & Assembly
Grammar and Composition	

Materials Identification & Grading	Drawing & Sketching
Money, Finance & Banking	Blueprint Reading & Quantity Surveys
Philosophy & Ethics	Specification Writing
Zoning, Codes & City Planning	Estimating
Introduction to the Sciences	Logic & Creative Thinking
Industrial Relations	Business Mathematics
Accounting, Statistics & Budgeting Practices	Public Speaking
Economic Principles	Contracts, Documents, Reports and Business Law
Business Organization & Management	Retailing and Marketing Principles

The report claims the study of these subject areas can only be found at a college or university. Most of the subjects are identified as already being taught at many universities across many different courses such as civil engineering, architecture, forestry, liberal arts, sciences and business administration. The challenge was to amalgamate the subjects into a complete course and assign the administration to a suitable academic home. By 1942, 11 universities are identified as having risen to this challenge and are offering courses in "light construction engineering and marketing". These are: Alabama Polytechnic Institute, University of Denver, Iowa State College, Massachusetts Institute of Technology, Michigan State College, University of Minnesota, University of New Hampshire, New York State College of Forestry at Syracuse, North Carolina State College, University of Wisconsin, New York State Agricultural and Technical College (Hood, 1942).

Following the publication of *New career opportunities in the building industry for high school graduates planning to enter college*, there appears to be additional institutions considering adding this curriculum (Kowalsky, 1942). Writing in *The Southern Lumberman*, Hood (1942) announces that there will shortly be similar courses at Iowa State College and the University of Wisconsin. As the second world war is drawing to a close, Hood is able to report that "Fifteen universities…have been persuaded to add new courses, which give the degree of bachelor of science in light construction engineering and marketing" (The Southern Lumberman. 1944). By 1946 there are 23 universities offering four-year courses in light construction leading to a degree and a further three courses being planned. These 23 institutions are set out in Table 4 (The American Lumberman, 1946).

Table 4.
Institutions offering four-year courses in light building leading to a degree in 1946

Institution	Location of Course
Massachusetts Institute of Technology,	Department of Building Engineering and Construction,
Rensselaer Polytechnic Institute	Department of Architecture,
Alabama Polytechnic Institute	School of Architecture and the Arts
North Carolina State College	Department of Civil Engineering
University of Minnesota	Department of Forestry,
Michigan State College	Department of Forestry,
University of Wisconsin	School of Commerce,
Oregon State College	School of Forestry
Georgia School of Technology	Department of Architecture
Massachusetts State College	Division of Engineering,
University of Maine	Department of Civil Engineering,
University of Kansas	Department of Architecture,
Colorado A & M College	Division of Science and Arts,
Syracuse University,	New York State College of Forestry
University of Denver	School of Commerce, Accounts and Finance,
University of Idaho	Department of Agricultural Engineering,

University of New Hampshire	Department of Architecture
Kansas State College	Department of Architecture,
Iowa State College	Division of Engineering
Oklahoma A & M College	School of Architecture
University of Kentucky	College of Engineering
Louisiana State University,	College of Commerce
Virginia Polytechnic Institute	Department of Architectural Engineering

Even though the program at MIT appears in table 1 as being a program in existence before Hood's initiative, up until 1942 there was not a "Light Construction" option being offered as part of the Building Engineering and Construction degree (Massachusetts Institute of Technology, 1941). By the following year, there are options being offered in both "Heavy" and "Light" construction (Massachusetts Institute of Technology, 1942). In 1946 Hood became the Vice President and Editor of the *American Lumberman*. In his introduction to readers he is described as "the greatest individual champion of the Nation's lumber and building material retailers" and his contributions to educational progress are also noted. His role in leading the campaign to establish courses in Light Construction Engineering and Marketing at universities and colleges is acknowledged and this educational progress is seen as the start of "an era of better merchandising and better building." (The American Lumberman, 1946). By the time of his death on December 8th, 1965 his obituary in the Building Materials Merchandiser (1966) that was spread over six pages claims he helped organize courses in light construction and marketing at over 30 institutions.

Discussion

This study identifies a number of "building Industry" courses operating in the United States prior to the start of the second world war. This number grew considerably after the end of the war and there is a strong case to be made that the "light construction" industry under the leadership of Arthur A. Hood played a significant role in this. It is evident from some of the names of programs listed in table 2 that there is a strong correlation with Hood's proposed name of "light construction engineering and marketing". A study of the course curriculum with the 50 subjects set out in *New career opportunities in the building industry for high school graduates planning to enter college* may well go some way in confirming Hood's influence, but this is beyond the scope of this paper (Hood, 1942).

The limited amount of scholarship conducted previously on this subject suggests this is an area of research requiring greater investigation. The existence of programs before the war in Architectural Engineering at colleges now having accredited construction programs such as Kansas State and Iowa State suggests they may have evolved from these programs, but only a thorough analysis of the institutions course catalogs or bulletins will answer this. The existence of a Building Construction program at MIT is also of interest. A construction program is currently not offered in either of the Schools of Architecture and Planning or Engineering at this world-renowned institution. What is the story behind this program's establishment, evolution and ultimate decline?

This study makes a significant contribution to the body of knowledge by setting out the history of undergraduate construction education in the United States prior to 1965. There is clear evidence of the construction industry's involvement in the establishment of programs during and after the second world war. This strong industry involvement in the creation of accreditation standards and practices is continued through the American Council for Construction Education (2019) which currently accredits 72 undergraduate construction programs and requires programs to establish an effective relationship with industry. By 1965, when the ASC was formed. It is interesting to note that of the nine schools represented at the inception meeting, five of them, Auburn University, Colorado State

University, Michigan State University, University of Minnesota and Virginia Polytechnic Institute appear to have acquired their start due to Hood's initiative. We correctly acknowledge the 14 attendees at that initial ASC meeting in 1965 as the founding fathers of ASC, but there is a strong case for Arthur A. Hood as the founding father of construction education in the United States.

References

Alabama Polytechnic Institute (1941). Alabama Polytechnic Institute Bulletin 1940-1941 available at http://content.lib.auburn.edu/cdm/compoundobject/collection/catalogs/id/14264/rec/3

Alabama Polytechnic Institute (1942). Alabama Polytechnic Institute Bulletin 1942-1943 available at http://content.lib.auburn.edu/cdm/compoundobject/collection/catalogs/id/14850/rec/7

Alabama Polytechnic Institute (1945). Alabama Polytechnic Institute Bulletin 1945-1946 available at http://content.lib.auburn.edu/cdm/compoundobject/collection/catalogs/id/15398/rec/10

American Council for Construction Education (2006), *Document 103: Standards and criteria for accreditation of post-secondary construction education degree programs*, p. 27

American Council for Construction Education (2019), *Document 103B: Standards and criteria for accreditation of post-secondary construction education degree programs*, p. 22

The American Lumberman. (1946). *University Preparation for Light Construction-Use* Chicago: American Lumberman.

The American Lumberman. (1946). *Arthur A. Hood Joins American Lumberman as Vice President and Editor* Chicago: American Lumberman.

American Society for Engineering Education. (1941). *Content of courses pertaining to construction: A survey report prepared by a subcommittee of Committee VI-Construction education, Civil engineering division, S.P.E.E. June 1941*. Pittsburgh

The Associated Schools of Construction. (2019). Inception. Retrieved from https://www.ascweb.org/about/inception/

Brown, L. H. (1940, April 1). The Lumber Dealer of the Future. *The Southern Lumberman* pp 43-44.

Building Materials Merchandiser. (1965, January). *Arthur A. Hood The Dean of Building Materials Merchandisers 1891 -1965* Chicago: Building Materials Merchandiser.

Burt, R., Hatipkarasulu, Y & Nobe, M.C. (2008). Evolution of Construction Education in the United States:Two Case Studies. 44th ASC Annual International Conference Proceedings. Auburn, AL: Associated Schools of Construction.

Colorado State University (2006). *"Celebrating the Past, Building the Future," A Historical Perspective of Construction Education at Colorado State University from 1946 to 2006*. Retrieved from https://issuu.com/csuconstructionmanagement/docs/cm_historybook?e=26579136/70647618

Hood, A. A. (1937, October 1). Come, Let Us Reason Together. *The Southern Lumberman* pp 51-55.

Hood, A. A., & Johns-Manville Sales Corporation. (1940). A working formula for integrating the building industry: [being an introduction to the housing guild]. New York: Johns-Manville Sales Corp.

Hood, A. A. (1942). New career opportunities in the building industry for high school graduates planning to enter college. New York: Johns-Manville.

Hood, A. A. (1942, September 1). New Career Opportunities in the Building Industry for High School Graduates Planning to Enter College. *The Southern Lumberman* pp 49-52.

Kansas State Agricultural College (1926). Kansas State Agricultural College Bulletin, Catalogue Sixty Third session, 1925-1926. Available at https://archive.org/details/catalogue63192526kans

Kowalsky, J. (1942). New Frontiers in the Building Industry. *Journal of Counseling & Development, 21*(4), 296-298.

Lovejoy, C. E. (1953). *Lovejoy's college guide*. New York: Simon and Schuster.

Massachusetts Institute of Technology (1927). Bulletin, Massachusetts Institute of Technology, Catalogue for 1927-28. Vol. 62 No. 6

Massachusetts Institute of Technology (1941). Bulletin, Massachusetts Institute of Technology, Catalogue for 1941-42. Vol. 76 No. 4

Massachusetts Institute of Technology (1942). Bulletin, Massachusetts Institute of Technology, Catalogue for 1942-43. Vol. 77 No. 4

Robson, K.F. & Bashford, H. H. (1995). The Emerging Construction Discipline. 31st ASC Annual International Conference Proceedings (pp. 171-180). Tempe, AZ: Associated Schools of Construction.

The Southern Lumberman. (1930, December 15). *Launch Financial Concern to Assist Home Builders*. Montgomery, AL: Hatton-Brown.

The Southern Lumberman. (1931, July 1). *$10,000,000 Corporation Formed to Finance Home Building*. Montgomery, AL: Hatton-Brown.

The Southern Lumberman. (1933, March 15). *Mississippi Dealers Hold Annual Meeting* Montgomery, AL: Hatton-Brown.

The Southern Lumberman. (1944, June 1). *Predicts Packaged Post- War Homes; Arthur A. Hood Advances Distribution Engineering Plan Based on End-Use* Montgomery, AL: Hatton-Brown.

Wisconsin Alumni Association. (1948). Wisconsin alumni magazine. Vol. 50 No. 2. Retrieved from http://digicoll.library.wisc.edu/cgi-bin/UW/UW-idx?type=article&did=UW.v50i2.RRatc&id=UW.v50i2&isize=M

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COVID-19 and the 2021 ASC International Conference: Opportunities and Challenges Ahead

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The COVID-19 pandemic caused massive disruption across the world, affecting all organizations. The Associated Schools of Construction (ASC) shifted its 2020 International Conference to a virtual, asynchronous event. In 2021, a virtual, synchronous ASC International Conference was sponsored by California State University-Chico and offered in April 2021. This study collected participant feedback on the 2021 virtual conference event to gage participation in a virtual event, determine perceptions of the online conference (as compared to an in-person event), and determine if there were aspects of the conference that could effectively be offered as a virtual or hybrid option in future ASC conferences. The results indicated that items such as the paper presentations could be effectively offered as virtual events in future conferences, and if a hybrid or virtual option was available, a significant portion of ASC members indicated that this would make them more inclined to participate in future conferences. Conversely, most respondents indicated that the conference was best held as an in-person event. Results suggests that although the in-person conference should continue, an opportunity may exist for ASC to broaden its engagement with construction education and further its mission to advance construction education.

Key Words: Schools of Construction, Construction Education, Construction Management, Conference, COVID-19

Introduction

Prior to 2020, the Associated Schools of Construction (ASC) held 55 conferences in-person (*ASC Website*, 2013). The 2020 ASC conference was held asynchronously focusing on paper presentations with a small welcome from the ASC President. The 2020 shift to an online event was made less than 45 days prior to the scheduled in-person conference due to the rapid development of COVID-19 worldwide and the associated threat to public health and safety. Despite the late change, faculty were able to publish and present their papers as originally planned. Scholars, students, and industry partners were able to watch paper presentations remotely at any time they elected to do so. In 2021, additional time allowed for a conference that delivered material synchronously attempting to engage membership in dialogue over a one-week period in April 2021.

Looking forward to 2022 and beyond, the ASC Board is committed to returning to an in-person event as ASC seeks to re-establish close faculty relationships and mentorship that has long been a staple of ASC conferences. The traditional modality affords opportunities that cannot be captured with a virtual event. These include spontaneous conversations and connections in hallways, breaks, receptions, and planned events. While an in-person event will continue in future years, a hybrid approach may allow opportunities to expand the reach of ASC providing additional benefits to members while minimizing constraints.

2021 saw a variety of responses to the pandemic from academic conferences. Some conferences canceled plans while others shifted to remote events. The pandemic offered an opportunity to connect academicians virtually without geographic limitations. Table 1 compares a small sample of academic conferences associated with architecture, engineering, and construction education and their actions in 2020-21.

Table 1

Conference Modalities of Various Construction Education Conferences

Conference	**2020 Modality**	**2021 Modality**
ASC	Virtual-Asynchronous	Virtual-Synchronous
ASEE	Virtual	Virtual
ARCOM	Virtual-Asynchronous	Virtual-Synchronous
CITC	Not originally scheduled	Moved to Spring 2022
IBEE	Canceled	Canceled
ASEE	Virtual-Asynchronous	Virtual-Synchronous
AIA	Cancelled	Virtual-Synchronous

Virtual conference events have existed for at least 25 years (Bauman et al., 1996). Multiple articles have reflected on these types of events including comparing face-to-face and virtual conferences (Sá et al., 2019). Still others have focused on how to organize and plan such virtual events (Gichora et al., 2010). Much of the benefit from virtual conferences mirrors those benefits realized by distance learning: budget concerns, travel challenges, time zone differences, travel restrictions, and a host of issues international partners face (Bauman et al., 1996; Gichora et al., 2010; Oester et al., 2017).

This introductory research effort analyzed responses from construction management faculty who participated in the 2021 ASC International Conference. If attendee perspectives could be better understood, ASC membership may better plan and facilitate future conferences at ASC and throughout construction education:

- To what degree did ASC faculty engage in and participate in the virtual conference in 2021?
- What was the attendee's impression of the online conference (as compared to an in-person event)?
- If hybrid or virtual options were included for future conferences, would participants be more inclined to attend as a virtual attendee?

This study contributes to the existing body of knowledge in several ways. First, there is little research on construction education conferences generally. Second, this study represents the only attempt to record and document construction educator responses to their participation in an online conference, as well as document the responses of the ASC to the pandemic in terms of their conference offerings.

With the continued worldwide pandemic, the paper is timely as other organizations prepare for a post-COVID conference environment.

Literature Review

History of ASC and the ASC Conference

Undergraduate construction education degrees were established in 1926 at Yale, MIT and Union University (Tennessee) (Gunderson, 2006). As time progressed, "Building Construction" programs such as the one at the University of Florida developed. "After WWII, Johns-Manville and representatives of the building industry approached colleges and universities to set up programs with curriculum that would train students to meet the demand for construction managers projected by the federal government."(Gunderson, 2006, p. 86) In the 1960s, construction faculty at multiple schools recognized the need for an association to focus on the teaching of construction. In a meeting at the University of Florida in 1965, the "Associated Schools of Construction" was envisioned and developed (*ASC Website*, 2013). Since that time, ASC members have met annually on both a regional and national level.

ASC's vision is to "inspire excellence in construction leadership, education and research (*ASC Website*, 2013). The mission statement is as follows: "Advance construction education by supporting members in teaching best principles and practices, research innovation, and service to their institution, community and the industry." (*ASC Website*, 2013)

Since 1965, the ASC International Conference has occurred each spring. Key milestones and accomplishments include the following:

- Sharing of best practices in teaching and research
- Publishing of Annual Proceedings of the Conference (Average of 75 papers disseminated annually)
- Conducting business of the organization
- Providing a platform for mentorship, networking, and professional development

Educational Conferences

Multiple reasons exist for academic conferences including the following:

- Faculty learn from others (Vito, 1999).
- Conferences strengthen the discipline (Reinhard et al., 2021).
- Faculty benefit directly.
    - Demonstrate research ability and presentation quality to peers (Neuilly & Stohr, 2016)
    - Provide opportunity to select course material (Reinhard et al., 2021)
    - Build reputation as a researcher and scholar (Alarid, 2016)
    - Advance social networking and professional collaboration (Alarid, 2016)
    - Leverage professional development opportunities (Vito, 1999)
    - Encourage "intellectual exploration" (Neuilly & Stohr, 2016, p. 287)

Neuilly and Stohr (2016) identify that the learning value of conferences varies by the individual. For example, the graduate student attending the ASC Conference might learn and be interested in learning things very different than someone with significant industry experience who has returned to the classroom.

Virtual and Hybrid Conferences

While the pandemic was the key driver for ASC to shift to a virtual conference, other reasons exist to consider such activities. First, early career academics may not be financially secure or have adequate travel funding to attend conferences (Reinhard et al., 2021). Such individuals are among the key beneficiaries of conferences as they share their research, learn about the work of others, and discover job opportunities (Applegate et al., 2009). Second, a virtual conference increases access to individuals across the globe. Determining the number of people that cannot attend an in-person event is difficult even in a year that lacks a pandemic. In addition to financial concerns, geographic reasons or travel restrictions, personal reasons, health considerations, and professional reasons all influence conference attendance (Reinhard et al., 2021).

Other academics point to a demand for alternative conference set-ups (Viglione, 2020). In a May 2021 event, Divya Persaud and Eleanor Armstrong led a conference at the University College of London called “Space Science in Context”. The goals of the conference included improved accessibility, reduced carbon footprint and a wider audience than could be generated with an in-person event. Participants were asked to watch recorded talks ahead of the event and then participate online in synchronous discussions on the day of the conference.

ASC conference attendees often express interest in events that occur simultaneously during previous in-person ASC conferences. Because of the short duration of the typical ASC conference, often proceedings paper presentations would conflict with committee meetings and/or roundtable educational settings. Pfeifer et al. (2014) referred to this as “program dilution” and recognized this as one reason for capturing events for later viewing by participants. A virtual event might offer opportunities such as this and make research more accessible to those across construction at low costs (Reinhard et al., 2021).

There are also concerns with virtual conferences. Research indicates concerns with no-show and ill-prepared presenters (Mueller et al., 2004; Pfeifer et al., 2014). And, some items associated with the in-person conference such as social networking, mentorship, and collaborative partnerships may be limited in a virtual format (Neuilly & Stohr, 2016). Some disciplines, like education and the humanities have been quick to adopt virtual conference formats due to objectives of the discipline (Fraser et al., 2016). One example of this is the openness within education to explore new technology within the classroom.

Virtual conferences require a high degree of planning and present technological challenges (Diethart et al., 2020). Raby and Madden (2021) specifically point to the need to tailor the format of the conference to suit the preference of online attendees. Their research also highlights strong potential in the area of scientific exchange while noting challenges with social events and networking. Several researchers recommend a hybrid approach to conferences (Reinhard et al., 2021) Referred to by some as a “bricks and clicks” method, this approach may allow participants to capitalize on the values provided by an in-person event or virtual event according to their individual needs and capacity. In such an approach, conference items that work well, and are demanded by both in-person and online attendees, can be offered in a hybrid format. Items that are in less demand, or perhaps have less impact, could be offered only online or only in-person.

Methodology

The purpose of this research was to identify the perceptions of attendees of the 2021 ASC International Conference to understand their impressions of participating in a conference utilizing virtual components. The study also sought to identify perceptions of hybrid conference components for future ASC conferences. Specific research questions addressed by the survey included the following:

- To what degree did ASC faculty engage in and participate in the virtual conference in 2021?
- What was the attendee's impression of the online conference (as compared to an in-person event)?
- If hybrid or virtual options were included for future conferences, would participants be more inclined to attend as a virtual attendee?

The first part of a survey asked the respondents to identify demographic information using open responses (text box) and one multiple-choice question. The purpose of these questions was to identify how many different universities the respondents represented, as well as their overall history of experience with ASC. This also aided in understanding the participant's history with in-person ASC conferences and how their perspective may compare to the 2021 virtual conference. Table 2 shows the list of questions used in the demographic survey.

Table 2

Demographic Survey Questions
What is the name of your university?
Which of the following were ways in which you participated in the conference? (select from list)
Prior to this virtual conference, how many previous ASC Annual Conferences have you attended?
What year was the last ASC Annual Conference you attended?

The second part of the survey focused on the respondent's impressions of the value of their experience attending a completely virtual ASC conference. Questions utilized an open-ended response (text box) and asked respondents to identify which components of the conference they believed were effectively delivered online as well as those that should instead be offered as in-person for future events. The questionnaire also asked if the respondents would be more inclined to attend an ASC conference as a virtual attendee if that possibility was an option using a 5-point Likert Scale. Table 3 shows the list of questions used for this part of the survey.

Table 3

Survey Questions on Perceptions of Virtual/Hybrid Components of the ASC Conference
Indicate which components of the conference you think could be effectively offered virtually or hybrid in the future. (Select from list of all events.)
Indicate which components of the conference you think should be offered as in-person events in the future. (Select from list of all events.)

Were there components/activities that you felt were missing from this year's conference because it was virtual?
If certain components of the conference were offered in a virtual/hybrid format, would you be more inclined to attend the ASC conference as a virtual attendee?

The survey was input into the SurveyMonkey® online platform and was distributed to all registered attendees of the 2021 ASC Conference (N=412). There were no registration fees for the ASC Conference. These attendees were asked to respond to the survey within 30 days of the initial inquiry. The initial inquiry was sent at the end of the virtual conference in April with a follow-up reminder sent again approximately two weeks after the end of the 2021 conference.

Results

The ASC Conference had the highest number of registered attendees of any previous ASC Conference with 412 people registered. A total of 51 people responded to the survey, representing a 12% response rate. It is interesting to note that although there were 412 people officially registered for the conference, only 126 participated in any session according to the data found in the Zoom meeting logs. If only those that participated responded to the survey, this would instead represent a response rate of approximately 40% based on actual attendance. This virtual attendance of 126 individuals is lower than a typical modern-day, in-person ASC Conference that usually has approximately 200 attendees.

The respondents represent 29 different universities from three different countries and all eight of the ASC Regions. The respondents participated in a variety of activities at the conference, with the largest percentage being paper authors at 42% of the respondents. Those responding to the survey on the virtual conference indicated that they had attended an average of over 6 ASC Conferences in the past, with 10 respondents indicated this was their first ASC Conference. 94% indicate that they had attended an ASC Conference in the last 3 years.

Regarding what items were effectively delivered in the virtual environment, there were several items that were positively viewed by the respondents. The paper presentations gained the most responses with 21 of the 51 respondents (41%) indicating those could be done virtually or as a hybrid. The other two items that had significant responses were the Regional Meetings and the Committee Meetings, with each having 10 responses (20%). Of note, 8 of the 51 respondents (16%) indicated that all aspects of the conference could be done virtual effectively.

When queried about items that should be conducted in-person with no virtual or hybrid offering, the respondents identified several components. There were 31 respondents (61%) that indicated all components of the conference should be done in-person. Comments included "in person events are always preferable" and "all the components of the conference should be in-person, not virtually or hybrid." For the balance of responses, two items received significant votes to remain as in-person events. The teaching roundtables were the most popular with 19 responses (37%) followed by the awards banquet with 17 votes (33%). All remaining activities received less than 4 responses of conference events that should be conducted in-person.

In terms of what the respondents said was missing from the virtual conference, over half indicated social events and faculty interactions. Comments such as, "I get more out of talking with others than I generally do at the presentations", and "the ability to network and connect with colleagues, I truly missed that aspect." Also 14 of the 51 respondents (27%) indicated that networking was lacking in a virtual environment. There were also individual responses stating that things such as site tours and the ability to meet construction companies were also missing from the virtual conference.

When asked if having an online or a hybrid option to attend the conference would make them more inclined to attend a future ASC Conference, 12 people (23%) indicated they strongly agreed, 12 (23%) indicated they agreed, 17 (33%) indicated they neither agree nor disagree, 7 (14%) disagreed and 3 (6%) strongly disagreed. Overall, this indicates that 47% would be more likely to attend an online or hybrid conference; 33% didn't think it would affect their decision to participate; and 20% Strongly Disagreed or Disagreed it would get them more engaged with an ASC Conference.

Recommendations and Conclusion

The results show that there a significant number of faculty members (47%) that believe they would be more inclined to attend a future ASC Conference if a virtual or hybrid option was available. While no one specific type of event at the conference was preferred as virtual, the results showed a large population of faculty that would engage in a virtual or hybrid ASC Conference if given the chance. Despite the numbers that suggests a virtual or hybrid option might make attendees more like to attend, the majority of respondents (61%) indicated that all elements of the conference should be held in person. These responses combined with the relatively low participation rate in the 2021 Conference suggests that moving to a fully online conference permanently for ASC may actually reduce engagement. However, the hybrid conference would allow participants to engage in either mode of their choosing.

Other results show that while some components of the conference would work well in a virtual or hybrid environment, such as the paper presentations or the regional and committee meetings, respondents indicated that there were components of the conference that were lacking because of the virtual environment. The teaching roundtables and the networking aspect of the conference were clearly limited in the virtual environment. These results match the literature review which noted limited social networking, mentorship, and collaborative partnerships were limited in a virtual format (Neuilly & Stohr, 2016).

From a perspective of the conference attendee, the authors believe that construction management academics will be unlikely to attend a conference in person unless the benefits of that conference are clear and compelling (and above what a virtual-only option would offer). ASC conferences that are in-person or utilize hybrid delivery will need to enhance engagement and present a compelling event for attendees. Panels and lectures will need to diminish with improved opportunities for collaboration, mentorship, and conversation. It is possible that fewer construction conferences will exist, and those that do will need to assure a high-quality event for those in attendance.

There is an opportunity for the ASC to expand its engagement with faculty across the globe by engaging in hybrid components of the ASC Conference. A fully online conference presented limitations and challenges, but a hybrid conference would allow for participants to select the best way for them to engage with the ASC conference. Faculty may prefer an in-person experience, but many factors such as budgetary limitations or travel restrictions may make physically attending a conference impossible (Reinhard et al., 2021). By offering a hybrid experience the ASC would be able to engage these members. This research suggests that initial targets for a hybrid conference may include at least one virtual paper track along with a virtual meeting option for regional meetings.

As ASC continues to pursue international engagement as a strategic goal, the addition of a hybrid option for the conference may provide a unique opportunity to connect with new international partners. Offering a hybrid conference may assist in recruiting schools to engage with ASC for the first time. Many universities outside of the US offer construction education programs. These universities may not have the funding or ability to travel or may not believe the ASC to be a priority since they are not familiar with the organization. By offering a hybrid conference, faculty at these universities could experience some of the benefits of an ASC Conference with minimal expense. This outreach to new universities would help further the mission of ASC.

This study only collected data for a single year of the ASC Conference and was limited to 51 responses. Future research could be conducted by surveying the entire ASC membership to identify their perceptions of the benefits of a hybrid conference and/or the effects of incorporating a hybrid format into future conferences. In addition, no written goals for the ASC International Conference were identified. If these goals could be better identified, a filter may be created that would allow ASC to better assess whether an in-person, virtual, or hybrid event would best meet those goals. In addition, one could consider how meeting conference goals varies across and between in-person and hybrid conferences.

References

Alarid, L. (2016). How to Secure Your First Academic Job Out of Graduate School. *Journal of Criminal Justice Education*, 1–15. https://doi.org/10.1080/10511253.2015.1128702

Applegate, B., Cable, C., & Sitren, A. (2009). Academia's Most Wanted: The Characteristics of Desirable Academic Job Candidates in Criminology and Criminal Justice. *Journal of Criminal Justice Education*, *20*, 20–39. https://doi.org/10.1080/10511250802687436

ASC Website. (2013, October 24). [Professional Organization]. Associated Schools of Construction (ASC). www.ascweb.org

Bauman, M., Hunt, R. A., Crump, E., & Schwalm, K. (1996). When Worlds Collide: Merging Face-to-face and Virtual Academic Conferences. In M. Sharples & T. van der Geest (Eds.), *The New Writing Environment: Writers at Work in a World of Technology* (pp. 217–236). Springer London. https://doi.org/10.1007/978-1-4471-1482-6_17

Diethart, M., Zimmermann, A., & Mulà, I. (2020). *Guidelines for Virtual Conferencing – inspired by the COPERNICUS Alliance Online Conference 2019*. https://doi.org/10.7892/boris.139254

Fraser, H., Soanes, K., Jones, S., Jones, C., & Malishev, M. (2016). The value of virtual conferencing for ecology and conservation. *Conservation Biology : The Journal of the Society for Conservation Biology*, *31*. https://doi.org/10.1111/cobi.12837

Gichora, N. N., Fatumo, S. A., Ngara, M. V., Chelbat, N., Ramdayal, K., Opap, K. B., Siwo, G. H., Adebiyi, M. O., Gonnouni, A. E., Zofou, D., Maurady, A., Adebiyi, E. F., Villiers, E. P. de, Masiga, D. K., Bizzaro, J. W., Suravajhala, P. N., Ommeh, S. C., & Hide, W. A. (2010). Ten Simple Rules for Organizing a Virtual Conferenc□ Anywhere. *PLoS Computational Biology*, *6*.

Gunderson, D. (2006). Needs assessment: Construction management doctoral programs in the United States /. *International Journal of Construction Education and Research*, *2*. https://doi.org/10.1080/15578770600906745

Mueller, D., Giacomazzi, A., & Wada, J. (2004). So how was your conference? Panel chairs' perceptions of the 2003 ACJS meeting in Boston. *Journal of Criminal Justice Education*, *15*, 201–218. https://doi.org/10.1080/10511250400085951

Neuilly, M.-A., & Stohr, M. (2016). The Art of Conferencing. *Journal of Criminal Justice Education*, *27*, 1–18. https://doi.org/10.1080/10511253.2015.1129101

Oester, S., Cigliano, J. A., Hind-Ozan, E. J., & Parsons, E. C. M. (2017). Why Conferences Matter—An Illustration from the International Marine Conservation Congress. *Frontiers in Marine Science*, *4*, 257. https://doi.org/10.3389/fmars.2017.00257

Pfeifer, H., Alarid, L., Sims, B., & Palacios, W. (2014). Improving the Quality of Academy of Criminal Justice Sciences Annual Meetings: Where do we go from here? *Journal of Criminal Justice Education*, *25*. https://doi.org/10.1080/10511253.2014.887740

Raby, C. L., & Madden, J. R. (2021). Moving academic conferences online: Understanding patterns of delegate engagement. *Ecology and Evolution*, *11*(8), 3607–3615. PubMed. https://doi.org/10.1002/ece3.7251

Reinhard, D., Stafford, M., & Payne, T. (2021). COVID-19 and Academia: Considering the Future of Academic Conferencing. *Journal of Criminal Justice Education*, *32*, 1–15. https://doi.org/10.1080/10511253.2020.1871047

Sá, M., Ferreira, C., & Serpa, S. (2019). Virtual and Face-To-Face Academic Conferences: Comparison and Potentials. *Journal of Educational and Social Research*, *9*, 35–47. https://doi.org/10.2478/jesr-2019-0011

Viglione, G. (2020). A year without conferences? How the coronavirus pandemic could change research. *Nature*, *579*, 327–328. https://doi.org/10.1038/d41586-020-00786-y

Vito, G. (1999). Research and relevance: Role of the Academy of Criminal Justice Sciences. *Justice Quarterly*, *16*, 1–17. https://doi.org/10.1080/07418829900094031

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