A BIM-based Approach for Communicating and Implementing a Construction Site Safety Plan

Salman Azhar, Ph.D.  
Associate Professor  
Auburn University  
Auburn, Alabama

Alex Behringer, B.S.  
Project Engineer  
The Whiting-Turner Contracting Company  
Orlando, Florida

There has not been a significant decline in fatalities, injuries and illnesses in the construction industry despite rigorous efforts of safety professionals and strong governmental enforcement of safety laws. Inappropriate work planning; insufficient communication between workers and supervisors; and lack of safety training are some of the key contributing factors. The utilization of BIM technologies can result in improved occupational safety by allowing designers and constructors to visually assess jobsite conditions and recognize hazards. By using digital models and simulations, the project team can more effectively communicate and implement a safety plan. This paper presents findings of a research study which investigated the effectiveness of BIM technologies in developing, communicating and implementing a construction site safety plan. The Recreation & Wellness Center project at the campus of the Auburn University (AU) was selected as a case study. Four-dimensional (4D) phasing simulations, 3D walk-throughs and 3D renderings were utilized for identifying hazards and communicating safety management plan to the workers. The results indicated that 3D/4D dynamic tools are more effective in safety planning and management as compared to the 2D static drawings because they closely simulate actual jobsite conditions.

Key Words: Safety planning, Building Information Modeling, Hazards analysis, Construction simulation, Safety management

Introduction and Background

Safety is one of the primary concerns of the construction industry. Safety statistics for construction indicate high fatality, injury and illness rates all over the world. Although dramatic improvements have taken place in construction technologies and processes in recent decades, the safety record in the construction industry continues to be one of the poorest (Huang and Hinze, 2006). Inappropriate work planning and supervision; insufficient communication between workers and supervisors; and lack of safety training and practices are identified as key contributing factors behind most fatalities and injuries (Lappalainen et al., 2007). Safety planning is part of the construction planning process but is typically carried out to a certain extent separately from other project planning and control tasks (Sulankivi et al., 2012). Traditional safety planning relies on manual observations, gut-feelings and experience of the safety planner. A typical safety plan depicts what safety measures are necessary, when, where, and why. The link between planning for safety and work task execution is often weak: for example, many contractors use two-dimensional drawings (2D) or field observations to identify hazards. Since their approach is manual and based on experience and gut-feelings, the observed results can be error-prone due to subjective judgments of the decision maker (Sulankivi et al., 2012).

Recently, there has been considerable interest in improving worksite safety through safer design and work method statements using Building Information Modeling (BIM) (Chi et al., 2012). A building information model allows constructors to visually assess jobsite conditions and recognize hazards (Azhar et al., 2012). The utilization of BIM technologies can result in improved occupational safety by connecting the safety issues more closely to construction planning, providing more illustrative site layout and safety plans, providing methods for managing and visualizing up-to-date plans and site status information, as well as by supporting safety communication in various situations, such as informing site staff about making safety arrangements in response to a particular risk or warning about
various risks. The use of BIM also encourages other project partners to involve in both risk assessment and planning (Sulankivi et al., 2012).

Rajendran and Clarke (2011) outlined the following areas where Safety and Health (S&H) professionals can use BIM technologies: (1) Design for safety; (2) Safety planning (job hazard analysis and pretask planning); (3) Worker safety training; (4) Accident investigation; and (5) Facility and maintenance phase safety. For these tasks, S&H professionals can use 3D renderings generated from the BIM models and walk-throughs animations. In addition, 4D phasing simulations focused on the safety procedures can be generated to show how temporary safety elements and areas of concerns transition throughout the duration of a project. A byproduct of integrating safety with BIM is safety related training videos for construction workers. Using a BIM model for safety training creates a visual tool that allows on-site labor to understand the actual project conditions. It can also help cross the common language barriers associated with foreign workers because training is done through visualization (Azhar et al., 2012).

The existing research studies on the utilization of BIM technologies for safety planning and management can be divided into the following categories: (1) Design for safety; (2) Design inspection and monitoring; (3) Safety planning; (4) Safety training; and (5) Facility management and emergency responses (Chi et al., 2012). A brief summary of some of the important studies is presented below.

Ku and Mills (2008) evaluated potential of BIM as a design-for-safety (DfS) tool. They indicated that BIM can facilitate early collaboration between architects/engineers and constructors, via automated checklists of rule-based safety information such as codes and regulatory information. Via a theoretical framework, they evaluated usefulness of BIM as a DfS tool and provided research suggestions for designing future BIM tools for safety. Based on this concept, Qi et al. (2010) designed a prototype Construction Safety Checking system. This tool automatically checks for fall hazards in a BIM model and provides design alternatives to the users.

Kim and Ahn (2011) used BIM technologies for temporary facilities planning of a building project. They mentioned that the temporary facilities planning process is tedious and requires a lot of attention due to the following reasons: Firstly, temporary facilities are generally not clearly delineated on the building drawings; secondly, the installation and dismantling of these facilities is one of the high risk activities on the jobsites; and thirdly, the designers typically overlook safety considerations in temporary facilities design which results in many safety hazards. They developed a prototype system for designing and depicting installation and de-installation of scaffolding in high rise building projects. Hu et al. (2010) used sub-building information models for 4D structural safety analysis during construction. A sub-BIM is a subset of main BIM model and focuses on a certain part/phase/trade of the project.

This concept is useful for complex projects where it is difficult to use a single BIM model for various analyses. The proposed approach was tested on the construction of the National Stadium of the 2008 Olympics. The authors claimed that their suggested approach is feasible, and resulted in remarkably reduced workload for safety planners.

Bansal (2011) integrated a BIM model with a Geographical Information System (GIS) for predicting places and activities which have potential for accidents. The prototype system was tested on a real life project in India. He concluded that the integration of geospatial information in a BIM model facilitates safety planners in examining what and where safety measures are required. Kiviiniemi et al. (2011) used 4D BIM models for managing and communicating construction safety plans. They demonstrated use of BIM for the following safety related activities: (1) Site layout and anti-crane collapse plan; (2) Wall demolition visualization; (3) Safety railing modeling; (4) Formwork plan with integrated fall protection; and (5) Design for safety model checking. They found that BIM-based safety demonstrations are an effective tool for discussing and communicating safety related issues at the jobsite with the project team. Kim (2012) suggested that a Building Life Cycle Management mechanism should be applied for the health and safety issues. He demonstrated this concept with the help of several case studies where BIM technologies were used to address safety issues in the design, construction and post-construction stages.

Problem Statement, Research Aim and Key Questions

Though existing research studies excellently demonstrate the effectiveness of BIM technologies for safety planning and management, they have following limitations: (1) The end product of many studies is either a conceptual framework or a limited-functionality prototype system for demonstrating the main concept; (2) Most prototype systems were tested on hypothetical simplified “square form” buildings which represent a low level of complexity;
and (3) The prototype systems were tested using “laboratory” settings with either no or very limited involvement of S&H professionals, site superintendents, and craft workers.

The aim of this research project is to demonstrate how contractors and sub-contractors can utilize onsite BIM technologies for safety planning and management in real life projects. The research seeks answers of the following key questions: (1) Is BIM technology feasible for safety assessment?; (2) What types of hazards can be best identified and addressed through a BIM model?; and (3) Can construction companies effectively use BIM-based safety plans for communication and workers training?

The presented study is unique because of: (1) It tested the BIM applications for safety in a real-life complex building project; (2) It utilized only those BIM tools which are well recognized in the construction industry; (3) It demonstrates how contractors and subcontractors can enhance BIM models initially prepared by the designers for safety planning and management; and (4) It exhibits how contractors can use these enhanced BIM models to communicate safety plans to the workers as well as to the project owners.

**Research Design**

A mixed-methods research design, consisting of qualitative and quantitative research instruments, was deployed. The project was divided into three phases as shown in Figure 1.

To demonstrate the research concept, the Recreation and Wellness Center project currently under construction at the campus of the Auburn University (AU) was selected as a case study. The key project details are as follows: (1) Cost: $50 million; (2) Size: 240,000 ft²; (3) Delivery system: CM agency; (4) Start date: October 2011; and (5) Completion date: April 2013. The exterior and interior renderings of the project are shown in Figure 2.
Methodology and Main Findings

Phase 1: Conceptual Planning

The purpose of conceptual planning was threefold: (1) to brainstorm ideas as how BIM technologies can be used for safety planning and management; (2) to identify a suitable project for the case study; and (3) to develop detailed methodology and outline an implementation procedure. For this purpose, a focus group of five BIM professionals was formed. These professional were selected from a BIM Advisory Group established at the Auburn University. The BIM advisory group is a 15 members group, from industry and academia that frequently meets to share their experiences in BIM technologies, discuss possible solutions of problems faced by the group members, and assist in BIM-related research projects. Based on discussions with the focus group members, it was decided to use BIM technologies to address “fatal four” construction fatalities and injuries namely (1) falls; (2) struck by objects; (3) caught in/Between; and (4) electrocutions. It was further decided to develop following five safety plans: (1) excavation risk management plan; (2) crane management plan; (3) fall protection plan for leading edges; (4) fall protection plan for roofers; and (5) an emergency response plan.

The following end products of the BIM technologies were shortlisted to develop the above-mentioned safety plans: (1) 3D renderings; (2) 3D Walk-through and fly-through animations; (3) 4D phasing simulations; and (4) Narrated videos for workers based on animations and simulations. The following software were selected for this purpose: (1) Autodesk Revit\textsuperscript{0} for modeling; (2) Google Sketchup\textsuperscript{0} for creating 3D equipment, characters and related families; (3) Synchro\textsuperscript{0} for 4D phasing simulations; (4) MS Project\textsuperscript{0} for scheduling; and (5) Camtasia\textsuperscript{0} and MS Movie Maker\textsuperscript{0} for producing videos.

Phase II: Hazards Assessment and Safety Planning using BIM Models, Simulations and Videos

The researchers acquired the base BIM models of the project from the project architect and enhanced them by adding missing design details. These models were used for hazards identification and development of BIM-based safety plans. The flowchart shown in Figure 3 outlines the phase-II workflow.

![Flowchart](image)

**Figure 3.** The workflow for developing BIM-based safety plans, simulations and videos.

The following sections briefly describe the five safety plans developed in this study.

Plan 1 - Excavation Risk Management Plan

The purpose of the excavation risk management plan was to safely coordinate earthwork operations at the jobsite. The earthwork phase required excavation up to 8 ft deep and then installation of sheet piles to avoid cave-ins. In the BIM model, the researchers created sheet piling components consisting of a sheet pile section and a base re-shoring stand made of a steel beam and a solid steel tube. The sheet piles were arrayed around the indented ditch and the stands were then arrayed behind them. The site utility work included installation of reinforced concrete pipes for sewage. These activities were modeled using 4D simulations to coordinate excavation equipment operations at the jobsite. Figure 4(a) shows screenshots of the 4D excavation simulations.
(a) Screenshots of 4D excavation simulations depicting installation of sheet piles and utility pipes.

(b) Crane work zone and steel truss placement in the crane management plan.

(c) Modeling of railing system for fall protection against leading edges.

(d) Selected screenshots from the roof construction simulations.

(e) Emergency response plan showing emergency vehicle route and severe weather shelter areas.

Figure 4 Screenshots of BIM-based safety plans for AU Health & Wellness Center project.
Plan 2 - Crane Management Plan

The purpose of the crane management plan was to: (1) identify swing radius of the crane to ensure its safe distance from the power lines and nearby temporary and permanent structures; and (2) identify what trade/crew would be utilizing crane at a particular day/time. On our case study project, two lattice-boom crawling cranes were utilized to pick and place the structural members. Figure 4(b) illustrates the crane management plan for steel trusses placement. The colored masses (yellow, orange and blue) were used to demonstrate the crane’s swing radius and zone of influence. Four dimensional (4D) simulations were utilized by the general contractor to visually identify the crane’s zone of influence at any day of the year and this information was used for properly barricading the site to ensure safe execution of construction activities.

Plan 3 - Fall Protection Plan for Leading Edges

The fall protection plan for leading edges was prepared according to OSHA subpart M: Fall protection standards. Two types of fall protection railings were modeled: 2x4 wooden railings on the second level (concrete structure) that were bolted to the concrete slab and 3/8" steel aircraft cable railings on the third and higher levels of the project (steel structure). Holes in the elevated slabs were covered by plywood coverings and roped in caution tape, as required by the OSHA. After modeling the fall protection railing components, the railings were placed on the structural BIM model. While preforming this process, the researchers were able to identify multiple fall hazards through the 3D view that were not easily identifiable in the 2D plan view such as not yet constructed stairwells and skylights. The modeled railings were then segregated by zones and levels, and the resulting railing sections were exported to Synchro® for developing 4D simulations. The 4D simulations provided complete details to the general and sub-contractors such as the location and date when the railings were to be installed or removed. Figure 4(c) depicts a typical railing family and their placement in the BIM model.

Plan 4 - Fall Protection Plan for Roofers

In the case study project, multiple crews were deployed to furnish the building’s roofing system. The roof was constructed in two phases consisting of decking the roof and then fusing membrane sheeting on top of the decking with rigid insulation. Initially, a corrugated metal roof decking system was installed directly on top of the building’s roof trusses with fastening screws. Anchorage points utilized for tying off roofing labor were adhered directly onto the metal roof decking in horizontal strands. As the metal decking process continued across the building’s footprint, the anchor points allowed the workers to chain-back and forth from the origin of their work to safely transition from either side of the roof. This entire operation was simulated to identify any safety issues. These simulations were used to brief roof workers about work conditions and hazards on a constantly changing roof structure. Figure 4(d) shows screenshots of the 4D simulation for roofers.

Plan 5 - Emergency Response Plan

The BIM-based emergency response plan consisted of 5 sub-plans namely Construction crew entrance/exit; construction equipment and deliveries route, temporary facilities and job trailer locations, emergency vehicle(s) route, and severe weather shelters to orient workers with the construction site. Three dimensional (3D) walk-through animations and renderings were generated from the BIM models to communicate emergency response plan to the workers. Figure 4(e) illustrates two sub-plans of the main emergency response plan.

Phase III: Implementation and Validation

The 3D walk-throughs and renderings, 4D simulations, and animation videos were used by the general contractor to communicate the site safety plan to the sub-contractors and workers. Both internal and external validations were performed to verify the research results and usefulness of this study. In the first cycle of the validation process, the BIM models with integrated safety elements and 4D simulations were shown to the focus group members. Based on their feedback, necessary modifications were made to improve the resulting models and simulations. These models and simulations were then provided to the general contractor for utilization on site. In the next cycle of the validation process, the site superintendent, site managers, and site safety staff were interviewed to identify the
benefits and any pitfalls of BIM-based safety plans. The consulted group described three main perceived benefits:
(1) improved communication of the safety plan to the construction personnel; (2) improved communication of the project’s safety plan to the OSHA and the owner; and (3) logistical details of construction safety tasks being fully addressed in the preconstruction phase. Following are some excerpts from the interviews:

- “…..BIM technology could have a very significant and positive impact on the safety planning and management…the 4D animations proved to be very helpful in the safety planning meetings and daily safety talks…..”
- “…..4D simulations are very helpful to fully involve owners in the safety process that may not be as fluent at visualizing safety practices from 2D drawings or written safety plans….”

The group expressed some concerns on the extra cost that may be involved in developing the BIM-based safety plans. They also suggested a close collaboration between the BIM modeler(s) and site S&H staff to ensure 100% accuracy of the resulting models and simulations.

The same group was also asked to complete a short questionnaire in an effort to compare the effectiveness of BIM-based safety planning to the traditional safety planning. Table 1 summarizes the questionnaire results.

Table 1

<table>
<thead>
<tr>
<th>Measure</th>
<th>Weighted Mean Scores (sample size: 14)</th>
<th>Cum. Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease in hazards assessment</td>
<td>1.51</td>
<td>1.81</td>
<td>1.41</td>
</tr>
<tr>
<td></td>
<td>1.52</td>
<td>1.55</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>1.50</td>
<td>1.55</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.55</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>1.35</td>
<td>1.53</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td>0.23</td>
<td>0.119</td>
<td>0.381</td>
</tr>
<tr>
<td>Ease in communication</td>
<td>1.63</td>
<td>1.72</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>1.63</td>
<td>1.55</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>1.50</td>
<td>1.55</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>1.10</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>1.59</td>
<td>1.59</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td>0.23</td>
<td>0.23</td>
<td>0.23</td>
</tr>
<tr>
<td>Accuracy</td>
<td>1.05</td>
<td>1.50</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.55</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>1.03</td>
<td>1.03</td>
<td>1.03</td>
</tr>
<tr>
<td>Incidents and accidents control</td>
<td>1.05</td>
<td>1.50</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.55</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>1.03</td>
<td>1.03</td>
<td>1.03</td>
</tr>
</tbody>
</table>

Degree of effectiveness/accuracy: -2: Highly ineffective/inaccurate; -1: Moderately ineffective/inaccurate; 0: No difference; +1: Moderately effective/accurate; +2: Highly effective/accurate

These results indicate that the BIM-based safety planning is moderately-to-highly effective and accurate in identifying hazards and communicating safety plan to the workers. The survey group indicated BIM-based approach moderately better in incidents and accidents control at the site as compared to the traditional safety planning. In a follow-up interview, some of the group members mentioned that a key aspect in incidents and accidents control is “human behavior” which sometimes is difficult to change. One interviewee said “…..some people will do and repeat the same mistakes no matter how sophisticated and high-tech the safety plans are…..”.

**Discussion and Concluding Remarks**

Despite the recent technological advances, the fatality and injury rates in the construction industry are still not significantly declined. It is partially because designers do not have adequate construction safety knowledge, which results in many inherent safety hazard loopholes in the project design. Similarly, it is very hard for contractors to identify all possible hazards in the project planning and preconstruction phases. Each construction site has its specific hazards and these differ from one location to another. New employees usually come on board without prior knowledge about the possible hazards they may have to face. Typically contractors use CAD based construction drawings to plan for safety. Current CAD systems represent a static and isolated design process. While these CAD-based models provide a topological description of buildings, they are not suitable for properly identifying construction hazards at jobsites. To improve the current situation, BIM technologies can be used as a new collaborative safety planning tool. Through BIM models and simulations, designers and constructors can take effective protective measures in the project planning phase to eliminate (or minimize) the construction site hazards. For example, BIM models can be used to identify locations of fall protection tie-off points for workers and as a result permanent anchorage points can be included in the design. Similarly, contractors can use BIM models and simulations to identify hazards and communicate mitigation plans to the workers. Through 4D simulations, the site staff can visually identify the sequence of activities, and materials and equipment requirements before commencing
work. They can discuss possible hazards and develop their specific safety plans. BIM models can also be used during an accident investigation to recreate event sequence and the incident scene. In the absence of an existing BIM model, laser scanning technology can be used to capture point cloud for developing a BIM model. In fact, the Building Information Modeling (BIM) along with the 3D High Definition (HD) laser scanning has recently emerged as a powerful new platform for facilitating both engineering and administrative safety planning and management at the maintenance/retrofitting stages of a facility. The utilization of BIM technologies for safety management poses several challenges such as additional cost involved for developing/enhancing BIM models; lack of knowledge of S&H personnel in using BIM; and technical issues such as non-availability of safety elements and equipment in BIM software library. Last but not least challenge is human behavior which cannot be changed quickly. In that respect, the BIM should not be considered as a panacea for solving all health and safety issues at the construction sites. The BIM technologies will help to improve the safety situation but the overall improvement might be visible in several decades. We strongly believe that dynamic 3D/4D tools are always more helpful in hazards identification than 2D static drawings because they closely simulate the actual jobsite conditions. In this paper, we demonstrated the useful of BIM technologies for identifying and communicating site hazards to the project team. The BIM-based safety planning is particularly very useful for academic buildings projects that are typically constructed on an active college campus environment. The BIM models and simulations can help university administers to ensure safety of their students and staff and plan campus activities accordingly.

References


