BIM for Facilitating Construction Safety Planning and Management at Jobsites

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Abstract

A key factor in safety planning and management is to properly identify any possible hazards before they occur. A building information modelling allows constructors to visually assess jobsite conditions and recognize hazards. It provides them sufficient time to develop adequate hazard mitigation plans well before the start of the construction activities. Currently few researchers have explored the feasibility of BIM for construction safety planning and management. However, most of these studies were either conceptual in nature or based on hypothetical simplified building models. This paper reports an in progress research project where BIM technology is utilized to perform safety planning and management for an ongoing construction project located at the campus of Auburn University. BIM models and 4D simulations are used to communicate the following safety plans: (1) Crane management; (2) Excavation risk management; (3) Fall protection for leading edges; (4) Fall protection for roofers; and an (5) Emergency response plan. 4D phasing simulations, 3D walk-throughs and 3D renderings are utilized to identify various hazards and communicate safety management plans to the workers at the jobsite. The paper highlights key research tasks and main findings, and depicts plans for the remaining part of this project.

Keywords

4D models, automation, Building Information Modelling, safety planning, safety management, risk analysis.

INTRODUCTION

Safety planning is an essential part of the construction planning process. Despite rigorous efforts of safety professionals and strong governmental reinforcement of safety laws, there has not been a significant decline in the frequency and severity of injuries and illnesses in the construction industry (Carter and Smith, 2006). Research concerning occupational deaths in construction concludes that the major safety problems are associated to falls, electrocution, struck-by, and caught in/between objects (Goetsch, 2012). Inappropriate work planning and supervision, insufficient communication between different partners and lack of safety training and practices were identified as key contributing factors behind most fatalities and injuries (Lappalainen *et al*., 2007). 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 in the way different objects are

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connected together and store specific architectural features and attributes, they are not suitable for properly identifying construction hazards at jobsites (Rozenfeld *et al*., 2009).

BIM technology can be used as a starting point for safety planning and communication. The utilization of BIM technology 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 or warning about risks. The use of BIM also encourages other project partners to involve in both risk assessment and planning. These partners are designers, sub-contractors, safety specialists, occupational health care professionals, etc. (Sulankivi *et al*., 2009).

Rajendran and Clarke (2011) outlined the following areas where Safety and Health (S&H) professionals can use BIM technology: (1) Worker safety training and education; (2) Design for safety; (3) Safety planning (job hazard analysis and pretask planning); (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. These types of simulations can be particularly helpful on large-scale academic construction projects. For example, higher education projects take place on an active college campus environment where the safety concerns extend beyond the project site. 4D phasing simulations can show the university administrators the steps contractor is taking to ensure the safety of its workers as well as the university community. A byproduct of integrating safety with BIM is safety related training videos for construction workers. Using the 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 construction personnel because training is done through visualization.

Eastman *et al*. (2011) reported two examples of the use of BIM in safety planning and management. In the first project, a theme park, the project team modeled envelopes for testing rides to ensure that no activities were taking place during the testing period within the test envelope. Using 4D simulations, they identified a conflict and resolved it ahead of time. On a second project, a steel frame building in Yas Island of Abu Dhabi, massing cylinders were used to model the spaces occupied by the activities of the welding crews. Clash detection between cylinders was then used to identify possible exposure of workers to dangers posed by other teams from time to time.

RESEARCH AIM, KEY QUESTIONS AND SCOPE

The aim of this on-going research project is to demonstrate how construction companies can use BIM technology for safety planning and management. The research seeks answers to the following key questions: (1) Is BIM technology feasible for safety assessment?; (2) What types of hazards can be identified through a BIM model?; and (3) How can construction companies use BIM models for safety planning in the different project phases? The scope of this research is limited to commercial and institutional building projects.

BIM FOR SAFETY: EXISTING EFFORTS AND RESEARCH GAP

During the last five years, extensive research has been conducted on the utilization of BIM technology for project planning, design, construction and post-construction phases (Azhar, 2011). However, very few studies were focused on the utilization of BIM for safety planning and management. This section highlights key research efforts, depicts the research gap, and outlines uniqueness of presented research.

Naji (in Aouad *et al*., 2007) developed a 3D virtual environment application, SIMCON®, to simulate equipment-based construction processes, such as materials handling, earth removing and crane operations, in real-time object-oriented graphical environment. The main objective of the SIMCON® project was to develop a tool by which safety in construction could be enhanced by having a test pad to graphically conduct *what-if* analysis for different scenarios of building, equipment, and site configurations, and provide a high level of user interaction.

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 constuctors, 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 the concept presented by Ku and Mills (2008), Qi et al. (2010) designed a prototype Construction Safety Checking system. This tool can automatically check for fall hazards in the BIM model and provide design alternatives to the users.

Kim and Ahn (2010) used BIM technology 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 consideration 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. They indicated that this approach is rational and feasible, and resulted in remarkably reduced workload.

Sattineni and Azhar (2010) investigated the movement of workers wearing Radio Frequency Identification (RFID) Tags in a BIM model. They indicated that this method of monitoring can be used to improve the safety and productivity of construction workers on a construction jobsite. Moreover this technique can also be used to track equipment and construction materials on a job-site thereby allowing S&H professionals to identify any associated hazards.

Godfaurd and Abdulkadir (2011) presented a conceptual framework for integrating BIM technology and planning software for health and safety site induction. They mentioned that such integration would be helpful for understanding onsite hazards. Bansal (2011) integrated 4D BIM and 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.

Kiviniemi *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 modelling; (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 project managers, site superintendents and workers.

Though these projects excellently demonstrated the use of BIM for safety planning and management, they have following limitations: (1) The end product of many projects is either a conceptual framework or a limited-capability prototype system to demonstrate 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.

The presented project is unique in the following manner: (1) It tests the BIM applications for safety in a real-life complex building project; (2) It utilizes existing BIM tools which are familiar to most project participants; (3) It demonstrates how contractors and subcontractors can enhance BIM models prepared by the designers for safety planning; and (4) It exhibits how contractors can use BIM-based safety models to demonstrate their safety plans to workers as well as project owners.

RESEARCH DESIGN

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

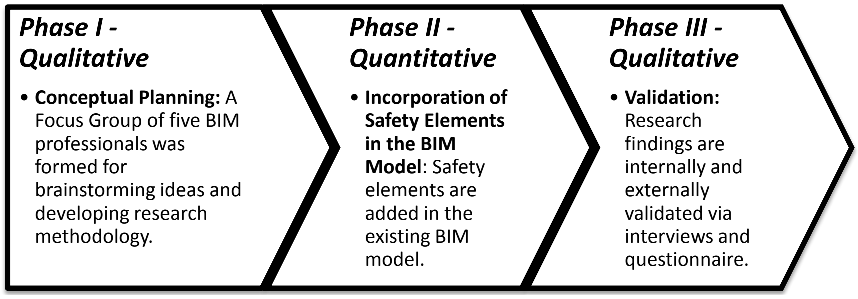


Figure 1. The Research Framework

The Recreation & Wellness Center project currently under construction at the campus of the Auburn University is selected as a case study. The project details are as follows:

- Owner: *Auburn University Facilities Division*
- Project Manager (Construction Team): *Robins & Morton*
- Architect: *360 Architecture*
- Cost: *$50,000,000*
- Size: *240,000 sq ft*
- Delivery System: *CM Agency*
- Start Date: *October 2011*

- Projected Substantial Completion Date: *May 2013*

Figure 2 illustrates a project rendering which is used by the architecture firm for marketing purposes.

Figure 2. 3D Rendering of Recreation & Wellness Center Project
(Courtesy of: *360 Architecture*)

METHODOLOGY AND MAIN FINDINGS

PHASE 1: CONCEPTUAL PLANNING

The purpose of conceptual planning is threefold: (1) To brainstorm ideas as how BIM can be used for safety planning and management; (2) To identify a suitable project as a case study; and (3) To develop methodology and outline procedures. For this purpose, a focus group of five BIM professionals is formed. These professional are selected from the *BIM Advisory Group* established at the McWhorter School of Building Science. The BIM advisory group is a 15 members group, from industry and academia that meets once a month to discuss their experiences in BIM technology, identify research needs, and discuss possible solutions of problems faced by the group members. Based on discussions with the focus group members, it is decided to use BIM technology to address "fatal four" construction fatalities and injuries (i.e. Falls, Electrocutions, Struck by object(s); and Caught in/Between). Table 1 depicts the safety plans that are developed for this purpose.

Table 1. BIM-based Safety Management Plans

No	BIM-based Safety Plan	"Fatal Four" Category
1	Crane Management Plan	Electrocutions; Struck by Object; Caught-in/between
2	Excavation Risk Management Plan	Caught-in/between; Struck by Object
3	Fall Protection Plan – Leading Edges	Falls
4	Fall Protection Plan - Roofers	Falls
5	Emergency Response Plan	Struck by Object

It is further decided that the following applications of BIM technology will be utilized to develop these safety plans: (1) 3D renderings; (2) Walk-through and fly-through animations; (3) 4D phasing simulations; and (4) Narrated videos for workers based on animations and simulations. The following software are used for this project: (1) Autodesk Revit® for modelling; (2) Google Sketchup® for creating 3D equipment, characters and related families; (3) Synchro® for 4D phasing simulations; (4) MS Project® for scheduling; and (5) Camtasia® and MS Movie Maker® for producing videos.

PHASE II: INCORPORATION OF SAFETY ELEMENTS IN THE BIM MODEL

The architecture firm, 360 Architecture based in Kansas City, Missouri, developed the base BIM model of this project for communication and visualization purposes. The research team acquired this model and enhanced it by adding missing design details and temporary safety features. The flowchart shown in Figure 3 outlines the study's workflow utilizing the aforementioned software.

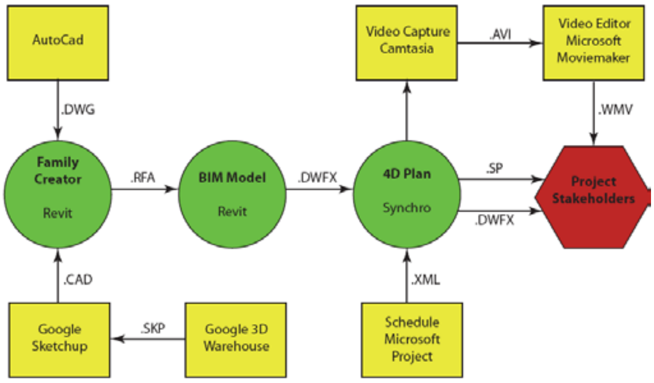


Figure 3. The "BIM+Safety" Workflow

The following sections briefly describe the five BIM-based safety plans generated from the base model to form the foundation of this project.

Crane Management Plan

The purpose of a crane management plan is 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 will be utilizing crane at a particular instant of time. On our case study project, two lattice-boom crawling cranes are utilized to pick and place the structural members. The crane being utilized on the North side of the project is a 110-ton Link-Belt 218 HYLAB unit and the crane on the South side is a 250-ton Manitowoc Model 999 unit. Figure 4 illustrates the steel truss placement in the crane management plan.

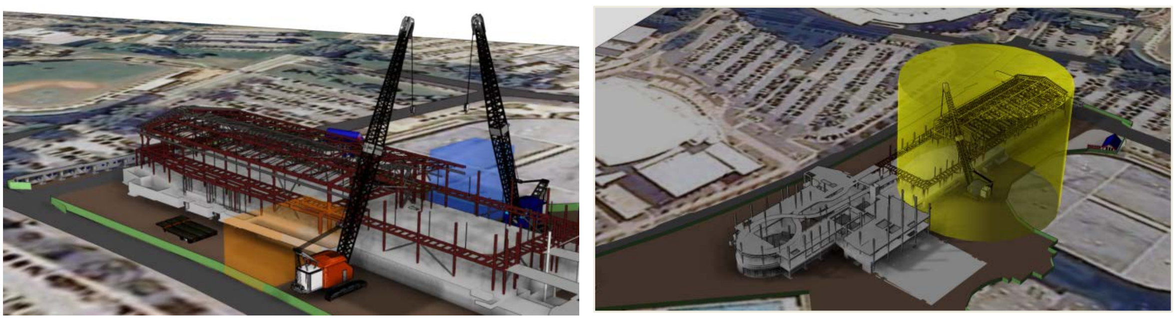
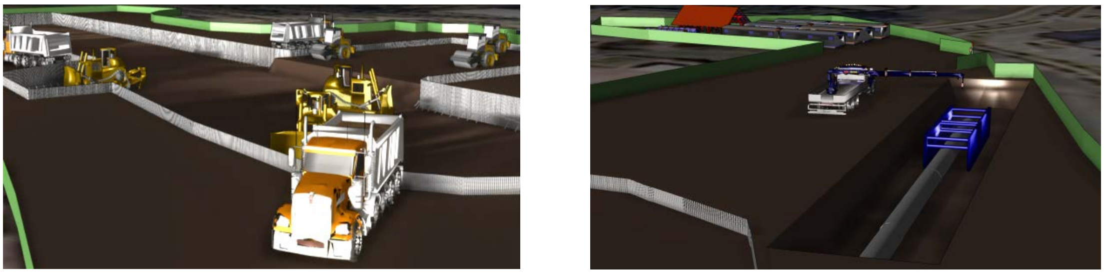


Figure 4. Crane Work Zone and Steel Truss Placement in Crane Management Plan

As depicted in Figure 4, the colored masses (yellow, orange and blue) are used to demonstrate the crane's swing radius and zone of influence. 4D simulations are utilized by the contractor to visually identify the mobile crane's zone of influence at any day of the year and this information is used for safely planning construction activities.

Excavation Risk Management Plan

The purpose of excavation risk management plan is to safely coordinate earthwork operations at the jobsite. The earthwork phase requires excavation up to 8 ft deep and then installation of sheet piles to avoid cave-ins. The researchers created sheet piling components consisting of a small section of sheet piling and a base re-shoring stand made of a steel beam and a solid steel tube. The sheet piling is arrayed around the indented ditch and the stands are then arrayed behind them as to create tension between the floor and the held back portion of soil. The site utility work includes installation of reinforced concrete pipes for sewage. These activities are modeled using 4D simulations to coordinate excavation equipment operations at the jobsite. Figure 5 shows screenshots of the 4D excavation simulations.



(a) Soil backfilling operation (b) Installation of RCC pipe

Figure 5. Screenshots of 4D Excavation Simulations

Fall Protection Plan – Leading Edges

The fall protection plan for leading edges is prepared according to OSHA subpart M: Fall protection standards. Two types of fall protection railings are modeled: 2x4 wooden railings on the second level (concrete structure) that are 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 are covered by plywood coverings and roped in caution tape, as required by OSHA. After modelling the fall protection railing components, the railings are placed on the structural BIM model. While preforming this process, the researchers were able to identify multiple falling risks through the 3D view that were not easily found within the 2D plan view. These conditions included not yet constructed stairwells and skylights, and fall protection railing was placed to protect from falls as a result of these hazards. The modeled railings are then segregated by zones and levels, and the resulting railing sections are exported to Synchro® for developing 4D simulations. The 4D simulation provides complete details to the contractor as to the location and date that the railings are to be installed or removed. Figure 6 depicts a typical railing family and their placement in the BIM model.

Fall Protection Plan for Roofers

In the case study project, multiple crews will be utilized to furnish the building's roofing system. The roof will be 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 will be installed directly on top of the building's roof trusses with fastening screws. Anchorage points utilized for tie-off safety of the roofing labor will be adhered directly onto the metal roof decking in horizontal strands. As the metal decking process will continue across the buildings footprint, the anchor points will follow to allow workers to chain-back and forth from the origin of their work to safely transition from either side of the roof. This entire operation is simulated to identify any safety issues. These simulation animations will be used to brief roof workers exposed to fall protection hazards on a constantly changing roof structure. Figure 7 shows a screenshot of the 4D simulation for roofers.

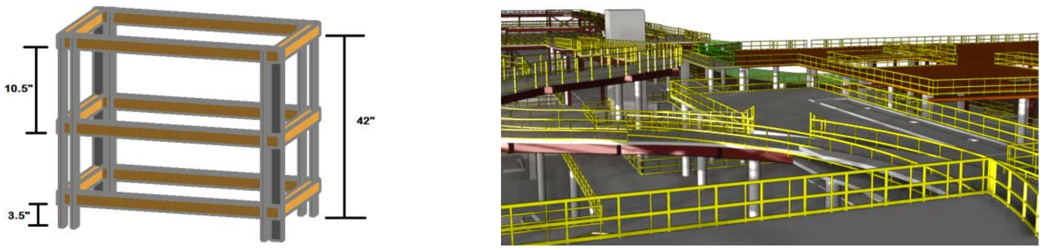


Figure 6. Modelling of Railing System for Fall Protection

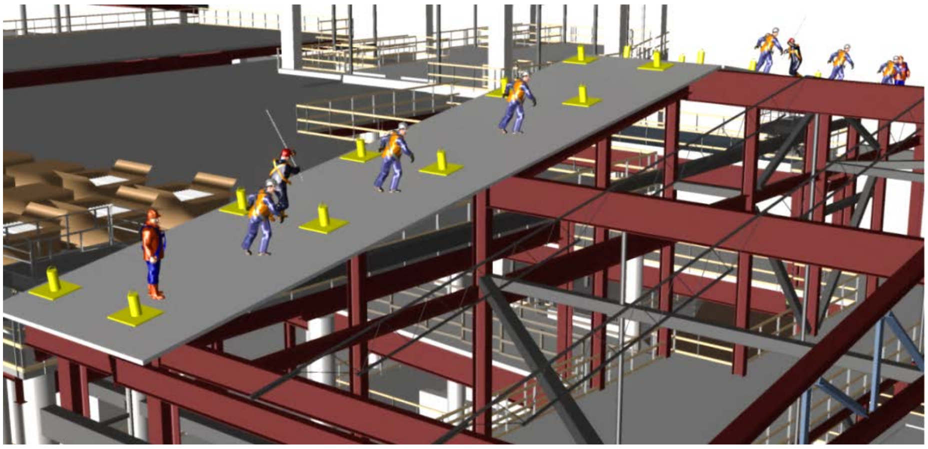
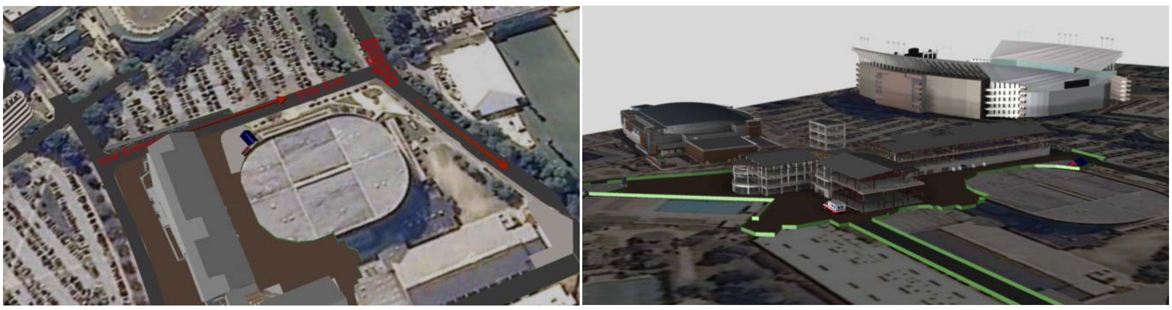


Figure 7. Simulation of Roof Construction using 4D BIM Model

Emergency Response Plan

The 4D emergency response plan makes use of five internal categories to orient workers with the construction site: delivery and construction directions, the labeled zones of the building, temporary facilities and job trailer locations, emergency situation precautions, and severe weather precautions. 3D renderings are generated from the BIM model to communicate emergency response plan to the workers. Figure 8 illustrates parts of the emergency response plan.



(a) Traffic Flow Directions (b) Ambulance Arriva Path

Figure 8. Screenshots of the Emergency Action Plan

PHASE III: VALIDATION

Both internal and external validations were planned and implemented to verify the usefulness of this study. The first cycle of the validation process was recently completed, in which, the BIM model with integrated safety elements and 4D simulations were shown to a Focus Group of BIM Professionals. The consulted members described three main perceived benefits: (1) Improved communication of the safety plan among the construction personnel; (2) Improved communication of the project's safety plan between OSHA and the owner; and (3) *Logistical details of construction safety tasks being fully addressed in the preconstruction phase.* Based on the industry members' feedback, necessary modifications will be made to improve the feasibility of integrating safety management and planning with BIM technology. In the following months, the project team will demonstrate the BIM models and simulations in regular safety meetings of the case study project and qualitatively and quantitatively evaluate their effectiveness.

CONCLUDING REMARKS

The construction industry has incurred more worker fatalities and injuries than any other industry in recent years. It is partially because designers do not have adequate construction safety knowledge, which results in many inherent safety hazard loopholes in the project drawings. Similarly, it is very hard for contractors to identify all possible hazards in the project planning and preconstruction phases. To improve the current situation, BIM technology can be used as a new collaborative design and construction planning tool. The BIM-based safety planning would enable designers to automatically check 3D building models and ensure their compliance with the OSHA specifications. Similarly through these models constructors can take protective measures in the project planning phase to eliminate (or minimize) the construction site hazards from the beginning of the project. Therefore in both the design and construction phases, significant measures to construction worker safety could be realized.

This study intends to develop a safety planning and management system based on the BIM technology which will enable construction managers to identify hazards at different project stages and develop suitable mitigation strategies. We strongly believe that dynamic 3-D tools are always more helpful in hazards identification than 2D static drawings because they closely simulate actual jobsite conditions. In this paper, we demonstrated the useful of BIM technology for identifying and communicating site hazards to the project team. More work on this project is planned in the coming months and complete findings will be presented in another paper.

PLANS FOR FUTURE RESEARCH

In the coming months, we plan to use integrated BIM-Safety models, simulations and related animation videos in project safety meetings to evaluate their effectiveness. Interviews and a questionnaire survey will be used as research instruments to gather relevant data. One more project at the campus of Auburn University is selected for this research. Based on the lessons learned from the current case study project, more enhanced BIM-based safety models and simulations will be developed for the next case study project.

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