Integration of Safety Risk Factors in BIM for Scaffolding Construction

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ABSTRACT

65% of US workers in the construction industry work on scaffolding. Of these workers 4,500 are injured and 50 die every year due to scaffold-related accidents. Proper safety management such as scaffolding safety inspections can support the hazard mitigation and prevention. This paper shares the results of a study of the levels of safety risk at each stage of the scaffoldings project life cycle for building a masonry wall and how these risks and related mitigation suggestions can be applied to Building Information Models (BIM). Safety is integrated with 4 dimensional (4D) BIM by linking the scaffoldings safety risks and mitigations with the project schedule. The 4D BIM can be used as a tool for the safety management to monitor and diminish the safety hazards associated with scaffolding work. Four different stages of research were conducted to determine the safety risks and implement them, and the mitigations, into BIM. (1) Determine the activities associated with working on scaffolding. (2) Collect data from industry professionals about the likelihood and severity of safety hazards at each stage of the scaffolding project life cycle. (3) Establish the safety risks using the collected data and a standardized algorithm. (4) Incorporate the safety risks into BIM and provide mitigation recommendations. As a result, the 4D BIM can be used throughout the project planning and construction progress to inform the safety management of activities associated with the scaffolding that have high safety risks and assist safety management in implementing preventative measures according to given mitigation recommendations.

INTRODUCTION

Fatalities and accidents are frequent parts of the construction industry because of construction sites ever-changing array of tasks that are often hazardous. With proper planning, these tasks can be better organized to reduce the risk. Safety managers or superintendents through onsite observation and enforcement typically implement safety prevention. However, safety managers and superintendents are always at a disadvantage due to the large and diverse amount of tasks completed on site each day and numerous numbers of safety rules and prevention measures provided by the Occupational Safety and Health Administration (OSHA). There is a need for developing an advanced method to assist onsite safety management and enforce safety on construction sites. As Building Information Modeling is receiving more and more attention and growth in the construction industry, in this study, we recognize and take advantage of BIM's capabilities to create a tool for construction site safety management. It focuses on safety for masonry wall construction using scaffolding due to its widespread presence in the construction industry. This tool links safety risks and mitigations to a schedule in BIM and then visually represents the safety risks in the model.

BACKGROUND

Construction sites are complex and dynamic working environments. Work teams are transient, the physical structure and spaces change constantly, and sites are exposed to the environment and changes in weather (Sacks et al. 2009), all of which make construction sites ever changing and hazardous places. As an outcome, the construction industry is responsible for almost one third of the OSHA fatality and accident reports. Although the number of these incidents has gone down through increased safety awareness and knowledge, there is still improvement needed to achieve the ‘Zero Incident’ goal. Realizing the informality of safety programs, Hallowell and Gambatese (2009a) analyzed the approximate success of different safety program elements through the elements aptitude to mitigate construction safety and health risks. It was concluded that the most influential programs are those heavily supported by the upper management and safety management. However, on most construction sites, it is the superintendents or safety managers that are responsible for monitoring and enforcing safety. Many of these professionals are relying solely on the knowledge they have acquired from their years of hands on experience and previous exposure to safety hazards in the field.

Hinze et al. (2013) investigated the effectiveness of using historical information, for instance OSHA recordable injury rates, to increase construction projects safety performances. Using leading predictors of safety performance has been found to be a worthwhile alternative to leverage historical information. The following section outlines existing research on safety predictors. Safety indicators or safety risks analysis are critical processes to prevent construction safety accidents from happening. Rozenfeld et al. (2010) developed ‘‘Construction Job Safety Analysis” (CJSA) to identify potential loss-of-control events and to assess their probabilities of occurrence. Shapira et al. (2012) developed an overall safety level index due to the operation of tower cranes. Instead of considering the use of tower cranes on a general construction site this added a factor that personalized the safety level to specific sites. Hallowell and Gambatese (2009b) developed safety risk levels quantification method for concrete formwork construction. Although researches have concentrated on developing safety risk levels, no practical suggestions existed on how the data can be used by practitioners in the industry. Hence, it is important to investigate more advanced methods to integrate this information in specific construction projects.

The benefits and potentials of BIM for construction have been gradually recognized. With copious amounts of unique information related to each project and additional information emerging daily, BIM provides us the opportunity to improve project management to effectively access, comprehend, and utilize the information. Sacks et al. (2010) constructed a BIM-enabled system to support production planning and day-to-day production control on construction sites. The system has the potential to improve work flow and reduce waste by providing both process and product visualization at the work face. Zhang et al. (2012) developed an automated safety rule-checking system based on BIM to detect fall related safety hazards. Safety risk levels and BIM were combined in Zhou et al. (2013) research on underground metro construction. Safety risks were created through data collected from monitoring the construction site that was turned into a growth curve. However, safety risk information has either been linked with construction activities or incorporated into BIM, which if realized can enhance onsite safety risk monitoring and management.

OBJECTIVE AND SCOPE

The objective of this study is to investigate and develop an approach to integrate safety risk factor with BIM to facilitate construction safety monitoring and management. Activity specific safety risk factors collected through survey will be linked with BIM and schedule to enable visualizing the risk level throughout the construction phase using 4D simulation. Additionally, mitigation recommendations are provided along with the schedule simulation to support decision-making. The scope of this paper is limited to masonry construction using scaffolding to demonstrate its usefulness and the feasibility. With 65% of US workers in the construction industry working on scaffolding (OSHA 2013), it is easy to take scaffoldings frequent occurrence on construction sites for granted and overlook how dangerous it is. However, safety records show that this activity is hazardous and is the cause of 4,500 injuries and 50 deaths every year (OSHA 2013).

RESEARCH METHODOLOGY

In order to develop a method to incorporate safety risk factors into BIM to assist construction safety monitoring and management, three research stages were conducted. The success and completion of each of these stages lead to the success and completion of the stages that followed. The first stage consists of investigating and evaluating the different steps associated with using scaffolding to build a masonry wall. A safety risk factor based on the likelihood and severity of an accident was obtained for each of the steps through industry survey. The job steps, their associated safety risk factors, and possible mitigations were then linked into BIM. A specific user-interface was then created to be used in BIM to easily navigate and display the steps, risk factors, and their mitigations.

Industry surveys on scaffolding activities. Determining the activities associated with working on scaffolding to build a masonry wall is the first step of the research process. Investigating the possible steps and procedures involved in erecting scaffolding, inspecting scaffolding, using scaffolding to build a masonry wall, and dismantling scaffolding laid the foundation for the following stages of research. This investigation was completed through online database research, construction manual research, and interviews of industry professionals. Later, through an online survey, these steps were then confirmed by industry professionals.

After the activities required to build a masonry wall using scaffolding were determined, the next step was collecting data from industry professionals about the likelihood and severity of safety hazards at each step. This data was collected through online surveys sent out to the same industry professionals surveyed to confirm the scaffolding steps. The online survey asked the professionals to rank the likelihood of an accident to occur at each step from one to five and the severity of an accident at each step from one to five. For likelihood, a ranking of one meant that the likelihood was rare, less than a 3% chance; a ranking of five meant that the likelihood was almost certain, greater than a 90% chance. For the severity of an accident, a ranking of one meant the severity would be insignificant, for example, no lost time at work; a rank of five meant that the severity would be catastrophic, for example, death.

Safety risks and mitigations. The results from the survey about likelihood and severity were used along with a standardized algorithm and a safety matrix to develop the safety risk for each step. The standardized algorithm was taken from the unit risk formula created by Hallowell and Gambatese (2009a): Unit Risk = (Frequency) × (Severity). For each step involved in the scaffolding process an average for the frequency, or likelihood as it has been named in this research, and an average for the severity was found based on the results of the survey of the industry professionals. Each likelihood and severity average is between one and five, which results in a unit risk value between 1 and 25. The calculated unit risk was used along with a risk matrix (Table 1) further developed based on a risk matrix from Iacucci (2011) to determine the safety risk levels. The safety risk matrix is a visual representation of the safety risk levels (Table 2) based on the averages for the likelihood and severity.

Table 1. Safety risk matrix

Likelihood \ Severity	**Insignificant** (ex: no lost time at work)	**Minor** (ex: some lost time at work)	**Moderate** (ex: significant lost time at work)	**Major** (ex: unable to return to work)	**Catastrophic** (ex: death)
Rare (<3% chance)	Low	Low	Low	Moderate	Moderate
Unlikely (3% - 10% chance)	Low	Moderate	Moderate	High	High
Moderate (10% - 50% chance)	Low	Moderate	High	Extreme	Extreme
Likely (50% - 90% chance)	Moderate	High	Extreme	Extreme	Extreme
Almost certain (>90% chance)	Moderate	High	Extreme	Extreme	Extreme

Table 2. Risk factor ranges

Risk level	Low	Moderate	High	Extreme
Risk Factor	1.0-3.0	3.1-7.0	7.1-11.0	11.1-25.0

After the safety risk levels were determined, mitigations were found for each step to help address the potential accidents that could occur at each step in using scaffolding to build a masonry wall. These mitigations were identified through the similar process as the steps to build a masonry wall were found: online database research, construction manual research, and interviews of industry professionals.

Incorporate safety risk factor into BIM. After risk factors and levels were obtained from the earlier steps, this information then needs to be incorporated into BIM to provide safety risk visualization. A plug-in was developed on top of a commercial available BIM platform for the integration of the visualization of risk factor and 4D simulation of the construction progress based on project schedule.

Scaffolding models were generated semi-automatically using algorithms developed in Kim et al. (2013) to match the masonry model. In terms of simulation, since the schedule typically remains on high level in BIM without showing detailed activities, the developed program is capable of populating the schedule into activity level based on the high level schedule. In addition, the smallest time step was set to minute in the developed program to match the activity.

IMPLEMENTATION AND RESULTS

The surveys were then sent out to 16 professionals through email to collect their opinion on likelihood and consequence of potential safety hazards associated with each of the job step. 6 professionals completed the survey whose time in the industry accumulates to about 150 years of practical work experience (Table 3). The ratio of participation is 37.5%. A total of 14 tasks required to build a masonry wall using scaffolding were identified in this study. Survey results were collected, analyzed, and shown in Table 4.

Table 3. Results to survey of industry safety professionals

Industry Safety Professional	Years of Experience
Corporate Safety Officer	40
Safety Manager	9
Superintendent	40
Superintendent	30
Superintendent	23
Assistant Superintendent	5

Based on the identified tasks, a Work Breakdown Structure (WBS) of masonry wall construction was built. Figure 1 shows an example of *Dismantling Scaffolding* sub-activity with allocated percentage of the time and risk factors obtained from the survey results.

Table 4. Scaffolding Safety Risk Survey Summary.

Step		Survey Results			
Setting up the scaffolding		**Likelihood**	**Severity**	**Risk Factor**	**Risk Level**
1	Prepare the scaffolding area	0.125	1.25	1.5625	Low
2	Set out the jacks	0.125	1.25	1.5625	Low
3	Install all braces and connectors prior to proceeding to the next tier of jacks	0.175	1.5	2.625	Low
4	Use scaffold boards to deck each level of scaffold before installing the next level	0.225	2	4.5	Moderate
5	Install safety features at each level	0.2	1.75	3.5	Moderate
6	Install ladder or stairway access to working platform above	0.2	1.75	3.5	Moderate
Building the masonry wall		**Likelihood**	**Severity**	**Risk Factor**	**Risk Level**
1	Stock the materials on the scaffold deck	0.25	2.75	6.875	Moderate
2	Prepare the surface: waterproofing, flashing, weeps, vertical support system, seals, etc.	0.2	1.75	3.5	Moderate
3	Measure and layout the wall	0.125	1.75	2.1875	Low
4	Lay the masonry while binding it together with mortar and making sure it is level	0.25	2.5	6.25	Moderate
Dismantling the scaffolding		**Likelihood**	**Severity**	**Risk Factor**	**Risk Level**
1	Access the top platform	0.2	2.75	5.5	Moderate
2	Dismantle from end bay	0.267	3	8.01	High
3	Dismantle planks	0.275	2.75	7.5625	High
4	Dismantle guardrails, mid-rails, ledgers, and etc.	0.275	3	8.25	High

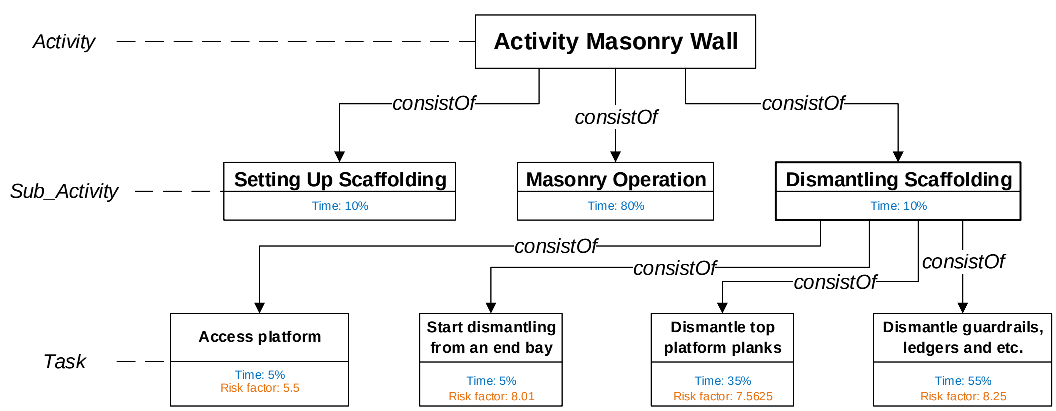

Figure 1. WBS of Masonry Operation.

The masonry model along with scaffolding was built as shown in Figure 2. Figure 3 shows the user-interface designed for construction safety risk visualization. Review date and representation mode can be set to control the project progress simulation of BIM. Ongoing tasks and its corresponding mitigations are displayed as well as the current overall risk factor. The risk factor color codes are reflected in the model as shown in an example in Figure 4.

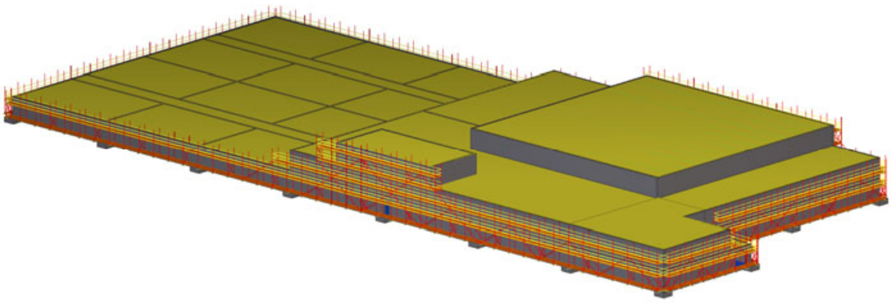

Figure 2. Masonry model with scaffolding.

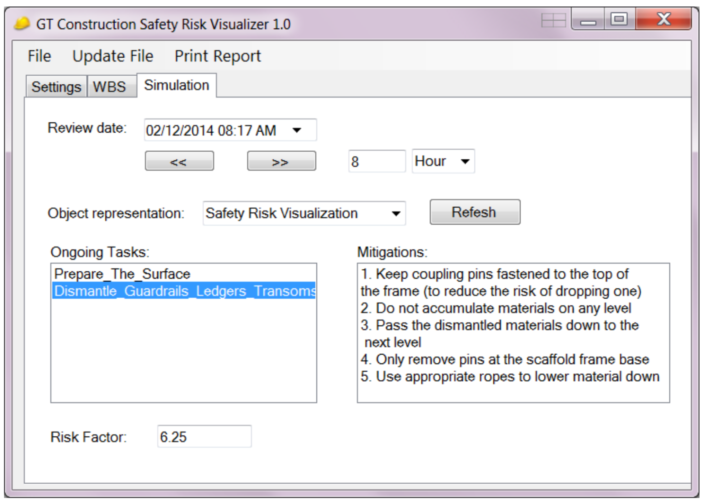

Figure 3. 4D simulation with safety risk level visualization.

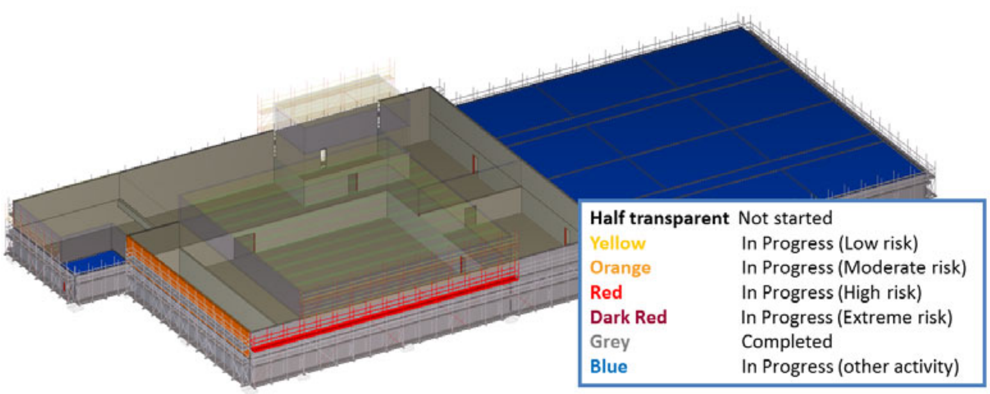

Figure 4. 4D simulation with safety risk level visualization.

CONCLUSION AND DISCUSSION

This study developed risk factors for masonry wall construction using scaffolding and then implemented these factors into BIM. A safety risk visualizer plug-in was developed on top of a commercially-available BIM platform for visualizing risk level along with risk mitigation information. The information found in this paper and its incorporation into BIM provides detailed information to help make construction sites safer. This method allows safety personnel to be aware of the potential risk of hazard at activity level on a construction site by providing risk visualization in BIM. At the same time, it also provides mitigations to assist decision maker in order to prevent accidents or fatalities from occurring. Future research will focus on developing risk profiles for construction activities to enhance and provide advanced risk analysis in BIM.

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