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Automated Safety Planning of Scaffolding-Related Hazards in Building Information Modeling (BIM)

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Abstract: Scaffolds are frequently used in construction projects. Despite the impact on the entire safety, scaffolds are rarely analyzed as part of the safety planning. While recent advances in BIM (Building Information Modeling) provides opportunity to address potential safety issues in the early planning stages, it is still labor-intensive and challenging to incorporate scaffolds into current manual jobsite safety analysis which is time-consuming and error-prone. Consequently, potential safety hazards related to scaffolds are identified and presented during the construction phase. The objective of this research is to integrate scaffolds into automated safety analysis using BIM. A safety checking system was created to simulate the movements of scaffolds along the paths of crews using the scaffolds. Algorithms in the system automatically identify safety hazards related to activities working on scaffolds. Then, the system was implemented in a commercially available BIM software program for case studies. The results show that the algorithms successfully identified safety hazards that were not noticed by project managers of the projects. The results were visualized in BIM to facilitate early safety communications.

Keywords: BIM, safety, scaffolding, construction planning, temporary structure

I. INTRODUCTION

A. Safety hazards related to scaffolds

According to the Occupational Safety and Health Administration (OSHA), more than 20% of about 800 worker fatalities in the US private industry occurred in the construction industry (OSHA 2014). For those worker fatalities, accidents related to scaffolds are responsible for a large proportion of the causes. While falls from scaffolds are one of the common causes of the entire fall fatalities and injuries, other types of hazards, such as falling objects from scaffolds, electrocution, and spatial conflicts with construction activities, occur due to improper planning and management of scaffolds.

According to OSHA, estimated 65% of the entire construction workers are using scaffolds frequently. Preventing accidents associated with scaffolds can protect US workers from 4,500 injuries and 50 deaths every year that is equivalent to spending of $90 million on lost workdays (OSHA 2003).

There have been investigations into the direct causes of scaffolding-related hazards, such as improper scaffolding designs and misplaced guardrails and planking (Halperin and McCann 2004). Also, existing regulations provides the guidance to the minimum requirements for scaffolding designs, installation, and inspection. However, safety inspection checklist tools widely used by the current industry are not suitable to identify and present safety problems in early design and planning stages (Whitaker et al. 2003). Such direct causes of scaffolding accidents can be generated by ineffective safety analysis and management.

B. Current practices of safety planning

To establish a safe construction plan, potential safety hazards need to be identified in the early design and planning stages so that protective measures can prepared and construction plans can be modified. However, current construction safety planning is often conducted independently from the construction planning efforts (Bansal 2011). Due to this drawback, safety managers in many construction projects simply inspect already established construction plans instead of involving in the efforts of creating and modifying construction plans. Furthermore, job hazard analysis (JHA) is usually conducted relying solely on labor-intensive efforts of safety manager or superintendent. Due to dynamically changing construction project environment, safety analysis is mostly labor-intensive and error-prone. Especially, scaffolds are considered as one of the most wasteful and challenging among various types of temporary structures.

In order to overcome the lack of temporary structures in safety planning and the reliance on manual efforts, this research created a BIM-based safety analysis system that incorporates temporary structures. The type of temporary structures in this research is limited to scaffolds that are used as elevated work platform for subcontractors. Automated safety checking algorithms were developed as embedded in the safety analysis system.

The related work section reviews existing computer-assisted approaches for planning and analyzing temporary structures. The following section introduces the framework and technical details of BIM-based safety analysis platform. In the case study section, the algorithms were applied in a realistic construction project. Finally, discussion section concludes the research and discusses

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contributions, limitations, and potential for future research studies.

II. LITERATURE REVIEW

Since temporary structures are used to assist in the construction of permanent structures, planning of temporary structures needs to take into account the construction site conditions and activities of crews using the temporary structures. Kim et al. (Kim et al. 2014) proposed a method to use geometric and action conditions to automatically select proper type of scaffolding. Kim and Teizer (Kim and Teizer 2014) created algorithms that automatically create scaffolding objects and integrate into 4D BIM.

Also, there were approaches that create temporary structure designs. Scia Scaffolding functions to facilitate manual creation of detailed scaffolding modeling (Nemetschek 2014). Smart Scaffolder (Smart Scaffolder 2014) can create detailed designs of scaffolds of specific vendors around walls. While these scaffolding design tools have capabilities to create scaffolding designs for visualization and material-takeoff, the scaffolding objects created by these tools are not connected to construction schedules in a way that can be used to analyze their impacts on safety.

In order to overcome the drawbacks of manual safety analysis, Zhang et at. (Zhang et al. 2011) developed an automated safety planning system using BIM. Focusing on fall protection, this research suggested a required direction toward creating safe construction plans. However, this research did not address safety hazards related to temporary structures.

Jongeling et al. (Jongeling et al. 2008) proposed an approach to identify safety and productivity problems caused by proximity between work crews. While this research incorporated spatial flows of crews and their temporary structure utilization to measure the distances between work crews, significant efforts are required to created detailed workflows and temporary structure utilizations as the input for the analysis.

Zhang et al. (Zhang et al. 2015) integrated the knowledge in JHA into BIM. Common safety hazards and associated preventive methods related to construction activities were shared automatically through the 4D BIM environment. However, this research did not presented a method to analyze construction site conditions automatically to identify safety hazards.

According to the review of existing approaches, it could be found that there still is a lack of method to efficiently analyze project and construction information to identify potential safety hazard related to temporary structures automatically. A few approach that attempted to include temporary structures into safety planning required extensive user-input before the safety analysis can begin. Taking these technical deficiencies into account, this research attempts to develop BIM-safety analysis system that creates details of activities automatically to analyze daily safety conditions of the construction site.

III. FRAMEWORK AND METHODOLOGY

This section presents the framework and methodology of the proposed automated safety hazard analysis incorporating scaffolds. Figure 1 below shows three components of the framework.

Figure 1. Framework of proposed safety hazard analysis

A. User input

Construction site conditions are formed by spatial and temporal interactions between work crews, temporary structures, and other components in the construction site. As the user-input for to the automated safety hazard analysis, BIM, construction schedule, spatial flows of work crews, and temporary structures used by the crews are manually inserted into the BIM-safety system.

B. Automated safety hazard analysis

For realistic construction site safety analysis, spaces occupied by work crews and scaffolds are first created automatically. By doing this, proper locations and sizes of workspaces and scaffolding spaces can be used for daily safety analysis. In this paper, (1) spatial conflicts between workspaces and scaffolding spaces, (2) falling objects from scaffolds to other activities, and (3) falling objects from other activities to scaffolds were analyzed.

C. Result reporting

The results of the simulation need to be communicated by stakeholders in efficient ways. This allows identified safety issues be discussed and resolved in advance.

IV. CASE STUDY

The BIM-safety analysis system was developed using APIs (application programming interfaces) of commercially available software programs and tested in a single-story commercial building construction project that used scaffolds for brick masonry exterior wall construction.

As shown in Figure 2, using the information in wall elements in BIM and masonry crew's work direction, workspaces and scaffolding spaces were created for each day. Limited access zones were created to detect other activities around the scaffolding space. As shown in Figure 2, a potential safety hazard of "falling objects from skylight installation” was detected. Even though this possibility does not lead to a fatality all the time, this can be detected and communicated by construction participants before they begin daily work tasks.

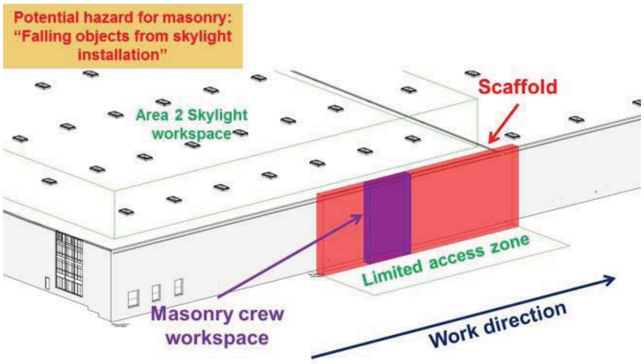
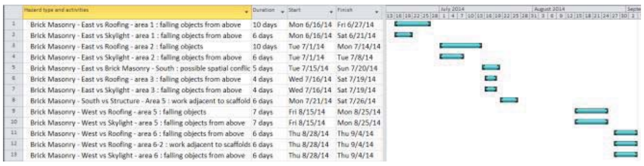


Figure 2. Hazard identification using workspaces and scaffolding spaces

Figure 3 illustrates an ongoing safety analysis along the construction schedule. Daily construction site condition is simulated and the results were shown in the graphic user interface.

Figure 3. Safety analysis in 4D BIM environment

All the safety hazard identified during the analysis can be communicated using various methods. In addition to the 4D BIM environment in Figure 3, a schedule of identified hazards was created automatically as in Figure 4. Other details such as scaffolding installation/inspection schedules can also be visualized as shown in Figure 5.



	Hazard type and activities	Duration	Start	Finish
1	Brick Masonry - East vs Roofing - area 1 : falling objects from above	10 days	Mon 6/16/14	Fri 6/27/14
2	Brick Masonry - East vs Skylight - area 1 : falling objects from above	6 days	Mon 6/16/14	Sat 6/21/14
3	Brick Masonry - East vs Roofing - area 2 : falling objects	10 days	Tue 7/1/14	Mon 7/14/14
4	Brick Masonry - East vs Skylight - area 2 : falling objects from above	6 days	Tue 7/1/14	Tue 7/8/14
5	Brick Masonry - East vs Brick Masonry - South : possible spatial conflic	5 days	Tue 7/15/14	Sun 7/20/14
6	Brick Masonry - East vs Roofing - area 3 : falling objects from above	4 days	Wed 7/16/14	Sat 7/19/14
7	Brick Masonry - East vs Skylight - area 3 : falling objects from above	4 days	Wed 7/16/14	Sat 7/19/14
8	Brick Masonry - South vs Structure - Area 5 : work adjacent to scaffold	6 days	Mon 7/21/14	Sat 7/26/14
9	Brick Masonry - West vs Roofing - area 5 : falling objects	7 days	Fri 8/15/14	Mon 8/25/14
10	Brick Masonry - West vs Skylight - area 5 : falling objects from above	7 days	Fri 8/15/14	Mon 8/25/14
11	Brick Masonry - West vs Roofing - area 6 : falling objects from above	6 days	Thu 8/28/14	Thu 9/4/14
12	Brick Masonry - West vs Roofing - area 6-2 : work adjacent to scaffolds	6 days	Thu 8/28/14	Thu 9/4/14
13	Brick Masonry - West vs Skylight - area 6 : falling objects from above	6 days	Thu 8/28/14	Thu 9/4/14

Figure 4. A schedule of identified hazards

V. CONCLUSION AND DISCUSSION

This paper presented the efforts to achieve an automated analysis of construction safety considering scaffolds. The framework and a case study were introduced. As a result of the analysis in the case study, potential safety hazards were detected that were not identified or discussed by the general contractor’s construction and safety managers. Since the project in the case study did not have a well-documented safety analysis actually conducted, our future research may compare the actual safety plans and automatically generated safety plans for validation.

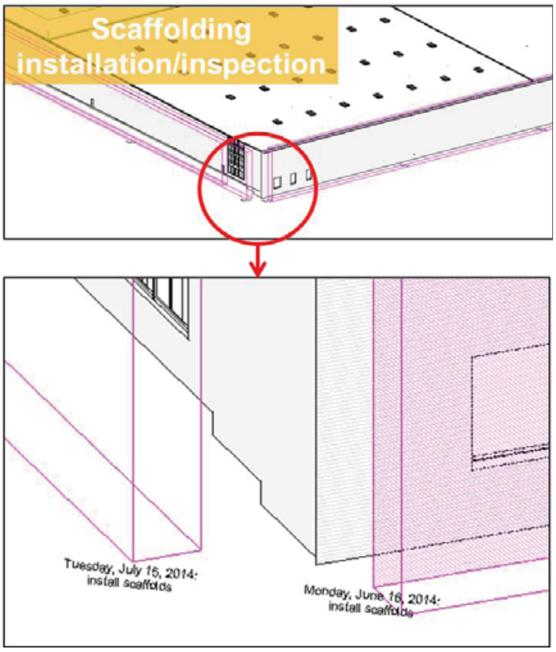


Figure 5. Scaffolding installation and inspection alert generation

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