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REVIEWING THE USEFULNESS OF BIM ADOPTION IN IMPROVING SAFETY ENVIRONMENT OF CONSTRUCTION PROJECTS

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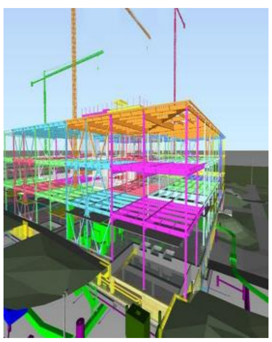
Graphical abstract



Abstract

Construction industry has always been beset with injuries and fatalities happened resulting from overlooking pertinent safety rules and regulations. In this regard, Building Information Modeling (BIM) has recently grabbed many practitioners' attention as a fruitful panacea in order to improve the safety issues of projects. Despite the fact that some studies have been conducted with regard to the usefulness of utilizing BIM in construction projects so as to minimize the accidents occurred in this sector, it is a great moot why there has not been any comprehensive review research scrutinizing the use of BIM in eliminating the safety hazards based on the past undertaken studies. Thus, the authors of this research have aimed at investigating in a great detail how the adoption of BIM in construction projects can bring about significant advantages. From the observations emerged, this conclusion can be drawn that BIM operation in construction industry, particularly prior to the construction stage, would considerably diminish the occurrence of accidents pertaining to safety matters emanating from improving the practitioners' perception of projects through modeling the diverse safety equipment, and foremost, identifying the potential hazards that may contribute to serious injuries.

Keywords: Injuries and fatalities, Building Information Modeling, safety hazards, and safety equipment

Abstrak

Industri pembinaan sentiasa dibelenggu kecederaan dan kematian berlaku akibat daripada menghadap peraturan keselamatan yang berkaitan dan peraturan-peraturan. Dalam hal ini, Bangunan Pemodelan Maklumat (BIM) baru-baru ini menarik perhatian ramai pengamal 'sebagai penawar membuahkan hasil bagi meningkatkan isu-isu keselamatan projek. menggunakan BIM dalam projek-projek pembinaan bagi mengurangkan kemalangan berlaku dalam sektor ini, ia adalah dipertikaikan besar mengapa tidak ada apa-apa penyelidikan kajian semula yang komprehensif meneliti penggunaan BIM dalam menghapuskan bahaya keselamatan berdasarkan kajian lepas yang dijalankan Dari pemerhatian muncul, kesimpulan ini boleh dilukis bahawa operasi BIM dalam industri pembinaan.

Kata kunci: Kecederaan dan kematian, Bangunan Pemodelan Maklumat, bahaya keselamatan dan peralatan keselamatan

1.0 INTRODUCTION

The improvement of construction quality and efficiency has seriously been restricted by construction conflicts and safety problems since a long time ago. The lack of advanced practical security technologies and management tools, which make it difficult to accurately analyze the dynamic construction process and security implications, accounts for the mentioned problems. In addition to that, problems such as unskilled labors, lack of safety awareness, and weak enforcement of construction safety regulations have resulted in the occurrence of fatalities [1].

In this regard, Building Information Modeling (BIM) has recently grabbed many practitioners' attention as a fruitful panacea in order to improve the safety issues of projects. BIM is defined as "shared digital representation of physical and functional characteristics of any built object which forms a reliable basis for decisions" [2]. There are myriad upsides involved in the utilization of BIM such as diminishing the design errors and reworks, enhancing the integration of time and cost, increasing the integration of design and construction phase, facilitating the site layout plan, to name but a few, throughout the whole lifecycle of construction projects [3-6,25 and 26]. Although some studies have been conducted with regard to the usefulness of utilizing BIM in construction projects so as to minimize the accidents occurred in this sector, it is a great moot why there has not been any comprehensive review research scrutinizing the use of BIM in eliminating the safety hazards based on the past undertaken studies. Thus, the authors of this research have aimed at investigating in a great detail how the adoption of BIM in construction projects can bring about significant advantages.

Sections 2 and 3 of this paper expound the different design for safety tools in terms of enhancing the construction workers' safety, and the benefits of employing BIM in healthcare respectively. On the other hand, Section 4 presents a new-designed safety software tool for improving the construction workers' safety. On top of all these, the utilizing of BIM in scaffolding system, and identifying and eliminating fall hazards based on an algorithm are elucidated in sections 5 and 6 in turn.

2.0 BIM ADOPTION FOR CONSTRUCTION SAFETY PLANNING

Kasirossafar *et al.* [9] administered a research to compare the impact of different DfS tools on construction worker safety with the aim of realizing sustainable design and construction. In order to fulfill the mentioned aims, a survey was conducted to contrast these different available types of tools. The printed copy of survey was distributed among 62 selected individuals as described below. Around 62 completed instruments from different stakeholders involved in design and construction were obtained through the survey.

Respondents were selected from experienced designers and engineers familiar with BIM, as well as the most prominent university professors in Iran, since BIM is a new and state-of-the-art topic. Respondents were asked to rate their perception about the impact of various DfS tools on worker safety. 95% (59/62) of the respondents were male and 5% (3/62) female in accordance with the gender. The mean was 26 years and the median was 29 based on the age data of the respondents. All of the respondents held college degrees, with 65% (40/62) holding graduate or professional degrees and 35% (22/62) holding bachelor degrees. The organizational role result was an indicative of the fact that 47% (29/62) of the respondents had a design role and 53% (33/62) had a construction or management roles. For Design Role, 38% (11/29) of the respondents were architects and 62% (18/29) were engineers.

Figure 1 illustrates the results emanate from conducting the mentioned survey. It can clearly be seen that visualization tools were more valued by 53% of respondents in comparison to the other current tools in terms of having more positive effects on improving construction safety. Buildings can be simulated at various stages of the project to allow designers, architects and contractors to identify potential safety hazards through Virtual Design and Construction (VDC). Extending the understanding of the proposed construction process so as to visualize virtually instead of imagining construction sequences was deemed as a powerful tool.

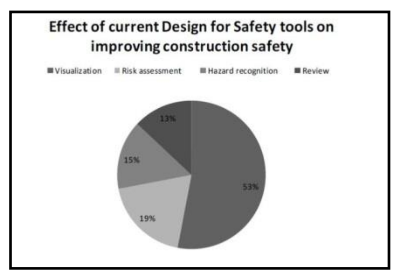


Figure 1 Current DFs tolls (Adapted from [9])

3.0 THE UTILIZATION OF BIM IN HEALTHCARE

Healthcare projects could capitalize on using BIM due to the complexity and rigorous build environment in healthcare facilities. The early adopters of BIM have experienced reduced project costs, shortened schedules, and increased project quality by modeling healthcare projects. Chellappa [10] addressed that BIM feeds the need for Evidence Base Design (EBD) to provide a healing environment for patients and staff in healthcare facilities. The following 5 aspects of why BIM benefits healthcare projects were pointed out by Manning and Messner [11]:

1. In order to avoid disease infection, the layout of facility in the hospitals should be arranged properly; 2. The coordination between complex mechanical, electrical and plumbing system; 3. Air ventilation and the simulation of lighting would be of paramount importance owing to the existence of patients in the hospital; 4. The information in design and construction stages could significantly benefit the operation phase of healthcare facility; 5. Savings compared to large investment into healthcare facility will be tremendous.

Two case studies were taken into consideration so as to evaluate the usefulness of BIM utilization: the first is a trauma hospital. Due to the discord of planning and facility reality, 2D conceptual drawings were abandoned after 7 months in this project. The benefits of adopting 3D BIM modeling in this project were: 1. The parametric design tools, the conversion of the drawing and dimensions between metric units (used by vendors/contractors) and imperial units (used by panning teams and users) in minimal time without any scaling or coding commands required; 2. The updates for drawing set cross-referencing are performed quickly and automatically. The second case study was the renovation of a Medical Research Lab. the team was able to save 20% man-hours through BIM compared to the historical data within the company to calculate division and department space, which was approximately 62% savings cost.

On top of all the mentioned benefits of operating BIM, noteworthy, it could be exploited in the different phases of healthcare facility commissioning including: pre-design phase, design phase, construction phase, transition to operational sustainability, post-occupancy and warranty phase, and retro- commissioning.

3.1 Case Study

Maryland General Hospital is of the highest quality and standard and university-affiliated teaching hospital. The project is the Central Care Expansion project of 92500 square feet expansion project, with the budget of more than $57 million [12].

The following systems needs to be commissioned near the completion of the construction: a new 500 KW emergency generator and paralleling switchgear, a new 2000KVA normal power substation three new automatic transfer switches and distributions, 2 new 650-ton electric centrifugal chillers and 650-ton cooling towers, temperature and humidity systems, and duct work, air handlers, dampers, and fans.

As regards the upsides of employing BIM in this project, firstly, using BIM in the commissioning process makes the whole project more transparent and understandable by the whole commissioning team, although it is a very demanding project of connecting new mechanical system to the existing system. Secondly, all information can be stored and shared in the tablet PC. Many errors can be avoided because large amount of paper work. Thirdly, the Tablet PC will be handed over to MGH facilities management staff for use in ongoing operations when the commissioning process is completed. In order to achieve immediate availability, data from Tekla and Vela systems are imported into the facility management system in use at the hospital with the aim of visualizing and managing documents and data updates to systems and equipment.

4.0 NEW-DESIGNED SAFETY SOFTWARE TOOL FOR CONSTRUCTION WORKER

Jia Qi *et al.* [13] carried out a research so as to formalize the collected design for construction worker suggestions through developing a dictionary and a constraint model, which could store the mentioned formalized suggestions. In doing so, a model checking software package to conduct designing for construction worker safety checking can be used during the design process. These tools make it possible for architects to optimize the drawings to ensure minimization of safety hazards during construction. In the meantime, constructors can take protective procedures to eliminate the construction site hazards from the beginning of the project.

In order to identify those provisions that deal with the fall protection, the designing for construction safety best practices were reviewed. Generally, more than thirty provisions which are related to the fall protections have been identified. These suggestions are classified into two categories. The first category of suggestions is constrained either by precise parameters or by certain materials. Another kind of suggestion is currently uncheckable. If a BIM did not have the information, or the information did not exist only on site in the actual building, or in the mind of an inspector, it would be regarded as an uncheckable concept.

As can be seen from Figure 2, once the collected suggestions have been formalized, the next step is to develop the proposed Construction Safety Checking System. The purpose of this system is to automatically check imported drawings which are in IFC format to alert designers to opportunities for improving construction safety. Designing for safety knowledge quickly, easily and economically needs to be provided by the system.

The model checking software is the cornerstone of the entire process, which is supported by a dictionary and a design for construction safety rule set.

The Construction Safety Checking software tool is based on a Model Checking Software. The AEC3 XABIO web-based test-bed or an online version of the Solibri software application can be adopted as the model checking application. AEC3 XABIO uses EPM and Octaga technology [14]. AEC3 XABIO can check a whole regulation or an individual clause and then generate a full explanation. This application is designed to find potential problems, conflicts, or design code violations in a building model. The other two important parts of the Construction Safety Checking tool are labeled as Constraint Model, and Main dictionary. A MS Excel spreadsheet is used to collect 'terms' and 'properties' from these suggestions when designing for construction safety suggestions are classified. It is also helpful to avoid having the concepts expanding in an uncontrolled fashion. Then, the dictionary is developed including terms, objects, properties critical for BIM authoring tools communication between Model Checking Software and the Constraint Model.

The constraint model, also known as rule sets, is the electronic format design for safety suggestions. It takes three steps to transfer the original paper-based design for safety suggestions to the Constraint Model. Transferring original design for construction safety suggestions into computer readable baseline electronic suggestions which are in XML format is done in the first step. Then, the logic between different 'terms' and 'term properties' in each suggestion is tagged by marking them with different colors. Finally, different logic is encoded.

Prior to defining the functionalities of the tool, the architecture of the tool needs to be determined. The safety checking system is expected to have two main functions. Checking the drawings against the design for construction safety rule set is included in one function. Additionally, safety information related to certain building components should be provided through this tool. On the other hand, existence of a large number of design suggestions in the textual form without any parametric information would make one of the differences between building codes and design for construction safety knowledge.

The process of checking a construction drawing includes the following steps:
First, the design is loaded into the rule checker by the user. Then the 3D view can be shown on the right hand side of the safety checking tool. The navigation functions usually include Zoom, Spin and Walkthrough. There are checkboxes on the left hand side, which are used to select objects and rule sets. The user could get detailed properties of any object by selecting an object tab. The user also can access all design for construction safety suggestions by selecting them from the rule sets. A detailed explanation of every suggested design provision will be provided and some graphs will also be given to illustrate complex issues. Next, the rules can be selected by the user that will be used to check against specific objects. Two sets of results will be produced after running the checking function. One is a list of all non-compliance issues identified in the drawings, along with suggestions about how to eliminate or mitigate these issues. The user could print the report out. On the right hand side, another set of results will be shown in the form of a 3D view. Red circles will show all the components which violate certain rule sets. The user can change drawings in the architectural modeling tools or keep the original design ideas if other requirements need to be met after getting the report from the model checker.

Next a case study of how to use the Safety Checking tool to check a building model is discussed. In order to check whether the slope of roof meets the requirement, the user imports the sample model into the Model Checking Software.

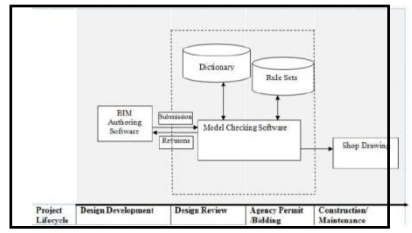


Figure 2 Architecture of Construction Safety Checking Software Tool (Adapted from [13])

The roof of the building model is so sloped that there is a possibility that the roof does not meet the requirement (See Figure 3). Then the pitch of the roof can be checked. Once the Model Checking Software has been run, the tool shows the results as can be observed in Figure 4.

In addition, the pitch of the subject roof does not meet requirements in accordance with the detailed description. According to OSHA standard, low-slope roof means a roof having a slope less than or equal to 4" in 12", the following requirement need to be met. "Minimize the roof pitch to reduce the chance of workers slipping off the roof."

Suppose, for example, the designers find the pitch of the roof exceed 4" in 12" after negotiation between the Design-Build team members. In order to solve the mentioned problem, they can go back and revise the building model. The pitch of the roof meets the safety requirement after changing the pitch of the roof in the BIM authoring software as illustrated in Figure 5.

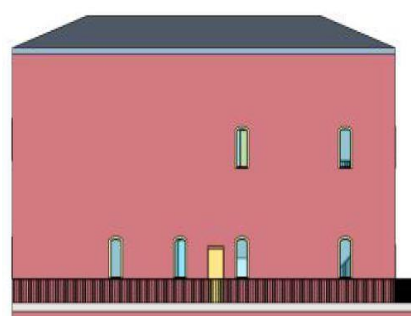


Figure 3 Sloped Building Roof (Adapted from [13])

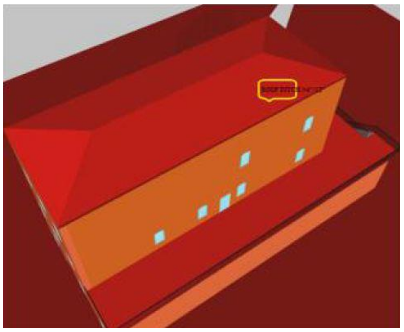


Figure 4 Checking Result (Adapted from [13])

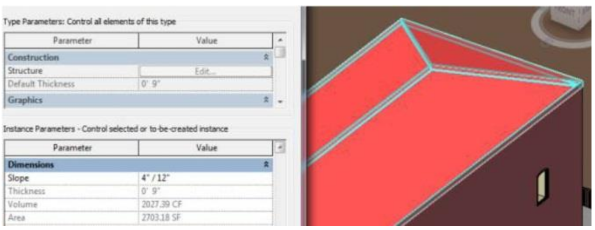


Figure 5 Change in the roof parameters (Adapted from [13])

5.0 EXPLOITING BIM IN SCAFOLDING SYSTEMS

Temporary facilities such as scaffolding systems, formwork, and shoring systems are structures that assist mainly in the placement of bulk materials. Most construction projects utilize temporary facilities frequently, and construction safety, quality, speed, and profitability are impacted by using temporary facilities [15].

Kim and Teizer [16] developed a rule based system that automatically plans scaffolding systems for pro-active management in Building Information Modeling (BIM). A rule was prepared based on the current practice of planning and installing scaffolding systems. The proposed computational algorithms automatically recognize geometric and non-geometric conditions in building models and produce a scaffolding system design which a practitioner can use in the field. An automated scaffolding system for commercially-available BIM software was implemented and tested in a case study project. The system thoroughly identified the locations in need of scaffolding and generated the corresponding scaffolding design in BIM.

The main emphasis was to address the articulated problems by integrating scaffolding systems into BIM-based construction planning through taking the advantage of the rich information available in BIM models including attempting to automate most of the processes of: assessing the construction site condition that changes according to the construction schedule, detecting required scaffolding systems and generating the design, visualizing them in the building model and construction simulation, and generating periodical utilization schedules and reports.

In order to automate these processes, an automatic rule checking system for temporary facility planning focusing on traditional pipe and board scaffolding systems was developed. The overriding concerns to be addressed were deciding where scaffolding systems were required, and how they can be built satisfying various design and safety requirements.

5.1 The Developed Algorithms

The developed algorithms were expounded as below:

- Recognize the geometric and non-geometric conditions in building models
- Suggest automatically generated scaffolding system designs to a user

The proposed algorithms first detect locations that require scaffolding systems and then provide the geometric information to each location. Design guidelines and best practices were incorporated into a construction plan to generate the necessary scaffolding design and utilization reports after obtaining the geometric information that is essential for the scaffolding design generation.

5.1.1 Previous Rule-Based Checking System

Myriad features from the available digital model geometry can be recognized through the rule-based checking approach. Feature recognition (FR) techniques are generally used to extract important features that are not explicitly expressed by the model. Features obtained from Computer-Aided Design (CAD) systems are used as the input for computer-aided analysis or automated manufacturing process planning systems. They save time and reduce potential human error [17]. Rule-based approaches were identified as a robust method among various FR techniques such as hint-based, graph-based, artificial neural network-based and volumetric decomposition [18].

In addition to that, rule-based systems are flexible and rational because the rules and facts are separated in the system structure [17].

A rule checking process can generally be structured into four stages [19]:

- Rule interpretation and logical structuring of the rules
- Building model preparation
- Rule execution
- Checking result reporting

5.1.2 Proposed Rule-Based Checking System For Temporary Facilities In BIM

Figure 6 shows the different steps involved in the framework to implement a rule-based checking system. Collecting project data from a building model and construction schedule is done in the initial step. Geometric information such as building object shapes and their locations within the model and non-geometric information such as materials, task information, and the stakeholder in charge of the task would be provided through BIM and schedule information.

Then, based on best practices and regulatory rules, the rules for detecting required temporary facilities from the model are established. These are provided either by industry, for example vendors and suppliers, or other closely related organization, for example OSHA.

The model geometry is interpreted using such placement rules and project information to identify the required temporary facilities.

The temporary facility design is then generated in compliance with corresponding OSHA regulations and industry best practices related to temporary facility design.

Finally, the temporary facility-loaded model and automatically generate reports in order to facilitate better communication and decision making can be utilized by project participants.

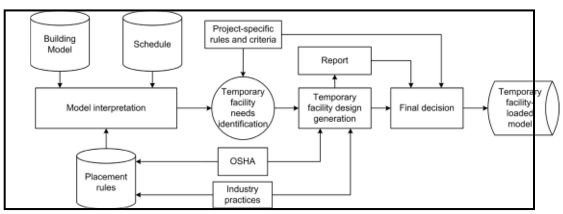


Figure 6 Framework to implement a rule-based checking system for temporary facilities in BIM (Adapted from [16])

5.2 Prototype Of a Rule-Based Algorithm For Scaffolding System

The proposed rule-based system is composed of two major parts. Implementing the rule-based model geometry interpretation is one of the two mentioned algorithms. Designing and planning algorithm that utilizes the information acquired from the geometry interpretation and generates the scaffolding design, incorporates it into the model, and generates the utilization reports is the other algorithm.

5.2.1 Rule-Based Model Geometry Interpretation

The building model geometry was analyzed for the implementation of the rule-based geometry interpretation, so that it contains a feature that can be evaluated by the placement rule. Each work face in the model is evaluated by the rule through reasoning the scaffolding height. The geometry interpretation algorithm first detects all the work faces in the model and then identifies the scaffolding height for each work face.

5.2.2 Geometry Interpretation Process

A face-edge representation methodology was implemented in order to enable the qualitative reasoning in the geometry interpretation system. This methodology was adopted in the fields of qualitative geometric reasoning, qualitative spatial reasoning, image recognition, and geographic mapping, and elsewhere [20–22]. Physical building objects were decomposed into geometric entities such as faces, edges, and vertices as same as what Chinowsky and Reinschmidt [20] did for CAD model interpretation. Then, the coordinate information available for each geometric entity is utilized to form the basis in determining the qualitative relationship between building objects and geometric entities. The geometry interpretation process is composed of four steps (See figures 7-11):

- object decomposition
- work face composition
- work face linking
- scaffolding space specification

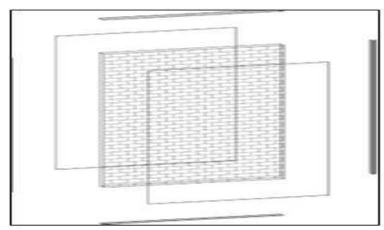


Figure 7 Wall object decomposition (Adapted from [16])

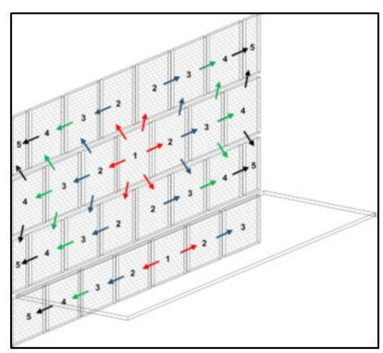


Figure 8 Work face composition (Adapted from [16])

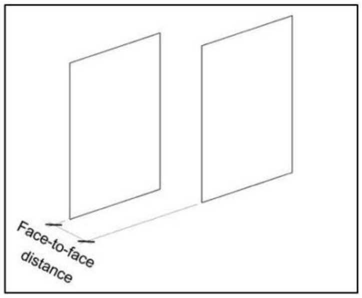


Figure 9 Face-to-face distance (Adapted from [16])

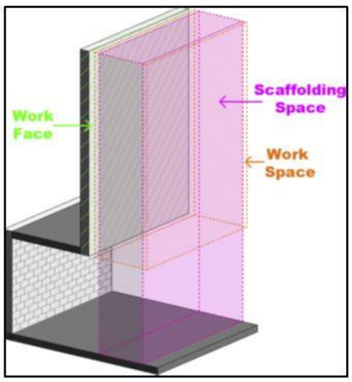


Figure 10 Scaffolding space and work space specification (Adapted from [16])

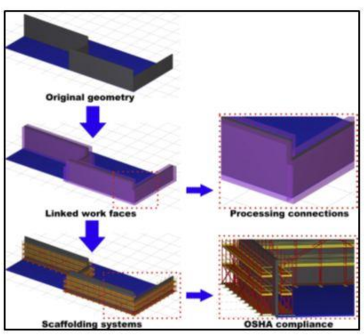


Figure 11 work-face linking (Adapted from [16])

5.3 Geometry Interpretation Test

The explained algorithm was applied to several test case studies so as to assess the performance of the geometric reasoning approach. Figure 10 illustrates the process of detecting work faces from a part of a realistic BIM. The model, created in Tekla Structure, is a three-story building model that is composed of three slabs and two wall objects (See Figure 12).

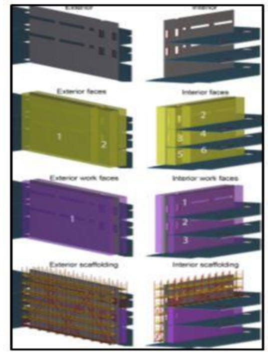


Figure 12 Visualization of the work face detection process in a test model (Adapted from [16])

Figure 11 shows scaffolding systems that were automatically linked to the construction schedule. Visualizing the construction sequence incorporating the scaffolding systems, and assisting pro-active procurement of scaffolding system materials by automatically notifying the upcoming needs were achieved through exploiting the capabilities of Tekla Structure. Tekla Structure visualizes the construction sequence by creating the virtual links between construction activities and set of building objects to be constructed by the activities. Furthermore, an automatically generated bill of materials for one of the generated scaffolding systems is shown in Figure 13.

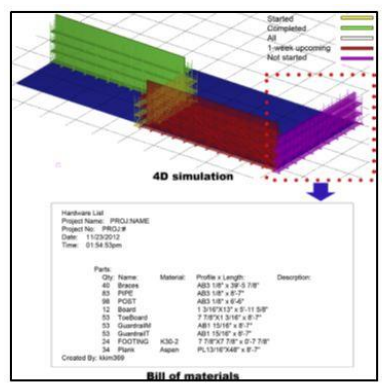


Figure 13 Incorporating schedule information to scaffold construction and generating automated reports (e.g., bill of materials) (Adapted from [16])

5.4 Case Study Implementation

The rule-based scaffolding planning system was implemented and validated in a BIM used on a life construction project after experimentation with various test models. The model for a hospital extension is shown in Figure 14. The developed geometric reasoning algorithm successfully detected work faces from the building model in the vast majority of the cases. The medical facility using scaffolding models of a standard pipe and board scaffolding system through BIM was shown in Figure 15.

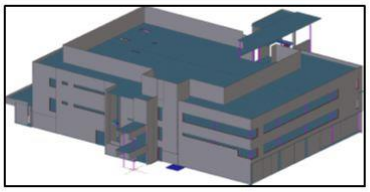


Figure 14 A realistic building project model (Adapted from [16])

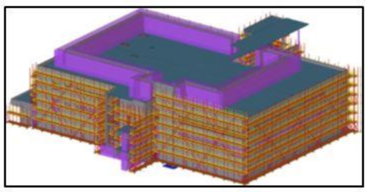


Figure 15 Scaffolding systems incorporated in a building model (Adapted from [16])

6.0 IDENTIFYING AND ELIMINATING FALL HAZARDS AT THE PLANNING STAGE OF CONSTRUCTION

Occupational health and safety (OHS) in building construction remains a worldwide problem due to the occurrence of workplace injury, illness, and fatality statistics. More than one third (36%) of all US workplace fatalities occur in the construction industry. Similarly, the Finnish construction industry is responsible for one out of four fatal occupational accidents [8].

Zhang *et al.* [23] carried out a research to develop an automatic BIM-based fall hazard identification and planning tool that (1) identifies potential fall hazards dynamically based on the construction schedule, (2) assists labor-intensive modeling and planning tasks of fall prevention system effectively, and (3) improves workers' safety awareness by visualizing the potential hazards. Additionally, the possibilities, benefits and development needs for automated safety code checking and planning were evaluated. Also, the usability and maturity of the developed BIM-based prototype tool that supports fall prevention planning in building construction projects were examined.

The rule-based checking system, whose procedures were explained before as a base for achieving the mentioned goals, was used. Rules can be applied for detecting safety hazards when the building information model is well constructed and the connections between the model objects and the schedule are established. A platform developed by Zhang *et al*. [7] can function as a tool for providing easily accessible and understandable visualization of up-to-date progress on construction and safety over time, and in particular, to detect dangerous hazard locations on the site. The method of Zhang *et al*. [7] could be explained as below:

- Slab edge protection: Figure 16 explains the algorithm for detecting required prevention methods according to OSHA safety rules
- Slab-hole protection: There are two methods in general to detect slab holes: geometry-based detection and object based detection.
- Wall-opening protection: The wall-opening detection process is similar to slab-hole detection. For the ones located at the edge of the slab, once the wall element has been installed, the guardrail for the slab edge protection can be removed, at the same time, wall- opening if exists need to be protected. If there is no slab hole, for example a hole for an elevator shaft, close to the interior wall, the wall-opening does not need to be considered or protected.

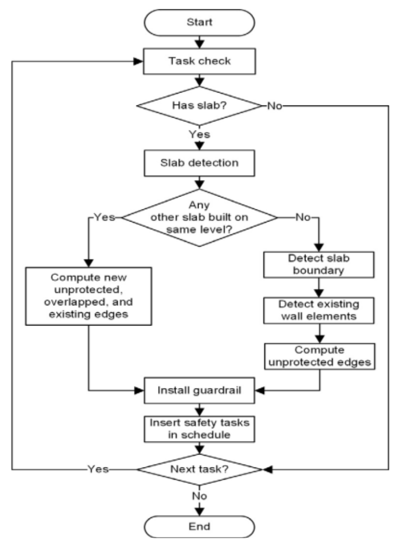


Figure 16 The rule checking algorithm for detecting required prevention methods for slab edge (Adapted from [23])

6.1 Case Study 1: Comparison Of Manual vs. Automated Modeling

Fall protection equipment was modeled both manually and automatically for cast-in-place concrete in the basement of an office building in the first case study. Benefits and limitations of both methods were compared.

6.1.1 Manual Modeling Of Safety Protective Equipment

A photo and the modeled 3D safety railing components were shown in Figure 17 as it is typically used at finish construction projects. The selected guardrail solution for leading edges on slab surfaces consists of guardrail posts and timber railings.

The 3D presentation of the customized safety components were modeled manually. In addition, safety railings in edges of cast-in-place slabs, and guardrail posts installed to pre-designed holes were presented in Figure 18 and 19 respectively.

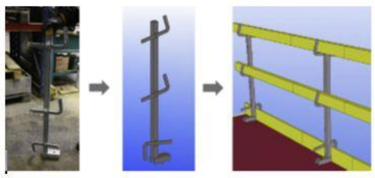


Figure 17 Safety railing equipment modeled for the project (guardrail post for surface installation used together with timber railings) (Adapted from [23])

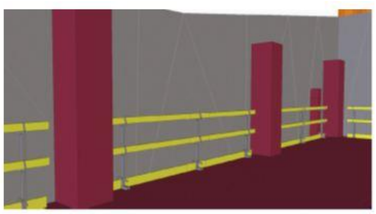


Figure 18 BIM-based falling prevention planning: safety railings in edges of cast-in-place slabs (adapted from [24]).

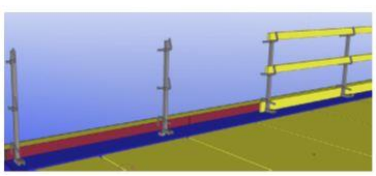


Figure 19 The same safety railing solution modeled into an upper office floor: guardrail posts installed to pre-designed holes in the prefabricated steel beams (adapted from [24])

The test project was an office building that was originally modeled by the project's structural engineer in Tekla Structures. A feasible approach that is useful for practitioners in the field was provided through the interactive 4D fall protection planning, especially scheduling and visualization of safety railings.

6.1.2 Automated Fall Hazard Detection And Protection Using Rule-Checking Algorithms

A good level of perception of potential fall hazards on the construction site coming typically with high level of detail was provided using manual modeling of fall protection methods. The automated modeling results of the developed system on one floor of the basement were illustrated in Figure 20.

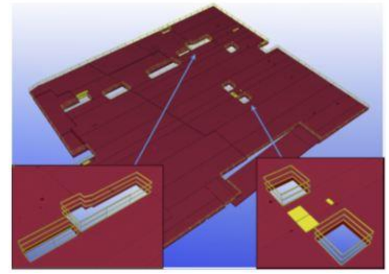


Figure 20 Automated slab edge and hole detection and guardrail installation results (Adapted from [23])

6.1.3 Experience on Manual BIM-Based Fall Protective Methods Modeling

The fall hazard detection and prevention planning was carried out by modeling safety railings and floor opening covers in the structural model of the same office building. The model pertaining to fall prevention plans were implemented in the BIM and construction site as can be seen in Figure 21. Due to slightly different viewpoints, there are some visual differences between pictures. Some pictures also show the models to the concrete formwork. While it influences the location of safety railings, its parts were modeled at a more abstract level than the safety railings. Materials, equipment, and other temporal construction objects were not modeled in BIM which could be regarded as one current difference.

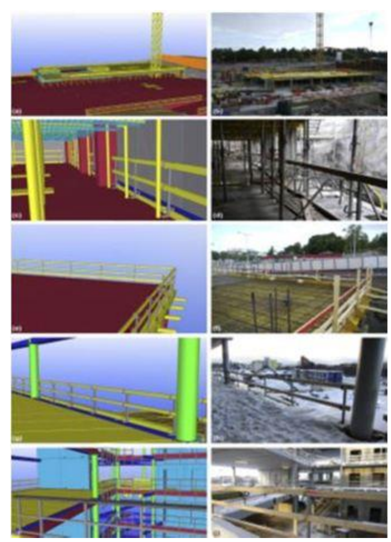


Figure 21 Comparing model and live situation (Adapted from [23])

6.1.4 Comparison Of Manual And Automated Fall Protection Modeling Methods

The following are the observed benefits of automated modeling approach:

(1) The time requirement using the automatic modeling method is significantly reduced compared to manual modeling

(2) Manual modeling requires higher safety expertise and modeling familiarity.

(3) It is difficult and time-consuming to update corresponding safety requirements manually when a design change or schedule update is made.

(4) Safety solutions with higher level of detail can be provided by manual modeling (see Figure 22).

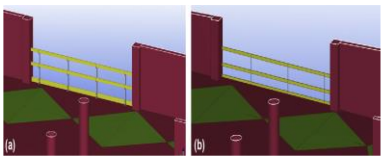


Figure 22 (a) Manual vs. (b) automated modeling results (Adapted from [23])

6.2 Case Study 2

The developed automated rule-checking tool was applied on a multi-story precast apartment building model in the second case study (see Figure 23). The goal was to demonstrate safety checking results dynamically based on the project schedule. Tekla Structures 17.0 modeling software was used to model the project's structural model. Based on information obtained from the contractor, the 4D schedule needed for the developed automated rule-checking platform was added to the structural model. This information was provided by the site engineer in the traditional format of a construction schedule and work breakdown structure (WBS) concerning the installation sequence.

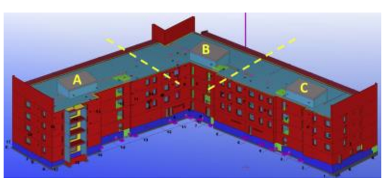


Figure 23 Overview of the multi-story precast apartment building model and its sections (Adapted from [23])

The fall prevention system was executed and visualized in the model automatically including guardrails after executing the rule checking algorithm
[7]. It also created subtasks for the installation and removal of safety-relevant equipment into the construction schedule. The updated schedule with the required safety solution is partially shown in Figure 24.

Figure 25 illustrates the object representation for the 4D simulation. Moreover, the installation and removal of the building sequence is shown in Figure 26(a) and (b) including detailed views of the slab edge protection and wall opening protection. The checking report, which can be exported into a MS Excel format as shown in Figure 27, was also generated automatically after the generation of the safety protective system in the model.

	Task Name	Planned Start Date	Planned End Date
1	Foundation	4/30/2012	5/4/2012
2	⊟ **Section C**	**5/7/2012**	**6/14/2012**
3	⊟ **1st floor**	**5/7/2012**	**5/15/2012**
4	Walls and Balcony panels	5/7/2012	5/10/2012
5	⊟ **Staircase slabs, Stairs, Balcony slabs**	**5/11/2012**	**5/11/2012**
6	Slab Edge Protection	5/11/2012	5/11/2012
7	Slab Hole Protection	5/11/2012	5/11/2012
8	⊟ **Hollow core slabs**	**5/14/2012**	**5/14/2012**
9	Slab Edge Protection	5/14/2012	5/14/2012
10	Slab Edge Protection Removal	5/14/2012	5/14/2012
11	Slab Hole Protection	5/14/2012	5/14/2012
12	Precast ducts	5/15/2012	5/15/2012
13	⊟ **2nd floor**	**5/17/2012**	**5/25/2012**
14	⊟ **Walls and Balcony panels**	**5/17/2012**	**5/22/2012**
15	Slab Edge Protection Removal	5/22/2012	5/22/2012
16	Wall Opening Protection	5/22/2012	5/22/2012
17	⊟ **Staircase slabs, Stairs, Balcony slabs**	**5/22/2012**	**5/22/2012**
18	Slab Edge Protection	5/22/2012	5/22/2012
19	Slab Hole Protection	5/22/2012	5/22/2012
20	⊟ **Hollow core slabs**	**5/23/2012**	**5/23/2012**
21	Slab Edge Protection	5/23/2012	5/23/2012
22	Slab Edge Protection Removal	5/23/2012	5/23/2012
23	Slab Hole Protection	5/23/2012	5/23/2012

Figure 24 Updated construction schedule with the installation and removal of fall prevention methods (Adapted from [23])

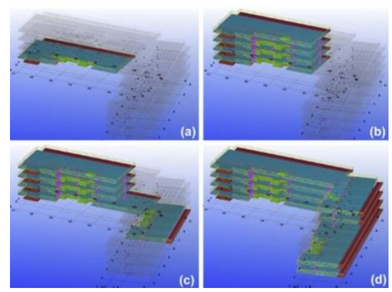


Figure 25 4D simulation of the model slab, column, and guardrail prevention systems (Adapted from [23])

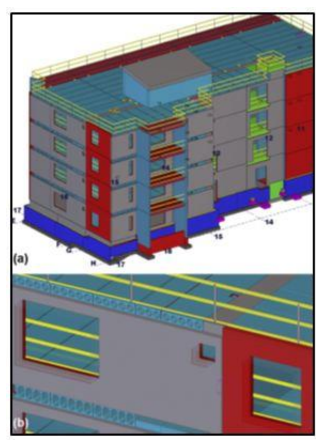


Figure 26 (a) Protective fall protection systems in Section A of the building and (b) close view of wall opening protection (Adapted from [23])

Slab Hole Checking Results								
Project Name:				Analyst:			Date: 1/28/2013 2:36:10 PM	
No.	GUID	Level	Distance to Lower Level (mm)	Length (mm)	Width (mm)	Area(m2)	Prevention Method	Check
1	2301919	1	3185	235.86	235.86	0.05	Cover	FALSE
2	1862884	1	3185	110	150	0.02	Cover	FALSE
3	1845126	1	3185	200.01	120	0.05	Cover	FALSE
4	1807649	1	3185	200	200	0.04	Cover	FALSE
5	1808525	1	3185	270	180	0.05	Cover	FALSE
6	1808623	1	3185	200	200	0.04	Cover	FALSE
7	1808591	1	3185	260.91	200	0.05	Cover	FALSE
8	1808719	1	3185	200	200	0.04	Cover	FALSE
9	3390930	1	3185	942.25	614.51	0.09	Cover	FALSE
10	1862931	1	3185	150	110	0.02	Cover	FALSE
11	3390851	1	3185	460	305.03	0.17	Cover	FALSE
12	3390827	1	3185	610	390	0.23	Cover	FALSE

Figure 27 Bill of materials: slab-hole checking results provide an Excel sheet for estimating and prefabrication of safety equipment (Adapted from [23])

7.0 CONCLUSION

Construction industry has always been beset with injuries and fatalities happened resulting from overlooking pertinent safety rules and regulations. Over the past few years, construction sector has drastically benefited from a significant improvement made in the visualization of myriad steps involved in its process. In light of this, there has recently been a strong tendency amongst the practitioners toward exploiting BIM in different construction phases with the aim of decreasing the number of incidents occurred. Hence, the authors of this paper have delved into the usefulness of using BIM in reducing safety accidents with respect to the past research conducted in this field including; expounding a new-designed safety software tool, comparing multiple design for safety tools, its utilization healthcare, and delineating an algorithm through which scaffolding systems and Identification and elimination of potential fall hazards would significantly be improved. It is observed that BIM operation in construction industry, particularly prior to the construction stage, would considerably diminish the occurrence of accidents pertaining to safety matters emanating from improving the practitioners' perception of projects through modeling the diverse safety equipment, and foremost, identifying the potential hazards that may contribute to serious injuries.

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