CASE STUDIES OF BIM-BASED DYNAMIC SCAFFOLDING DESIGN AND SAFETY PREVENTION

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Abstract: Scaffolding systems are essential in construction site to assist workers with transport and placement of bulk materials and equipment. A traditional approach of conducting scaffolding design is heavily based on documentations and the limitations are quite apparent such as less effective, reactive and labour intensive. It is also noticeable that the limited level of design automation can repetitively incur compliance issues of code-of-practice, design regulations, workplace health and safety and as such. Given the merits of Building Information Modelling (BIM) and the prevalence of adopting BIM technologies in the life cycle of construction project, i.e., design, construction and operational phase, this study tentatively proposes a BIM-automated approach to reduce or eliminate the aforementioned compliance issues in scaffolding engineering. The case study demonstrates a commercially available BIM system that dynamically generates scaffolding design by taking into account the design and OHS rules/regulations (parametric-driven) and reacts to the real-time modification of project features for fall prevention purpose. From the case study it will conclude that such an approach will facilitate the automated rule-checking process of erecting scaffolds, deliver smarter scaffolding erection plan and enhance workspace safety.

Keywords: scaffolding, BIM, OSH, fall prevention

1. INTRODUCTION

There have been a growing number of construction projects across in a global context. To ensure an efficient design of construction scheme without impacting health and safety requirements, construction practitioners have already started to address the productivity and workplace occupational health and safety (OHS) challenges (Loosemore & Andonakis, 2007). As temporary facilities, scaffolds are quite commonly seen in the practice of constructing/maintaining buildings and facilities. Despite of less significance against the overall construction activities, scaffolding construction indeed involves a considerable amount of resources and efforts, particularly in very large scale and complex projects (Kumar et al., 2013). It is expected that as a growing complexity of industrial projects (Vidal & Marle, 2008), there is a growing demand of studying the scaffolding activities and the associated issues that can averagely lead to a very large amount of capital and labor input against the overall project. To remedy the productivity loss during scaffolding design and construction, the current research work has attempted Building Information Modeling (BIM) aided approaches to tentatively deliver parametric design paradigms and design methodologies (Azhar et al., 2008). But there are currently still several problems in operational phase for the industry (Azhar, 2011), given the phenomenon that the present-day market is still lack of commercially available systems and scientific proofs that support their effectiveness (Chi et al., 2012). Besides, the attention to the productive and effective front-end design and planning of temporary facilities is still not enough, which can be seen from the fact that design drawings and documentations of scaffolds produced by scaffolding vendors are most often reviewed only to assess scaffolds impact on their adjoined buildings (Halperin & McCann, 2004). Apart from this, construction workers who are frequently working at scaffolds are yet having a growing concern about health and safety, i.e., fall and item dropping hazards. This is another reason why smart scaffolding design tools are crucial to be invented. Construction industry has reported a quite high volume of incidences including injuries and fatalities across nations and there is a need for construction conditions to be dynamically adjusted to the constantly changing settings of space and time (Huang & Hinze, 2003; Hsiao, 2008).

2. LITERATURE REVIEW

Productivity and safety issue have recently aroused an urgent need for the construction industry to resort to technological aids, given the complexity and uniqueness of the individual project. Digital representation and information management within BIM are currently a welcoming trend for construction practitioners to apply in a growing amount of construction projects (Wang et al., 2013a; 2013b; Wang et al., 2014a; Shou et al., 2014). As stated by Zhang et al. (2013), the construction industry is in need of improving the efficiency of manually processing paper documentations, which include building design, engineering conduct, safety rules and regulations, scheduling, work face planning and so on (Zhou et al., 2012). An overview of literature helps identify there are great research interests and fruitful works of applying BIM methods and systems in the practices of design, planning, construction, operation and maintenance (del Puerto & Clevenger, 2010; Sulankivi et al., 2009; Benjaoran & Bhokha, 2010; Ku & Mills, 2010: Lew & Lentz, 2010). As a result, how to mitigate site hazards through improving design has become one of the major challengers in the OH&S context, for instance, fall hazard identification and protection (Chantawit et al., 2005: Kiviniemi, 2011). As there would never be a single factor or two to influence construction design and planning, identifying potential risks on construction site was deemed arduous and inaccurate before BIM was invented. This can be seen from statistical data of historical incidences all around the world due to not using guardrails, fences and safety nets and adopting the relevant safety precautions (Construction 2003, Huang & Hinze, 2003). There is frequent OHS code-compliance problems related to scaffolding systems (1, 2). For example, an average amount of 4500 injuries and 50 deaths takes place annually in construction industry in the USA and the cost associated with compensation reaches more than $90 million (3). Despite the mandatory regulations, hazards still take place sometimes in the context of dynamic jobsite situations where temporary changes constantly happen. Since work site productivity and safety go hand-in-hand, these statistics justify additional efforts towards optimizing design, planning, and utilization of scaffolding systems. There are many reasons, for instance, changings are not updated in time, and preventive measures for safety consideration are easily overlooked (Gambatese et al., 2005). The related research works and studies have looked into various fields for instance, safety accident analysis (Whitaker et al., 2003: Rubio-Romero et al., 2012), Building Information Modelling (BIM) supported occupational health and safety design (Teizer et al., 2007: Kim & Teizer, 2014), automated scaffolding design (Kim & Ahn, 2011), estimating and planning tool of scaffolding (Kumar et al., 2013), and prediction of the type of scaffolding system (Kim & Fischer, 2007). Safety as a factor, has been embedded into BIM to extend 3D design and 4D schedule to 5D feature associated with the construction design (Benjaoran & Bhokha, 2010: Sulankivi and Kiviniemi, 2010; Kähkönen et al., 2010). Research focus has also been casted in development of conceptual frameworks to help formulate principles or approaches that might be able to bridge these gaps (Hammad et al., 2012; Kim & Fischer,. 2014; Kim & Teizer, 2014; Zhang et al., 2015). Looking at the non-traditional projects, there are more types of complex scaffold structures, for instance, Independent, Suspended, Tower, Birdcage and Cantilever. Nevertheless, standardized procedures of instructing the scaffolding practitioners about how to plan and update the scaffolding design in diversified project scales are still deficient, which leaves a probable barrier for productivity and safety improvement to the project managers. BIM is an IT enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository (Gu & London, 2010; Wang et al., 2014b; Wang et al., 2014c). BIM is a subset of a technology innovation, and like other emerging paradigms that have potential to expedite a project in terms of lean design and construction, OHS planning and industrialization (Thanoon et al., 2003; Emmitt et al., 2004; Løvset et al., 2013). Most important in its successful application is its need to be integrated throughout the project lifecycle and therefor its need be easily adopted by all partners in the construction process (Lu et al., 2011). In this regard, this study aims to provide feasible solutions, as stated in the case study, to support the best practice of applying am unique BIM tool in scaffolding engineering.

3. CASE STUDY

3.1 Methodology

Parametric design is used to modeling scaffolding structures. Designers define the geometric figures of parts applying the dimension parameters and constraints. The geometric figures and models will be renewed as the dimension parameters and constrains changing. Parametric model construction, constraint relation extraction, as well as solving method of constraints are the crucial steps in parametric design.

As the primary objective of the BIM-supported scaffolding design is to forewarn the potential fall hazards and minimize the risk, there accordingly is a need to consider the OH&S compliance in the demonstrated work. The first and foremost effort is to identify and generalize the potential categories and consequences of the risks as specifically as possible from the existing OH&S Codes of Practice, for instance, WA Australia, as stated from Table 1. Furthermore, to set forth the rationales of risk assessment in BIM the paper applies LEC hazard assessment method (Dai et al., 2006) to rank the dangerous source of scaffolding activities (Table 1), which provides specific methods and basis for risk calculation and control in BIM. The LEC method specifies that:

$D=L\times E\times C$ (the bigger the D is, the higher the risks are)

D−level of danger; L−level of likelihood; E−frequency of personnel exposure to risk, and C−Consequence of risk.

Table 1. Risk identification of scaffolding engineering activities

Scaffolding Activity	Conditions for Occurring Risks	Possible Outcomes	Risk Level and Frequency	D=L*E*C

Prepare Scaffolding Scheme	1. Undue construction schemes 2. Lack of inspection for scaffolding structural calculation and technical details	Collapse	Highly risky and frequent	≈20
Vehicle and Workforce	1. Hit against scaffolds due to driving errors or vehicle break failure 2. Dismantle connective components randomly 3. Lack of personal protective measures, e.g., not wear safety belt, helmet, etc.	Collapse/Fall from height	Risky and less frequent	≈3
Scaffolding Framework	1. Miss scaffold floor and trestle somewhere 2. Scaffold platform not stable 3. Miss lock 4. Use materials with wrong specifications	Fall from height	Highly risky and very frequent	≈40
Preventive Measures	1. No prevention net and guardrail around scaffolds 2. Damage or lack of safety precautions 3. A poor sense of responsibility and safety awareness	Fall from height/Object strike	Highly risky and very frequent	≈43
Load	1. Lack of inspection and maintenance for structural tilt caused by overloading (wind, rainstorm, personnel evacuation, etc.) 2. Undesirable layout of tools and other assets	Collapse/Object strike	Risky and frequent	≈25

3.2 Case study 1 – BIM for 3D parametric – driving scaffolding design

In a BIM model, objects are defined by built-in and user-specified parameters, and external data such as physical, aesthetic, functional data accessed through databases. Parametric modelling enables parameters to be processed by mathematical formulas and computational algorithms before being passed among objects.

Discussions with contractors have revealed that there are a number of decisions which play a role in how the rules derived from manufacturers' specifications and safety standards affect scaffolding composition. What these decisions reflect are the influence of specific project constraints, including the component types and sizes readily obtainable, and practices that individual contractors have observed to increase onsite productivity, generally by reducing assembly times. In order to accurately reflect both project requirements and contractor preferences, it is essential to provide users with control over input parameters relating to both the chosen scaffolding system and applicable design codes and construction standards for the given location and conditions. At the same time however, certain restrictions must be put in place that limit allowable inputs to options within the range of compliance defined by scaffolding specifications and standards, as this ensures that minimum safety requirements are always met and designs can be deemed-to-satisfy.

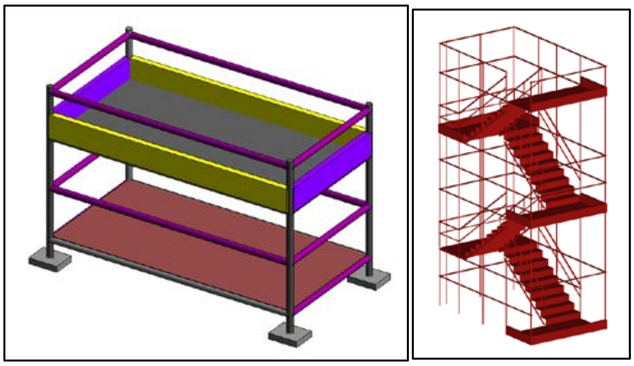

Figure 1. Parametric-driving modular scaffold designs

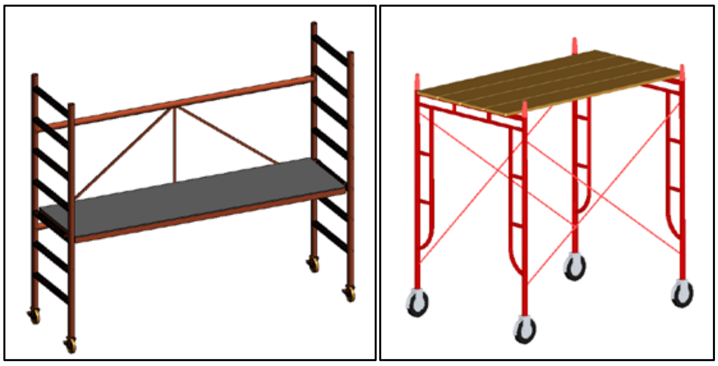

Figure 2. Parametric-driving mobile scaffold designs

The parametric models include modular scaffold, mobile scaffold and stairs.

Different preferences are accommodated within the prototype through user-controlled variables that act as modifiers on fixed project and scaffolding parameters, altering the inputs to design rules and thus the scaffolding composition generated. Combined with individual project constraints, these preferences manage the rule algorithms that control face conditions and corner junctures. The prototype is based on the specification for a type of scaffolding known as modular scaffolding, since it has a significant presence in the Australian market.

3.3 Case study 2 – BIM for automatic detecting of different types of openings and falling prevention planning

Developing BIM-based falling prevention planning and opening detection is one of the main targets of the research project. BIM was used for detailed falling prevention planning, including temporary safety railings and floor opening coverings.

The different contexts are determined by acquiring the corresponding spatial and geometric information of each object: (1) the internal gap between the inner edge of the length of the platform and the face of the building or structure immediately beside the platform are detected to define where edge protection is needed; (2) holes in scaffold platform are detected to prevent fall through openings; (3) openings in edge protection at points of access to stairways or ladders are detected to determine where additional opening protection is required. After object identification, firstly, safety rules of different types of openings are inputted to scaffold model and different conditions are categorized according to specific geometry attributes. Secondly, corresponding rules are executed and visualized for supporting decision-making. After applying and visualizing an automated version of rule checking, human input is optional to assist in the final decision making process. Finally, the checking results and visualization are updated in the BIM. Each hazard is detected and the proper protection method is shown. The geometry of the created safety equipment is based on identifying the unprotected leading edges, holes, and openings in scaffolding, etc... Two types of fall protection scenarios were identified and are listed in illustration.

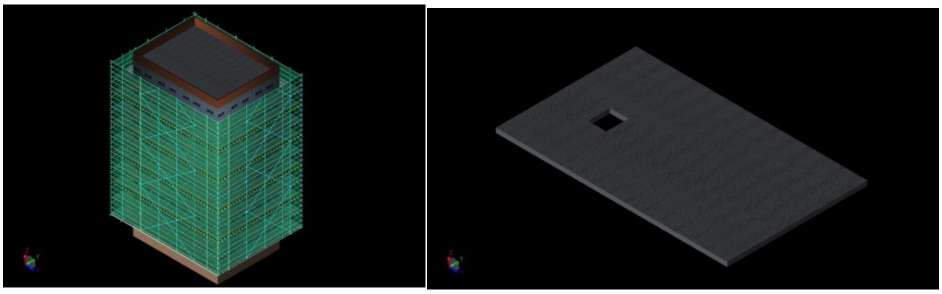

Figure 3. Building scaffolds and rule-based hole and edge detection

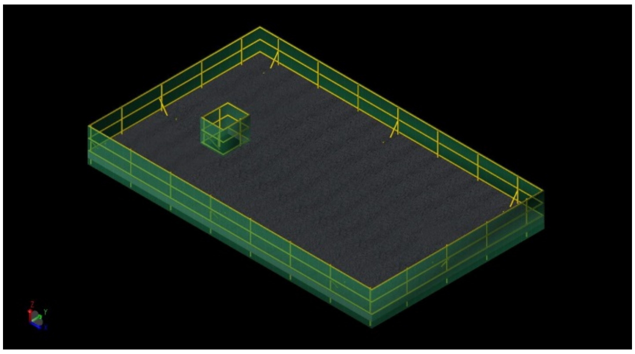

Figure 4. Guardrail systems at edge and cover access opening

4. CONCLUSION AND SUMMARY

In order to improve robust scaffolding design and prevent from severe incidences, this study believes that BIM technology are promising to address those challenges, as demonstrated by BIM-based approach and case study to facilitate smarter and safer scaffolding design. At present, the prototype is awaiting to capture practical knowledge related to scaffolding construction and safety guidelines by encoding design configurations from different construction settings. It provides decision-support by presenting user choices as explicitly-defined input parameters that allow the design intent and assumptions behind a particular scaffolding solution to be communicated amongst different project stakeholders, establishing a shared understanding of project-specific requirements and constraints. The conclusion also acknowledges that the emergence of BIM has brought about a new way of design, construction and facility management and maintenance with everything digitalized: using 3D graphical models to reconstruct a virtual and immersive site scene where time, cost and other associated dimensions can be easily added, monitored and managed.

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