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EXAMINING THE LAYOUT OF SCAFFOLDS AND DECKS USED IN CONSTRUCTION PROJECTS FROM THE PERSPECTIVE OF BUILDING INFORMATION MODELLING

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Abstract. *A 2014 report conducted by the Council of Labour Affairs in Taiwan indicated that falls from a height accounted for the highest percentage of occupational accidents in the construction industry, in which system scaffolds are a commonly used shoring system. However, no clear guidelines are available for construction safety concerning scaffolds. Thus, to effectively increase the overall safety of construction workers and reduce the likelihood of occupational accidents, this study applied the concept of building information modelling (BIM) to generate 3D models for constructing system scaffolds or other safety facilities, simulate the images of safety passages and temporary stairs, propose preventative measures to reduce errors that can occur when installing system scaffolds, and serve as a reference point for construction workers to perform their work.*
Keywords: Building information modelling (BIM), Decks, Safety passages, System scaffolds

1. Introduction.

1.1. Construction phase of construction projects. The lifecycle of a building or civil engineering structure can be divided into the construction phase and use phase. The main factors to be considered in the use phase include seismic force, wind force, live load, and dead load, whereas those to be considered in the construction phase involve newly poured concrete, reinforcement steels, formworks, construction personnel, and construction equipment vibrations [1]. In other words, these two phases are affected by different patterns of external loads. Construction professionals mainly focus on the safety problems involved in the use phase of a building structure. Existing regulations, guidelines, or specifications for structural designs also emphasize building structure safety in the use phase, and the building structure is strengthened to resist external forces such as seismic force and wind force. A temporary structure in the construction phase is generally referred to as a temporary work (or falsework), which, dismantled immediately at the end of the construction project, is often overlooked in importance. Kwak and Kim have analyzed shoring systems installed to support applied loads during construction [2]. Currently, design specifications for temporary works used in the construction phase are few. Construction professionals typically refer to the design specifications for the use phase to calculate the required structural strength of the temporary structure. Therefore, the accuracy of the calculation is not guaranteed. Reinfurt et al. have described the design, construction, and monitoring of a temporary shoring support system which permitted the construction of two urban stations for the Metro Link St. Louis Light Rail System [3]. As temporary works in construction, system scaffolds are often overlooked to the extent that accidents have frequently happened because of their failure. Stauffer et al.

have presented the design and construction of an innovative shoring system in Seattle, Washington [4]. Large-area concrete pours involving the use of elevated structures must be conducted by multiple construction workers at the same time. The falling of system scaffolds has often led to mass casualties of construction workers and substantial loss of life and properties. Figure 1 shows site template support collapsed for New Activity Centre Building Project in Taoyuan Chin-Shi Elementary School on July 21, 1996. This incident caused one death. Figure 2 illustrates the fallen formwork used as scaffolds for constructing the Beishan Interchange on Freeway No. 6 in Nantou County, September 30, 2010. This incident caused seven deaths and three injuries.

Figure 1. Fallen formwork used as scaffolds for constructing in Chin-Shi Elementary School in Taoyuan

Figure 2. Fallen formwork used as scaffolds at the Beishan Interchange on Freeway No. 6 in Nantou County

1.2. **Motivation and objectives.** The visualization interface provided by BIM software can effectively assist construction workers in performing their work and display 3D visual images rather than the conventional two-dimensional (2D) floor plans. In general, people who are not experienced and well-trained engineers have difficulties determining all the possible information of a 3D space by examining 2D images, let alone discovering possible safety concerns or problems from these plans that can occur during construction projects. Automatic identification of construction safety issues using Building Information Models requires an understanding of the safety risk drivers that are detectable during the design phase [5]. The construction of scaffolds is typically laborious. Consequently, once any errors are identified after the scaffolds are constructed, construction workers basically only enhance the weak spots rather than dismantle and rebuild the scaffolds. Under this circumstance, occupational accidents can easily occur. The 2011 analysis of major occupational accidents in the construction industry conducted by the Council of Labor Affairs [6] indicated that, among all the industries in Taiwan, the construction industry accounted for the highest percentage of occupational accidents. Furthermore, among the major occupational accidents that occurred in the construction industry, falls from a height accounted for the highest percentage of occurrences, followed by structural collapse (Figure 3). Therefore, effectively designing safety passages and temporary stairs that permit workers to ascend or descend safely is essential to reduce the possibility of occupational accidents at construction sites. BIM technologies can be used to draw the images of system scaffolds used as temporary works in construction projects, simulate the scaffolds' onsite functions, and thus assist engineers to visually identify any possible flaws in the construction of scaffolds as well as adjust the construction methods or locations through a computer. This practice can save the construction workers from the trouble of dismantling and reconstructing temporary works when they notice an error at the construction site. Accordingly, the objectives of this study were as follows.

A. Examine the current usage of the system scaffolds as temporary works in construction projects and the types and cases of occupational accidents at the construction sites.
B. Use BIM technologies to simulate the actual procedures of constructing system scaffolds and safety facilities at the worksites to provide a platform for engineers to discuss whether the scaffolds have been constructed properly.

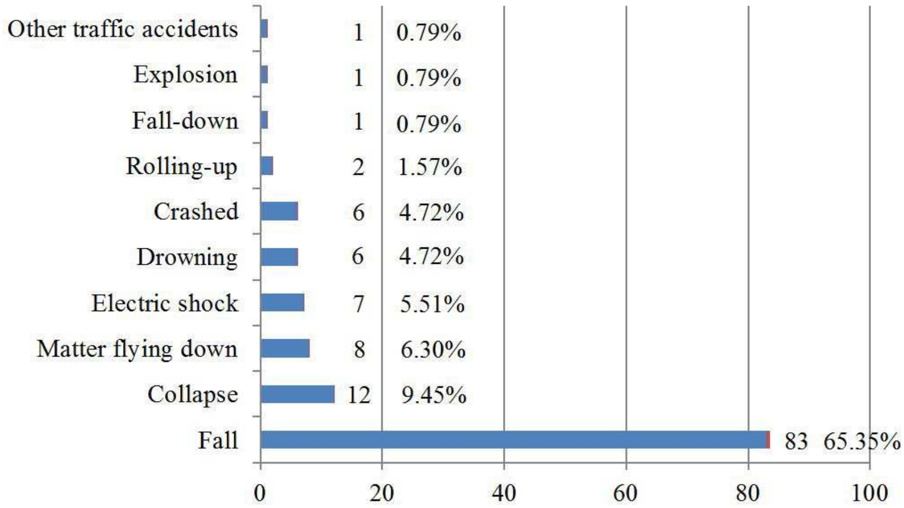

FIGURE 3. Types of occupational accidents in the construction industry in 2011

The literature review such as BIM and current safety measures for system scaffolds are introduced in Section 2. The methods used in this study and results of the article are discoursed in Section 3. The conclusion of the essay is dissertated in Section 4.

2. Literature Review.

2.1. Introduction of building information modeling. Building information modeling (BIM) has become a prominent trend for construction projects across the world. With the capability of connecting three-dimensional (3D) building models to various analysis tools, BIM can increase the precision level of construction, decrease errors, synchronize designs, enhance energy efficiency, and facilitate sustainable development. BIM is a solution for integrating the concepts and practices of 3D building software, enabling fundamental module technology to be comprehensively linked to building design databases and digital information to be exchanged during the construction process. Globally, BIM has gradually been applied extensively in the architecture, engineering, and construction industries as well as in the integrated design process that considers all the phases of the lifecycle of a building [7]. BIM is a solution based on 3D building modeling software that integrates concepts with real-world implementation. Construction management includes phases of planning, design, commission, construction, and maintenance [8]. During the process of construction, it comprehensively integrates basic modeling technologies with building design databases and ensures the exchange of digital information between the modeling technologies and databases. In addition, BIM generates coordinated, consistent, and calculable information for a construction project that is in the design phase or under construction. According to the engineering characteristics and needs to select the appropriate software in BIM products will save a lot of manpower and resources in construction projects [9]. A BIM system generally refers to a system that can build, integrate, and reuse all the information and professional knowledge about the building in its lifecycle [10]. BIM is used to construct jointly coordinated, consistent, and computable information for construction projects during design and construction phases. A BIM system can be used to integrate, use, and share the information during building life cycles [11].

2.2. **Current safety measures for system scaffolds.** Through the use of BIM software, this study created images of the scaffolds installed at construction sites, assisted with the design of safety passages at these sites, and examined the usage of system scaffolds and safety passages through onsite observation, interviews, and a literature review. Currently in Taiwan, workers installing wales and safety nets to construct system scaffolds risk falling because of a lack of safety facilities, passages enabling easy access, and appropriate temporary stairs that permit the workers to ascend or descend safely. In addition, when installing the aforementioned safety facilities, construction workers often neglect the reliability and security of these devices. Thus, cases of structural collapse have been frequent. However, comprehensive and reliable regulations or guidelines for how to install safety facilities and when to use which type of devices at construction sites are currently lacking. Therefore, even though safety facilities that provide a certain extent of protection are installed, sometimes they only appear to be safe, and construction workers are not fully protected. For instance, when they install decks on passages, the workers may not fully cover the passages with decks or install any safety rails.

3. Methods and Results.

3.1. **Using BIM to examine system scaffolds.** Through the use of Revit, a building design program developed by Autodesk, this study created images to simulate the construction of system scaffolds at a construction site, and thereby provided a communication platform for engineers, scaffold contractors, and labor safety and health inspectors. To create a reasonable and safe work environment, this study has generated 3D images with BIM environment to examine the work environment for construction workers, inform scaffold contractors about the types and numbers of construction materials and safety facilities they must prepare, discuss whether safety concerns exist for any particular construction work, and analyze the construction interface conflicts between various building material contractors on a construction site.

In accordance with the progress of a bridge construction project, this study simulated the usage of system scaffolds at a construction site by using a BIM software program to draw 3D images to arrange the layout of the scaffolds. Figure 4 shows the images of the scaffold components created in this study. Figure 5 illustrates a cross-section image of the system scaffolds. Figure 6 displays an elevation image of the system scaffolds. Figure 7 demonstrates a 3D perspective image of the system scaffolds.

3.2. **Using BIM to examine decks used in construction projects.** The 3D models developed by this study can be used to examine the feasibility and security of safety passages. The current methods used for installing decks tend to block easy access or increase the probability of falling off. The disadvantage of diagonal scaffolds in blocking easy access is difficult to discern on 2D floor plans. However, the 3D image in Figure 8 enables scaffold builders to easily notice that the decks must be moved to the left because

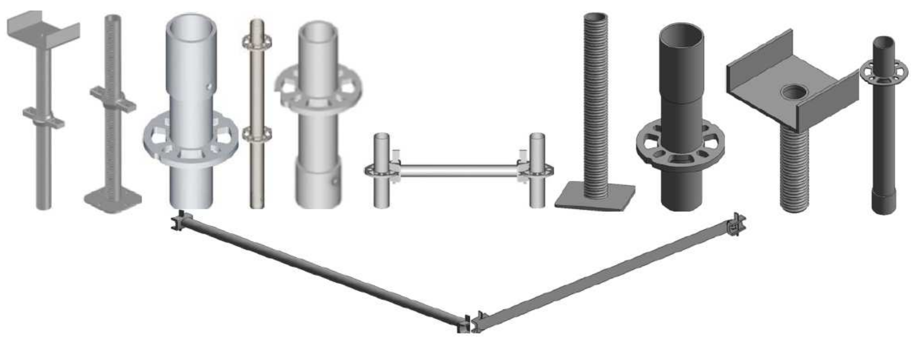

Figure 4. Scaffold components used in this study

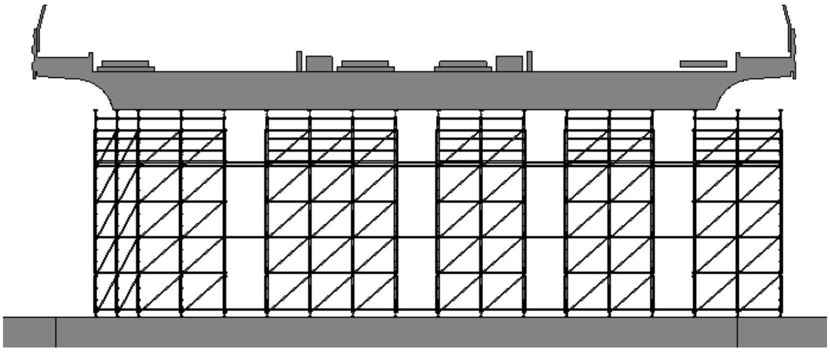

FIGURE 5. Cross-section image of the system scaffolds

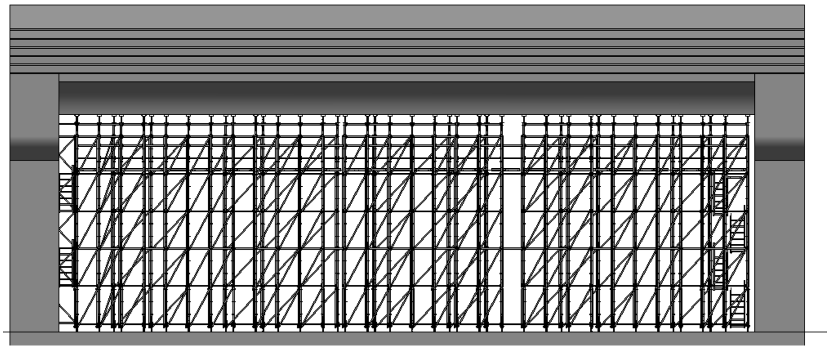

FIGURE 6. Elevation image of the system scaffolds

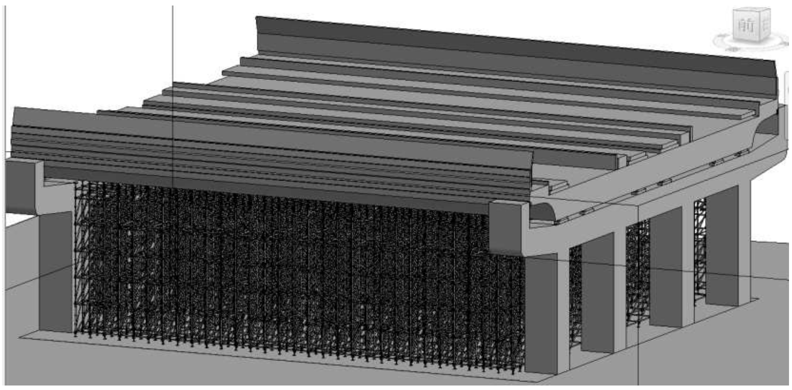

FIGURE 7. 3D perspective image of the system scaffolds

their location is inaccessible to workers. Figure 9 shows that the deck enables easy access for workers after being moved to the left. In Figure 10, a large gap appears between the deck in the middle and those transversely placed, which increases the probability of falling off. Therefore, an additional deck must be inserted (Figure 11). In addition, Figure 11 shows that the two vertically placed decks in the middle are not aligned with the other vertically placed decks. In this circumstance, construction workers may make a false step if they do not pay attention. Therefore, a warning sign may have to be installed in this area. Moreover, the bird's eye view in Figure 12 indicates that workers or objects could easily fall off because the safety passages are too narrow and the decks are too widely spaced. Through the BIM technologies, this study adjusted the layout of the decks (as demonstrated in Figure 13) in advance to widen the safety passages, narrow the space between each deck, and minimize the possibility of falling off.

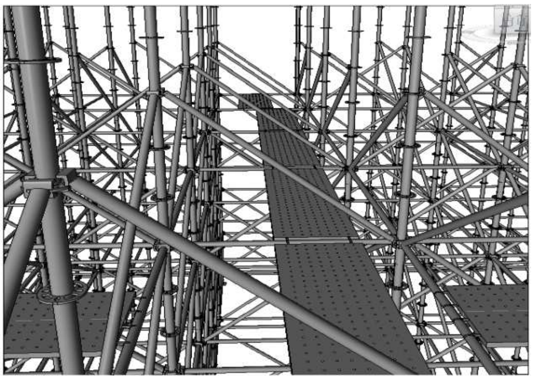

Figure 8. Improperly placed decks that block access for construction workers

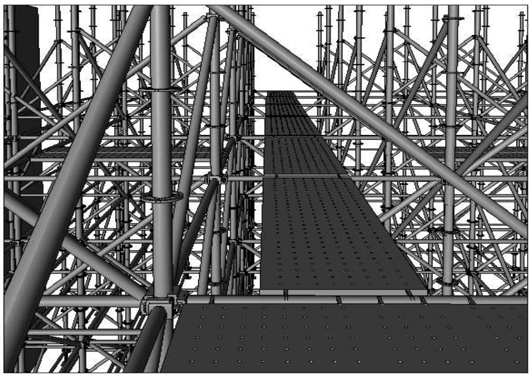

Figure 9. Decks moved to the left to enable easy access

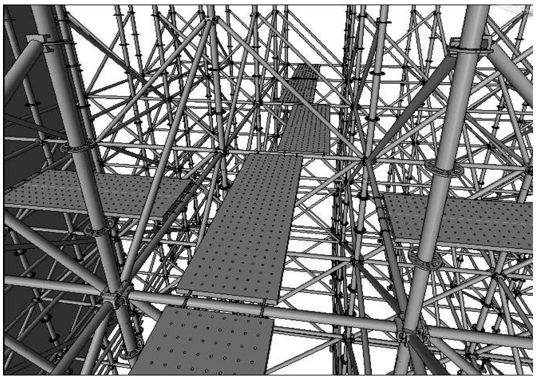

Figure 10. Widely spaced decks that can cause accidents

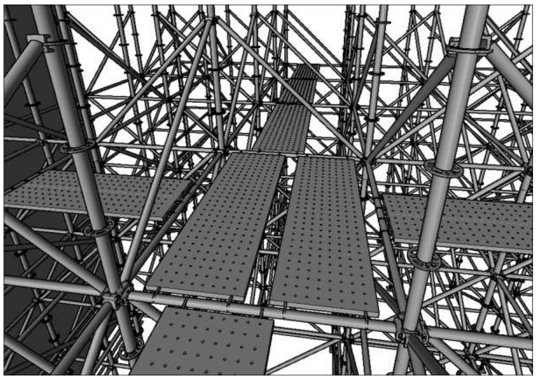

Figure 11. Adjusted and newly inserted decks for preventing possible accidents

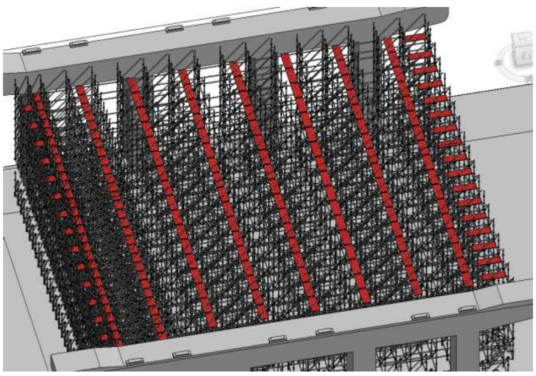

Figure 12. BIM simulation of a regular deck layout

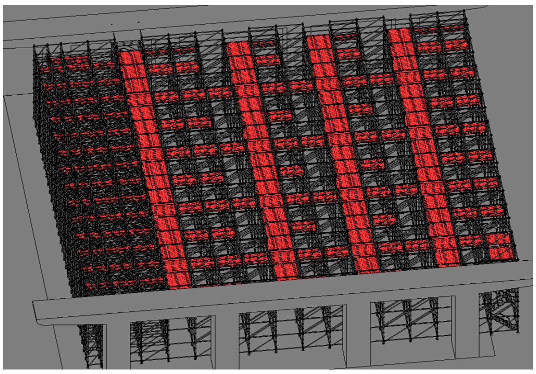

Figure 13. BIM simulation of an adjusted deck layout

3.3. **Examining the layout of temporary stairs and marking decks with colours through BIM technologies.** The government has published guidelines for the numbers and specifications of the temporary stairs used at construction sites [12]. In most cases, the requirements only instruct the construction workers to ensure an adequate number of temporary stairs and maintain suitable passage slope and width. Figure 14 illustrates the BIM simulation results of the temporary stairs [13]. In addition, BIM technologies can be used to mark the decks with different colors to illustrate for construction workers the areas that they can access and those that they cannot. In Figure 15, the areas marked in light green are the decks that the workers can access.

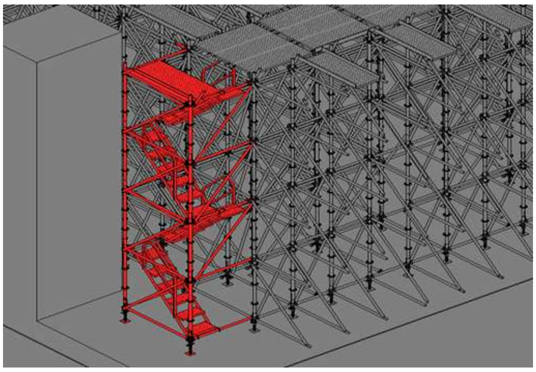

FIGURE 14. BIM simulation of temporary stairs

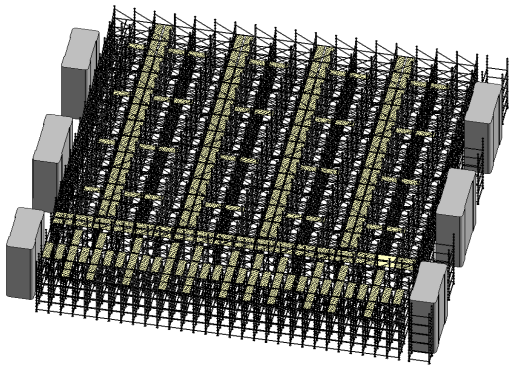

FIGURE 15. Light green areas that construction workers can access

4. **Conclusion.** By using BIM technologies to generate 3D images for simulating the layout of system scaffolds, this study obtained the following conclusions:

A. BIM software can be applied to ensure the safety of main working areas that are composed of safety passages or decks located on top of the system scaffolds, and to ensure conformation to the laws and regulations for the layout of temporary works. If not fully covered with decks, the working areas must be installed with construction pallets or safety nets to ensure the safety of workers.

B. In the early phase of the design process, the layout of safety passages, temporary stairs, and other safety facilities can be more effectively arranged using BIM software, compared with the layout arranged using conventional 2D floor plans.

C. Given sufficient funds and construction period, ensuring that the working areas are fully covered with decks can enhance the safety of construction workers, prevent them from falling off, and provide a relatively safer work environment for formwork workers to construct formwork structures.

This study suggested that further studies adopt the component-based development approach of BIM to statistically analyze the required type and number of building components used at construction sites.

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