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Designing a Knowledge-based Safety Risk Assessment System for Vertical Formwork Construction

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Abstract: In recent years, construction organizations are showing more interest in implementing new safety knowledge management (SKM) strategies to enhance companies' performance of safety and productivity. The objective of this study was to design a safety risk assessment prototype, to assess and review fall-related safety risks associated with vertical formwork construction in India. The prototype contains the activities involved in the vertical plywood formwork used in the construction projects. The safety knowledge of fall-related safety risks associated with formwork construction was captured from construction experts and then structured using a Microsoft Excel worksheet based on risk level and stored in prototype to allow users (safety experts) to disseminate safety knowledge for current and future projects. The prototype is being experimented with and validated with a panel of users involved in the risk assessment process of construction projects to use it effectively. It is anticipated that the safety risk assessment prototype could aid users in providing decision support based on fall-related safety risk assessment and review for preventing accidents or injuries associated with formwork in the construction industry.

Keywords: Safety knowledge, Construction Industry, Indian Companies, Prototype, Web-based system

1. Introduction

Working-at-height is one of the riskiest jobs in construction. Workers at construction sites are exposed to fall risks across the project lifecycle (Chellappa and Salve, 2020; BSI, 2012). Falls in many countries' construction sectors account for a large number of fatal incidents and injuries, including the US (Bobick, 2004), the UK (HSE, 2018), and Hong Kong (Wong et al., 2016). This accident rate is due to the fragmentation of the industry and its nature (Cárdenas et al., 2013).

Globally, risk assessment in the construction industry is mandatory (Azhar, 2011) and a knowledge-intensive process (Ding et al., 2016) for fall protection in any projects during the pre-construction stage. This is carried out by assessing the safety risks involved in construction activities and drawing steps to control the risks during the construction stage (Dong et al., 2018). Considerable safety knowledge is needed to execute the risk assessment process (Eskesen et al., 2004). Traditionally, safety experts perform a risk assessment based on their individual experiences and information such as regulations, national or international guidelines, accident reports, records, and 2D drawings (Hadikusumo and Rowlinson, 2004). The control measures are put in place once the possible risks are evaluated. The safety knowledge of safety experts is of greater importance in this case. Nonetheless, safety experts face significant challenges during risk assessment in the Indian construction sector, such as identifying potential hazards, identifying the steps involved in each activity, understanding of risk scoring system, selection of control measures, and insufficient time to conduct a risk assessment (Vigneshkumar and Salve, 2021a).

Many researchers (e.g., Javernick-will, 2012) recommended knowledge management (KM) as an effective strategy to improve organizations' efficiency and competitiveness. Integrating the concept of KM into safety management will eliminate these challenges and continually enhance the risk assessment process's performance (Carter and Smith, 2006). According to Kamardeen (2009), KM is a method of disseminating knowledge from various sources as a resource for organizations to use to facilitate continuous improvement. It is a new and evolving practice for construction companies. KM can assist in capturing a company's collective expertise wherever it resides and distributing it to where it can produce the most significant payoff (Hadikusumo and Rowlinson, 2004).In the construction firm, safety knowledge is resourceful and capitalized (Carol et al., 2014). Companies should develop a method for capturing and re-using safety knowledge to create a safety culture (Sherehiy and Karwowski, 2006).

It is hypothesized that a virtual safety knowledge base would aid in addressing the challenges associated with effective risk assessment. The safety knowledge base should contain (1) a breakdown of activities into sub-activities and risks involved in each sub-activity, (2) causes of fall/ hazards and the population at risk involved in each sub-activity, and (3) safety practices and fall risk control measures for the sub-activities. As a result, the goal of this study was to create an

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effective risk assessment and review system that incorporates KM and organizational learning into safety management at the same time. The goal was met by (1) developing the concepts and contents of a knowledge-based risk assessment framework, (2) developing a conceptual model of a web-based system for knowledge-based risk assessment, and (3) prototyping and validating the web-based system.

Construction entails a wide range of tasks and a plethora of trades. Due to time constraints, it was nearly impossible to cover all of the trades in a construction project in this study. As a result, the research was presented in traditional vertical formwork (i.e., wall and column). Nonetheless, the knowledge base can be populated with information for other trades using the frameworks and system model incorporated into the proposed system. Furthermore, the research was conducted in the context of the Indian construction industry.

The study was divided into four stages: safety knowledge acquisition, model development, system implementation, and system validation. To begin, a thorough literature review aided in the identification of vertical formwork and job procedures. Following that, the system's knowledge base was populated with safety knowledge by analyzing documents and publications that describe sub-activities that could cause falls, people who could be harmed in each activity, best safety practices, and control measures. A Delphi survey was carried out with construction experts in two rounds to evaluate the risk of each activity and to understand the influence of causes of falls/hazards and the population at risk during each activity. Following, a thorough literature review aided in identifying terms of reference for the proposed system and, as a result, the development of the system's conceptual model. The conceptual model was then put into action with Justinmind, an open-source content management system. Finally, the system was validated against the research hypothesis by safety experts in the construction industry.

2. Capturing of safety knowledge for risk assessment

Conventional vertical formwork is made up of plywood sheathing for decking. Formwork materials are shaped and mounted into frames, and the frames are installed in the proper position and orientation. After the concrete has been poured and healed and the formwork has been removed, the formwork materials could still be used for another concrete pour (Vigneshkumar and Salve, 2021b). Safety knowledge for risk assessment related to vertical plywood formwork was captured through a document analysis process and Delphi surveys. Safety practice manuals, guidelines, accident records, textbooks, and research publications were analyzed to identify the activities that can have the risk of fall, hazards/causes of fall, people who can be harmed, best safety practices, and possible control measures. Following, Delphi surveys were conducted with 16 construction experts in two rounds. Construction experts with civil engineering were chosen because they are the one who handles formwork activities at the site and has better workplace safety knowledge (Chellappa et al et al., 2020). In the first round, the causes of falls and people at risk were identified and retained. In the second round, the influence of causes of falls and people at risk were estimated, along with the risk of each activity (probability x severity) involved in the formwork were evaluated. Further, the best control measures for each activity associated with vertical formwork were suggested by the construction experts during the survey. The captured safety knowledge was structured in the Microsoft excel worksheet for updating in the proposed system. Due to word limitations, the detailed safety knowledge acquisition procedure is not discussed here; however, it can be found in Vigneshkumar and Salve (2021c).

3. Knowledge-based safety risk assessment framework

Figure 1 depicts a framework for the knowledge-based risk assessment advocated in this study. The framework describes the basic activity flow and resources involved in the risk assessment process.

- The safety knowledge base, which includes work-at-height safety regulations, guidelines, accident records, and research publications, is an essential component of knowledge-based risk assessment. When new knowledge emerges, a dedicated knowledge worker updates this knowledge base on a regular basis.
- Knowledge-based risk assessment entails analyzing the situational variables, retrieving safety knowledge from the knowledge base, developing an effective fall prevention plan (FPP) for the situation, and putting it into action on the job site.
- The scope of the project and the type of activity to be performed are examples of situational variables. For each activity, these variables are thoroughly studied, and relevant potential hazards/causes of falls and control measures are drawn from the knowledge base. These result in the creation of an FPP plan for the activity.
- The FPP is implemented and monitored on-site. If any new hazards or risk controls are discovered, they should be documented and considered for updating in the knowledge base.

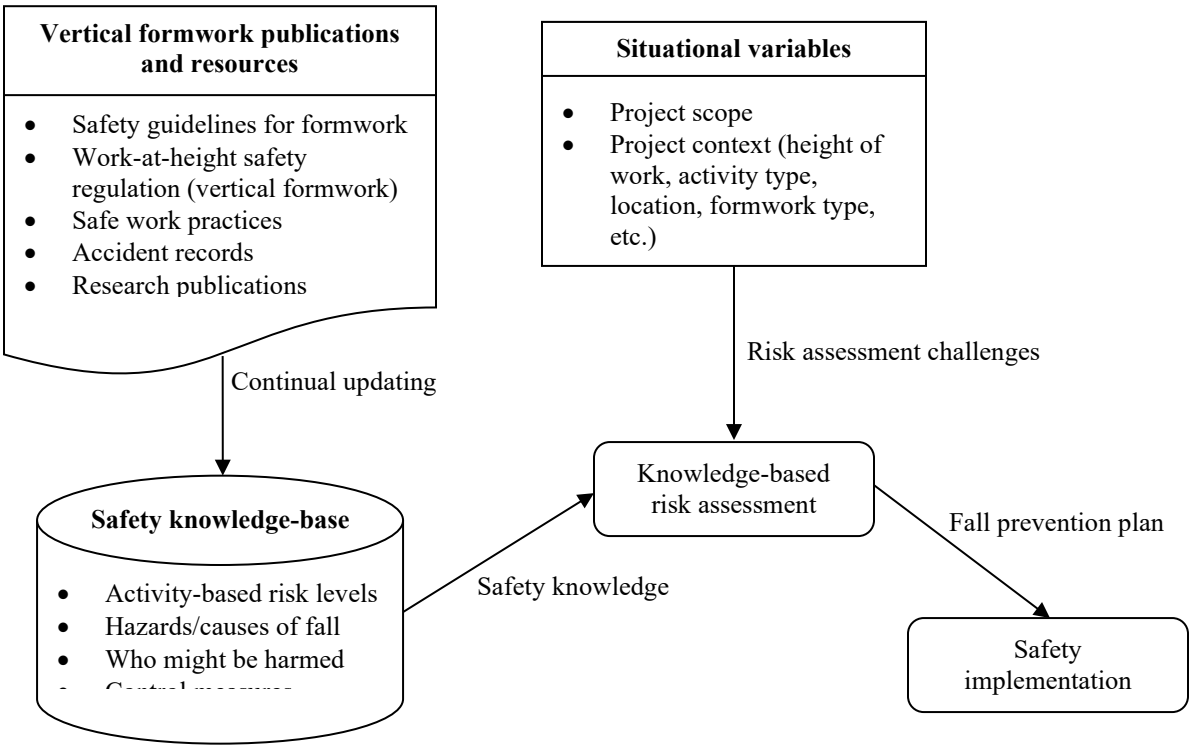

Figure 1. Knowledge-based Safety Risk Sssessment Framework

4. Web-based safety risk assessment system development

The above model was converted into a web-based system to get the most out of the proposed knowledge-based safety risk assessment strategy that

- offers a structured and widely accessible repository for safety knowledge,
- allows for the recording and storage of activity-based hazards/causes of falls and control measures in easily retrievable and exploitable formats
- allows safety experts from a contractor's various project sites to use the safety knowledge base.

5. System modeling

Figure 2 depicts the web-based safety risk assessment system architecture and distinguishes the various functional components within the system. The system is built on 3-tier architecture with three logical layers: a user side, a middle layer, and a server-side. The user side (tier one) is linked to the server-side (tier three) via the middle layer (tier two) and has access to all of the safety knowledge contents in the knowledge base.

The main functional set of the system's interface is the safety knowledge retrieval and update sets. Users from construction sites can gain access to the knowledge retrieval system after completing the access authentication process. The knowledge retrieval set enables users from various locations to access activity-based hazards/causes of falls, populations at risk, and risk control measures for activities. This knowledge would help the safety director with intensive fall prevention on the job.

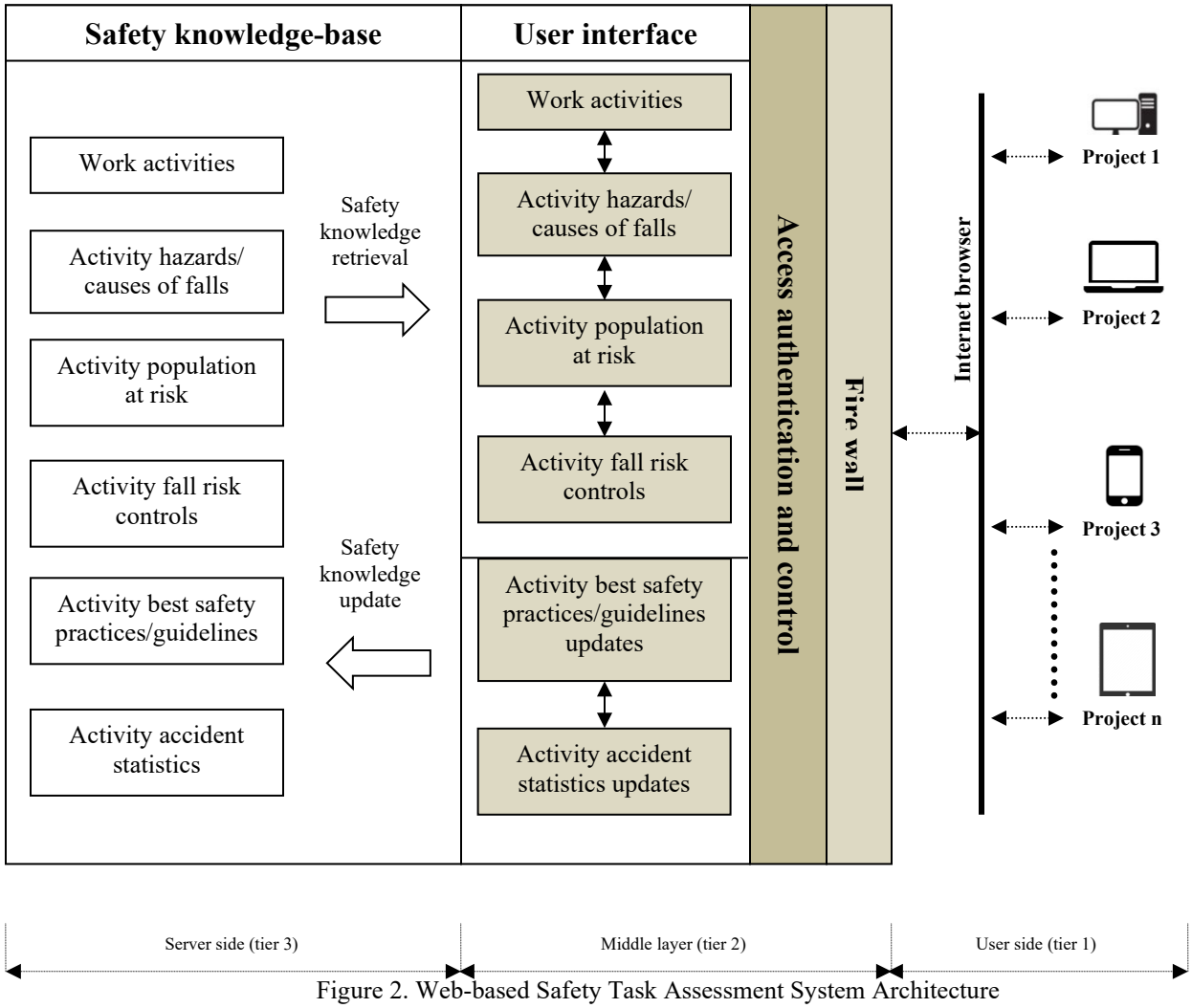

Figure 2. Web-based Safety Task Assessment System Architecture

6. Prototype development

A prototype was developed by two methods: (1) by using a content management system (CMS), Justinmind, and (2) by coding using a web development programming language, PHP. CMS is a software program that enables users with markup languages to create, edit, maintain, and manage dynamic websites using built-in tools and templates (Kamardeen, 2009). According to Robertson (2003), using a CMS can provide a variety of benefits such as greater consistency, support for decentralized authoring, the faster turnaround time for new pages and changes, improved site navigation, increased site flexibility, reduced site maintenance, greater capacity for growth, reduced duplication of information, increased security, and streamlined authoring process. Therefore, first, it was decided to create the proposed system's prototype (medium-fidelity) using a CMS. The front page of the prototype is shown in figure 3. The cognitive walkthrough was conducted with five evaluators from different research domains to evaluate the interface design of the prototype. More information about the cognitive walkthrough procedure can be found in Vigneshkumar and Salve (2021d). The evaluators' feedback was taken into account, the interface design of a prototype was improved, and a high-fidelity safety risk assessment prototype was created using PHP programming language. Being a web-based tool, the user can access the system anywhere and anytime on personal computers, tablets, laptops and smartphone’s. Figure 4 depicts the front-end of the proposed web-based system, and figure 5 shows its back-end.

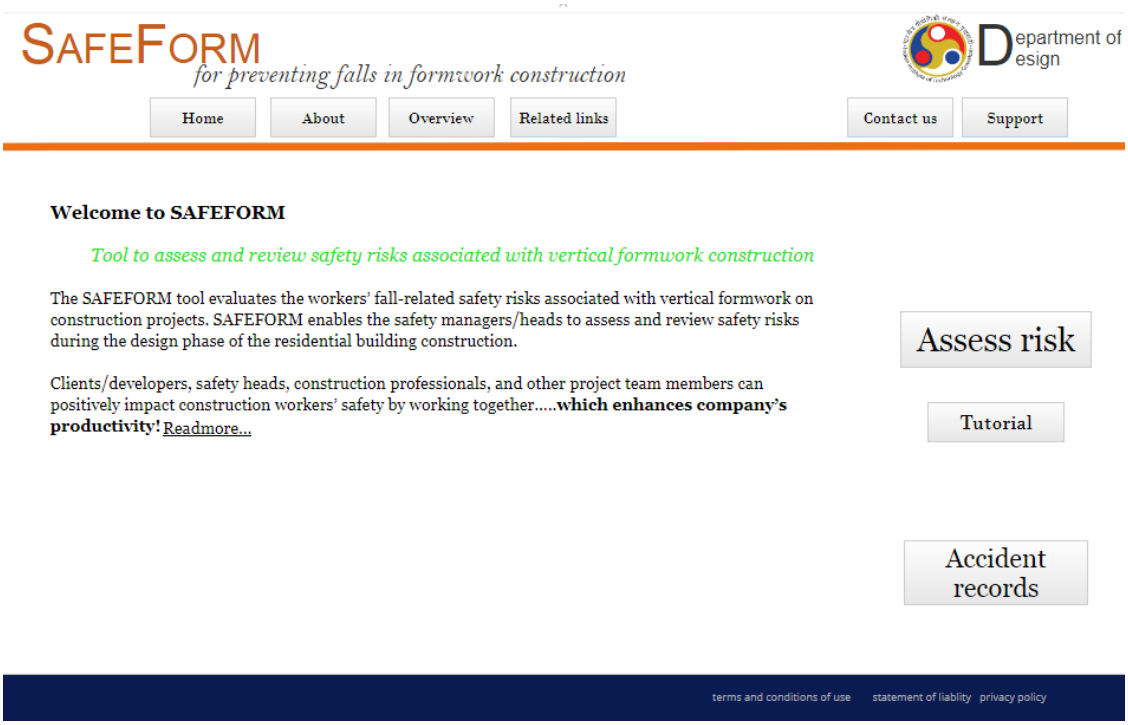

Figure 3. Medium-Fidelity prototype front page

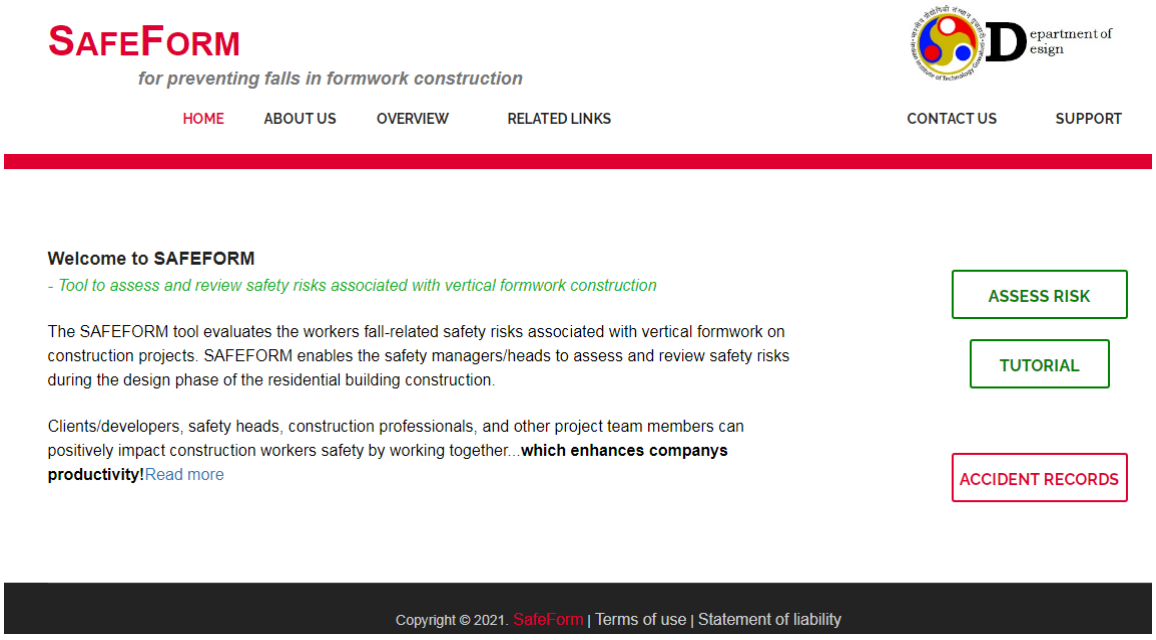

Figure 4. Front-end of the proposed safety risk assessment prototype

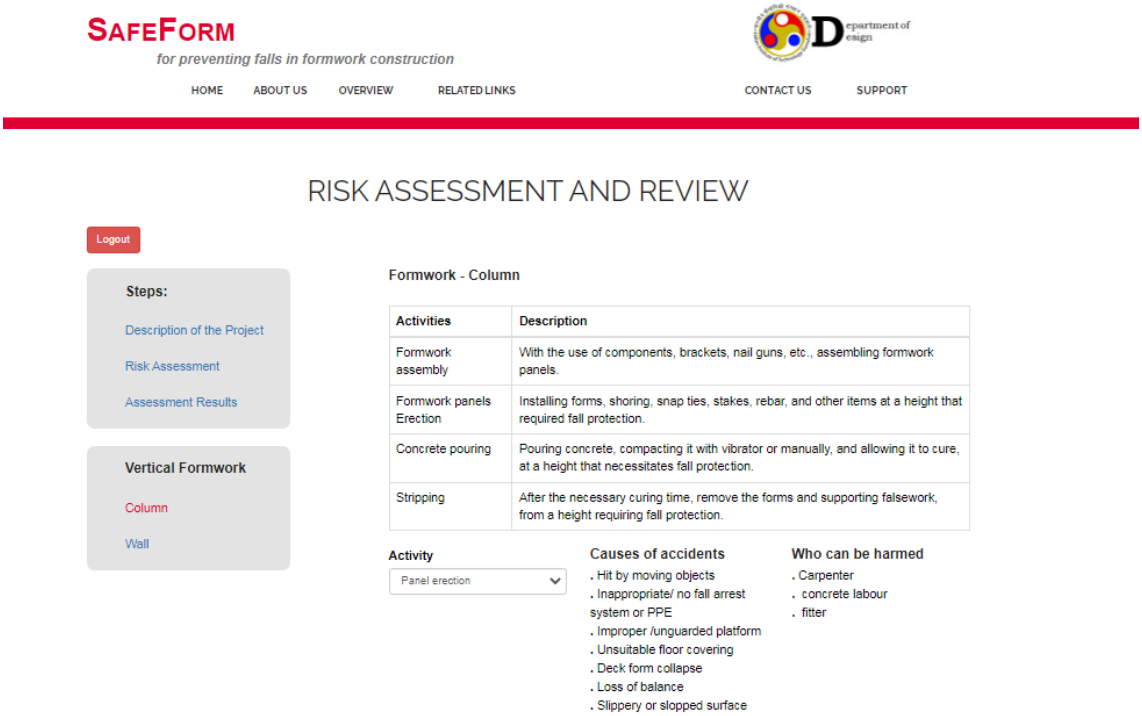

Figure 5. Back-end of the proposed safety risk assessment prototype

7. Conclusion and future work

In recent years, construction companies are formulating new strategies and adopting new methods to manage safety knowledge to improve organization safety performances. In this paper, a prototype was developed to address the challenges faced by users during the safety risk assessment for vertical formwork in India. For system evaluation, ergonomic cognitive psychology assumes three dimensions: usefulness, usability, and acceptability. Evaluation criteria will be established in the future to measure the degree of utility, usability, and acceptability of the system to validate. The major limitation of this system is that it only addresses the fall-related safety risks associated with vertical formwork (column and wall) construction. In the future, the researchers could consider other safety risks involved in vertical formwork construction and other formwork activities such as slab and beam to carry out a risk assessment for better safety performance. This system could also be widely applied in other countries for similar projects based on the nature of activities.

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