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Development and evaluation of context-based assessment system for visualization-enhanced construction safety education

Akeem Pedro ^a, Hai Chien Pham ^b, Jung Ui Kim^a and Chansik Park ^{c*}

^aDepartment of Architectural Engineering, Chung-Ang University, South Korea; ^bFaculty of Civil Engineering, Ton Duc Thang University, Vietnam; ^cConstruction Technology Innovation Laboratory, Chung-Ang University, South Korea

Construction jobsites remain among the most dangerous workplaces, with fatalities, accidents and injuries still plaguing the industry. Safety education is critical in fostering graduates capable of ensuring safe construction work; however, current learner assessment methods in pedagogy fail to ascertain the possession of safety knowledge and skills as they would be required in practice. This article aims to address this problem by proposing context-based learner assessment in construction safety education. A novel assessment system is developed and deployed with final-year construction management students, with learner testing through visualization-enhanced safety theory questions, site inspection scenario questions and job safety analysis review questions. The cognitive impact of the assessment approach is investigated through the NASA task load index, and its effectiveness is verified through educator and learner trials. Results demonstrate that the proposed system has significant potential as an innovative assessment tool for safety education.

Keywords: construction safety; safety education; virtual reality; assessment; context-based

1. Background and introduction

Construction is one of the largest industries, encompassing millions of enterprises and employees and contributing greatly to the gross domestic product of many countries [1]. Despite the consistent growth of global markets and the emergence of cutting-edge technologies, construction jobsites remain among the most dangerous workplaces, with fatalities and recurring accidents still plaguing the industry [2]. Addressing this issue requires concerted efforts in not only industry practice, but in tertiary construction education as well.

Effective safety education plays a pivotal role in fostering knowledgeable and skilled personnel to confront the deep-rooted safety challenges of construction work. However, universities and tertiary institutions vary in their approaches to safety education, with some programs incorporating safety topics into their curricula while others do not. Many construction management curricula do not include any stand-alone safety courses [3]. Moreover, in the institutions where safety topics are included, conventional methods of assessing learners' safety knowledge are not aligned with how the actual knowledge and skills are required for application in practice. It is often impossible to depict complex safety scenarios which involve dynamic construction processes and site environments in existing text-based assessment methods [4]. In addition, traditional paper-based tests have been described as poor predictors

of job performance, as learners' often resort to cramming, question spotting and short-term retention without deeply understanding curriculum contents [5]. As mentioned by Poikela [6], traditional assessments are characterized by rote learning, which places an emphasis on the acquisition of facts rather than their application to realistic problems [7]. However, merely repeating certain skills or retrieving propositional pieces of information based on memory is not valid proof of knowing. In essence, results from conventional assessment approaches fail to discern whether learners actually possess a true understanding of course contents and whether they are capable of applying safety knowledge and skills in the real construction industry.

Over the past decade, increasing attention has been paid to advanced visualization technologies such as building information modeling (BIM) and virtual reality (VR) and their potential to enhance various processes in the construction industry. VR refers to artificial, computer-generated environments which are experienced through sensory stimuli in a seemingly realistic way. Several studies have applied VR for construction safety education with noteworthy pedagogic benefits at the tertiary level. For example, Le and Park [8] developed a model for construction safety training based on the *Second Life* virtual world platform, then extended the approach and developed a collaborative virtual-world-based platform to facilitate safety education with construction jobsite visualization,

*Corresponding author. Email: cpark@cau.ac.kr

role playing, social interaction and dialogic learning [9]. Similarly, Pedro et al. [3] utilized mobile VR simulations with an emphasis on game-based modalities to integrate safety contents into building construction education. The approach improved learners' captivation and engagement, and also effectively disseminated safety knowledge. VR and simulation-based applications have been found to have the potential to improve learning outcomes and afford benefits such as detailed visualization of complex processes, improved motivation, engagement and support for interactive learning to enhance construction safety education [10,11].

The majority of studies thus far have focused on enhancing safety knowledge dissemination and acquisition through innovative VR-enhanced instructional methods. However, despite progress in these facets, there is a lack of research focused on developing effective assessment measures not only in construction safety education but in construction education as a whole. On the other hand, increasing evidence on the need for and benefits of innovative technology-enhanced assessment has emerged in various science and engineering-related disciplines [12–14]. However, the impact and potential of simulation-based mechanisms to enhance assessment in construction education is still underexamined.

Effective assessment measures are necessary to ascertain that construction graduates possess the safety knowledge and skills required to improve safety performance in the construction industry. However, traditional modes of assessment fail to provide suitable structures for assessing learning [15]; and despite significant improvements in assessment science, the assessment of learning in tertiary institutions still remains resistant to change [16]. Effective assessment is the foundation for successful teaching that produces flexible and employable graduates [17]. Considering the poor safety record of the construction industry, developing means of effectively assessing and confirming safety skills at the university level would be beneficial to the industry as a whole. It is now crucial that modern forms of assessment provide a more accurate depiction of students' safety learning achievements.

This article aims to address the aforementioned problems and fill the current research gap by developing a context-based approach for learner assessment in construction safety education. Context-based assessment is an alternative assessment approach that embraces innovative methods such as simulations in order to situate student assessment in realistic settings [5]. By deploying visualization-enhanced assessment, the proposed system provides an experiential opportunity for learners to demonstrate an applied understanding of safety matters, prior to entering the construction industry.

The article is structured as follows. An overview of the research methodology is presented, then a context-based safety assessment framework and approach are proposed

based on the limitations of current pedagogic methods. Next, the context-based assessment system is presented, and its constituent modules are described in detail. Prototype scenarios are presented, and the effectiveness of the assessment approach is investigated through educator and learner trials, followed by interviews and quantitative experience questionnaires. Lastly, results of the study are presented and the pedagogic implications of the approach are discussed. Future research directions are also suggested.

2. Research methodology

The primary objective of this study is the development of a theoretical framework as well as a novel context-based approach and system to improve the assessment process for construction safety education at the university level. The secondary objective of the study is to evaluate the impact and effectiveness of the proposed system as an innovative assessment tool. In order to achieve the aforementioned objectives, a mixed-methods approach comprising several processes was implemented. Firstly, a comprehensive literature review was conducted, and construction curricula were analyzed to assess existing assessment methods in construction safety education. Compliance with guidelines from regulatory bodies is an important factor in the design of assessment methods [14]. Hence, educational contents pertinent to the Korean construction industry were acquired through the Korean Occupational Safety and Health Agency (KOSHA) regulations and the standard risk evaluation model [18]. Through the literature review, a theoretical framework for context-based safety assessment was proposed, providing the core approach for the development of the assessment system.

Next, the context-based safety assessment approach was designed based on Bloom's taxonomy of educational objectives, and the prototype system was developed in accordance with the acquired KOSHA contents. Particularly, storyboarding was required to design VR-based assessment scenarios and clarify how learners could interact with simulated environments to demonstrate specific safety skills and knowledge. Three-dimensional (3D) building models were designed through Autodesk Revit Architecture Version 2013, a leading building information modeling proprietary software; while virtual scenarios were modeled and animated through Blender Version 2.7, an open source C++ graphics software with advanced game engine functions. In addition, 360° panorama VR scenarios were developed by capturing and rendering imagery from a real construction site. Next, the user interface was designed to allow learners to interact with the system.

Finally, system trials were conducted and the evaluation addressed the potential of the system in three facets. Firstly, cognitive workload assessment provided

insights into the instructional effectiveness of didactic activities [19]. Cognitive load is a critical consideration in simulation-based pedagogy, hence the NASA task load index (NASA-TLX) was deployed to ascertain that the system demands cognitively feasible performance. Secondly, an effectiveness evaluation was conducted focusing on gauging the authenticity of assessment tasks, which is a crucial step in appraising assessment tools [20]. Thirdly, a transparency evaluation was performed, which focused on fairness, clarity and other related quality criteria for assessment [21,22]. Lastly, open feedback sessions were conducted to comprehensively corroborate findings and account for user perceptions.

3. Context-based assessment for construction safety education

This study develops a context-based assessment system to address the shortcomings of conventional assessment measures in construction safety education. This section begins by introducing context-based assessment theory, and then discusses its significance for tertiary construction safety education.

3.1. Framework for context-based assessment in construction safety education

Ideally, students in engineering disciplines should be trained to construct solutions to problems in the real world [23]. Educational contents should mirror real-world situations in order to reflect the way knowledge would be applied in practice [24]. In this regard, alternative assessment approaches can afford opportunities for authentic and meaningful feedback, improved motivation and student retention [25]. Context-based assessment is an alternative assessment approach, which contextualizes learners in realistically simulated applications [5]. Context-based pedagogy emphasizes student-centered activities and inquiry-based investigations rather than traditional passive approaches [26].

Assessment systems should be capable of testing higher-order cognitive abilities, which require the application of knowledge and skills in new contexts [22]. Higher-order capabilities pertain to students' abilities to relate their knowledge to elements beyond those encountered during learning [27]. However, in the case of construction safety training, it is difficult to convey authentic assessment tasks which are representative of construction environments solely through conventional teaching tools [4]. Furthermore, conventional assessments in construction education present questions in text form, which is associated with rote learning and cramming [7]. In addition, safety is a low priority in construction education and there is a serious dearth of research on safety assessment at the tertiary level.

Context-based assessment in simulated environments can enable situational awareness and enhanced perception of construction site environments, and can also convey safety problems which invoke higher-order safety skills effectively. Based on the aforementioned limitations in the literature, this article develops a theoretical framework (Figure 1) for the context-based safety assessment system (CBSA), to orient learners toward authentic demonstration of knowledge, understanding and realistic application of safety skills, rather than mere memory and reproduction.

As depicted in Figure 1, the theoretical framework for CBSA illustrates the depth of conventional assessment and the envisioned CBSA approach. In order to classify students' expected cognitive performance during each assessment stage, six hierarchical levels are presented based on Bloom's revised taxonomy of educational objectives [28]. The assessment levels are arranged hierarchically, hence progress onto more advanced assessment levels requires achievement of prior levels. The taxonomy serves as a basis for determining the congruence of educational activities and assessments. In this study, higher-order skills refer to the application, analysis, synthesis and evaluation, and creation levels of the hierarchy.

As illustrated in the top two levels, conventional training in construction focuses on knowledge and observance of legal safety requirements [29], without affording experiential opportunities for knowledge analysis and application. Li et al. [4] also emphasize that current safety training practices deploy assessment tools with low content fidelity, which test general knowledge and fail to present complex safety problems pertaining to specific work types. Contrarily, the CBSA is designed to test safety knowledge with a safety theory domain; and to also reach deeper assessment levels by providing learners with opportunities to analyze realistic safety scenarios and apply their safety knowledge and skills in context through the site inspection domain (middle two levels). In addition to analysis and application of knowledge, quality assessments should stimulate higher-order thought processes such as exploring and articulating relationships, predicting effects of parameters and redesigning contents to suit specific scenarios [30]. In this regard, the CBSA requires learners to synthesize safety knowledge with situational observations in scenarios, evaluate safety problems in provided contexts and create solutions (bottom two levels).

3.2. Context-based safety assessment system

Based on the theoretical framework for context-based safety assessment, the novel CBSA approach is developed. Figure 2 provides an overview of the CBSA approach and outlines the assessment targets, educational objectives, levels and methods for the constituent assessment modules. As illustrated in Figure 2, the proposed CBSA system comprises of three novel safety questioning modules, namely,

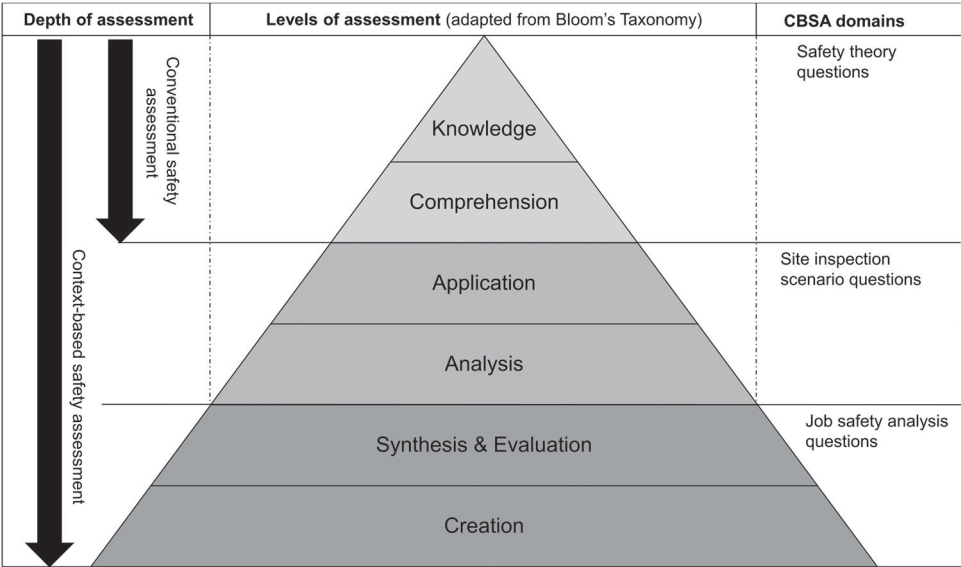


Figure 1. Theoretical framework for context-based safety assessment.
Note: Adapted from Krathwohl [28]. CBSA = context-based safety assessment.

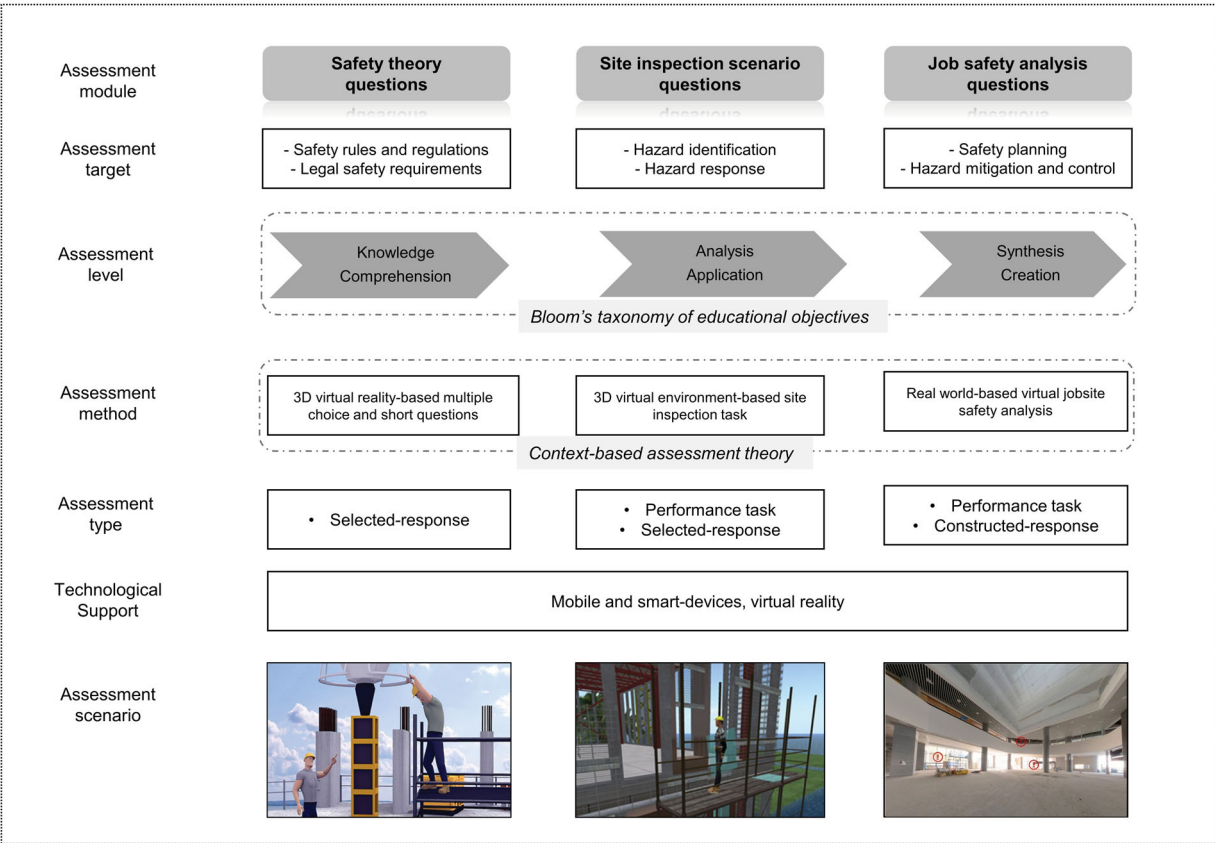


Figure 2. Overview of context-based safety assessment approach.
Note: 3D = three-dimensional.

safety theory questions (STQ) and site inspection scenarios (SIS), with close-ended response formats, and job safety analysis (JSA) tasks, with a constructed-response format. The three assessment modules are deployed to comprehensively evaluate critical safety knowledge and

competencies relating to safety regulations, safety planning, hazard identification and hazard mitigation. CBSA modules are designed to ensure students are capable of applying their knowledge in a realistic simulated context, resembling the real world. Authentic contexts are

facilitated through 3D VR and real-world-based virtual panorama scenarios, which students interact with through mobile and smart devices. The processes involved in each questioning module are delineated as follows.

Firstly, the STQ domain comprises multiple-choice questions (MCQs), true or false questions and description questions. While questions with selected-response formats in construction pedagogy typically focus on assessing factual knowledge in a context-free approach, the STQs in CBSA deploy a context-rich stimulus format, designed to ensure that safety information, knowledge and facts are applied within the context of a realistic construction jobsite scenario. One main benefit of this approach is automated computer scoring, which reduces educators' workload and enables faster feedback to learners. CBSA STQs allow learners to analyze various scenarios and situations and apply safety information in new situations. In line with Bloom's six hierarchical assessment levels (Figure 1), questions in the domain pertain to the first two levels, i.e., knowledge and understanding of safety rules and regulations, awareness of safety violations and hazards as well as knowledge of ideal work methods.

Secondly, the SIS domain delivers performance tasks paired with selected-response assessments. Rather than assessing factual knowledge, SIS evaluate students' abilities to predict, identify and address construction hazards. Safety inspections on construction jobsites are carried out to examine working environments, machinery and equipment, and to ensure that all personnel on site are safe. Hazard recognition and response skills are crucial in preventing accidents and injuries on the jobsite, hence their cultivation and assessment in safety education is critical. In this module, learners are required to conduct a safety inspection and identify hazards on a virtual construction site. Conditions which are typically difficult to convey in text and graphical formats are presented visually; and learners can explore virtual site environments from a first-person perspective, click on equipment, workers, materials or work areas and then select the relevant hazards from an array of predefined options. Within Bloom's taxonomy of educational objectives (Figure 1) the SIS module focuses on the middle two levels, i.e., analysis of site environments and application of hazard identification and response skills.

Thirdly, the JSA module requires students to complete a JSA performance task with a constructed-response format. Construction workers, foremen, managers and other personnel are consistently exposed to various risks, due to the dynamic and highly unpredictable construction jobsites. JSA, which is also referred to as job hazard analysis, is a proactive technique for effectively identifying, assessing and controlling safety risks and hazards [31]. When conducting JSA, the task under consideration is subdivided into a series of basic steps, and then all potential loss-of-control incidents are identified. Subsequently, the risk level

for potential hazards is assessed based on probability of occurrence and potential severity. For JSA performance in the CBSA, learners assume the roles of safety managers and review JSA documents. Subsequently, they virtually assess the corresponding jobsite for which the JSA has been prepared and evaluate its comprehensiveness. This final questioning domain goes beyond the analysis and application, and targets higher-order cognitive functions which require situational observations, knowledge synthesis and analytical thinking from learners. As illustrated in Figure 1, the JSA module focuses on the bottom two levels of educational objectives, demanding evaluation of provided information, synthesis with existing knowledge and, lastly, the creation of a new JSA.

4. CBSA prototype modules

In order to evaluate the STQ domain, a sample MCQ is developed along with a corresponding virtual scenario. A question relating to concrete works was selected, since concrete is one of the most widely used materials in modern building and construction. As illustrated in Figure 3, the scenario depicts two laborers pouring concrete for a column from a mobile platform. The question requires students to select the choice which correctly describes the situation. The CBSA STQs provide a dynamic context which enables site perception and situational awareness during assessment tasks.

Next, the SIS domain provides students an opportunity to apply their safety knowledge and hazard identification and response skills through virtual jobsite simulations with first-person gameplay dynamics. In order to evaluate the SIS, a scenario involving temporary works was developed, since accident statistics reveal that many jobsite injuries involve temporary structures such as formwork, false-work, etc. As illustrated in Figure 4, the site scenario portrays two workers carrying a formwork panel away from a cured concrete column. However, there are several hazards in the vicinity. For instance, fall hazards, which are the leading cause of fatalities in construction. In addition, inadequate fall protection is the top cited violation. The developed SIS question requires the learner to inspect the aforementioned scenario and click on various elements to identify the existing risks and hazards.

Lastly, the JSA module presents a real-world-based virtual site for a JSA performance task pertaining to finishing works for ceiling installation (Figure 5). JSA is a risk assessment procedure conducted to increase awareness of workplace hazards and ensure compliance with safety rules and regulations. For the JSA domain, learners review a generic JSA document (Figure 5a) and assess the corresponding site environments through a 360° virtual site panorama (Figure 5b). If there are deficiencies in the JSA or hazards that have been overlooked, learners are required



Figure 3. Sample multiple-choice question (MCQ) from safety theory questions domain for context-based safety assessment: (a) proceeding to answer MCQ after viewing virtual scenario; (b) selecting answer for MCQ.

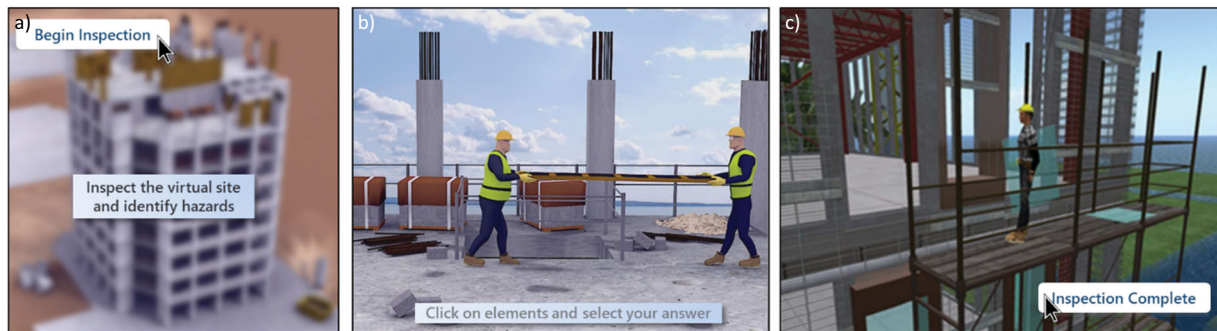


Figure 4. Virtual jobsite and site inspection scenario for context-based safety assessment: (a) beginning inspection in virtual site; (b) identifying hazards; (c) completing virtual inspection.

to develop corrective measures and document safe practices in a revised or recreated JSA document (Figure 5c). Through this process, learners are required to demonstrate their JSA documentation competencies in conjunction with a realistic virtual site context. This creates an opportunity to assess higher-order skills such as JSA, safety plan comparison, appraisal and creation in high-fidelity environments representative of real construction.

5. CBSA evaluation and results

Following the prototype development of the CBSA system, pilot experiments were conducted to evaluate the pedagogic effects and effectiveness of the CBSA for enhancing tertiary construction safety assessment at the Construction Technology Innovation Laboratory of Chung-Ang University in Seoul, South Korea. Figure 6 provides an overview of the evaluation scheme, depicting the pre-evaluation and evaluation procedures executed. The process commenced with a briefing session, whereby the CBSA system functions and features were explained, and a safety lecture was delivered, giving participants an opportunity to acquire safety knowledge pertaining specifically to personal protective equipment (PPE), concrete works and temporary works.

Pilot safety tests were implemented with a group of 15 construction professionals (educators and safety experts)

and 30 final-year building construction students. Trials were conducted with two treatments on the same subject group, utilizing conventional 'paper-based' testing and CBSA testing, with one sample question provided for the STQ, SIS and JSA domains. Subsequently, participants evaluated the potential of the CBSA as an assessment tool, in terms of the following three main clusters comprising several assessment quality criteria: (a) cognitive and mental workload assessment, considering the mental demands and impacts of the approach on learners; (b) effectiveness evaluation, pertaining to whether the CBSA is authentic and in alignment with the knowledge and skills for safety performance in realistic contexts; (c) transparency evaluation, focusing on fairness, clarity and related criteria. This cluster considers whether assessments are free from bias and appropriately designed to reduce obstacles to performance.

During the effectiveness and transparency evaluation, quantitative data were gathered through questionnaires issued to participants. Lastly, open-ended feedback sessions were facilitated through panel discussions and interviews, in order to ascertain the credibility of subjects' cognitive, effectiveness and transparency evaluations and to provide subjects with an opportunity to freely express their opinions regarding the CBSA. Procedures and results for each evaluation domain are detailed as follows.

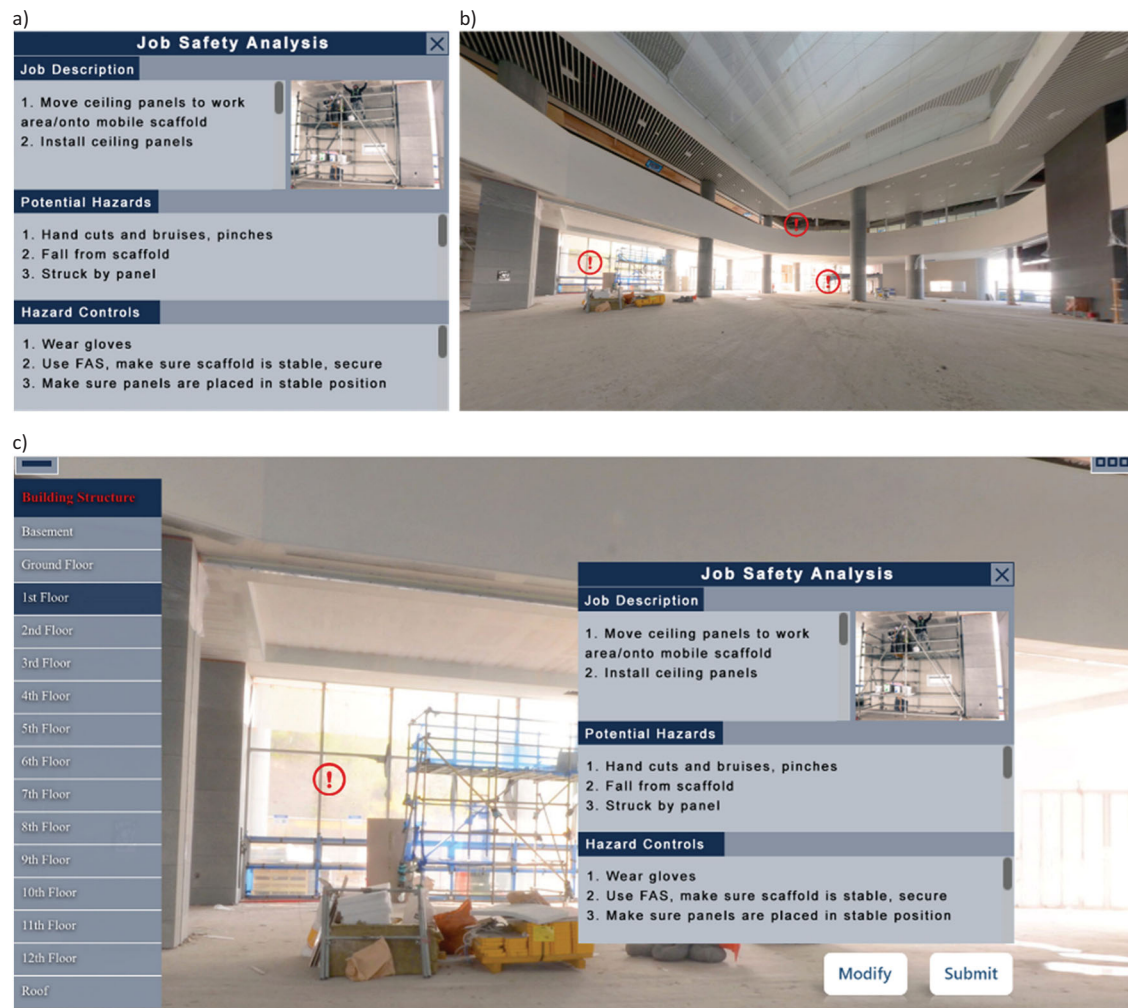


Figure 5. Job safety analysis task for context-based safety assessment: (a) reviewing a generic job safety analysis document; (b) assessing the corresponding site environment; (c) creating a revised job safety analysis. Note: FAS = fall arrest system.

5.1. Stage 1: cognitive and mental workload evaluation

Firstly, the cognitive and mental workload assessment applies the NASA-TLX [32] to examine the temporal, mental and psychological workload impacts of the CBSA. The NASA-TLX is a multidimensional technique which has been effectively used to assess workload in a variety of industries and disciplines. Figure 7 illustrates the NASA-TLX scale, which defines six task load criteria including mental demand, physical demand, temporal demand, performance, effort and frustration level and gauges them on a scale from 1 = *low* to 5 = *high*. This presented workload evaluation focused predominantly on extraneous cognitive workload, which pertains to the instructional design and nature of assessment tasks, and on intrinsic cognitive workload, which relates to the inherent characteristics of the safety contents being assessed [20].

After administering the NASA-TLX, repeated-measures statistical *t* tests were conducted in order to analyze the impacts of the CBSA in comparison to conventional

paper-based testing. For each of the six task load criteria, two hypotheses were computed: null hypothesis – the results from both assessment approaches are the same; and alternate hypothesis – there is a statistically significant difference between the two assessment approaches. The task load data was analyzed with a 5% significance level, using the statistics package of Microsoft Excel version 15.0.

As presented in Table 1, the mental demand required for CBSA STQ (M 2.34) and SIS (M 2.42) activities was reasonable and the JSA module was considered most mentally demanding (M 2.62, SD 0.68). Feedback from discussions revealed that learners initially expected the CBSA would be difficult to use; however, once learners became familiar with the assessment process, their concerns dissipated. In addition, learners expressed concerns regarding the temporal demands during the CBSA. However, following system trials, temporal demands were significantly lower with CBSA STQs (M 2.14) than with paper-based examinations (M 2.40) ($p = 0.009$). On the

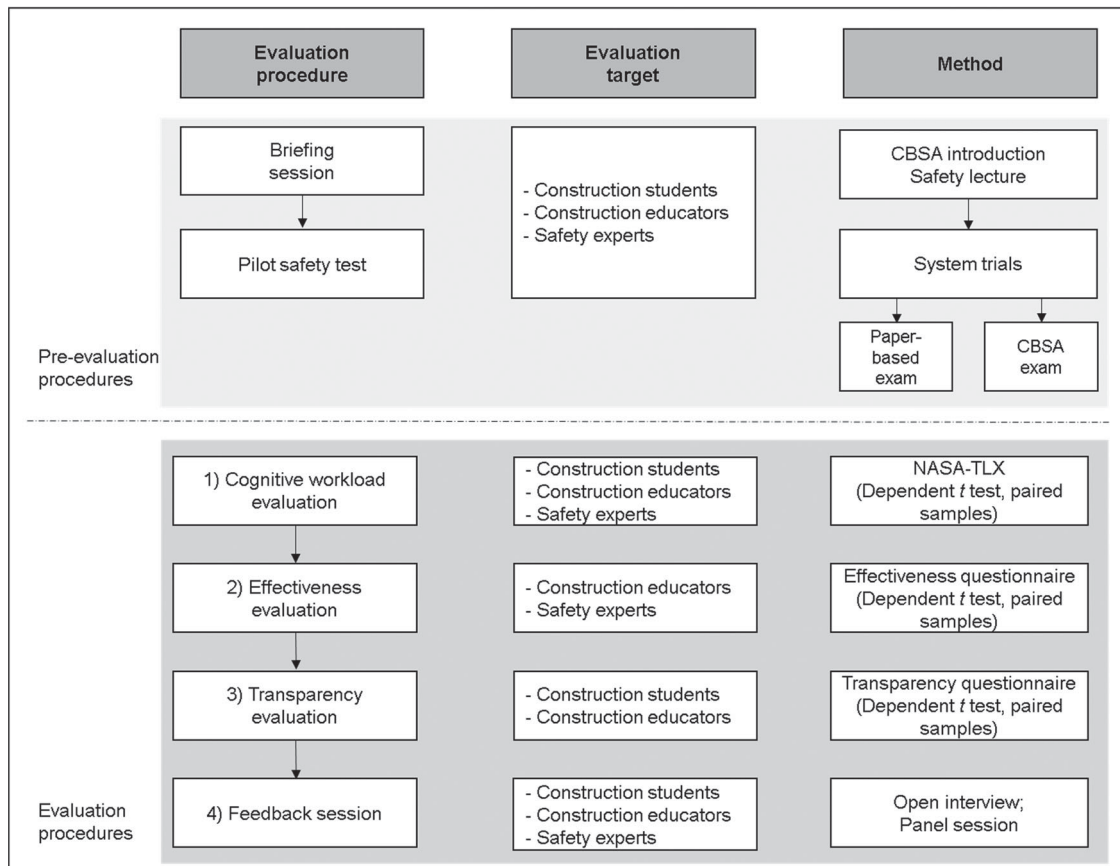


Figure 6. Overview of evaluation procedure.

Note: CBSA = context-based safety assessment; NASA-TLX = NASA task load index.

other hand, temporal demands were significantly higher during CBSA JSA tasks ($M\ 2.86$; $p = 0.002$). In terms of effort, subjects reported significantly less effort expended during CBSA STQs ($M\ 1.54$) as compared to paper-based MCQs ($M\ 1.94$) ($p = 0.001$). Frustration levels were also significantly lower during CBSA STQ ($M\ 1.09$) and SIS activities ($M\ 1.20$) than those during paper-based examination ($M\ 1.40$) ($p = 0.006$ [STQ]; 0.035 [SIS]) and subjects did not report any irritations or discouragements during interaction with CBSA environments. Furthermore, significantly higher performance satisfaction was observed among subjects for all three CBSA modules (STQ, $p = 0.018$; SIS, $p = 0.000$; JSA, $p = 0.006$).

5.2. Stage 2: effectiveness evaluation

The effectiveness domain entails the authenticity of assessment tasks, considering whether they comply with the knowledge and skills that enable performance in realistic contexts. The effectiveness of the CBSA was examined by safety experts and educators in terms of the following four key criteria: (a) relevance [5], which considers how representative activities in the STQ, SIS and JSA assessment domains are in addressing the required safety knowledge, skills and competencies; (b) content fidelity

[33], which considers the meaningfulness of assessment tasks and contents for appraising students' safety performance; (c) cognitive complexity [21], which refers to the effectiveness of the assessment tasks in stimulating and gauging higher-order safety skills and cognitive abilities; (d) content coverage, which addresses the capability of the appraisal tasks to convey the required scope of safety contents [21].

Participants quantitatively graded the aforementioned criteria through a 5-point Likert scale along a continuum from 1 = *strongly disagree* to 5 = *strongly agree*. Cronbach's α was computed for the four effectiveness criteria, demonstrating a high level of internal consistency ($n = 4$, $\alpha = 0.86$). As illustrated in Figure 8, results suggest that the proposed approach presents context-based assessment tasks which are perceived to be relevant, meaningful and closely aligned to real industry practice ($M\ 4.67$, $SD\ 0.60$). Similarly, content fidelity for CBSA tasks was high ($M\ 4.07$, $SD\ 0.68$). Among the effectiveness criteria, cognitive complexity scored the lowest value ($M\ 3.8$, $SD\ 0.75$). Despite this, professionals considered the CBSA especially suitable for appraising higher-order safety skills such as hazard recognition, mitigation and JSA. The lower rating could be attributed to the limited number of prototype scenarios, which could make it difficult to perceive

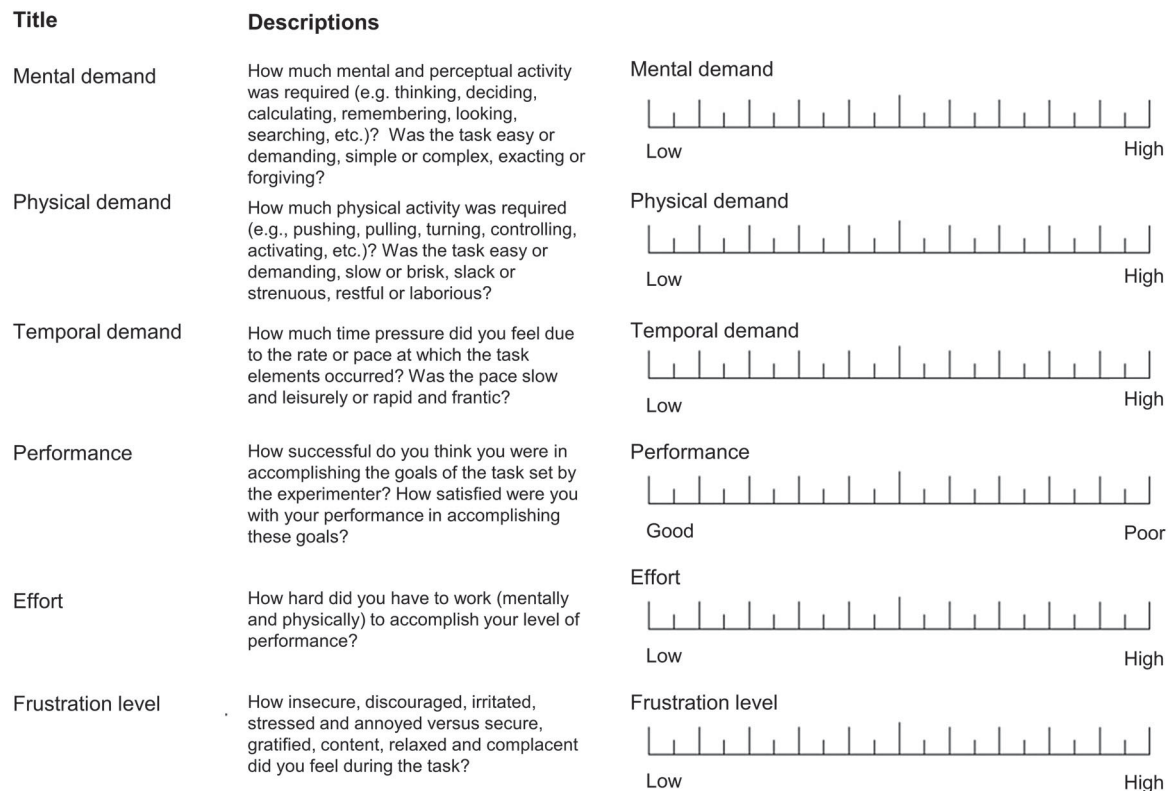


Figure 7. NASA task load index rating scale.

Table 1. Workload assessment for context-based safety assessment.

NASA-TLX	Context-based safety assessment							
	Paper-based examination		STQ		SIS		JSA	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Mental demand	2.37	0.86	2.34	0.58	2.42	0.50	2.62	0.68
Physical demand	1.51	0.50	1.45	0.55	1.63	0.54	1.69	0.46
Temporal demand	2.40	0.49	2.14	0.54	2.43	0.76	2.86	0.83
Performance	4.25	0.73	4.51	0.50	4.71	0.45	4.60	0.60
Effort	1.94	0.67	1.54	0.49	1.97	0.65	2.20	0.71
Frustration level	1.40	0.49	1.09	0.28	1.20	0.40	1.31	0.46

Note: JSA = job safety analysis; NASA-TLX = NASA task load index; SIS = safety inspection scenarios; STQ = safety theory question.

the comprehensive scope of CBSA. Safety experts also emphasized that visualization-enhanced CBSA activities were favorable in covering safety contents and conveying safety topics (M 4.33, SD 0.79).

5.3. Stage 3: transparency evaluation

While the aforementioned effectiveness evaluation was centered on the authenticity of assessment contents, the transparency evaluation focused on the assessment procedures after system trials, considering whether students are afforded fair and equal opportunities to demonstrate safety knowledge and proficiency with CBSA tasks. The following criteria were examined under the transparency cluster:

(a) fairness, which refers how unbiased the approach is, i.e., how well the assessment tasks afford an equal opportunity for learners with diverse learning styles and preferences to demonstrate their safety knowledge skills and abilities [31]; (b) clarity, which specifically demands the understandability of assessment instructions and tasks; (c) practicality, which considers how realistic and reasonable is the performance required from students [34].

Results for the transparency evaluation are illustrated in Figure 9. The majority of educators and learners rated CBSA assessment tasks as fair and absent of bias (M 4.58, SD 0.58). Clarity with CBSA was also high (M 4.29, SD 0.54). Instructions in the system were also described as 'clear' and 'easy to follow', and educators reported that

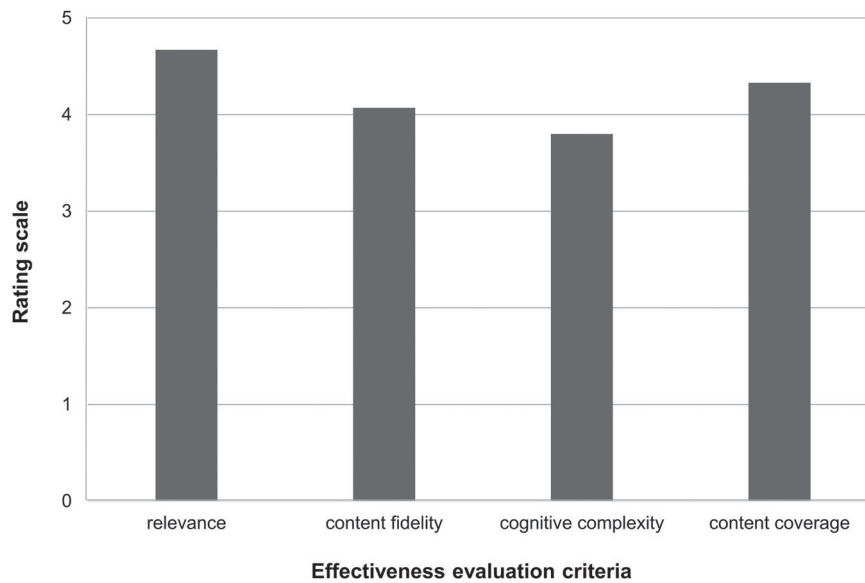


Figure 8. Effectiveness of conventional and context-based safety assessment.

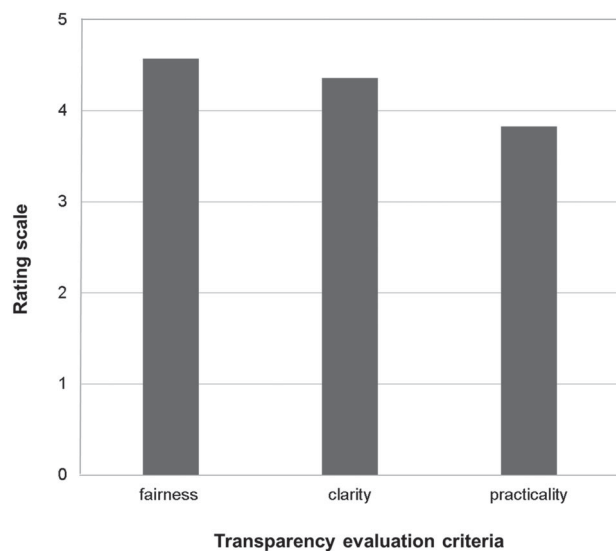


Figure 9. Transparency of conventional and context-based safety assessment.

the incorporation of virtual scenarios greatly improves the understandability and perception during assessment tasks. Educators reported that the required performance in the CBSA was unambiguous and clearly specified. Among the transparency criteria, practicality was the lowest scoring item (M 3.82, SD 0.64). In correlation with the task load criteria (mental workload, temporal workload and effort), the majority of subjects considered CBSA questioning practical and the difficulty level and time allocated was considered reasonable.

5.4. Stage 4: feedback session

In order to gain further insights into the cognitive, effectiveness and transparency evaluations, feedback sessions

were conducted through panel discussions with educators and open-ended discussions with learners. Noteworthy comments regarding learners' experiences and educators' perspectives are summarized as follows:

- Student 17: 'The CBSA visualizations make the testing process more interesting and enjoyable, more than paper-based exams which can be stressful. I just think better graphics would improve immersiveness of assessment tasks, and improve the whole assessment experience'.
- Student 21: 'Working through CBSA tasks was comfortable'.
- Student 5: 'Even though the JSA took some time and effort to complete, it was still a fun experience'.
- Educator 6: 'Considering the lack of safety education and assessment in tertiary construction programs, immersing learners in simulated contexts for training and testing would be a step in the right direction for construction management education'.
- Educator 4: 'Context-based assessment with VR simulations bridges the gap between education and the real industry situation. It has significant potential for improving assessment not only for construction safety, but also construction education as a whole'.
- Educator 9: 'JSA tasks in particular can bring a new level to safety assessment, targeting higher safety capabilities in construction education. Students can really demonstrate their knowledge with this'.

6. Discussion

This study introduces and develops a novel context-based safety assessment approach and provides empirical

evidence on its impact and effectiveness for construction safety knowledge and skills. For innovative pedagogic approaches, evaluation studies are necessary to ensure suitability for training and assessment. Previous studies emphasized the usability of visualization-enhanced instruction for safety knowledge dissemination and effectiveness for improving learning outcomes, without investigating the impact and effectiveness for assessment. Moreover, prior research efforts have not considered the capability of visualization-enhanced systems in appraising higher-order cognitive capabilities. In order to fill this gap, CBSA was developed as an assessment tool for tertiary construction safety education. Based on the quality criteria for assessment, the CBSA questioning modules were authentic, fair and deemed cognitively sound for didactic application.

Results revealed that mental, temporal and physical demands with the CBSA were reasonable for all three questioning modules. Moreover, in comparison to conventional paper-based testing, temporal demands during STQs were significantly lower. This could be attributed to the virtual contents provided, which enabled scenario perception and easier comprehension of required performance. Educators reported that one of the main benefits of the CBSA was its ability to accommodate diverse assessment tasks which afford experiential opportunities to demonstrate their safety skills contextually in simulated environments. In contrast with written tests which typically disadvantage visual learners, the provision of aural instruction complemented with compelling visuals in the CBSA was found appealing and satisfactory to students. Among the three modules, JSA tasks required the highest mental, temporal and physical demands and effort from learners. This is not surprising, since the JSA was designed to target higher-order abilities in line with Bloom's taxonomy of educational objectives. Furthermore, despite the high performance demands, subjects reported high performance satisfaction and low frustration levels with the JSA. The CBSA also satisfied the effectiveness criteria; however, educators noted that further development would be necessary to demonstrate the system's broad potential to gauge higher-order safety capabilities (cognitive complexity). Furthermore, even though interim results are promising, larger-scale system development would be necessary to investigate the practicality of the CBSA. Also, institutional support and well-defined feedback procedures will be necessary to cultivate continuous improvement through the development process.

Further research would be necessary to thoroughly evaluate the practical implications of CBSA in terms of the effects of visualization environments as a core examination tool and the impact of the CBSA on learning outcomes (as a formative assessment tool). Furthermore, it would also be worthwhile to consider the effect of the CBSA on short-term and long-term knowledge retention from an 'assessment for learning' perspective. Future works

should also establish grading standards for the CBSA and design web-based system modalities for non-proctored testing.

7. Conclusion

Despite consistent advances in construction methods and technologies, construction jobsites are still the most dangerous workplaces, with extremely high injury and fatality rates. In addition to the ineffective tertiary safety training, safety assessment also faces several deficiencies which have not been addressed. From an institutional perspective, assessment is vital in evaluating students' learning achievements and deficiencies in construction education. However, pedagogic models in construction education often depend on abstruse assessment methods which do not afford learners realistic and authentic environments where relevant safety knowledge and skills can be tested and higher-order capabilities can be demonstrated as necessary in industry. As a consequence, students can graduate without actually possessing the required safety competencies. In response to this dilemma, this article develops the CBSA system in order to deliver relevant safety assessments closely aligned to industry practice. Based on Bloom's taxonomy of learning objectives, the assessment approach comprises three domains: (a) STQs that assess safety facts and knowledge in context with close-ended response formats; (b) SIS that evaluate learners' hazard identification and response abilities; (c) JSA that requires learners to combine their safety knowledge and skills, analyze new situations and present solutions, with an open-ended response format.

The didactic impacts and effectiveness of the proposed approach was evaluated through learner, educator and safety practitioner trials, followed by a series of quantitative interview questionnaires. Based on criteria for quality assessment, a scheme comprising of a cognitive and mental workload evaluation, effectiveness evaluation and transparency evaluation was implemented. Results and findings suggest that the CBSA approach has significant potential to transform tertiary safety assessment by affording assessment tasks which are relevant, authentic and capable of targeting the higher-order safety skills which are required in practice. Just as the concept of safety culture exists in construction practice, this study contributes to establishing a safety culture in tertiary construction education. Considering the poor safety record of the construction industry, the CBSA could not only support quality assessments but also promote deeper learning of the 21st-century skills necessary to improve safety outcomes in the modern construction industry.

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ORCID

Akeem Pedro  <http://orcid.org/0000-0002-7884-5316>

Hai Chien Pham  <http://orcid.org/0000-0001-7830-7967>

Chansik Park  <http://orcid.org/0000-0003-2256-300X>

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