BIM-A AND BIM-VR SYSTEMS FOR CONSTRUCTION WORKER’S SAFETY COGNITION DEVELOPMENT

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The creation of a system capable of recognizing the reciprocal interactions between psychological, behavioural, and situational variables of safety management is a viable solution to safety cognition development. Thus, this research suggests a qualitatively validated conceptual model of BIM—animation and virtual reality—system for improving construction workers' safety cognition. Combining BIM technologies with safety cognition components and choosing two BIM technologies that are beneficial for fostering and enhancing workers' safety cognition led to the creation of the system. Workers will only follow safety rules and regulations if they have mental models of safety knowledge that are relevant to the laws and regulations, according to the study.

Keywords: BIM; BIM-A; BIM-VR; safety management; cognition development

INTRODUCTION

The construction industry is a socio-technical setting in which a safety management system must convince employees and managers to display specific safety behaviours to achieve a safe climate (Pousette *et al.,* 2008). This demonstrates that the apex of the safety management system is the development of construction worker safety policies, rules, and regulations. Unfortunately, studies indicate that workers do not always adhere to safety laws while on the job (Dekker, 2003). Hence, the most effective method of safety management is to assist construction workers in adapting safety information to their actions by strengthening their safety cognition (Dekker, 2003). By doing so, the burden on construction workers to comply with safety standards and procedures will be alleviated.

As well, it will increase their knowledge of safety issues. In addition to the fact that a safety management system cannot guarantee safety climate in the absence of safety behaviour, safety climate (a representation of workers' and managers' safety practices within a sociotechnical setting) is dependent on attitude and risk perception, which are characteristics of safety behaviour (Goncalves and Waterson, 2018). In essence, safety behaviour represents the difference between safety rules and practices. This

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claim is corroborated by Gherardi *et al.,* (2008), who claimed that safety behaviour is instinctual and the most crucial aspect of safety culture (Gherardi *et al.,* 2008).

The five parts of safety behaviour are safety training and education, safe work methods, management's commitment to safety, accident investigation and disaster management, and safety performance. Among these safety behaviour components, safety training and education are the most significant (Goh and Sa'adon, 2015; Pousette *et al.,* 2008). This is because safety behaviour is innate, and its essence is safety cognition, but safety cognition is primarily the result of safety training and instruction (Shin *et al.,* 2014). Safety cognition development through safety training and education is important due to the degree of exposure of construction workers to risks and hazards (Biggs *et al.,* 2013), the high rate of safety-related human errors and the need to heighten construction workers' sensitivity to risks, and the high exposure of construction workers to risks and hazards (Saurin *et al.,* 2008; Li *et al.,* 2012).

Zhang *et al.,* (2015) say that during the planning and design phases of a project, technological opportunities must be used to remove work hazards and put in place safety standards and best practices. Park and Kim (2012) also said that construction workers need to be better at recognizing risks, that managers and workers need to be able to talk to each other in real time, that latent safety risks need to be found, that a proper and consistent safety management process needs to be put in place, that safety information needs to reflect the real construction work environment, and that visual-based safety education needs to be put in place.

A visual safety training and education system will make sure that safety measurement in the construction industry can move forward in a way that is useful for safety stakeholders (Chouldry *et al.,* 2007). Also, it will make sure that a safety management system is made that can see how psychological, behavioural, and situational aspects of safety management and measurement affect each other. This study therefore presents and validates a conceptual building information modelling—animation (BIM-A) and virtual reality (BIM-VR)—system for enhancing the safety cognition of construction workers. It is anticipated that interactive BIM technologies such as the BIM-A and BIM-VR systems will promote visual-based safety training and instruction by interacting with the mind of the worker (Guo *et al.,* 2012; Olugboyega and Windapo, 2019). This is predicated on the fact that virtual-based training has yielded comparable results in the fields of rehabilitation (Rutkowski *et al.,* 2020), orthopaedic surgery (Vaughan *et al.,* 2016), and mechatronics (Kamińska *et al.,* 2021).

LITERATURE REVIEW

The Concept of Safety Cognition

Goh and Sa'adon (2015) defined safety cognition as the mental models of safety that control the conduct of employees through the mind. Shin *et al.,* (2014) defined safety cognition as the capacity to be aware and conscious of workplace safety issues. Goh and Sa'adon's (2015) and Shin et al.'s (2014) definitions of safety cognition are complementary since they include the same safety cognition characteristics (attitude, concentration/mindfulness, situational awareness, and risk perception). It is necessary to synthesize the proposed dimensions of safety cognition to apply them to construction safety and provide a more comprehensive description of safety cognition.

A summary of the data in Table 1 reveals five primary elements of safety cognition associated with construction (attention, situational awareness, concentration/mindfulness, task prioritizing and adjustment, and risk perception).

Four of these five dimensions are associated with mental models of safety knowledge, as specified by safety policies, rules, and regulations (Goh and Sa'adon, 2015). This reclassifies construction-related safety cognition dimensions as mental models of safety knowledge (attention, situational awareness, concentration/mindfulness, task prioritizing, and modification) and risk perception.

Based on the construction-related aspects of safety knowledge that have been found, a full definition of safety knowledge for the construction industry can be made. Therefore, safety cognition in the construction industry is the mental process of safe behaviour that comes from being able to recognize construction safety risks and apply mental models of safety knowledge (safety policies, safety rules, safety regulations, and safe work procedures) to construction activities. This definition of safety cognition puts safety behaviour first, just like safety culture puts safety behaviour first (Saurin *et al.,* 2008).

Table 1: A summary of the dimensions of safety cognition

References	Dimensions of safety cognition
Stanton *et al.,* (2001)	Reflection on the situation, orientation to the situation, development of knowledge and mental models, perception, and representation
Saurin *et al.,* (2008)	Knowledge models of self, knowledge models of the environment, task modification
Wallace and Chen (2011)	Perception, memory, motor function
Sacks *et al.,* (2013)	Attention, concentration
Pires, (2005); Tan *et al.,* (2015)	Attention, awareness
Goh and Sa'adon, (2015)	Attitude, perceived behavioural control, subjective norms
Shin *et al.,* (2014)	Risk perception, attitude, intention, behaviour, outcome
Fang *et al.,* (2016)	Obtaining information, understanding information, perceiving responses, selecting a response, taking actions

Use of interactive BIM technologies for safety cognition development of construction workers

According to Guo *et al.,* (2012), the most effective technique to enhance safety training and instruction is to employ interactive BIM technologies, which can connect with the workers' thoughts. Virtual reality and animation have been highlighted as interactive BIM technologies beneficial for construction worker safety training (Guo *et al.,* 2013; Zhao and Lucas, 2015; Li *et al.,* 2012; Le *et al.,* 2015; Sacks *et al.,* 2013; Pires, 2005; Tan *et al.,* 2015; Guo *et al.,* 2012). Sacks *et al.,* (2013) investigated what would happen if virtual reality was used to teach construction workers about safety. Before and after the virtual reality-based safety training, the workers were tested on how well they followed directions and paid attention to their work. The study showed that workers' attention and ability to focus got better after they learned about safety using virtual reality.

Guo *et al.,* (2012) did a case study on safety training for construction plant operators. They did this by using animation technology. The study concluded that animation-based safety training and education enhanced plant operators' risk perception. In another animation-based safety training and education study, Pires (2005) replicated the cognitive behaviour of humans during fire evacuation emergencies. As a result of animation-based simulations of fire emergency evacuation scenarios, the study uncovered a higher degree of attention to uncertainties and a heightened awareness of risks. These studies show that BIM-based virtual reality and animation-based safety training and instruction can help construction workers become more aware of safety issues. Unfortunately, the BIM literature doesn't have many useful steps for making BIM-A and BIM-VR systems to help construction workers learn more about safety. Also, existing approaches to the use of virtual reality and animation in safety management have focused on safety training for specific job tasks, with little or no consideration for safety cognition development. This paper proposes a strategy for incorporating virtual reality and animation into BIM-based procedures for the development of safety cognition. As discussed by Guo *et al.,* (2013), Zhao and Lucas (2015), and Pires (2005), safety cognition is a mental process that involves more than attention to instructions, concentration on work, and danger awareness. This paper argues that the focus of BIM-based safety training must be expanded to include the enhancement of workers' level of attention to instructions and uncertainties, situational awareness, level of concentration to work, ability to modify and prioritize tasks, and risk perception to adequately improve the safety cognition of construction workers and utilize interactive BIM technologies. The overall benefit of this kind of safety training is that it helps construction workers learn more about safety and creates a culture of safety in any construction environment.

METHOD

This study employs interview-based quantitative research. A quantitative research interview is a standardized discussion in which the researcher and respondents discuss industry-specific references such as terminologies, theories, and models (Frels and Onwuegbuzie, 2013). The interview method is ideal for collecting data from a representative sample in quantitative research. Dworkin (2012) recommends a sample size of 5-50 participants for an interview. Therefore, a handy sample of three BIM professionals and two safety experts was chosen as a representative sample for this research. The BIM specialists are men with around three years of BIM experience and ten years of construction experience. There is one male and one female safety expert.

The female participant has accumulated eight years of expertise in construction safety management, while the male safety expert has accumulated more than ten years of experience. Conceptual models of the BIM-A and BIM-VR systems were used to come up with the interview questions. By determining the methods for utilising BIM-animation and BIM-virtual reality technologies, the model was created. The stages at which safety cognition aspects may be handled were identified in the procedures. The model was produced by outlining the methods and combining similar BIM-animation and virtual reality procedures. The questions were shared with the participants on a Google Doc. Participants were asked to assign a number indicating whether they agreed (1) or disagreed (0) with the model's concepts. The relevance of the concepts was determined using the frequency distribution and percentage of the obtained data. The significance threshold was set at 50 percent.

FINDINGS

BIM-A and BIM-VR System for Construction Workers' Safety Cognition Development

Figure 1 presents a conceptual model of the BIM-A and BIM-VR systems for the development of construction workers' safety cognition. The model's theoretical foundation is based on the link between animation and virtual reality as interactive

BIM technologies. This association is illustrated in Figure 1. The basics of Figure 1 are to show how safety managers can produce a realistic three-dimensional image or environment, as well as an illusion of motion and shape change that workers can perceive as real and learn safety procedures from. As depicted in Figure 1, the model investigates the integration of BIM technologies with the components of safety cognition by finding two BIM technologies that are effective for developing and enhancing workers' safety cognition. All the safety cognition components (risk perception, attention to work, situation awareness, heightened focus, and knowledge-based task prioritization and modification) influence safety cognition.

Safety training that does not include all these components will not result in the formation of safety cognition. To make sure that safety training covers all aspects of safety knowledge, each scenario must successfully model all of them. The BIM-A and BIM-VR systems are organized into four process operations (see Figure 1). The initial two phases are applicable to both BIM-A and BIM-VR (outline the objectives of the safety training and develop the scripts for safety cognition). This suggests that either of the technologies may be utilized to cultivate safety cognition. Yet, the level of interactivity afforded by the technologies is distinct. BIM-VR provides an interactive space that simulates the real world, as well as the flexibility to employ a variety of animation techniques. The figure also displayed the two separate processes that are unique to BIM-A and BIM-VR. With BIM-A, it is necessary to create a visual representation of the scripts to simulate the scripts' scenarios.

Modelling 3D animation for each simulated scenario utilizing BIM animation technologies such as Autodesk Maya and 3DS is the second critical step. In addition to recommending suitable animation tools, the BIM-A system identifies 3D animation as the most suitable animation type for BIM-based safety cognition development. Because it promotes practical solutions and realistic methods, 3D animation was suggested. The specific procedures for BIM-VR are to create a fully immersive virtual reality of the scripts and build a 3D virtual environment for the fully immersive simulated scenarios utilizing BIM virtual reality technologies. Fully immersive simulations were recommended as the optimal virtual reality technique for the BIM-VR system because they facilitate the creation of a more credible and realistic experience.

Figure 1 presents ten concepts drawn from the BIM-A and BIM-VR systems suggested. The concepts were given to the participants as statements for them to indicate whether they agreed or disagreed with them. Table 1 contains an analysis and presentation of their responses. As demonstrated in Table 1, most participants (>50%) felt that virtual reality and animation are beneficial for creating and enhancing construction workers' mental models of safety knowledge and risk perception. The majority also agreed with the BIM-A and BIM-VR safety cognition system development approaches. This validates that the BIM-A safety cognition system should be designed as a sequence of animations that illustrate the objects and concepts necessary for the development of mental models of safety knowledge and risk perception.

By incorporating BIM-A technologies into safety training, construction workers will be able to personalize their learning experiences and advance at their own speed. They will receive precise information from the system. This will successfully accelerate training sessions because participants will spend less time visualizing and comprehending complicated concepts or procedures. Additionally, the BIM-A system will aid in their retention by making material more memorable and delivering it in both auditory and visual formats. The results of the study show that BIM-VR can simulate dangerous situations without putting safety at risk. With the BIM-VR system, workspaces and jobs can be duplicated in a realistic virtual space. This lets construction workers do hands-on training without having to worry about getting hurt. This implies workers can make mistakes without risk and gain knowledge through practice.

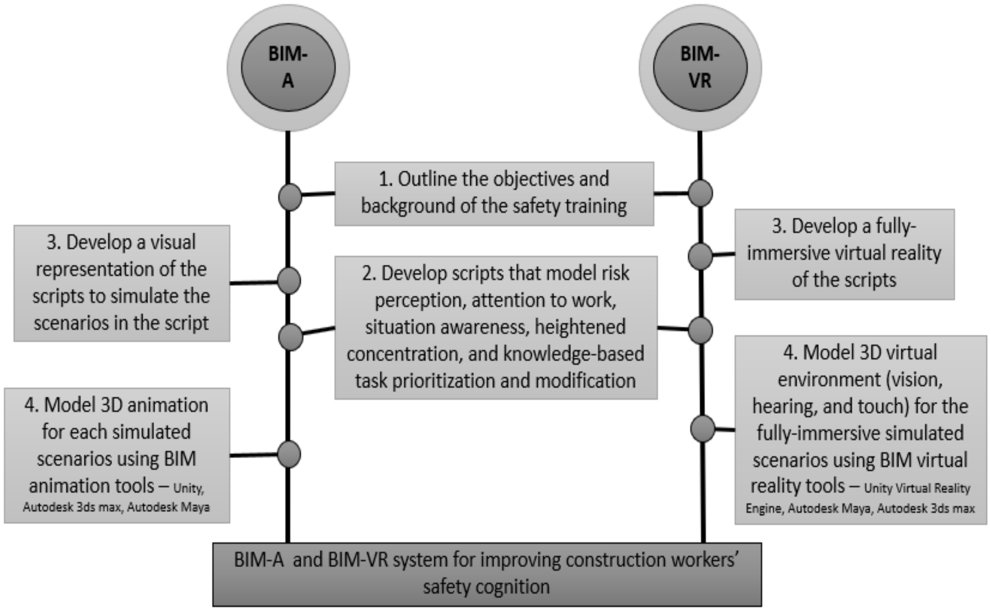

Figure 1: BIM-A and BIM-VR system for improving construction workers' safety cognition

Qualitative Validation of the BIM-A and BIM-VR System for Construction Workers' Safety Cognition Development

The purpose of safety cognition is to remove the load of safety rules and regulations from the minds of construction workers and make them second nature. With standard safety training and teaching, this has proved impossible to do (Li *et al.,* 2012). The BIM-A and BIM-VR systems enable construction employees to practice and perfect safety procedures. The systems are also useful in empowering construction workers to make safe and independent decisions when confronted with hazards, to have a better understanding of safety policies and regulations, to be able to relate to conditions and regulations that have a life-or-death significance, and to have a well-developed risk perception (the capacity to visualize invisible dangers and choose the appropriate responses based on knowledge and experience) (Zhao and Lucas, 2015).

CONCLUSIONS

Working in a construction setting can be dangerous, and the key to minimizing safety risks is a highly skilled and trained staff. Yet, a dangerous environment is not the best place to teach important safety skills, especially for people who work in high-risk jobs. Based on the nature and requirements of construction work, BIM-based safety cognition training is required for safety training that is suitable for each work purpose and scenario. This study suggests a BIM-A and BIM-VR system as a BIM-based safety cognition training system that would help construction workers quickly learn visual safety training content. The study concluded that the system is a great way for construction workers to improve their working memory, learn about safety management in an interesting and effective way, and practice and perfect safety rules and norms.

Table 2: Level of agreement with the BIM-A and BIM-VR system for construction workers' safety cognition development

Concepts from the model	Agreed	Disagreed
The objectives of the safety training should be outlined in the BIM-A and BIM-VR system	4 (80%)	1 (20%)
BIM-A and BIM-VR model should include risk perception as mental models of safety	4 (80%)	1 (20%)
BIM-A and BIM-VR model should include attention to work as mental models of safety	5 (100%)	0 (0%)
BIM-A and BIM-VR model should include situation awareness as mental models of safety	4 (80%)	1 (20%)
BIM-A and BIM-VR model should include heightened concentration as mental models of safety	5 (100%)	0 (0%)
BIM-A and BIM-VR model should include knowledge-based task prioritization and modification as mental models of safety	5 (100%)	0 (0%)
The scenarios in the BIM-A model should be simulated virtually	4 (80%)	1 (20%)
BIM-VR model is best developed as a fully immersive virtual reality	4 (80%)	1 (20%)
3D animation in BIM animation tool is appropriate to develop BIM-A safety cognition model	5 (100%)	0 (0%)
3D virtual environment in BIM virtual reality tool is appropriate to develop BIM-VR safety cognition model	5 (100%)	0 (0%)

The study's conclusion is that workers' safety cognition can be improved by helping them pay more attention to their work, be more aware of their surroundings, focus more, change, and prioritize tasks based on their knowledge, and understand risks. The parts of safety cognition that were found were these parts of mental models of safety knowledge. The study additionally finds that workers will only follow safety rules and regulations if they have mental models of safety knowledge that are relevant to the rules and regulations. This has ramifications for construction site safety management approaches. The study shows that when workers' safety cognition is developed, they will be able to use safety information in their work and be able to spot safety risks while doing their jobs. The study also says that construction and safety managers should use relevant BIM technology to improve safety awareness in the construction sites where they work.

To comprehend safety laws and regulations, workers require safety training and instruction. The relevance of these models in relation to safety training and education is that the use of BIM technologies makes safety training and education meaningful and effective. Workers must make mental models of safety knowledge before they can follow safety policies, rules, and regulations at work. This study will also help construction and safety managers see that workers need to learn how to think about safety. The models will also be valuable for construction managers in developing the most efficient safety management system to achieve safety targets within a predetermined timeframe. This study offers a novel approach to achieving safety awareness in the construction setting. The system should not be used on the job site to help with safety compliance or safety management. The system is suitable in real-life scenarios for worker safety training on work procedures and technologies prior to on-site operations. The system can be used in training sessions and safety education activities. Future research should study the relationship between better worker safety awareness and construction site performance. Additionally, the effect of BIM integration on the development of safety cognition should be examined.

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