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INVESTIGATING BIM-BASED CONSTRUCTION SAFETY EDUCATION TECHNIQUES

Abstract: *Building construction projects are dynamic and hazardous, incorporating complex and dangerous tasks. As a result, health and safety of workers in the construction sector are at risk. Improving the worker's perception of dangerous situations can reduce site accidents and reduce injuries and fatalities. However, safety training and education in the construction industry continue to rely on traditional methods.*

This study investigates the safety training approaches developed using BIM to improve construction workers' safety skills and perceptions. Based on a systematic review related to BIM-based health and safety systems, articles in the field of safety training and education were acquired. Findings suggest that innovative teaching tools such as Augmented and Virtual Reality (AR/VR) linked to BIM may be more effective than traditional teaching methods. However, BIM-based safety education is still in its initial phase, and future development requires a more extensive and enhanced training module using interactive, BIM-based, 4D visualisation systems to support construction safety education and training.

Key words: Construction Education; Safety Training; Building Information Modelling (BIM); Construction Health and Safety.

INTRODUCTION

In the AECO (Architectural, Engineering, Construction, and Operation) sector, relentless health and safety measures to prevent construction accidents are being implemented. However, construction workers have the most severe accident and death rates among other sectors (Ahn et al., 2020).

In 2019, 199,200 injuries were recorded in the AECO sector by the Occupational Safety and Health Administration (OSHA). The AECO sector is responsible for 9.5 fatalities per hundred thousand full-time workers. Likewise, one in five worker fatalities were in the AECO sector (Labor, 2019). According to the U.S. Labour statistics, the major causes of accidents and injuries are struck-by-objects, falls, stuck-in, and electrocution. These causes were responsible in 2019 for 58.6% of deaths of AECO workers (Labour, 2019).

A recent theory for accident causes and prevention has been based on five accident causation factors that are important to eliminate in accident prevention (Wang, 2018). These factors are Environment and heredity, Management, Personal factors, Job factors, Unsafe actions, and conditions. Thus, staff members must undergo special and elaborate safety education and training to avoid dangerous behaviours prior to on-site construction activities. In addition, the construction site should constantly be monitored and inspected to prevent accidents (Wang, 2018). However, according to OSHA, construction safety procedures are not communicated properly. In particular, workers who have limited worksite experience, especially new workers and interns, are more likely to get injured than experience workers (Mason et al., 2017).

Traditional safety measures rely on manual monitoring and inspection. Thus, these methods are error prone (Eleftheriadis et al., 2017). Traditional accident prevention methods are still being executed, highlighting the urgent need to transform AECO safety management into a digitalised one (Zhou et al., 2015). Building Information Modelling (BIM) is shown to be a promising tool aiding in the automation of the safety management of the AECO sector (Eleftheriadis et al., 2017). Many studies investigate the possibilities of integrating (BIM) into safety education and training (Clevenger et al., 2015). The visualisation may enhance the worker's and the students' ability to conceptualise and understand construction concepts. BIM facilitates the visualisation to students and workers (Sidani, et al., 2021, a; Sidani, et al., 202, b). Alongside safety training and education, BIM tools are widely utilised in numerous safety areas: safety planning, safety monitoring, design for safety, safety inspection, and safety at the facility and management phase (Clevenger et al., 2015).

The main objective of this review is to analyse the existing proposals in the field of BIM-based construction safety education and training incorporating ICT technologies to evaluate the degree of advancement of safety training and education in the construction industry. In addition, highlight the essential tools, techniques, and architectural frameworks to guide future BIM-based technology research and application on the use of safety training and education in the AECO industry.

Methodology

This short review is based on a systematic review of BIM-based technologies for construction health and safety. The systematic review was done with the top multidisciplinary, electronic databases for scientific literature on construction and safety. The study will also follow the snowballing technique by looking through the articles' references to see relevant studies from any other database that were not collected during the search (Wohlin, 2014). Four keywords are considered for the search strategy: ("Building Information Modelling, Construction, Occupational Health and Safety") and considering synonyms of each keyword, such as BIM, work health and safety, accidents, and risks.

After screening the articles and following well-defined exclusion and inclusion criteria, for the exclusion criteria, conference, review, discussion, and unpublished articles were excluded. Similarly, studies not related to the AECO sector will be refused. Finally, 78 articles were considered for the review, among which only five articles were targeting the fields of safety training and education (Figure 1). Figure 1 mentions the number of fields each article targeted, considering that some articles mentioned more than one field totalling 114 fields targeted by the 78 articles. The authors decided to include a previously excluded article as a conference and not a journal article for this study. The article was the only excluded conference article targeting BIM-based health and safety training and education. The article was considered because it demonstrated relevant input for the current review and interesting results (Giusti & Bruttini, 2018).

The following sections will demonstrate the results of the collected articles, following a discussion of the main finding, limitations, and the most promising tools to be considered—finally, conclusions and future proposals.

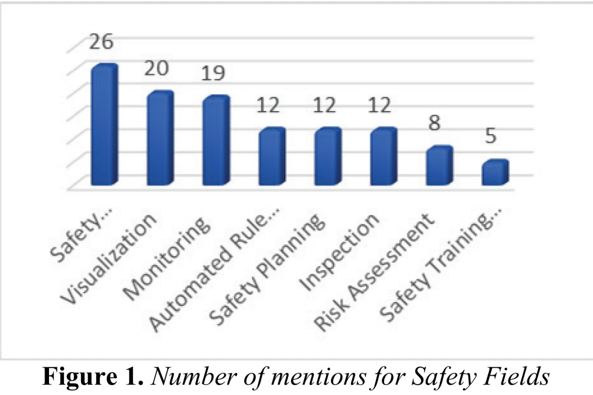

Figure 1. *Number of mentions for Safety Fields*

Results

The results of the articles targeting training and education are classified into several categories, target groups, construction phases, targeted risks, assessment methods, BIM needs and dimensions, programs, and regulations and standards.

The main target groups are workers with five times (Afzal & Shafiq, 2021; Ahn et al., 2020; Giusti & Bruttini, 2018; Li et al., 2015; Park & Kim, 2013). Clevenger developed a prototype of an interactive safety training module targeting university students (Clevenger et al., 2015) and one mention for safety managers (Cheng et al., 2017) (Figure 2). Furthermore, all articles focused on the construction or preconstruction phase, as well half of the articles considered off-site training while the other half considered on-site training.

Concerning the safety risks implemented in the training sessions, two authors focused on general site risks (Giusti & Bruttini, 2018; Park & Kim, 2013). Afzal and Ahn targeted falls and struck by falling objects (Afzal & Shafiq, 2021; Ahn et al., 2020), one article aimed towards scaffolding safety measures (Clevenger et al., 2015), and one involved near miss and equipment maintenance (Li et al., 2015).

All authors represented an assessment method that varied from case studies, pilot tests, and surveys. Park presented a case study where a field safety accident occurred during a school construction project's reinforcement and formwork work. Safety managers tested and evaluated the educational sessions for a week (Park & Kim, 2013). Furthermore, Ahn conducted two training experiments developed and tested through testing trainees (Ahn et al., 2020). Afterwards, a survey was made directing safety managers, in which the workers evaluated the life-like quality of the training, active learning, and enjoyment that each of the training methods can promote. Finally, a case study was implemented at a high-rise building. Likewise, a case study and a survey targeting safety managers were made to assess the developed framework was done by Afzal (Afzal & Shafiq, 2021).

BIM was used by three authors as a geometric tool with non-geometric data such as schedule for time sequencing (4D) (Afzal & Shafiq, 2021; Giusti & Bruttini, 2018; Park & Kim, 2013), whereas the rest of the authors relied on BIM only for Geometric representations (3D).

The program used to develop the BIM models is Autodesk Revit. Revit was used by four out of the six authors, while the remaining two articles did not specify which BIM program was utilised. Most of the authors used a game engine to implement the training scenarios. Park used Microsoft XNA Game Studio to create an AR phone Application (Park & Kim, 2013). In comparison, Afzal implemented the BIM model into Unreal Engine, the VR Oculus Rift Headset (Afzal & Shafiq, 2021). Similarly, 3D Unity was used by (Li et al., 2015).

On the other hand, Ahn used Navisworks to create animations clarifying the accident hazards and types along with texts or narrations (Ahn et al., 2020). However, Clevenger adopted another method for training with Adobe Captivate, the safety training module was published to an HTML file, and an executable file was created to view using an Abode flash player or an internet browser (Clevenger et al., 2015). Finally, Giusti implemented the training module in VR but did not mention any of the utilised software (Giusti & Bruttini, 2018).

Only two authors developed their training simulations based on official standards. Afzal based his training on the regulations for fall hazard prevention following Abu Dhabi Occupational Safety and Health Centre (OSHAD) requirements for safety planning (Afzal & Shafiq, 2021). At the same time, Clevenger based his work on the OSHA requirements for scaffolds (1926 subpart L – Scaffolds) (Clevenger et al., 2015).

Figure 2. *Target Groups*

DISCUSSION AND CONCLUSION

The articles focus on training construction workers directly before or during the construction project. For instance, Park proposed an AR system where workers could visualise the continuous safety planning process, receive on-site education, and assist with site inspections. This shows that the workers received specific training and education associated with the construction project. The developed tool relies on accident cases, training material, and inspection checklists' databases (Park & Kim, 2013). On the other hand, VR utilisations were off-site and showed a general training simulation to improve the identification of on-site safety risks and increase the risk recognition capacity of workers. In addition, Afzal developed multilingual training scenarios for international projects in VR (Afzal & Shafiq, 2021; Giusti & Bruttini, 2018). On the other hand, Li applied a proactive Construction Management System (PCMS) designed for real-time warnings and analyses for safety training by automatically monitoring and recording workers' unsafe location-based behaviours. A link between safety training and facility management was expected, but no study targeted this issue.

VR and AR showed considerable potential to assist workers and students to visualise the risks on the construction site. VR places the user in a virtual location, while AR adds layers or geometry to the actual surroundings.

The developed systems are essential for understanding the dynamics of construction sites and different construction tasks. The mentioned applications are advantageous for safety managers, who can adequately apply specific safety training and education. However, the findings show that BIM application for safety training and education has not been explored sufficiently. The studies highlighted several limitations, including the inability to identify many unsafe working conditions or risky worker behaviours, the fact that tracking workers violate privacy policies that cannot be implemented in various countries, the need for owners to be motivated to invest in implementing such tools, the necessity for consistent Level of development (LOD), and the fact that the process of developing simulations is time-consuming

Thus, future research should focus on applying BIM-based tools, considering the barriers to implementing BIM-based safety training, such as a standardised architecture framework or plugins to reduce the model development and simulation time.

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Adeeb Sidani was born in Beirut, Lebanon, in 1991.
He received a diploma in Architectural Engineering and **is** currently a Ph.D. candidate in Construction Health and Safety at the University of Porto.
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