# Digital Technologies for Safety Training in Construction

P. Mésároš[1], C. Vigneshkumar[2, a)], M. Spišáková[3,] M. Špak[4] and P. Kaleja[5]

[1,2,3,4,5]*Faculty of Civil Engineering, Technical University of Kosice, Kosice - 042 00, Slovakia*
[2]*Department of Design, Indian Institute of Technology Guwahati, Guwahati - 781039, India*

[a)] *Corresponding author: vigneshkumarchellappa@gmail.com*

**Abstract.** Digital technologies have been adopted to train and educate employees and workers in the construction industry for the better safety performance of organizations. This study aimed to understand the state-of-art digital technologies adopted for safety training in construction since 2000. A total of 59 journal articles were retrieved from the Scopus database using keywords such as "virtual reality" OR "augmented training" OR "safety training," etc. From this study, Virtual reality (VR) was found to be the most widely used method followed by augmented reality (AR) for safety training in construction. In terms of research areas, most of the digital technologies focused on hazard recognition (HR), safety awareness (SA), and safety operations (SO). It is expected that the research findings could assist construction practitioners and academicians in selecting the best digital-based training methods to enhance the performance of safety training.

## INTRODUCTION

The construction industry (CI) offers more job opportunities to youngsters [1] and CI corresponds to 13% of gross domestic product (GDP) [2]. On the other hand, CI is responsible for a large number of fatalities and injuries which is higher than any other industry [1]. This results in project delays, and loss of work [3], and also individuals are highly influenced by financial damage due to fatal accidents in construction [4].

Poor hazard identification skills, lack of awareness of safety, ineffective safety training, and so on were leading causes of construction accidents [5]. To overcome these challenges, an effective strategy proposed by many researchers is safety training which could enhance hazard identification skills and safety awareness of individuals [6]. However, some research [7,8] indicated that conventional safety training is not effective to transfer safety knowledge and fails to visualize the risks involved in construction sites [9].

In recent decades, digital technologies such as virtual reality (VR), augmented reality (AR), sensor-based (SB), and mixed-reality (MR) have been documented as safety training tools due to their nature of effective safety knowledge sharing [10]. Digital technologies are computer-aided design methods that provide visualization from immersive and interactive views [11]. Digital technologies can improve the involvement of users in training by visualizing the construction environment [12]. Therefore, many studies proposed different digital technologies for safety training over conventional training methods [13-15].

In this study, a review of literature on digital technologies used for safety training in construction has been conducted. Up to the authors' knowledge, the development and implementation of digital technologies for construction safety training have not been carried out till now. Such a review of literature could help to understand the state of research on the particular domain [16]. A Scopus database was used to retrieve the documents that fall under the scope of the research and within the period from 2000 to 2021, 59 articles were retrieved.  This study adds to the knowledge in the following ways (1) to show the publications distribution per year; (2) to list out the highly influential journals in which documents were published; (3) to explore the different digital technologies used for safety training and their application areas.

## REVIEW METHOD

Due to the broader coverage of studies [16], the Scopus database was chosen to collect documents for review in this study. Also, the Scopus database was widely used in construction management and built environment review studies such as falls from height [17], thermal comfort [18], health and safety [19], corporate social responsibility [20], and MCDM (multiple-criteria decision making) [21] to retrieve data for literature review. The keywords used to retrieve documents were “construction industry” OR “safety training” OR “virtual reality” OR “augmented reality” OR “BIM” OR “building information modeling” OR “mixed reality” OR “workers safety” OR “digital technologies” OR “design for safety” OR prevention through design” OR “computer-aided design” AND “health and safety in construction”. Initially, a total of 353 documents were identified from the database. Next, advanced filtering was carried out by filtering the documents published from 2000 to 2021, selecting the source type as journal articles, and the documents published only in the English language. Only the journal articles were chosen due to their reliable knowledge sources [22]. Also, the documents that do not focus on safety training but mentioned the keyword “safety training” in the abstract were removed. After careful refinement, finally, 59 journal articles were selected for this review study that falls under the scope of this research. Based on the publication year, journal sources, document title, and author keywords, the gathered documents were classified and stored in the MS Excel worksheet. The following sections will discuss the results of the study based on the document's year of publication, documents per journals, and the digital technologies and their application areas for safety training in construction.

## FINDINGS AND DISCUSSION

### Selected documents overview

Figure 1 shows the number of documents published per year. From the year 2000 to 2019, no significant growth was observed in the research focusing on applications of digital technologies for safety training in construction. In the past two years, i.e., 2020 and 2021, it can be seen that a large number of documents were published 10 and 16, respectively. In terms of document sources, Automation in Construction (12 articles) was the highly influenced journal followed by the Journal of Information Technology in Construction (6 articles) and Advanced Engineering Informatics (4 articles) (see figure 2). Some of the other influential journals were Engineering, Construction and Architectural Management, Journal of Computing in Civil Engineering, and Safety Science with 3 publications each. It can be seen that, out of 59 retrieved documents, 33 documents (59%) were published in the journals that are shown in figure 2.

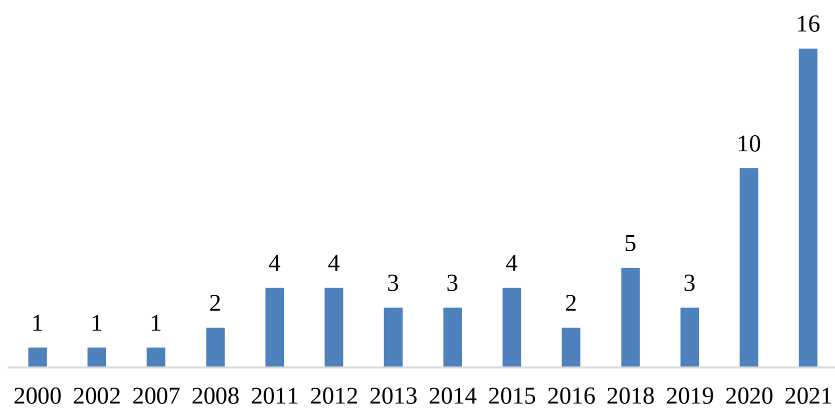


**FIGURE 1.** Documents published per year

### Application of digital technologies for safety training

Among 59 retrieved documents, the application of VR for safety training in construction was found in 53 documents (90%) followed by AR (5%), SB (3%), and MX (2%). It can be seen in figure 3 that VR has been used widely for safety training in construction since 2000. After 2006, studies adopted AR technologies for safety training, followed by SB from 2011 and MX from 2016. In terms of application areas, digital technologies for safety training were used for hazard recognition (HR), safety operation (SO), safety awareness (SA), and multipurpose (MUL) i.e., HR and/or SO and/or SA. Figure 4 depicts the application areas in which digital technologies were used for safety training in construction. It was observed from figure 4 that most of the studies from retrieved documents focused on SO (37%), followed by HR (34%), MUL (21%), and SO (7%). The digital technologies and their application areas are discussed in the following sections.

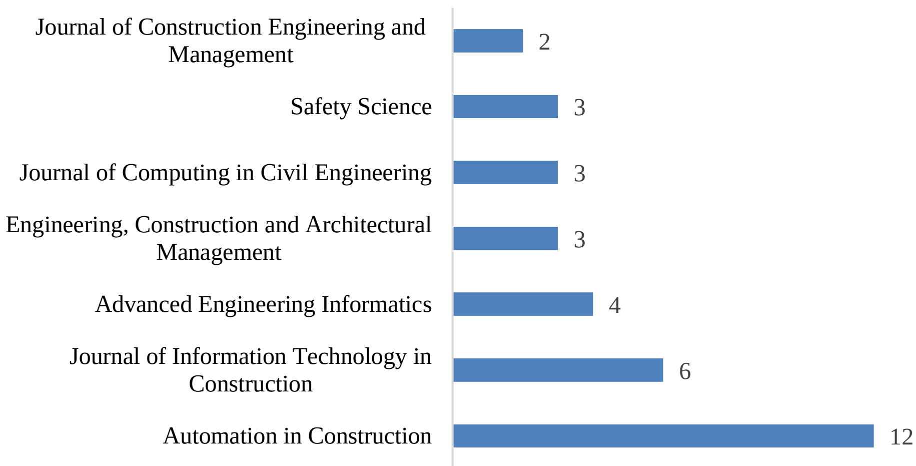


**FIGURE 2.** Documents published per journal source

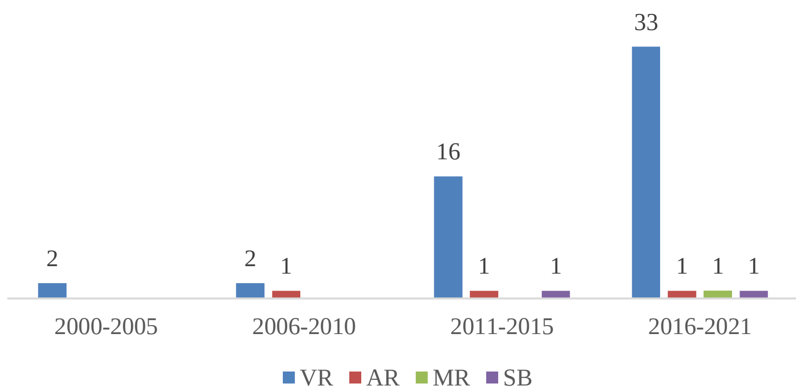


**FIGURE 3.** Distribution of documents characterized by digital technologies and publication year

*VR-based training*

Based on four different methods Immersive, BIM-based, desktop-based, and game-based, VR-based training was categorized. Out of 53 VR-based studies, 25 studies (42%) used immersive VR for safety training followed by desktop-based (31%), game-based (12%), and BIM-based (5%). Figure 5 shows the distribution of the VR-based training methods for different application areas. It was observed from figure 5 that immersive VR training has been mostly used for HR followed by SO. Immersive VR consists of a head-mounted device (HMD) that gives an immersive environment to users [13]. To provide real-time feedback, treadmills, controllers, and sensor gloves are also added to the immersive VR setup [23]. For instance, construction management students were trained and educated through immersive VR training for recognizing the fall hazards in the electrical trade of construction projects [24]. The second most widely used training method is desktop-based VR. The virtual environment is visualized on a computer desktop without any tracking equipment [13] and accessed through a mouse and keyboards

[23]. Among other VR-based training methods, this is considered to be cheaper. Desktop-based training was used mainly for HR and to carry out SO [e.g., 25,26]. Covering multiple areas such as HR and creating SO among construction workers, immersive [27] and desktop-based [28] VR training methods were used. It was observed from figure 5 that 7 studies were documented with the game-based VR training method. According to Wang et al. [13], game-based VR is a computer-based multi-user operating system that focuses on game object interactions. This method has been widely adopted to perform SO at construction sites. For example, for dismantling tower cranes, Li et al. [29] used multi-user game-based training system. Similarly, students were trained through safety games to enhance their knowledge about trench safety [30]. The BIM-based VR method was limited to safety training and has been used for HR, SO, and to create SA. Building information modeling (BIM) is concerned with 3D objects and relies on the model to replicate the construction process [13]. For instance, a BIM-based prototype was developed by Park et al. [12] for HR and validated by construction practitioners.

| | VR | AR | MR | SB |
|---|---|---|---|---|
| MUL | 11 | | | |
| SO | 20 | 1 | | 1 |
| SA | 4 | | 1 | 1 |
| HR | 18 | 2 | | |

HR SA SO MUL

**FIGURE 4.** Digital technologies application areas for safety training

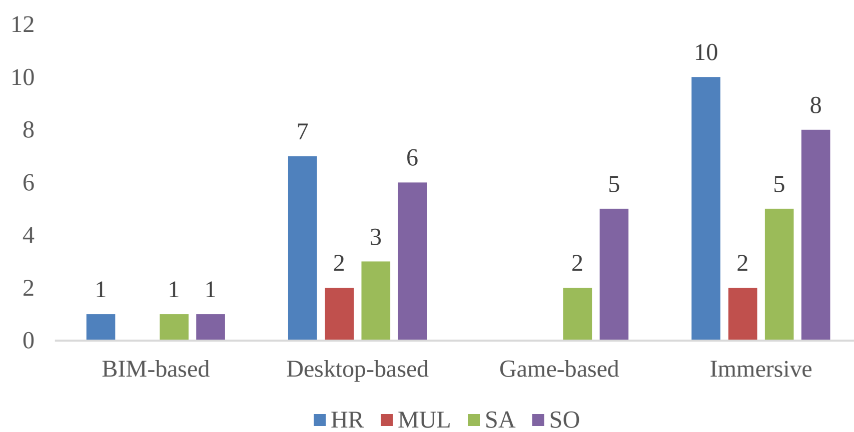


**FIGURE 5.** VR methods applied in different areas

*AR-based training*

AR is similar to VR but AR projects digital images into the real world [31]. The application of AR for safety training has been found in 3 documents in which 2 studies focused on HR and one on SO. Based on the studies that focused on HR, AR was used to enhance the worker's HR skills [32] and to examine how emotions influence HR [33]. In another study, AR was applied to train heavy construction equipment operators [34]. The findings of this study indicated that AR has the potential to save cost and time for safety training programs.

*SB and MR-based training*

According to the SB training method, one study aimed to enhance the SA of equipment operators using real-time motion-sensing technology [35]. The results revealed that the SA of operators was improved by adopting such technology. In another study, real-time location and data visualization technology was proposed to train workers [36]. This study's results show that the proposed method was effective in detecting safety hazards and timely providing warnings to avoid accidents proactively. According to Bosché et al. [37], MR is referred to as a hybrid reality that creates visualizations and a new environment in which digital and physical objects co-exist in real-time. Only one document was found among 59 documents that applied MR for safety training in construction. Bosché et al. [37] adopted the MR training method to train workers, particularly in the working-at-height trade including roofing, scaffolding, painting, etc.

## CONCLUSION

In this study, the applications of digital technologies for safety in the construction industry were presented. The articles for the literature study used the Scopus database to retrieve articles. The results show that the number of publications was scattered from 2010 to 2019, however, in the past two years (i.e., 2020 and 2021) the documented articles were high indicating that the scope of this research is getting much attention among researchers. It is expected that a greater number of studies to be documented in upcoming years in this domain. In terms of digital technologies, VR has been widely used for safety training since 2000. Other technologies that have been used for safety training were AR, MR, and SB. Among VR-based training methods, immersive safety training was found to be adopted mostly due to their effectiveness compared to other VR methods such as BIM-based and game-based technologies. Concerning application areas, most of the studies focused on HR followed by SO and SA. The study findings are expected to assist construction practitioners in selecting the best optimal digital-based safety training method for enhancing training performance. This study chose journal articles in the English language that were published only in the Scopus database. Future studies could use other databases and article types to have a broader view of this study's scope.

## ACKNOWLEDGMENTS

This research is supported by the National Scholarship Programme of the Slovak Republic.This research was also supported by Erasmus+ 2019-1-SK01-KA203-060778: “Construction Safety with Education and Training using Immersive Reality” and KEGA 009TUKE-4/2022: “An interactive tool for designing a safe construction site in an immersive virtual reality”.

## REFERENCES

1. V. Sousa, N. M. Almeida and L.A. Dias, *Saf. Sci*. **66**, 75–86 (2014).
2. A. Barbosa, J. Gambatese, A. Das and A. C. Pestana, “Mapped workflow for safety and reliability assessments of use and re-use of formwork,” in Proceedings of Construction Research Congress (ASCE publishing, Atlanta, Georgia, 2014), pp. 1821–1830.
3. R. Y. Sunindijo and P. X. W. Zou, *J. Constr. Eng. Manag.* **139**, 1144–1153 (2013).
4. J. Yuan, W. Yi, M. Miao and L. Zhang, *Int. J. Environ. Res. Pub. Health* **15**, 345 (2018).
5. C. S. Park and H. J. A. Kim, *Autom. Constr.* **33,** 95–103 (2013).
6. E. Sawacha, S. Naoum and D. Fong, *Int. J. Proj. Manag.* **17**, 309–315 (1999).
7. S. Demirkesen and D. Arditi, *Int. J. Proj. Manag.* **33**, 1160–1169 (2015).
8. S. Bhandari and M. Hallowell, *J. Constr. Eng. Manag.* **143**, 1–10 (2017).
9. L. Ge and F. Kuester, *J. Comput. Civ. Eng.* **29**, 1–10 (2015).
10. M. Akinlolu, C. Theo, D. J. Edwards and F. Simpeh, *Int. J. Constr. Manag.* 1-13 (2020).
11. X. Li, W. Yi, L. Chi, X. Wang and A. P. C. Chan, *Autom. Constr.* **86**, 150–162 (2018).
12. M. Zhang, L. Shu, X. Luo, M. Yuan and X. Zheng, *Autom. Constr.* **135**, 1-13 (2022).
13. P. Wang, P. Wu, J. Wang, H. Chi and X. Wang, *Int. J. Environ. Res. Pub. Health* **15,** 1– 18 (2018).
14. J. Goulding, W. Nadim, P. Petridis and M. Alshawi, *Adv. Eng. Inform.* **26**, 103–116 (2012).
15. J. Goedert, Y. Cho, M. Subramaniam, H. Guo and L. Xiao, *Autom Constr.* **20**, 76–87 (2011).

16. M. R. Hosseini, I. Martek, E. K. Zavadskas, A. A. Aibinu, M. Arashpour and N. Chileshe N, *Autom. Constr.* **87**, 235–247 (2018).
17. C. Vigneshkumar and U. R. Salve, *Constr. Econ. Build.* **20**, 17-35 (2022).
18. V. Chellappa and V. Srivastava, *J. Eng. Des. Technol.* ahead-of-print (2022).
19. V. Chellappa, S. Vasundhara and U. R. Salve, *J. Eng. Des. Technol.* **19**, 1488-1504 (2021).
20. C. Vigneshkumar, G. Ginda, and U. R. Salve, "Potential Benefits of Corporate Social Responsibility (CSR) in the Construction Industry," in *Ergonomics for Design and Innovation*, edited by D. Chakrabarti, *et al.* (Springer, Singapore, 2022), pp. 1741-1749.
21. C. Vigneshkumar and G. Ginda, "Multiple Criteria Decision-Making (MCDM) methods for Construction Safety," in 18th Colloquium on New Trends in Construction Management (Krakow, Poland, 2022). \
22. C. Vigneshkumar and U. R. Salve, "Science Mapping to Visualize the Factors Influencing Workers' Fall from Height in Construction Projects," in *Ergonomics for Design and Innovation*, edited by D. Chakrabarti, *et al.* (Springer, Singapore, 2022), pp. 409-418.
23. R. Eiris, A. Jain, M. Gheisari and A. Wehle, *Saf. Sci.* **127**, 104703 (2020).
24. C. Vigneshkumar, M. Peter, S. Matej, S. Marcela and K. Pavol, "VR-based Safety Training Research in Construction," in 45$^{th}$ Civil Engineering Conference (Kosice, Slovakia, 2022).
25. D. Zhao and J. Lucas, *Int. J. Inj. Contr. Saf. Promot.* **22**, 57–67 (2014).
26. H. C. Pham, N. N. Dao, S. Cho, P. T. Nguyen and A. T. Pham-Hang, *Appl. Sci.* **9**, 4477 (2019).
27. M. Nykänen, V. Puro, M. Tiikkaja, H. Kannisto, E. Lantto, F. Simpura, J. Uusitalo, K. Lukander, T. Räsänen, T. Heikkilä and A. M. Teperi, *J. Safety Res.* **75**, 205–221 (2020).
28. A. Pedro, H. C. Pham, J. U. Kim and C. Park, *Int. J. Occup. Saf. Ergon.* **26**, 811–823 (2020).
29. H. Li, G. Chan and M. Skitmore, *J. Comput. Civ. Eng*. **26**, 638–647 (2012).
30. J. K. Dickinson, P. Woodard, R. Canas, S. Ahamed and D. Lockston, *ITcon* **16**, 119-134 (2011).
31. A. Muneeb, S. T. Muhammad and A. J. Hamad Al Jassmi, *ITcon* **26**, 319-340 (2021).
32. A. Albert, M. R. Hallowell, B. Kleiner, A. Chen and M. Golparvar-Fard, *J. Constr. Eng. Manag.* **140**, (2014).
33. S. Bhandari, M. R. Hallowell, L. V. Boven, K. M. Welker, M. Golparvar-Fard and J. Gruber, *J. Constr. Eng. Manag.* **146**, (2020).
34. X. Wang and P. S. Dunston, *ITcon* **12**, 363-380 (2007).
35. Y. Fang, Y. K. Cho, F. Durso and J. Seo, *Autom. Constr.* **85**, 65–75 (2018).
36. H. Li, M. Lu, G. Chan and M. Skitmore, *Autom. Constr.* **49,** 163–174 (2015).
37. F. Bosché, M. Abdel-Wahab and L. Carozza, *J. Comput. Civ. Eng.* **30**, (2016).