VR-based Safety Training Research in Construction

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Abstract. Safety training in the construction industry widely adopted virtual reality (VR) technologies to train and educate employees and workers to enhance the safety performance of projects. In this study, a review of VR-based safety training research in construction was carried out to understand the body of literature. Using keywords such as "construction industry" OR "safety training" OR "safety learning," etc., a total of 52 journal articles published between 2000 and 2021 were collected from the Scopus database after advanced filtering. A two-stage analysis of VR-based safety training methods and application areas was carried out were followed by a review. The results indicate that the immersive safety training method was widely used followed by desktop-based, game-based, and BIM-based training methods. VR-based safety training methods are largely applied to hazard recognition (HR), safe operations (SO), and safety awareness (SA). The study findings could assist both academicians and construction practitioners in choosing the best optimal VR-based safety training methods to improve training performance.

1. Introduction

Globally, the construction sector offers more job opportunities for many individuals [1]. Also, the construction sector corresponds to 13 percent of the gross domestic product (GDP) worldwide [2]. Despite its benefits, the construction industry contributes to poor safety performance. According to global statistics, accident rates in construction were higher than in other sectors [1]. Furthermore, the harmful nature of accidents in construction results in unintended consequences such as loss of work and project delays [3]. In addition, fatalities cause serious financial damage to individuals and society [4].

Previous studies indicated that most construction accidents were caused by a lack of proactive control measures such as identifying hazards, awareness of safety, workforce training, and so on [5]. To avoid accidents at construction workplaces, safety training has been recognized as an effective strategy to improve individuals' safety awareness and risk identification skills [6]. On the other side, many researchers (e.g., [7,8]) indicated that traditional safety methods are not effective in transferring safety knowledge during the training process. Also, due to the limitations of workplace visualizations, it is challenging to visualize the risks involved in the construction work through traditional training methods [9].

With the evolution of innovative technologies, virtual reality (VR) has been recognized in construction as a promising tool for safety training programs due to its effective nature in enhancing such programs [10]. Hence, VR has been hailed as the appropriate solution to the aforementioned shortcomings. VR is a computer-assisted method of providing visualization from immersive and

interactive views [11]. The benefits of VR technology include the ability to visualize complex construction environments and the use of a gamification strategy to improve users' involvement and enhance knowledge-based training [12]. Hence, many studies established VR technology as an effective safety training method compared to traditional training methods [12, 13-15].

Despite the growth of VR technology in construction for safety training, no review of studies on the development and execution of VR-based safety training methods in construction has been conducted till now up to the authors' knowledge. According to Chellappa and Srivastava [16], conducting a periodic review of existing studies in a particular domain can help to understand the state of research. Therefore, in this study, a review of the literature was conducted on VR-based safety training methods in construction using a Scopus database. A total number of 52 journal documents were retrieved from 2000 to 2021. The following are some of how this study adds to the knowledge: (1) to visualize the distribution of the paper by publication years; (2) to show the distribution of articles by journal sources; (3) to expose methods used for VR-based safety training in construction.

2. Research method

A literature search was conducted on the Scopus database to retrieve relevant documents for the review. Due to the broader coverage of studies, Scopus was chosen in this study [16]. Also, previous literature review studies [17,18] in the construction management domain used the Scopus database to collect documents.

The keywords used to search and collect suitable articles were:

TITLE-ABS-KEY ("construction industry" OR "occupational health and safety" OR "safety management' OR "safety training" OR "safety learning" OR "safety education" OR "virtual reality" OR "game technology" OR "health and safety training." AND "virtual environment").

The research methodology framework is shown in Figure 1. It can be seen in figure 1 that 323 documents were yielded initially from the database. The identified documents were limited through advanced search rules i.e., 'from 2000 and before 2022" for the timeframe, "English" was the language, source type was "Journal", and "Article" as the document type. Due to reliable sources of knowledge, only journal articles were selected [17]. The articles that do not target VR for safety training but still used the term in the abstract were omitted. Finally, after careful refinement, 52 journal documents were chosen for this study. The MS Excel sheet was used to classify and store the retrieved documents based on the publication year, journal name where it got published, the title of the document, and the author keywords used in the documents. In the next section, the study results are presented based on the number of documents published per year, publications per journal, and the existing studies carried out on VR for safety training.

3. Results and discussion

3.1. Overview of selected documents

The documents published per year in the selected period are shown in figure 2. From figure 2, no significant growth in studies focusing on VR-based safety training was observed during the period 2000 to 2019. It can be seen the highest number of publications was documented in the year 2021 (16 publications). It is anticipated that a greater number of documents could be published in upcoming years in this research domain due to its positive impact on safety performance, although there is a slight deviation in past years.

The number of documents published per journal source is listed in table 1. Table 1 shows the list of journals with at least 2 articles published within the scope of this study. It can be seen that the most influential journal is Automation in Construction (8 articles), followed by the Journal of Information Technology in Construction (5 articles), Advanced Engineering Informatics (4 articles), and Engineering, Construction and Architectural Management (3 articles). Overall, the listed journals in Table 1 published 54% of the documents that were retrieved for this study.

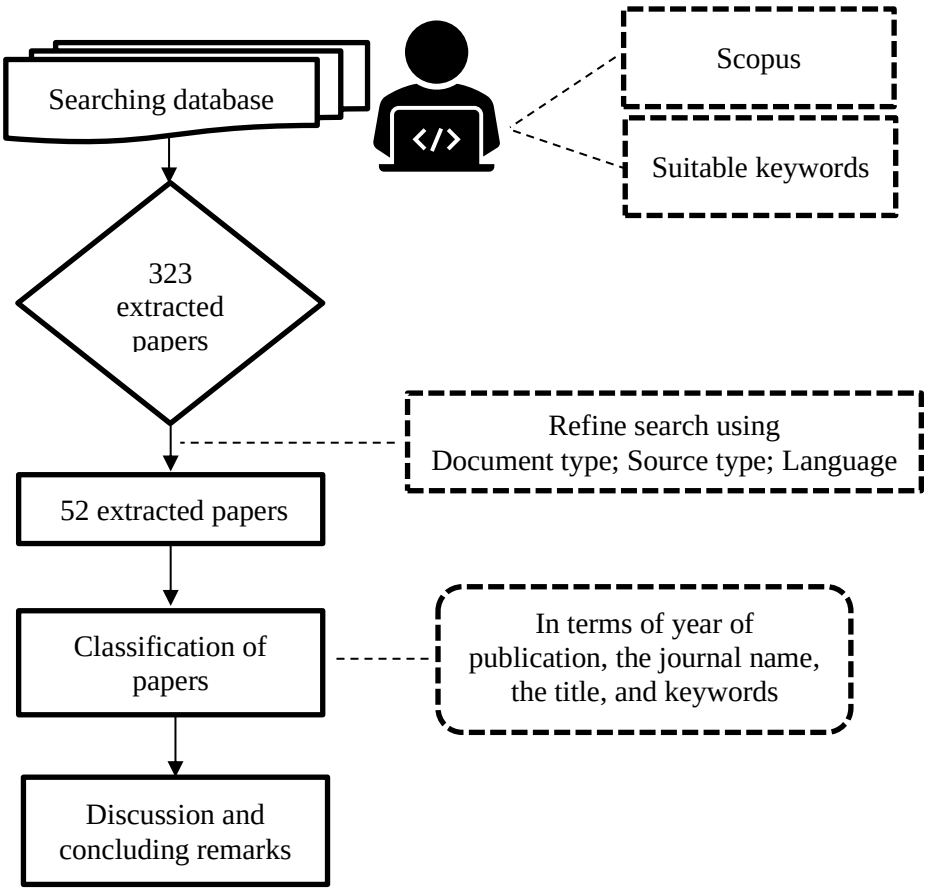

Figure 1. Research methodology framework.

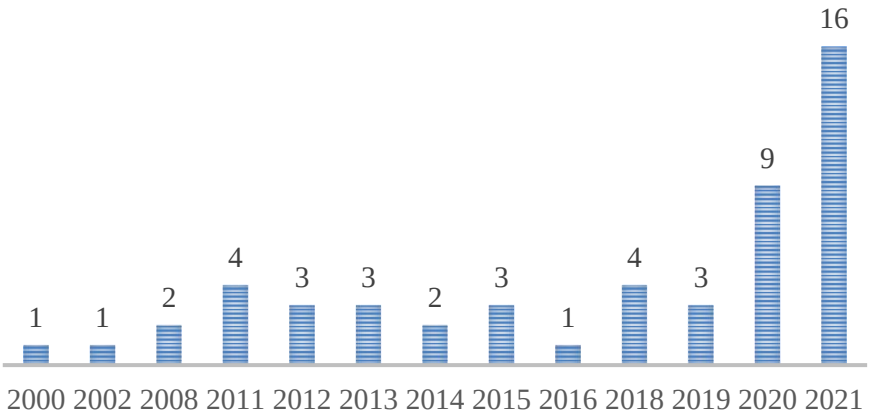

Figure 2. Number of documents published each year.

3.2. Overview of the identified studies

VR-based safety training studies in construction were categorized based on four different methods such as BIM-based training, desktop-based training, game-based training, and immersive training. Figure 3 shows the distribution of the retrieved articles characterized by VR methods. It was observed from figure 3 that immersive training (48%) followed by desktop-based training (34%) were most commonly used for safety training in construction. In terms of growth, the immersive training method gained much attention among the construction safety management research community in the recent

decade with 25 publications (48%) from 2011 to 2021, although there is a little growth in the desktop-based training method. Also, BIM-based and game-based safety training methods emerged in the year 2011.

Table 1. Documents published per journal source.

S.No	Source	No of publications
1	Automation in Construction	8
2	Journal of Information Technology in construction	5
3	Advanced Engineering Informatics	4
4	Engineering, Construction and Architectural Management	3
5	Construction Innovation	2
6	Safety Science	2
7	Journal of Computing in Civil Engineering	2
8	Sustainability	2

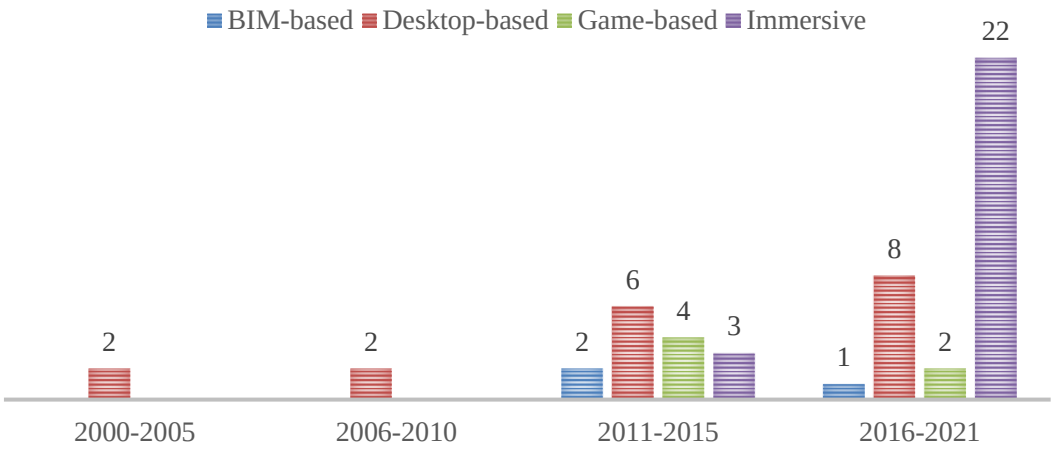

Figure 3. Distribution of documents characterized by publication year and VR methods.

The retrieved documents distribution characterized by research areas is shown in figure 4. Since 2000, the application of VR focused mainly on training and educating about safe operations (SO) (37%) of construction activities. Since 2011, the research focus was also placed on hazard recognition (HR) training (34%) and safety awareness (SA) (21%) in the construction workplace. It can also be observed in figure 4 that a few studies (8%) were focused on combining different areas such as HR and SA [19-22]. The VR methods and their application in different fields are discussed in the following sections.

3.2.1. Immersive training

Among 52 retrieved documents, 25 documents (48%) were focused on safety training through immersive VR. According to Wang et al. [23], immersive VR depends on the adoption of a head-mounted display (HMD for providing an immersive world to the users by withdrawing them from the physical environment. Various sensors and other equipment such as sensor gloves, controllers, and treadmills are also added to the immersive VR setup to provide real-time feedback [24]. Figure 5 shows the example applications related to immersive VR for safety training.

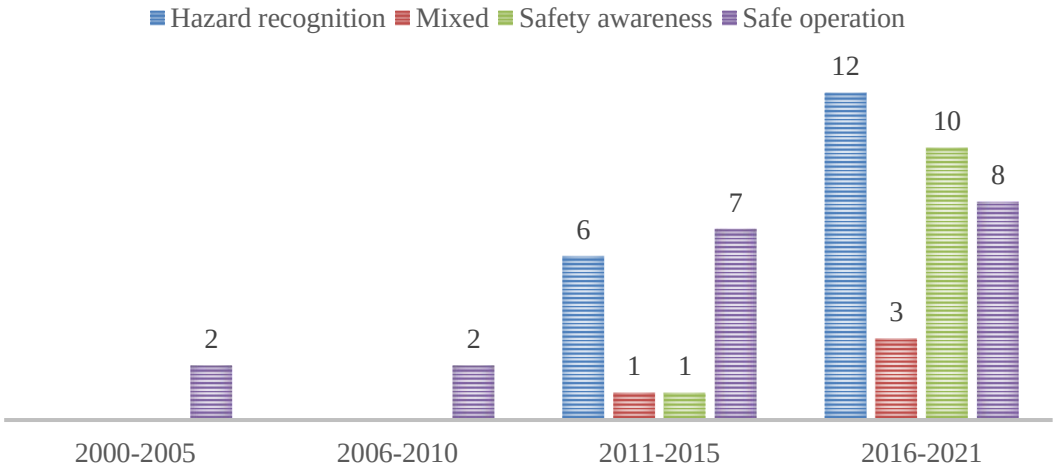

Figure 4. Distribution of documents characterized by research areas for VR safety training.

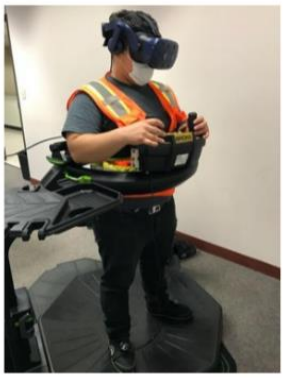

Figure 5. Immersive virtual training ([25]).

Figure 6 shows the VR safety training methods applied to different research areas. It can be seen in figure 6 that 25 (48%) out of 52 retrieved documents used the immersive VR method for safety training. Among 25 documents, most of the documents (i.e., 10) focused on training for HR. For instance, Eiris et al. [26] conducted an immersive VR safety training with construction management students to recognize fall hazards in the electrical trade of construction projects. The findings of this study indicated that the proposed VR method could reduce the time spent on HR compared to traditional methods. Similarly, several studies (e.g., [27]) adopted the immersive VR method for HR at construction workplaces. The immersive VR method has also been widely used to train and educate about SO (8 documents), followed by SA (5 documents). In addition, some studies adopted the immersive VR method to cover different areas. For example, Nykänen et al. [21] developed a novel safety training method for HR and to create SA among construction workers [22].

3.2.2. Desktop-based training

Desktop-based VR training has been a widely used VR method for safety training in construction since 2000 (see figure 3). Without the use of any tracking equipment, the desktop visualizes the virtual environment (VE) on the computer screen [23,28]. Mouse and keyboards were used to perform the tasks. This method is considered to be cheap for VR safety training compared to other VR methods. An example application related to desktop-based VR for safety training is shown in figure 7.

Figure 6. VR methods applications in different research areas.

From figure 6, it can be observed that the desktop-based method has been adopted for HR (7 documents), to perform SO (6 documents), followed by creating SA (3 documents). In terms of HR, Pham et al. [29] developed a prototype to improve the learning skills of educators. The desktop-based method has also been used by some studies to cover different areas. For example, Pedro et al. [30], developed a system to visualize the construction environment for HR and to create SA among workers.

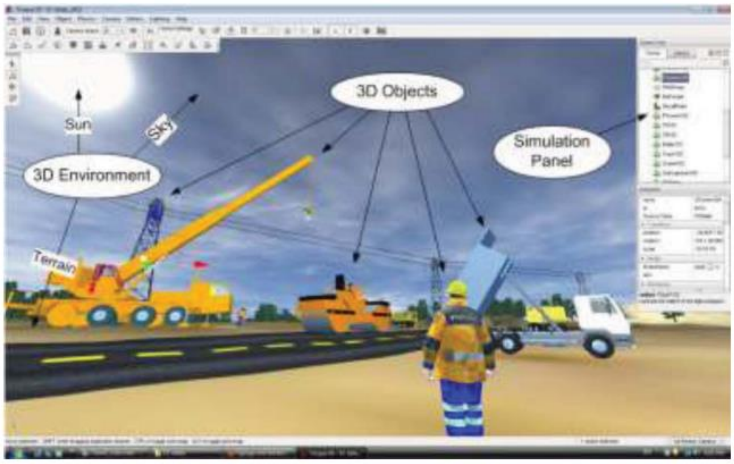

Figure 7. Desktop-based VR safety training ([28]).

3.2.3. Game-based training

Game-based technology is a computer-based setting that contains multi-user operating technologies, networks, interactive, and so on to improve user interactions [23] and focuses more on interactions of game objects. According to Wang et al. [23], game-based VR can minimize the complexity of complex objects like cranes and excavators in construction. Figure 8 shows the example applications related to game-based VR for safety training.

From figure 3, it was observed that 6 documents (12%) focused on game-based VR. In which, a game-based VR method has been adopted to perform SO and create SA, with 4 and 2 documents, respectively (see figure 6). In terms of SO, Li et al. [31] developed a multi-user safety training system for dismantling tower cranes at construction sites. Similarly, Dickinson et al. [32] adopted safety games with students to enhance their knowledge of trench safety.

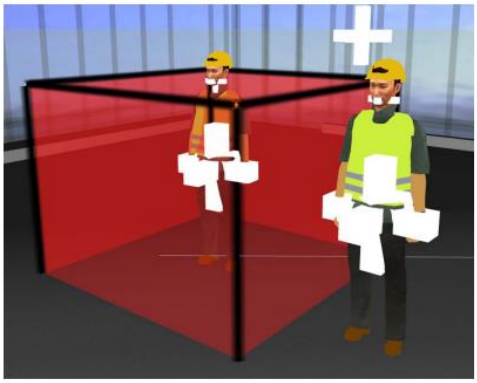

Figure 8. Game-based VR for safety training ([31]).

3.2.4. BIM-based training

Among other VR methods, BIM-based training use was limited to safety training (3 documents). BIM is concerned with the development and usage of three-dimensional objects [23]. Unlike other VR categories, BIM-based VR relies on the model to replicate construction processes and operations, stressing the data binding and linkages behind it [23]. The example application related to BIM-based VR for safety training is shown in figure 9.

Figure 9. BIM-based VR for safety training ([33]).

In research areas such as HR, SO, and SA, the BIM-based method has been used. Park et al. [12] developed a BIM-based system prototype for HR and validated it with construction practitioners. Likewise, game-based virtual training was conducted to perform SO [33] among construction workers and create SA [34] among construction university students.

4. Conclusion

This study conducted a literature review on VR-based safety training research in construction to understand the VR-based methods used and their application research areas. The articles for the literature review were retrieved from the Scopus database from the year 2000 to 2021. The findings indicated that although the studies were scattered from 2000 to 2019, the scope of this research got much attention among researchers in 2020 and 2021 with the highest number of publications. It is expected that a greater number of studies could be carried out in upcoming years focusing on VR-based safety training research in construction. The most influential journals under the scope of the study were Automation in Construction, followed by the Journal of Information Technology in construction and Advanced Engineering Informatics.

In terms of methods, the immersive safety training method has been widely used particularly after 2010. The desktop-based training method was found to be a stable method for safety training since

2000 and it is considered to be cheaper. Other methods such as game-based and BIM-based training were used less for safety training. This is because the software for creating VE is expensive. Concerning research areas, most of the VR-based methods were used for HR followed by performing SO and SA. Some of the studies were also found to cover multiple areas. The findings of this study are expected to assist construction practitioners in choosing the best optimal VR-based safety training method to improve training performance.

This study comes up with some limitations. First, this study retrieved articles only from the Scopus database. Next, only journal articles were selected from the Scopus database that is published in English by omitting all other sources such as conference papers, book chapters, and so on. In the future, other databases and other sources of publication could be used to have a broader view of this study's scope.

5. References

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