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Review

Augmented and Virtual Reality (AR/VR) for Education and Training in the AEC Industry: A Systematic Review of Research and Applications

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Abstract: With updated equipment and maturing technology, the applications of augmented and virtual reality (AR/VR) technologies in the architecture, engineering, and construction (AEC) industry are receiving increasing attention rapidly. Especially in education and training, an increasing number of researchers have started to implement AR/VR technologies to provide students or trainees with a visual, immersive, and interactive environment. In this article, a systematic review of AR/VR technologies for education and training in the AEC industry is conducted. First of all, through comprehensive analysis, 82 related studies are identified from two databases, namely Scopus and Web of Science. Secondly, the VOSviewer is used to analyze the current status of AR/VR for education and training in the AEC industry. Thirdly, the identified studies are classified into different categories according to their application domains by qualitative analysis. Fourthly, after a further filtering, 17 out of the 82 studies are included in the meta-analysis to quantify the actual impact of AR/VR. The results indicate that there are some limitations in the applications of AR/VR for education and training in the AEC industry. Finally, to further explore the reasons for the existence of limitations, the 82 studies are summarized to analyze the current challenges of AR/VR for education and training in the AEC industry. This study also provides insights into future trends in AR/VR for education and training in the AEC industry.

Keywords: augmented reality (AR); architecture, engineering, construction (AEC); education; training; virtual reality (VR)

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1. Introduction

Augmented reality (AR) is an emerging technology that integrates digital information, such as text, images, videos, and 3D objects, into the real world. The term "Augmented Reality" was first proposed by Boeing employees in 1990 [1]. Sutherland, who is a pioneer in AR development. led the research of the Sword of Damocles system, which is generally considered to be the first prototype of the AR head-mounted display (HMD) [2]. Until 1997, Azuma published the first report about AR and proposed a definition of AR which was widely cited [3]. The definition of AR in the report included three elements (Figure 1): (a) A connection between the virtual world and the real world; (b) real-time interaction; and (c) 3D-based tracking and positioning. Since then, AR started its explosive development. Compared with AR, virtual reality (VR) is a different technology, and is a completely immersive tool allowing all users to be immersed inside a virtual environment (VE) [4]. The first mention of the concept of VR can be traced back to Aldous Huxley's novel "Beauty New World" published in 1932 [5], in which VR can provide users with a series of sensory experiences (e.g., images and sound). In 1963, Gernsback proposed a specific name for VR in the first time, "Teleyeglasses", which clearly described the composition of VR equipment [6]. Until 1990, the formal term of VR was proposed [7]. At present, with the popularization of the concept of "Metaverse", VR is attracting increasing attention all over the world [8–10].

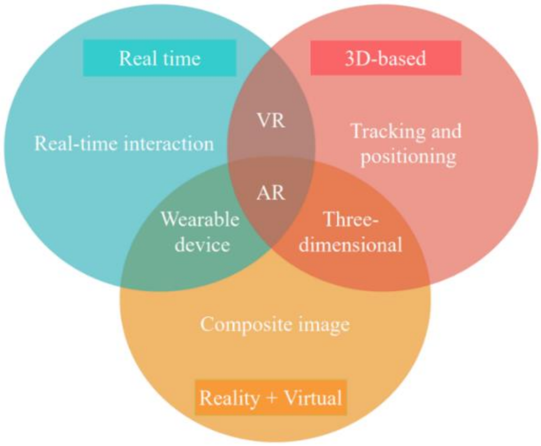


Figure 1. Three elements of AR summarized from the studies of Azuma [3].

The development of AR/VR technologies is inseparable from the support of devices. At the preliminary stage of AR/VR development, heavy computers and large projectors were often used to present AR/VR effects [11]. With the rapid development of handheld devices, smart phones and tablets are widely used considering their lightness and popularity [12]. Users can experience AR/VR effects through their own handled devices instead of purchasing other expensive devices. However, users must hold and touch handheld devices when using the AR/VR application, making it difficult to perform other work simultaneously. With the development of HMDs, this limitation can be partially overcome [13]. Some HMDs can free users' hands and provide immersive views with a better experience. Therefore, HMDs have the potential to become one of the mainstreams for AR/VR devices in the future. Since the 1960s, various HMDs appeared and were employed in various fields [14]. By analyzing and summarizing the emergence of the most used AR/VR devices in the past ten years (Figure 2), the constantly updated AR/VR devices are more reliable and also bring a better experience to users [15]. In addition, many companies have also been constantly updating their iterations of HMD, aiming to improve the performance of HMDs. For example, HTC have released the HTC VIVE in 2016, the HTC VIVE Pro with higher resolution in 2018, and the HTC VIVE cosmos in 2019 to give users an increasing comfortable experience. In 2021, HTC have released the HTC VIVE Focus 3 and HTC VIVE Pro2 with higher configurations in quick succession.

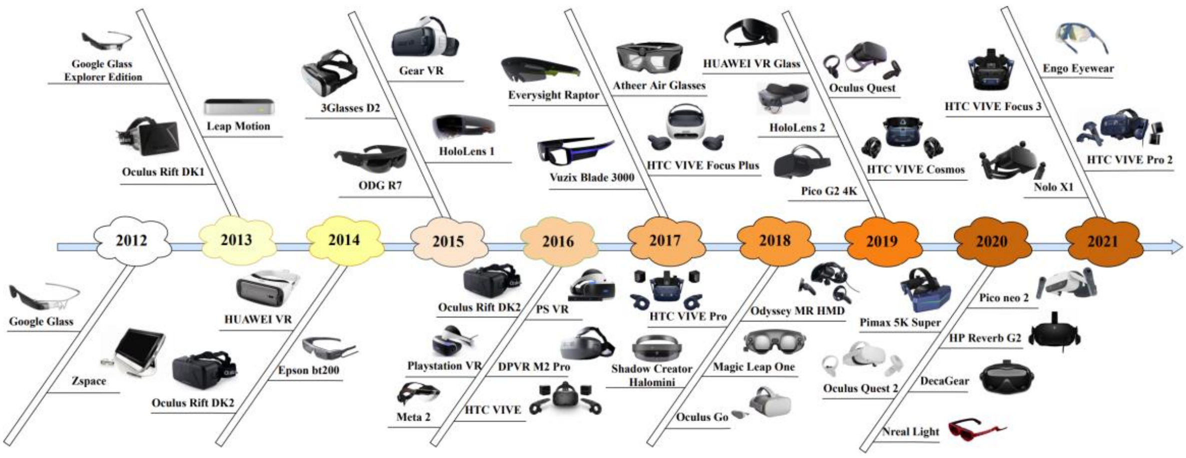


Figure 2. The emergence of the most used AR/VR HMDs in the past ten years.

Currently, augmented and virtual reality (AR/VR) technologies, which perform excellently in providing users with an interactive and immersive environment, have been rapidly recognized and widely used in many fields [16–19]. The education in the architecture, engineering, and construction (AEC) industry always has high requirements for students in terms of knowledge understanding and application ability. Therefore, AR/VR are effective tools which have been widely used in AEC education settings [20,21]. The application of AR can help students establish a connection between the real environment (RE) and the virtual environment (VE) [22]. Meanwhile, using VR enables students to carry out immersive simulation learning. Thus, a lot of research about AR/VR for education and training in the AEC industry has been conducted. For example, Peng et al. [23] conducted an in-depth literature review which was followed by a three-stage analysis on VR technologies, applications, and future directions. Diao and Shih [24] illustrated several problems in VR implementation, such as the selection of system types and equipment, the application of research methods, the adoption of learning strategies, and teaching methods. Soliman et al. [25] showed in their study that VR was an excellent tool in engineering education, which has improved students' understanding of subjects, grades, and educational experience. Lanzo et al. [26] discussed the use and effect of VE as a teaching tool in the specific field of engineering education in detail. The findings have indicated that, as a supplement to the traditional teaching environment, the virtual classroom environment was beneficial to students' learning of related skills. Many studies have reported the positive effect of AR applications. However, currently few studies have reviewed the current status of AR/VR for education and training in the AEC industry. Therefore, this review tries to reveal the current status of development based on bibliometric analysis, and classifies the applications of AR/VR for education and training in the AEC industry and quantifies the effectiveness of AR/VR for education and training in the AEC industry. In addition, this review also aims to offer a readily available of reference for researchers, schools, and education research institutions, raising the level of awareness of AR/VR for education and training in the AEC industry.

The remainder of this paper is structured as follows. Section 2 presents the research methodology. Section 3 provides an analysis of the selected publications by year, journals, and conferences. Section 4 uses the bibliometric analysis to draw conclusions from an abstract co-occurrence topic analysis of the 82 studies and proposes the research questions of this study accordingly. Section 5 illustrates the classification of the 82 studies and provides details of the application of each category. Section 6 explores the effect of AR/VR on education and training in the AEC industry. Section 7 summarizes the current challenges in the application of AR/VR to education and training, followed by the conclusions and future work in Section 8.

2. Methodology

In this review, the specific search was conducted in Scopus and Web of Science, which are two commonly used academic databases. Studies published from 1997 to 2021 were filtered with the following keywords: (a) "augmented", (b) "virtual", (c) "mixed", (d) "reality", (e) "education", (f) "course", (g) "learning", (h) "training", (i) "architecture", (j) "engineering", and (k) "construction", in the title, abstract, or keywords. In order to improve the searching efficiency and ensure the accuracy of search results, the search rules were: ((augmented OR virtual OR mixed) AND reality) AND (education OR course OR learning OR training OR architecture OR engineering OR construction). In total, 36,612 studies were found from two databases: Web of Science (n = 20,662) and Scopus (n = 15,950). First, the duplicate studies were removed and 31,231 studies were remained. The studies were further filtered via the exclusion of non-journal or conference studies (n = 5231) and non-AEC industry (n = 25,679) papers. Therefore, 321 articles were reserved through the initial screening. Next, a full-text screening process was adopted to ensure all retrieved articles were related to the education and training in the AEC industry. A total of 82 studies were finally reserved for bibliometric analysis. Figure 3 shows the database literature screening process.

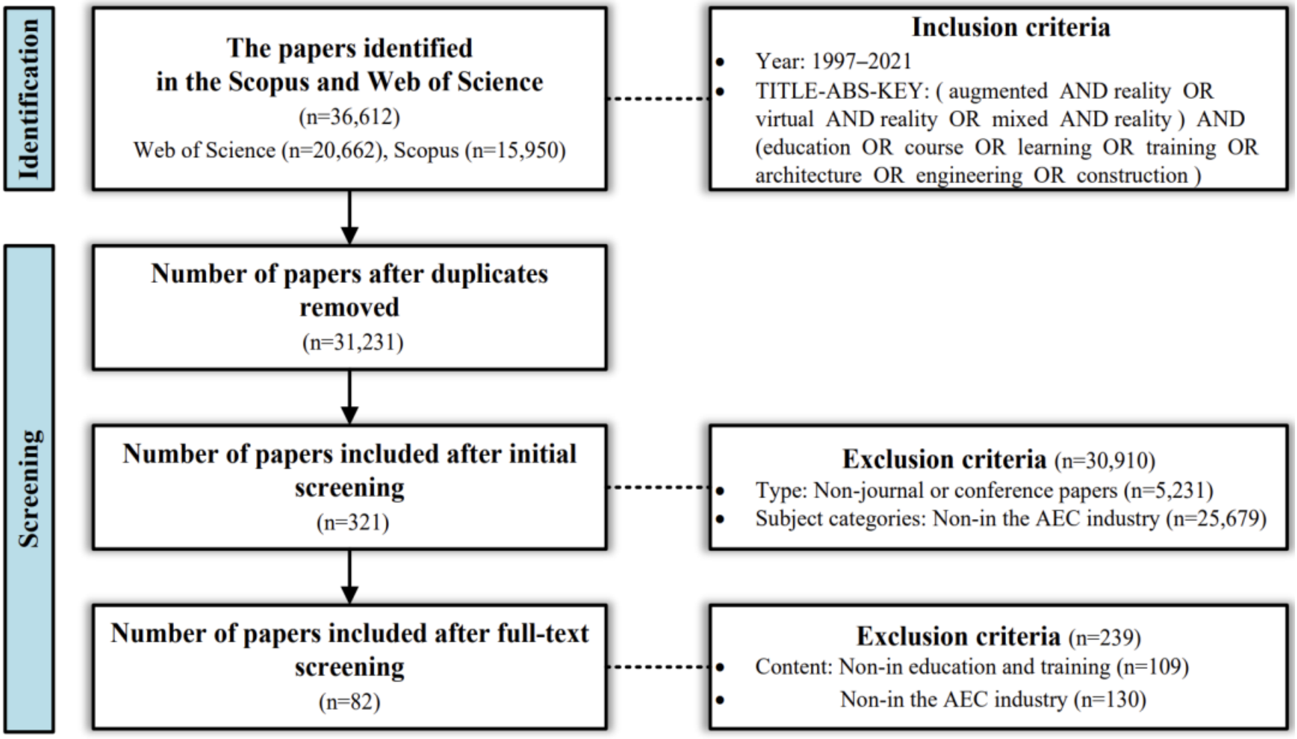


Figure 3. Database literature screening process.

After screening 82 studies, an analysis of the selected publications by year, journals, and conferences was performed. In addition, analysis based on four methods (i.e., bibliometric analysis, qualitative analysis, meta-analysis, and summary analysis) was also conducted. As shown in Figure 4, firstly, 82 studies were analyzed for abstract co-occurrence topic using the VOSviewer to obtain the current status of AR/VR applications for education and training in the AEC industry. Based on the results of the co-occurrence analysis, two research questions for this study were formulated. Secondly, in this review, the application of AR/VR in the field of AEC education referred to the teaching exploration conducted by researchers on courses or specific knowledge points for students. The application of AR/VR in AEC training referred to the training activities carried out by companies or research institutions to improve the relevant professional skills of workers. According to this classification, this study used NVivo 11 for qualitative analysis and coding to classify the 82 studies into 55 studies in the education domain and 27 studies in the training domain. In the education domain, these 55 studies were further classified into immersive AR/VR learning, AR/VR for structure analysis, visual-aided design tools, and AR/VR-based teaching aids in application domains. In the training domains, these 27 studies were further classified into AR virtual operation guide and safety training. Thirdly, 17 studies were included in the meta-analysis based on the inclusion criteria. The actual impacts of AR/VR were quantitatively counted, and the results were obtained in accordance with the analysis. Finally, the results of the meta-analysis showed that AR/VR technologies had a positive effect on education and training in the AEC industry. However, the positive impact was not very significant, suggesting that there are still some limitations to the application of AR/VR in education and training in the AEC industry. Therefore, the current challenges of AR/VR for education and training in the AEC industry are also discussed at the end.

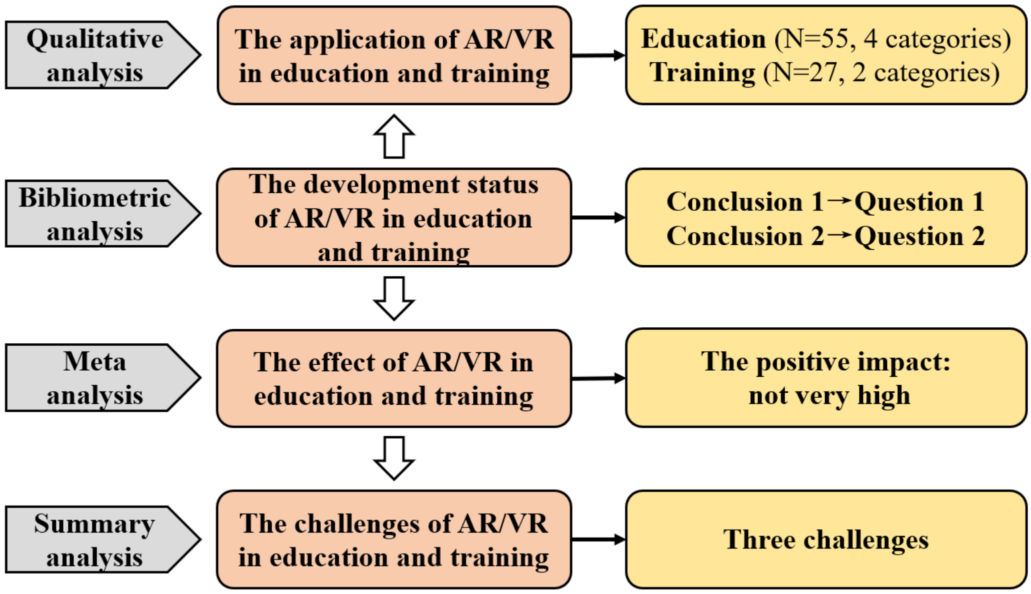
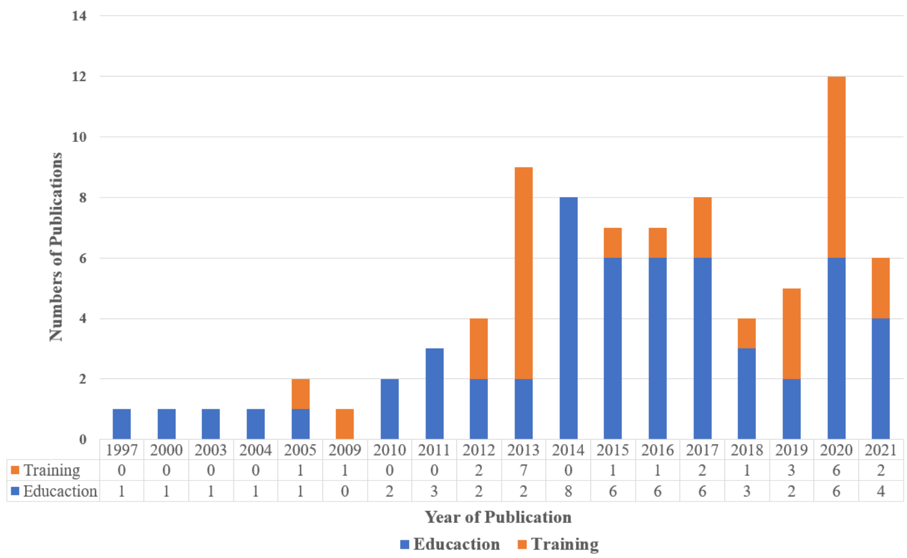


Figure 4. Flow chart of analysis based on the four methods.

3. Overview of Identified Publications

3.1. Number of Published Studies by Year

From 1997 to 2021, 82 studies on AR/VR for education and training in the AEC industry were identified (Figure 5). The annual number of related publications has shown an upward trend in general. Around 80.49% of studies were published after 2013 which means that AR/VR has become more popular from 2013 onwards. The number of studies has reached the highest value in 2020, demonstrating that AR/VR has received increasing attention in education and training in the AEC industry, and thus indicating the demand in exploring new ways of teaching reform through AR/VR technologies.



	1997	2000	2003	2004	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Training	0	0	0	0	1	1	0	0	2	7	0	1	1	2	1	3	6	2
Educaction	1	1	1	1	1	0	2	3	2	2	8	6	6	6	3	2	6	4

Figure 5. Number of publications from 1997 to 2021.

3.2. Number of Published Studies by Journals and Conferences

As shown in Table 1, over 33 journals and conferences containing related studies were identified. Among all the journals and conferences summarized in the Table 1, *Automation in construction* (24.24% of the total) and *Professional Issues in Engineering Education and Practice* (21.21% of the total) are the most popular venues for AR and VR in education and training.

Many studies about AR/VR for education and training in the AEC industry were also published in several other journals and conferences, showing that there is great potential for exploring AR/VR for education and training in the AEC industry.

Table 1. List of journals and conferences of 82 studies.

Journal/Conferences Title	Number of Studies
Automation in Construction	8
Professional Issues in Engineering Education and Practice	7
Construction Research Congress	6
Computing in Civil Engineering	6
International Symposium on Automation and Robotics in Construction	6
American Society for Engineering Education	3
Computer Applications in Engineering Education	3
Engineering, Construction and Architectural Management	3
Journal of Computing in Civil Engineering	3
Journal of Architectural Engineering	3
Advances in Engineering Software	2
Advances in Engineering Education	2
Advanced Engineering Informatics	2
Computing in Civil and Building Engineering	2
International Journal of Engineering Education	2
Universal Access in the Information Society	2
Structures Congress	2
Safety Science	2
Proceedings of the 2011 Winter Simulation Conference	2
Assembly Automation	1
Construction Management and Economics	1
Computers in Human Behavior	1
Computers & Graphics	1
Electronic Journal of Information Technology in Construction	1
European Group for Intelligent Computing in Engineering	1
International Journal of Production Research	1
International Journal of Construction Education and Research	1
International Foundations Congress and Equipment Expo 2021	1
IEEE MultiMedia	1
Journal of Intelligent & Robotic Systems	1
Journal of Information Technology in Construction	1
Journal of Construction Engineering and Management	1
Journal of Civil Engineering Education	1
Total	82

4. The Development Status of AR/VR in Education and Training: Bibliometric Analysis

With the help of a Java-based scientific visualization tool named VOSviewer [27] which was developed by the Nees Jan van Eck and Ludo Waltman Centre for Science and Technology Studies Leiden University, the co-occurrence abstract field analysis was selected to output the network and time visualization of abstract field co-occurrence in education and training, as depicted in Figures 6 and 7. On the basis of many experiments, five was chosen as the minimum number of occurrences of a term. Thus, 118 of the 2215 items met the threshold in education studies and training studies. As these networks are usually weighted networks, edges not only represent the relationship between nodes, but also the strength and weight of the relationship [28]. The co-occurrence abstract field was grouped into several clusters with various colors. Through the combined analysis of Figures 6 and 7, as the years increase, new application fields continue to emerge, such as "safety education", "equipment operation", and "hazard recognition". In addition, we took "student", "study", and "training" as the main items, and observed the relationship between other items and them. It was found that "ability", "performance", "skill", and "improve" items related to them (Figure 8). Then, the content of the selected 82 studies was reviewed again. The current status of AR/VR for education and training in the AEC industry was revealed. Two conclusions were obtained as follows:

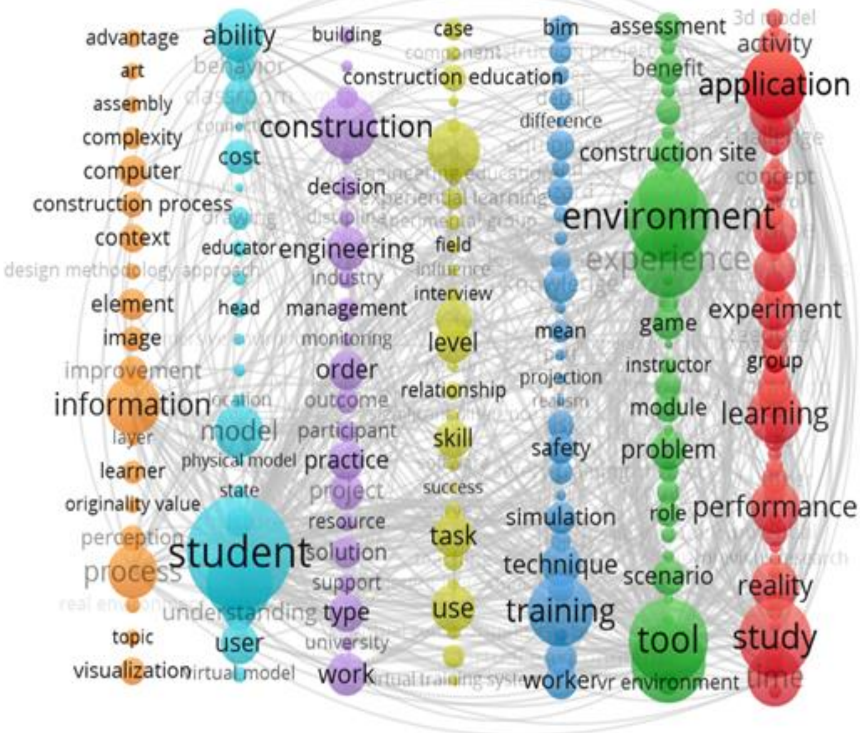


Figure 6. Mapping on network visualization of abstract field co-occurrence in education and training.

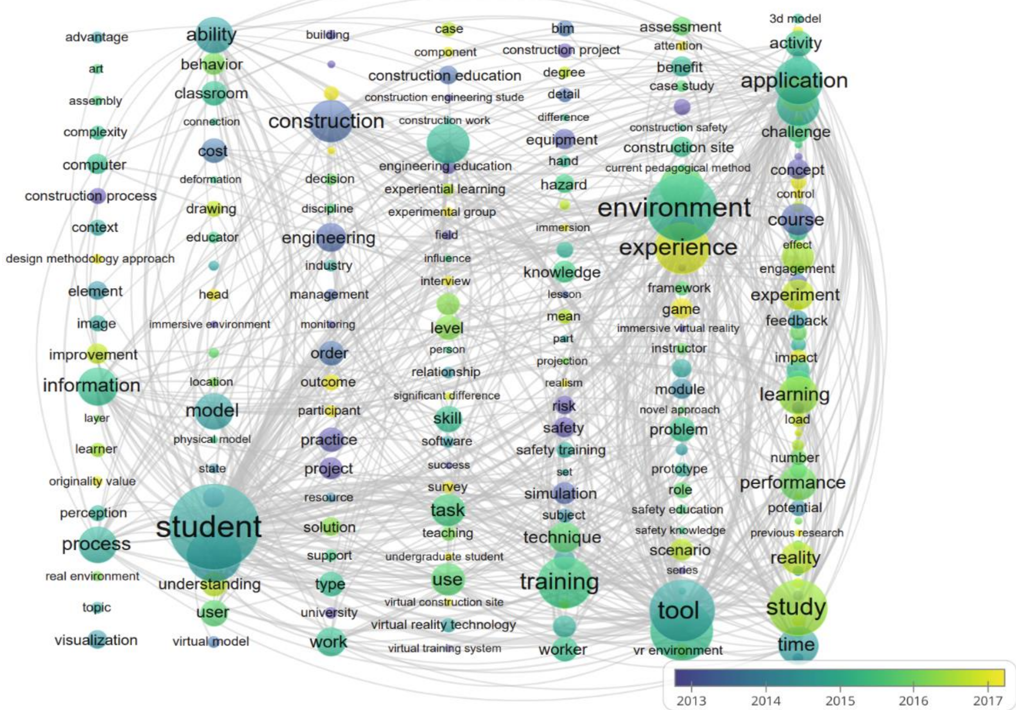


Figure 7. Mapping on-time visualization of abstract field co-occurrence in education and training.

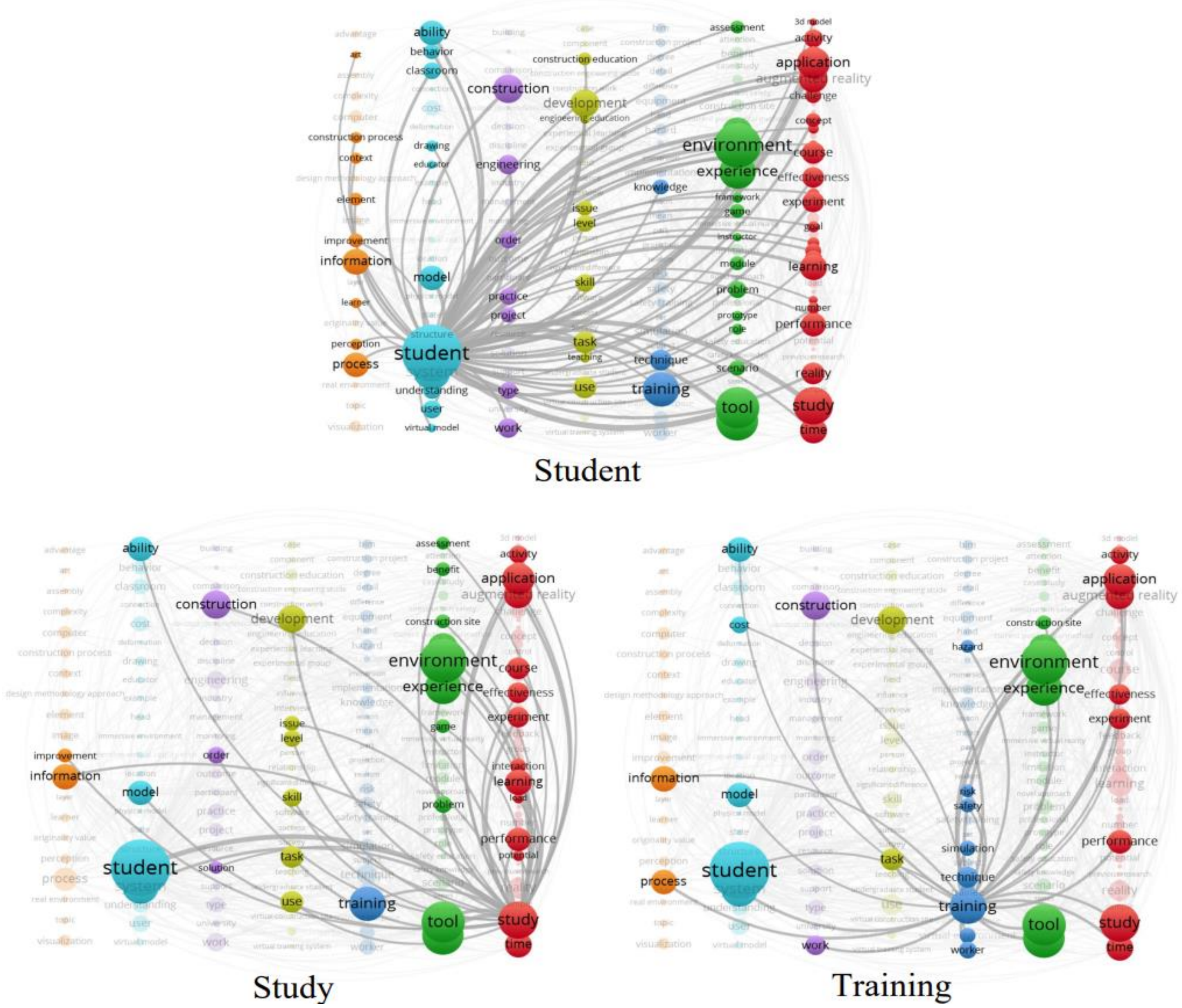


Figure 8. The relationship between the main item and other items.

Conclusion 1: During these 24 years, the application of AR/VR for education and training in the AEC industry has shown a diverse trend.

Conclusion 2: The purpose of AR/VR for education and training in the AEC industry is primarily used to improve the effectiveness of education and training.

Based on the two conclusions drawn from the bibliometric analysis, the corresponding research questions for this study were formulated as follows.

Question 1: What specific applications of AR/VR technology are commonly used for education and training in the AEC industry?

Question 2: Does AR/VR have an impact on the effectiveness for education and training in the AEC industry?

5. The Application of AR/VR in Education and Training: Qualitative Analysis

A qualitative analysis of 82 studies was conducted using NVivo 11. The 82 studies were coded and classified by application domains according to a three-level coding based on rooting theory. The coding analysis is shown in Figure 9. After these nodes were classified, 55 studies on education were divided into four categories, namely (a) immersive AR/VR learning, (b) AR/VR for structure analysis, (c) visual-aided design tools, and (d) AR/VR-based teaching aids. Immersive AR/VR provides a risk-free environment for learning by simulating an actual construction environment [29]. AR/VR for structure analysis aims to help student visualize and understand complex spatial arrangements, which usually deform or move under external actions [30]. A visual-aided design tool is beneficial for enhancing the learning ability of students for interior and exterior design as well as making appropriate design decisions, as teaching contents are well visualized using AR/VR-based teaching aids [21]. Twenty-seven studies on training were divided into two categories, namely (a) the AR/VR virtual operation guide and (b) safety training. The first category taking up 59% of the identified studies of training relates to manipulate complex equipment, while the second category accounting for 41% was used to deliver various elements of instructional training for hazard identification and accident prevention (shown in Figure 10). More details of each category of AR/VR application are introduced in the following sections.

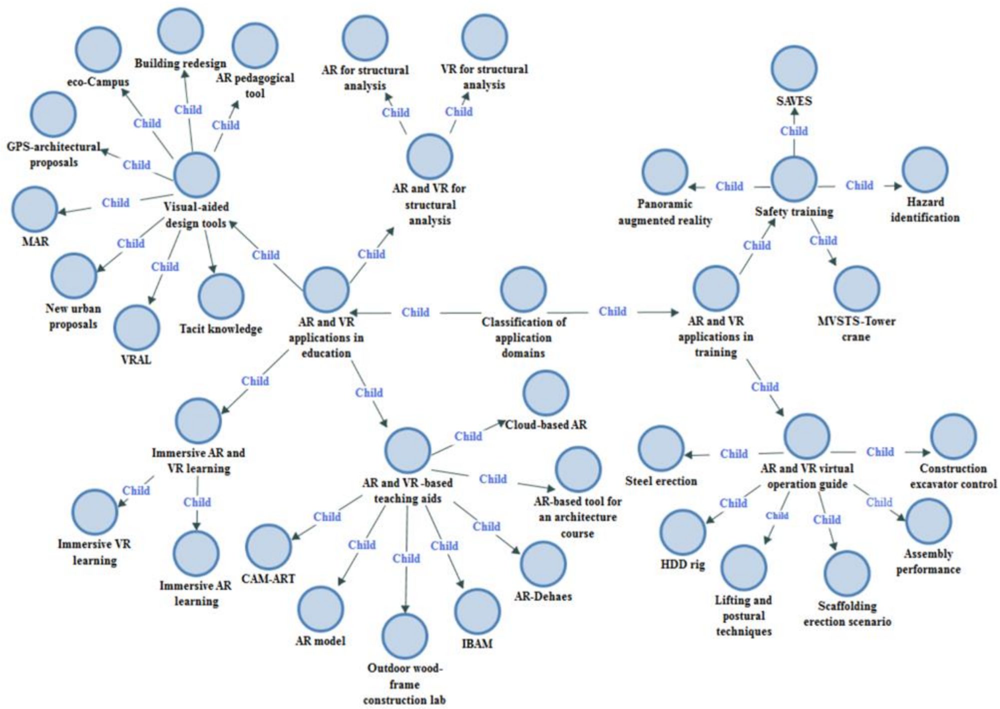


Figure 9. Node analysis.

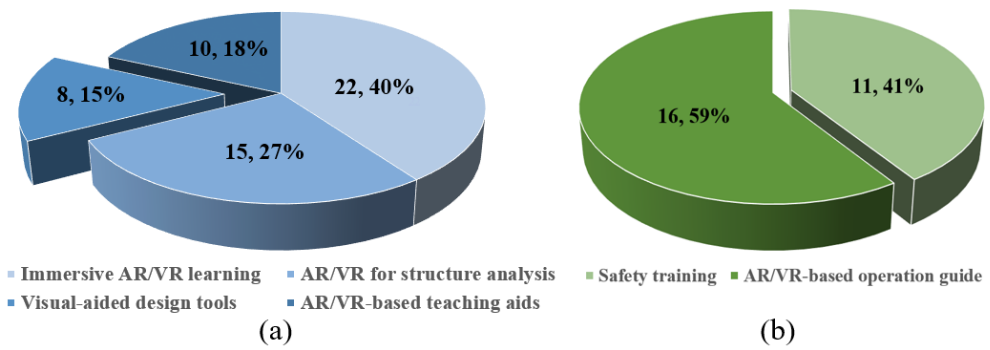


Figure 10. (**a**) The percentage of AR/VR applications in education. (**b**) The percentage of AR/VR applications in training.

5.1. Immersive AR/VR Learning

Building engineering is a visual course, which requires students to have a high spatial imagination ability [31]. However, the limited visualization capabilities presented by 2D drawings have limited the understanding of application concepts. Hence, Messner et al. [32] illustrated the possibility of creating a virtual and interactive experience system, teaching students to plan the sequence of construction projects. Behzadan et al. [33] designed and implemented interactive AR learning tools to help students fully understand construction equipment, processes, and operational safety. Sampaio and Martins [34] proposed an immersive VR system to guide students to understand the construction sequence of bridge construction. The system realized visualization and interactive information transmission related to physical behavior. In the same way, Ku and Mahabaleshwarkar [35] confirmed that using BIM for design reviews in an immersive VR environment can help improve the understanding of students in building operation management. In order to overcome the limitations caused by overcrowded classrooms or a small number of equipment, Vergara et al. [36] developed an immersive laboratory training system to guide students in concrete compression experiments.

Construction sites, consisting of tremendous uncertainties, can be extremely complex and dangerous. Therefore, it is particularly important to conduct safety immersive learning before students enter the construction sites [37]. However, safety issues have not obtained enough attention in traditional courses, and they fail to encourage students to learn safety knowledge [38]. To improve this situation, Le et al. [39] proposed an experiential building safety education framework based on mobile reality technology and AR technology. In addition, Pham et al. [40] proved that using the VR immersive safety learning can fully attract students to acquire safety knowledge. Equally, Pedro et al. [41] used interactive virtual technology to combine safety education with construction methods, and developed a virtual safety education system for college students. The system used VR and smart equipment to integrate safety into architectural education. Clevenger et al. [42] showed in their research that AR can strengthen scaffolding-related safety training, and the feedback from students was very positive. Similarly, Eiris et al. [43] stated that students using VR safety training were more active and engaged than those using traditional safety training based on lectures.

Nowadays, the problem-solving ability of civil engineering students is usually limited by the lack of experience in real on-site construction process, resulting in a weak understanding of dynamic and complex space constraints [44]. This problem can also be addressed by virtual construction with AR/VR devices. For example, Mutis and Issa [45] utilized AR to simulate the construction background, and image overlay was used as a teaching mechanism introducing field experience into the classroom. Behzadan and Kamat [46] developed an innovative teaching tool that used remote video recording, AR, and ultra-wideband (UWB). The developed tool brought the implementation video of the remote construction site to the classroom to create an intuitive interface for students, which was convenient for students to interact with the objects in the video [46]. Similarly, Beh et al. [47] proposed an immersive training method based on games to improve the practical experience of students. By way of contrast, Wang et al. [48] and Burcin et al. [49] focused on the discussion and research on the role of 3D virtual learning environment in teaching. They both declared that the immersive learning environment can improve the motivation of students for learning. In addition, strong communication skills and teamwork skills are necessary to ensure that graduates of civil engineering majors work efficiently in the team. Dong et al. [50] presented a new software called ARVita, which allows multiple users wearing HMDs and sitting and observing around a table to interact with dynamic visual simulations of the engineering process.

5.2. AR/VR for Structure Analysis

Structural analysis is a fundamental knowledge point in civil engineering education. As it involves abstract concepts and complex algorithms, structural analysis has become a major difficulty in teaching [51,52], and it also increases the difficulty in imagining and appreciating complicated spatial arrangement [52]. Therefore, AR/VR can be utilized to better visualize implicit structural knowledge through a combination of real and virtual entities [53]. For example, Weigel [54] designed an internet virtual classroom for structural analysis. The study illustrated that the virtual classroom was more attractive than conventional classrooms, and computer grading reduced the burden on teachers. Similarly, Turkan et al. [55] presented a new method combining mobile AR and interactive 3D visualization technologies for teaching structure analysis. In addition, the VR-based system developed by Setareh et al. [56] did not abandon the traditional teaching methods, but also combined with traditional lecture notes and slides to become an effective teaching tool. In order to effectively convey structural connection information, such as connection details and lateral torsional bucking, Fogarty and El-Tawil [57] developed a fully immersive VR environment. In their VR system, the model can be easily modified, updated, and expanded without being restricted by cost and safety issues, like the physical model.

In the meantime, exploring the potential of AR/VR in the analysis of large-scale components, such as steel structures, also increased. Dib and Adamo [58] designed and developed an AR interactive learning environment to help students visualize the stress, deformation, and limit state of each type of steel connection. In the research of Sun and Gramol [59], a variety of functional modules have been added, such as those for measuring steel structures. The interactivity of these modules was realized using simulation, animation, and sound. Many structural failures are caused by connection failures. Therefore, a good connection design requires students to have a good understanding of mechanics and steel properties. Dib et al. [60] illustrated that the interactive virtual steel structure model can provide an effective learning method, allowing students to see the structure from multiple angles anytime. In their system, they could show a close-up view of each connection and describe their operating instructions.

In the field of structural engineering, when components are deformed or moved under load or other external stimuli, the difficulty of learning will increase significantly [61]. By integrating scientific visualization technology, Huang et al. [62] proposed an AR-based framework that integrated sensor measurement and finite element simulation. In their framework, real-time data measured by sensors were directly superimposed on real-world objects and provided an intuitive interface for enhanced data. In addition to learning abstract theories, students were also required to overcome the challenges of using commercial finite element software which had unintuitive user interfaces. Fogarty et al. [63] enhanced and visualized the finite element analysis results on the physical structure and performed experiments to evaluate the learning effect. The results showed that students can effectively master finite element analysis and avoid too rigid learning curve. Apart from these, in 2018, Luo and Cabico [64] developed an Android application to help learn various types of bridge structures. Although the facade and isometric view of the bridge and the corresponding force analysis were provided in the lecture notes, it may be not enough to help students fully understand the spatial relationship among different bridge elements. Advantages of the developed application are as follows: (1) the bridge model according to the target image can automatically be presented, providing students with the opportunity to rotate, tilt, and zoom the 3D model; (2) the selected bridge elements can be highlighted, and the load transfer path can be visualized.

5.3. Visual-Aided Design Tools

Two-dimensional (2D) drawing is one of the most common communication approaches in the civil and construction engineering domain [65]. However, the information represented in traditional 2D drawings often struggles to display the complexity of the design [66]. Compared with 2D drawings, the use of AR/VR technologies can immerse students in a 3D environment, which enable students to learn related courses more actively. For example, Ayer et al. [67] proposed an educational game based on AR that enabled students to design, evaluate, and visualize the exterior curtain walls. Their research showed that students, who used the AR game, can generate more design inspiration, and their overall performance was better than those who used paper design. Furthermore, Shirazi et al. [68] and Hartless et al. [69] both focused on exploring architectural design based on AR/VR technologies to provide immersive virtual experience. In particular, research by Hartless et al. [70] showed that the effect was more significant in the design of barrier-free facilities. In 2016, a method used to incorporate AR technology into the framework of architecture and urban design education was proposed, enabling students to reorganize streets and form new urban designs through AR technology [71]. Afterwards, in 2019, Chang et al. [72] developed an application of mobile AR in interior design teaching. Using AR, students can place virtual objects such as chairs and tables on the design plane and interact with these objects on their mobile devices. In addition, in terms of evaluating the architectural design generated by students, the spatial imagination skill of students can be improved by integrating AR with a global positioning system (GPS) [73].

5.4. Visual-Aided Design Tools

Teaching aids usually help teachers to deliver lectures. Many architects and researchers concluded that AR/VR have the potential to be teaching aids in the AEC industry [74–76]. For example, Martín-Gutiérrez et al. [77] showed that tablet AR and mobile AR were better options as teaching aids as opposed to traditional teaching aids. An AR-based enhanced book was proposed to help students perform visualization tasks in the course, which can promote the development of their spatial abilities. In the same way, Shirazi and Behzadan [78] presented an AR book which used computer-generated 3D objects and other virtual multimedia to enhance the content of general textbooks. In addition, Chen et al. [79] developed an AR teaching aid which aimed to allow students to better understand the relationship between 3D objects and their projections in the engineering graphics course. Similarly, Wen et al. [80] illustrated the possibility of creating cloud-based AR teaching aids. In their study, the cloud-based AR teaching aids virtually superimposed the interactive 3D building information model on the 2D paper drawings, so as to realize the 3D re-generation of the 2D drawings. In addition, students usually thought that the operation of wooden structures was difficult to understand. Therefore, Wu et al. [81] created VR outdoor wooden structure teaching aids, and validated the effectiveness of VR teaching aids in understanding on-site construction activities. Additionally, Chu et al. [82] found that learning with AR-based teaching aids significantly improved the academic performance and learning motivation of students, and also reduced the cognitive load of students.

5.5. AR/VR-Based Operation Guide

The improper use of construction equipment causes the risk of injuries, damages equipment, and increases costs [83]. Therefore, AR/VR have been widely used for guiding the operation of construction equipment. For example, Wen et al. [84] developed a virtual training system for horizontal directional drilling (HDD) operation training. In this virtual training, the trainees can fully understand the drilling operations. Moreover, Irizarry and Abraham [85] illustrated that it was possible to create a VR-based system to improve the safety of workers during steel installation. Su et al. [86] presented a virtual training system to improve the control skills of operators using construction excavators. Moreover, Mastli and Zhang [87] proposed a crane simulation VR system that covered the areas from the storage location to the installation location in cave automatic virtual environment (cave), which could help operators plan crane routes during the construction planning stage and improve construction efficiency. Wang et al. [88] presented the personalized training VR to establish virtual scaffolding scenes where workers can experience dangerous environments without any real risk of injury. In addition, Jochen et al. [89] created a new method that integrated real-time location tracking and 3D immersive data visualization into the existing construction worker training environment. According to the above research, the AR/VR system can effectively simulate dangerous, expensive, and difficult-to-set training scenarios [90].

Some researchers also focused on how the AR/VR systems affected the assembly performance. For example, Hou and Wang [91] showed that guiding operation through AR technology can achieve better performance than traditional training. Hoedt et al. [92] proved that it was faster to operate in a VE. Considering that the current aging rate is accelerating, the shortage of labor will cause major problems. Ojelade and Paige [93] evaluated the VR environment and the posture estimation teaching tool based on a RGB camera, aiming to solve the lack of training in the existing construction industry. Furthermore, Frédéric et al. [94] illustrated that simulating the real environment of working at height can eliminate occupational harmful factors and safety risks. Lei et al. [95] stated that AR-based operational training gave providers a higher level of immersive and interactive spatial awareness. These applications illustrated the trend of using AR/VR in operational guidance.

5.6. Safety Training

The AEC industry is a high-risk industry as there are many potential risk factors on the construction site. Therefore, safety issues have attracted widespread concern, and companies all over the world are implementing safety management systems to ensure that their employees are protected from death and injury [96,97]. At the same time, people have also begun to realize the potential of AR/VR in safety training and have conducted some researches on the implementation of AR/VR. For example, Assfalg et al. [98] developed a virtual training system called Virtual Environments for Construction Workers' Instruction and Training (VECWIT), which improved the current ways of teaching construction tasks in safety training.

In the meantime, increasing tools are designed to improve the safety awareness and hazard identification capabilities of construction workers. In order to enable construction personnel to quickly identify on-site hazards, Chen et al. [99] proposed a VR system which integrated a BIM and a 2D image of the construction site, creating a clear mapping between site hazards and identification. In addition, Jeelani et al. [100] conducted a robust, realistic, and immersive environment and a controlled experiment was conducted. The results showed a 39% improvement in hazard identification and a 44% improvement in hazard management performance. Their experiment showed that the use of VR for training can improve the hazard identification and management skills of construction professionals and workers. Similarly, Perlman et al. [101] also proved that the construction personnel could better identify potential hazards in the VE. Furthermore, Sacks et al. [102] presented building safety training in a VE, which showed that VR training was more effective in the training of cast-in-place concrete work. Li et al. [103] proposed a multi-user virtual safety training system which allows multiple users to work in a dynamic VE.

A great number of research focused on the development of functions and systems, while few researches focus on application effect evaluation. Among such limited studies, Zhang et al. [104] adopted a comprehensive evaluation of the VR safety training system with the analytic hierarchy process and the fuzzy logic technology. Moore et al. [105] used 360-degree panoramic images as a traditional safety training program to compare against the hazard identification training scene developed by VR technology. In addition, some researchers combined AR/VR with other technologies to build AR/VR systems. Pereira et al. [106] introduced the development of a virtual safety training system based on panoramic AR technology. The adoption of panoramic AR technology improved the participation sense of users. The aforementioned studies illustrate the potential application of AR/VR in safety training.

6. The Effect of AR/VR in Education and Training: Meta-Analysis

A full reading of the selected 82 studies revealed that the answers of different studies on the question, "Does AR/VR have an impact on the effectiveness for education and training in the AEC industry?", which is proposed in Section 4, differed or even contradicted, making it difficult to consolidate them to reach a clear conclusion. Therefore, this study used meta-analysis to explore the effect of AR/VR on education and training in the AEC industry. Meta-analysis is a statistical method used to summarize data from original research studies for a given question; this involved combining the results of independent studies to test for sources of variation between studies, and quantitatively synthesizing those results with sufficient similarity [107]. In total, 17 studies that met the inclusion criteria were screened out of 82 studies and a meta-analysis of these 17 studies was conducted using Review Manger 5.4. In order to ensure the consistency of the meta-analysis studies and the rigorousness of the results [108], the inclusion criteria include the following five aspects:

(1) The studies must have AR or VR applications for education or training;
(2) The studies must include experimental and control groups, or the experiment must include pre-test and post-test;
(3) The studies must include sufficient descriptive data, such as mean (M) and standard deviation (SD), and the results of significance analysis represented by p values and other data;
(4) The subject of the study must be students or trainers related to the AEC industry;
(5) The publication date of the research results must be between 1997 and 2021.

6.1. Quality Assessment

Meta-analysis is a method of secondary synthesis and evaluation from original studies, and the quality of the meta-analysis is directly affected by whether the quality of the included studies is accurately and critically evaluated [109]. Therefore, it is particularly important to evaluate the quality of the included studies in the meta-analysis. In this study, two researchers assessed the risk of bias for all selected studies based on the Cochrane risk bias assessment tool in six fields: (1) selection bias; (2) performance bias; (3) detection bias; (4) attrition bias; (5) reporting bias; and (6) other bias [110], as shown in Table 2.

Table 2. Evaluation content based on the Cochrane risk assessment tool.

Fields	Evaluation Content
Selection bias	
Random sequence generation	Whether a random allocation sequence is generated to assess comparability between groups.
Allocation hidden	Whether the random allocation scheme is hidden to determine whether the allocation of the intervention can be predicted.
Performance bias	
Blinding of participants and personnel	Whether the researcher and the subject are blinded to prevent them from knowing about the intervention on the subject.
Detection bias	
Blinding of outcome assessment	Whether the evaluators of the study results are blinded to prevent them from knowing about the intervention on the subjects.
Attrition bias	
Incomplete outcome data	The study reports data for each of the key indicators, including lost to follow-up and exits.
Reporting bias	
Selective reporting	The information described allows the system evaluator to judge the possibility of selective reporting of findings and related circumstances.
Other bias	Whether there are other sources of bias.

The results of the risk of bias assessment for the included studies are shown in Figures 11 and 12. The assessment of each area of the 17 studies is as follows. (1) The 17 studies are all randomized controlled trials. (2) None of the studies mention allocation concealment methods. (3) Considering the feature of education and training in the AEC industry, limited studies currently use blinding [108]. Blinding is commonly used in experimental epidemiological studies and is susceptible to information bias during the design, data collection, or analysis stages due to subjective factors of the study population and the researcher [111]. (4) In 1 of the 17 studies, some responses are considered invalid due to an incomplete questionnaire, but the study itself has a large sample size, so this part of the data missing has little impact on the overall results and is still assessed as "Low risk of bias". (5) All studies are assessed as having a low risk of selective reporting. (6) Two studies show that factors such as small sample size may affect the results.

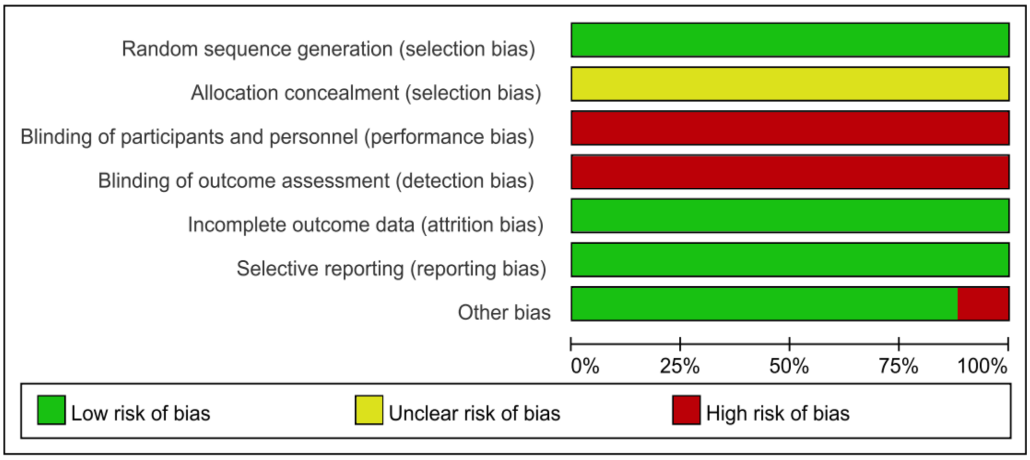


Figure 11. Risk of bias graph.

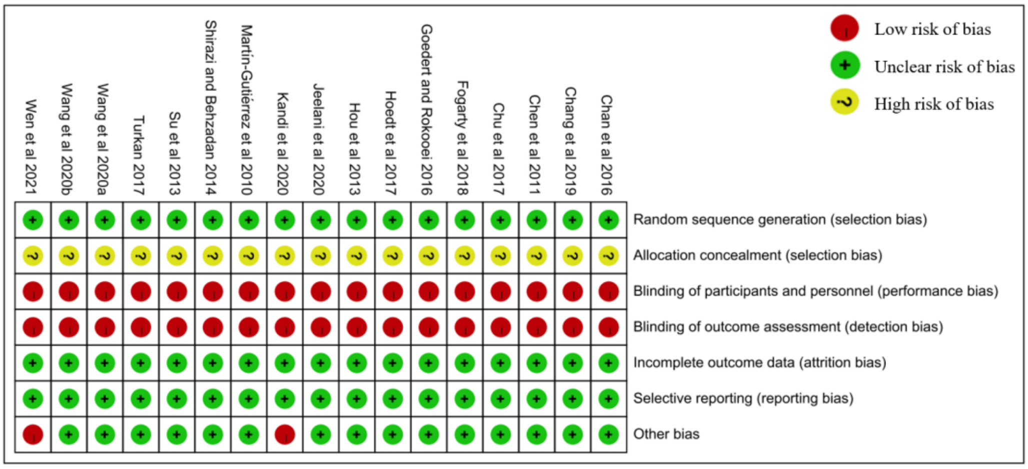


Figure 12. Risk of bias summary.

6.2. Heterogeneity Test

It was hoped that the studies included in the meta-analysis all had the same outcome (i.e., homogeneity). However, the actual results often did not show homogeneity. There were still instances where inappropriate amounts of combined data occur due to factors such as the study population, study design, and outcome measures, leading to unreliable conclusions from conducting a meta-analysis. Therefore, before combing effect values, the Q-test and I^2 test of RevMan were used to identify the presence of heterogeneity between the included studies. The higher the I^2 value, the greater the heterogeneity when using I^2 test. I^2 values of 25%, 50%, and 75% were used to indicate the limits of low, medium, and high heterogeneity, respectively. The Q test was based on the total variance test. If $p > 0.10$, there was homogeneity, and statistics could be calculated and combined using a fixed-effect model, while if $p \leq 0.10$, there was heterogeneity and a random effect model was used for analysis [112]. The data were extracted from the 17 studies and entered into RevMan for a heterogeneity test. The results of the heterogeneity test (Q = 280.61,

I^2 = 87% > 75%, p < 0.00001) based on the above criteria are shown in Figure 13. Analysis of the data suggested that the study was more heterogeneous and that a random effect model should be selected for analysis. According to the classification criteria for effect values, an effect value of 0.2 was generally considered to have a minor impact, 0.5 a moderate impact, and 0.8 a significant impact [112]. The overall effect value of the 17 studies was 0.44 (SMD = 0.39, 95% CI: 0.16–0.62) between minor and moderate effects, indicating that AR/VR technology had a positive effect on education and training in the AEC industry. However, the positive impact was not very high, suggesting that there are still some limitations to the application of AR/VR in education and training in the AEC industry. To further explore reasons for the existence of limitations, Section 7 summarizes the current challenges in the application of AR/VR in education and training.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Chan et al 2016	1.34	0.13	15	1.46	0.166	15	2.5%	-0.78 [-1.53, -0.04]
Chang et al 2019	17.01	1.84	52	13.35	2.13	48	2.9%	1.83 [1.36, 2.30]
Chang et al 2019	16.79	2.32	52	13.92	3.17	48	3.0%	1.03 [0.61, 1.45]
Chang et al 2019	16.04	1.95	52	14.48	3.11	48	3.0%	0.60 [0.20, 1.00]
Chang et al 2019	16.94	1.88	52	15.15	2.39	48	3.0%	0.83 [0.42, 1.24]
Chang et al 2019	16.13	1.69	52	15.52	2.36	48	3.0%	0.30 [-0.10, 0.69]
Chen et al 2011	0.59	0.021	12	0.44	0.015	12	0.6%	7.94 [5.35, 10.52]
Chen et al 2011	5.67	1.62	12	7.08	1.49	12	2.3%	-0.87 [-1.72, -0.03]
Chen et al 2011	7.08	1.26	12	7.63	1.03	12	2.3%	-0.46 [-1.27, 0.35]
Chen et al 2011	4.69	1.26	12	6.37	1.7	12	2.3%	-1.08 [-1.95, -0.22]
Chen et al 2011	0.05	0.018	12	0.04	0.014	12	2.3%	0.60 [-0.22, 1.42]
Chen et al 2011	0.45	0.13	12	0.47	0.13	12	2.4%	-0.15 [-0.95, 0.65]
Chu et al 2017	1.23	12.08	20	1.39	11.16	19	2.7%	-0.01 [-0.64, 0.61]
Fogarty et al 2018	8.32	1.43	29	8.94	0.919	29	2.8%	-0.51 [-1.03, 0.01]
Fogarty et al 2018	8.74	1.37	29	9.21	1.18	29	2.8%	-0.36 [-0.88, 0.16]
Goedert and Rokooei 2016	3.5	0.65	26	2.96	0.77	26	2.8%	0.75 [0.18, 1.31]
Goedert and Rokooei 2016	3.5	0.81	26	3.08	0.89	26	2.8%	0.49 [-0.07, 1.04]
Goedert and Rokooei 2016	3.42	0.76	26	2.85	0.92	26	2.8%	0.67 [0.11, 1.22]
Goedert and Rokooei 2016	3.19	0.94	26	2.65	0.8	26	2.8%	0.61 [0.05, 1.17]
Goedert and Rokooei 2016	3.15	0.92	26	2.65	0.8	26	2.8%	0.57 [0.02, 1.13]
Goedert and Rokooei 2016	3.08	0.89	26	3.04	0.92	26	2.8%	0.04 [-0.50, 0.59]
Hoedt et al 2017	4.163	0.61	14	3.275	0.59	14	2.3%	1.44 [0.59, 2.28]
Jeelani et al 2020	1.92	0.5	53	1.887	0.614	53	3.0%	0.06 [-0.32, 0.44]
Jeelani et al 2020	2.3	0.3	53	1.5	0.424	53	2.9%	2.16 [1.68, 2.65]
Martín-Gutiérrez et al 2010	27.71	7.83	24	22.08	9.94	25	2.7%	0.62 [0.04, 1.19]
Martín-Gutiérrez et al 2010	38.46	7.05	24	33.52	6.77	25	2.7%	0.70 [0.12, 1.28]
Shirazi and Behzadan 2014	12	2.39	50	12.5	2.33	50	3.0%	-0.21 [-0.60, 0.18]
Su et al 2013	3.73	0.8	15	3.93	0.59	15	2.5%	-0.28 [-1.00, 0.44]
Turkan 2017	6.66	1.89	19	6.84	1.96	22	2.7%	-0.09 [-0.71, 0.52]
Wang et al 2020a	38.61	5.46	74	31.08	5.37	74	3.1%	1.38 [1.02, 1.74]
Wang et al 2020a	34	6.31	74	34.24	6.64	78	3.1%	-0.04 [-0.35, 0.28]
Wang et al 2020a	7.04	9.78	74	5.47	9.29	78	3.1%	0.16 [-0.15, 0.48]
Wang et al 2020a	4.14	10.99	74	4.69	11.16	78	3.1%	-0.05 [-0.37, 0.27]
Wang et al 2020a	25.6	5.78	78	24.57	6.43	74	3.1%	0.17 [-0.15, 0.49]
Wang et al 2020a	29.55	6.16	78	29.86	6.64	74	3.1%	-0.05 [-0.37, 0.27]
Wang et al 2020b	17.41	1.34	16	16.87	1.21	16	2.5%	0.41 [-0.29, 1.11]
Wen et al 2021	9.76	1.2	17	8.12	1.54	17	2.5%	1.16 [0.43, 1.89]
Total (95% CI)			**1318**			**1306**	**100.0%**	**0.39 [0.16, 0.62]**

Heterogeneity: Tau² = 0.42; Chi² = 280.61, df = 36 (P < 0.00001); I² = 87%
Test for overall effect: Z = 3.31 (P = 0.0009)

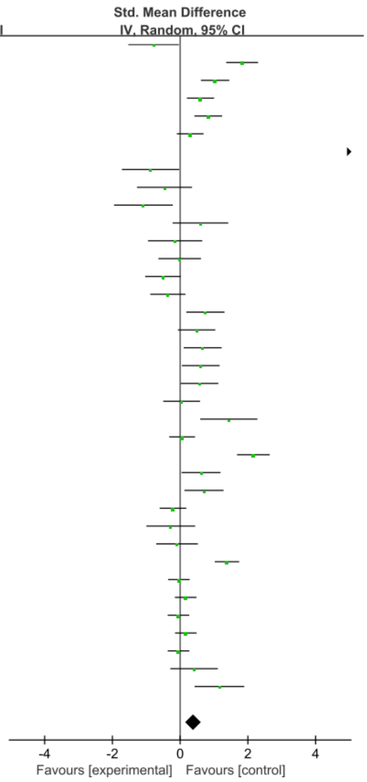


Figure 13. Forest plot.

6.3. Sensitivity Analysis

This study used meta-analysis to explore the effect of AR/VR for education and training in the AEC industry. Due to the high heterogeneity (Q = 280.61, I^2 = 87% > 75%, p < 0.00001) of this study, sensitivity analysis should be used to verify the accuracy of the results derived from the meta-analysis in this study. This study used a sensitivity analysis of the 17 studies by removing significantly different studies and observing changes in the total effect sizes [108]. After removing data from four studies [71,78,91,99], the heterogeneity in the effects of AR/VR for education and training in the AEC industry decreased to 67%, p = 0.03. Heterogeneity was significantly reduced. Comparing the studies with large differences in significance with other studies, it can be inferred that the different design protocols and measurement methods were the main reasons for the high heterogeneity in the meta-analysis of this study. The results of the analysis could be used, and the effectiveness of use in education and training was significantly correlated with AR/VR.

7. The Application of AR/VR in Education and Training: Summary Analysis

The applications of AR/VR in education and training are still in the development stage. Effectively training and educating students or construction workers in the AEC industry has become a challenge faced by educational researchers. Some challenges in applying AR/VR to the education and training in the AEC industry are discussed in the following sections.

7.1. The User Friendliness of AR/VR Devices

One challenge is the user friendliness of AR/VR devices. User-friendliness refers to the user experience provided by the AR/VR devices [30]. In the early days, due to the limitations of screens and chips, a huge set of equipment was required to achieve AR/VR for education and training systems, and the effects achieved were not very satisfactory [112]. However, with the further development of mobile technology in recent years, many portable and more effective simulation display devices have emerged [39]. The percentage of applied AR/VR teaching devices in the 82 studies is shown in Figure 14. Most studies install AR applications on mobile devices (41). Among them, smartphones have been adopted the most (25), followed by tablets (10) and laptops (6). Smartphones and tablets are widely used because of their lightness and popularity. Mobile devices are usually equipped with a gyroscope to record the movement of the user to provide correct relative position between the real environment and the virtual object [12]. By assigning different meanings to different touch screen gestures, users can operate the applications by directly touching the screen. However, those who employ mobile devices for AR-based education or training report that this approach provides an inconvenient and uncomfortable process for performing tasks [113]. A limitation of the screen size of mobile devices determines the size of the range in which the model can be displayed. Moreover, students need to hold the iPad in their hands for learning, which will occupy their hands [56]. Additionally, the mobile device produces a glare effect on the screen, making it a bad viewing experience for the user.

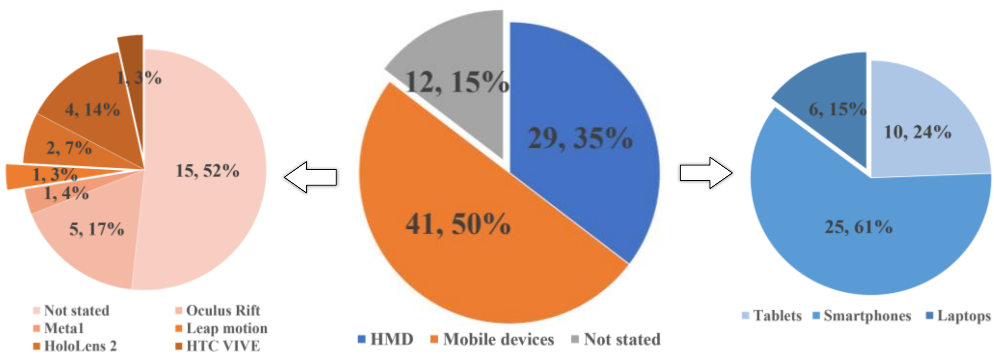


Figure 14. The percentage of applied AR/VR education and teaching devices.

AR applications developed based on HMDs can partially overcome the above limitation, and some of them can free the hands of users [94]. The latest HMDs are often equipped with higher configuration and more complete development environment, providing a better user experience. However, there are still limitations in user friendliness of modern HMDs. For example, Microsoft HoloLens, one of the most advanced AR devices, offers a limited view in front of the eyes of users and is not enough to provide a fully immersive experience [108]. Additionally, the battery life of HoloLens is short, creating non-negligible gap time in education or training as they must charge the HoloLens. Wearing HMDs for a longer period of time will also bring considerable weight burden to the neck of users, greatly reducing the comfort of using AR/VR devices [20]. The limitations of AR HMDs are even more obvious when it comes to outdoor education or training. For example, most AR HMDs are not waterproof and cannot be used in rainy days. Furthermore, directly exposing AR HMDs to sunlight, especially in summer afternoons, can produce a glare that makes users uncomfortable and heats up AR HMDs. HTC VIVE, a representative device of

VR HMDs, consists of two optical lenses with a field of view (FOV) capacity of 1080 pixels each, but it does not fully support users with visual impairment [23]. Near-sighted users reported that they cannot see VR scenes clearly when using the developed applications, have difficulty using VR tools to control the learning environment, and develop motion sickness [65]. In conclusion, currently, the majority of users report a poor experience when wearing HMDs for learning or training. There are still many aspects of HMDs that need to be improved, and the ever-improving HMDs are expected to be the future of AR/VR devices.

7.2. The Accessibility of AR/VR Systems

The accessibility of AR/VR systems refers to the difficulty of using and developing AR/VR systems among users [113]. Usually, AR/VR systems consist of digital information and development engines (Figure 15). The digital information includes 2D information and 3D building information models. Among them, 2D information mainly includes text information, image information, and video information. The role of 2D information is mainly to help users better understand the augmented environment (AE) and virtual environment. A 3D building information model, formed through modelling and rendering, provides the user with an immersive environment and is an important part of digital information. However, models in the AEC industry are generally larger and more complex than those in other fields [38]. The size and complexity of large models can increase import and rendering time, making it more difficult to iterate on the model during development. To facilitate the development, Google, Microsoft, and other suppliers have launched development tools, including off-the-shelf packages or a software development kit (SDK) [113]. The role of the tools is to assist developing specific functions within the development engine. In summary, the AR/VR system developing process includes a series of preparation operations such as creating 3D models, defining interactive components, converting formats, and designing interfaces [42]. The tasks mentioned above undoubtedly put forward higher requirements for the teaching ability of teachers. AR/VR systems are generally developed by computer experts, so teachers or workers with only an AEC or educational background have to face many difficulties when developing AR/VR systems.

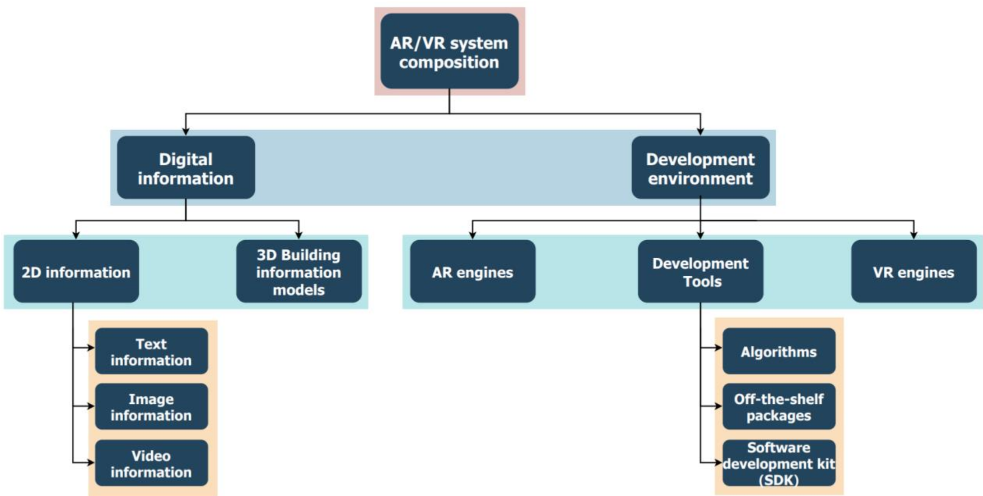


Figure 15. AR/VR system composition.

In terms of the difficulty of using AR/VR systems by users, some users indicated that the interaction features developed in AR/VR systems do not exactly reflect actual activities. Moreover, the current system can only achieve simple operations such as picking, moving, and placing [48]. The complexity and variety of operations in the real construction field make it difficult for these simple interactive operations to meet the requirements of teaching or training [42]. In addition, the interactions between users and virtual objects require gestures to be performed accurately and voice commands to be pronounced accurately. Therefore, this can be difficult for the normal user without systematic training, increasing learning time cost for beginners to become familiar with the AR/VR system. Therefore, it can be concluded that the development of AR/VR system is still in the preliminary exploration stage, the development difficulty has to be reduced, and the natural human–computer interaction (HCI) has to be improved [49].

7.3. The Accuracy of AR Localization

AR localization can combine the virtual world and the real world through the appropriate relationship of relative positions [55]. This ability is regarded as the key functionality of AR. Localization accuracy is a key index used to evaluate the performance of the AR system. In general, AR can be divided into two types based on the spatial registration method: marker-based and markerless (Figure 16).

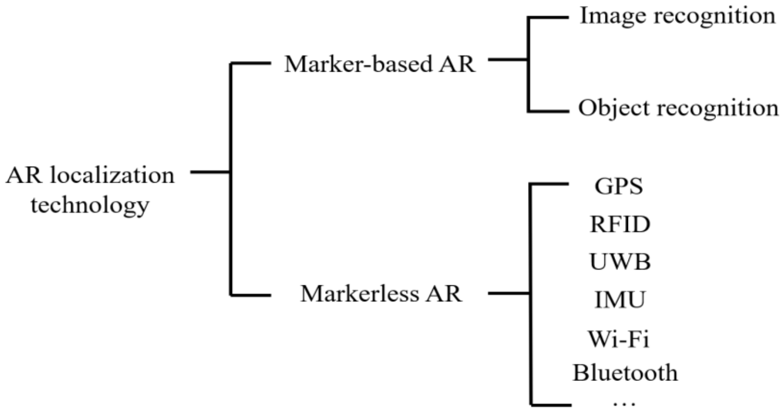


Figure 16. AR localization technology.

For marker-based AR applications, markers can be two-dimensional images with easily extracted visual features or natural objects in real environments. In the AEC industry, the use of marker-based AR for localization in education and training is common [62]. Usually, the localization accuracy of marker-based AR applications can be satisfactory because it directly superimposes virtual objects onto the markers. However, the accuracy decreases if a marker is registered for an object that is far from its location [58]. For example, when users hold a 2D drawing in one hand and an iPad in the other for viewing AR applications, it exacerbates the problem of drifting and misaligning the augmented object location [79]. The occurrence of this phenomenon increases the error rate of users when performing tasks. In addition, the production of markers requires a lot of preparation time and can affect the aesthetics of the room [64]. When identifying the marker, the users had to point the camera of mobile device at the marker and maintain that location at all times while interacting with the AR application and reviewing the results. Some users reported having to hold the device up in the air while swiping it, which can become tiresome after a long time [55], leading to a decrease in user satisfaction with AR applications. Therefore, marker-based AR sometimes may not be applicable when it comes to education and training in the AEC industry.

Markerless AR typically does not track marked features, but uses some type of localization technique to control the relative position relationship between the real environment and the virtual objects. Some markerless location techniques have been used in the AEC industry [114]. For example, GPS is a space-based localization system that can use satellites to provide real-time information on location which is currently the most widely used technology for the spatial registration of markerless AR [115]. The user range error (URE) for civil commitments cannot be less than 0.8 m [116]. The localization accuracy of GPS is even worse in indoor environments considering the blockage of signals by building facilities. The low accuracy of GPS is not suitable for activities that require high accuracy or occur mainly indoors. Some other localization technologies can provide higher accuracy compared to GPS and can be applied to indoor activities [78]. Several real-time localization systems have been developed based on RFID and the potential of integrating AR with RFID has been investigated. In order to implement RFID in AR, RFID tags must be attached to the target object and RFID readers are required to detect the corresponding tags. The required preparation and additional equipment lead to great inconvenience in using RFID-based AR applications [69]. Another option for AR localization is UWB. However, similar to RFID, utilizing UWB requires a special signal receiver, which suggests difficulties in incorporating UWB-based AR into daily routines of people [113]. The inertial measurement unit (IMU) can also be used for AR spatial registration by tracking the movement of users. The current location of the users can be obtained based on the original position and subsequent motion [81]. However, a combination of other methods, such as marker detection, is needed to obtain the original position. Another option for AR localization is Wi-Fi fingerprinting, which has better performance than GPS in terms of accuracy in indoor environments [72]. However, one prerequisite of using Wi-Fi fingerprinting is that the target area should be covered with Wi-Fi signals, which is difficult to achieve in many places, such as a large construction site. Similarly, Bluetooth localization also requires signal coverage. For complex spatial environments, Bluetooth systems are less stable. To summarize, all these methods of localization have their limitations in terms of accuracy or practicality [90]. To promote the application of AR/VR for education and training in the AEC industry, more advanced or improved localization methods that can provide higher accuracy and can be easily accessed are needed.

8. Conclusions and Future Work

The global spread of COVID-19 has significantly impacted education. Researchers and educational research institutions urgently need to learn from the COVID-19 crisis. People receiving higher education aim to reflect on how to create a more creative and flexible educational paradigm. In the AEC industry, the rapid development of AR/VR technologies indicates its potential for implementation in education and training. This article reviewed 82 studies on AR/VR technologies for education and training in the AEC industry. Then, 55 out of the 82 studies, focusing on the education field, were classified into the following four categories: (a) immersive AR/VR learning; (b) AR/VR for structure analysis; (c) visual-aided design tools; and (d) AR/VR-based teaching aids. The remaining 27 studies, focusing on the training field, were divided into two categories: (a) AR/VR virtual operation guide and (b) safety training. Based on meta-analysis, the results show that the positive impact is not very high, which indicates that there are some limitations in the application of AR/VR for education and training in the AEC industry. To further explore the reasons for the existence of limitations, this study analyzed the current challenges of AR/VR for education and training in the AEC industry (e.g., the user friendliness of AR/VR devices, the accessibility of AR/VR systems, and the accuracy of AR localization technology). Based on this review, it can be seen that the emergence of AR/VR has provided an opportunity to reform education and training in the AEC industry. In addition, the application of AR/VR technologies to education and training can not only improve existing teaching strategies in a more diversified educational environment, but also has great significance for the AEC industry. Although the current AR/VR systems are still imperfect, it is believed that all shortcomings and limitations will be properly addressed in the near future. The major trends of future development are predicted as follows:

(a) Advanced HMDs can be expected to be the future trend of AR/VR devices because they can integrate different interaction methods and free the hands of users. Companies need to focus on developing more cost-effective portable AR/VR devices to increase the popularity of AR/VR devices and improve the current HMD display methods and human–computer interaction. The use of myopic goggles on AR/VR devices will help improve the comfort of nearsighted users wearing the devices. In terms of immersive interaction methods, AR/VR devices capable of 3D display, ultra-high resolution, large live view, somatosensory interaction, and even deeper immersive interaction methods through brain-machine interfaces are needed.

(b) The process of experiencing AR/VR sometimes can be treated as a process of cheating the brain. Therefore, in the future, more attention should be paid to creating a more believable virtual experience. Through the simulation of senses such as sight and hearing, users are presented with an illusion of being in the real world. In addition, the development of cloud computing helps to further improve the experience of users with low latency and high realism. With the help of cloud storage and computing, large projects can be visualized and multiple functions can be implemented on mobile devices.

(c) In general, teachers or practitioners in the AEC field have limited programming skills. Hence, it may be necessary to promote the development of low-code and zero-code AR/VR application platforms which have the advantages of generality and high efficiency. These platforms allow users who cannot understand the code to complete the AR/VR system construction by dragging, dropping components, and shortening the development cycle.

(d) To facilitate the use of AR for education and training in the AEC industry, there is a need for more advanced localization methods that can provide higher accuracy and can be easily accessed. Currently, the emerging fifth generation mobile network (5G) technology has the potential to fill these gaps. Given the high efficiency of communications and the high density of base stations, 5G-based localization accuracy can improve. In indoor environments, the performance of 5G is also strong, demonstrating the suitability of 5G for indoor localization. In addition, ordinary smartphones can be used with 5G without any external receiver. It is expected that the popularity of 5G for AR in the AEC industry will further promote the application of AR in education and training. In conclusion, all existing localization technologies for AR have their limitations in terms of accuracy or usefulness, and the emerging 5G has the potential to fill these gaps.

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References

1. Akçayır, M.; Akçayır, G. Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educ. Res. Rev.* **2017**, *20*, 1–11. [CrossRef]
2. Zhou, F.; Duh, H.B.-L.; Billinghurst, M. Trends in Augmented Reality Tracking, Interaction and Display: A Review of Ten Years of ISMAR. In Proceedings of the 2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality, Cambridge, UK, 15–18 September 2008; pp. 193–202. [CrossRef]
3. Azuma, R.T. A Survey of Augmented Reality. *Presence Teleoperators Virtual Environ.* **1997**, *6*, 355–385. [CrossRef]
4. Akbulut, A.; Catal, C.; Yıldız, B. On the effectiveness of virtual reality in the education of software engineering. *Comput. Appl. Eng. Educ.* **2018**, *26*, 918–927. [CrossRef]

5. Mazuryk, T.; Gervautz, M. Virtual_Reality—History, Applications, Technology and Future Computer Science and Engineering. 1996. Available online: https://www.cg.tuwien.ac.at/research/publications/1996/mazuryk-1996-VRH/TR-186-2-96-06Paper.pdf. (accessed on 16 August 2022).
6. Hall, R.; Miller, J. Head-mounted Electroocular Display: A New Display Concept for Specialized Environment. *Aerosapace Med.* **1963**, *8*, 316–318. [CrossRef]
7. Lanier, J. Virtual Reality: The Promise of the Future, Interact. *Interact. Learn. Int.* **1992**, *8*, 275–279.
8. Park, S.; Kim, S.P.; Whang, M. Individual's Social Perception of Virtual Avatars Embodied with Their Habitual Facial Expressions and Facial Appearance. *Sensors* **2021**, *21*, 5986. [CrossRef]
9. Falchuk, B.; Loeb, S.; Neff, R. The Social Metaverse: Battle for Privacy. *IEEE Technol. Soc. Mag.* **2018**, *37*, 52–61. [CrossRef]
10. Nevelsteen, K.J.L. Virtual world, defined from a technological perspective and applied to video games, mixed reality, and the Metaverse. *Comput. Animat. Virtual Worlds* **2018**, *29*, e1752. [CrossRef]
11. ElSayed, N.A.M.; Zayed, H.H.; Sharawy, M.I. ARSC: Augmented reality student card. *Comput. Educ.* **2011**, *56*, 1045–1061. [CrossRef]
12. Kucuk, S.; Kapakin, S.; Goktas, Y. Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load. *Anat. Sci. Educ.* **2016**, *9*, 411–421. [CrossRef]
13. Jensen, L.; Konradsen, F. A review of the use of virtual reality head-mounted displays in education and training. *Educ. Inf. Technol.* **2017**, *23*, 1515–1529. [CrossRef]
14. Alhalabi, W. Virtual reality systems enhance students' achievements in engineering education. *Behav. Inf. Technol.* **2016**, *35*, 919–925. [CrossRef]
15. Wang, P.; Bai, X.L.; Billinghurst, M.; Zhang, S.S.; Zhang, X.Y.; Wang, S.X.; He, W.P.; Yan, Y.X.; Ji, H.Y. AR/MR Remote Collaboration on Physical Tasks: A Review. *Robot. Comput. Integr. Manuf.* **2021**, *72*, 102071. [CrossRef]
16. Alam, M.F.; Katsikas, S.; Beltramello, O.; Hadjiefthymiades, S. Augmented and virtual reality based monitoring and safety system: A prototype IoT platform. *J. Netw. Comput. Appl.* **2017**, *89*, 109–119. [CrossRef]
17. Milgram, P.; Colquhoun, H. A Taxonomy of Real and Virtual World Display Integration. In *Mixed Reality*; Springer: Tokyo, Japan, 1999; pp. 5–30. [CrossRef]
18. Milgram, P.; Takemura, H.; Utsumi, A.; Kishino, F. Augmented reality: A class of displays on the reality-virtuality continuum. In *Proceedings of the Telemanipulator and Telepresence Technologies*; International Society for Optics and Photonics: Bellingham, WA, USA, 1995; Volume 2351, pp. 282–292. [CrossRef]
19. Rosenberg, L. The Use of Virtual Fixtures as Perceptual Overlays to Enhance Operator Performance in Remote Environments. *Stanf. Univ. CA Cent. Des. Res.* **1992**, 52. Available online: http://www.dtic.mil/dtic/tr/fulltext/u2/a292450.pdf. (accessed on 16 August 2022).
20. Bacca-Acosta, J.; Baldiris, S.; Fabregat, R.; Graf, S. Augmented Reality Trends in Education: A Systematic Review of Research and Applications. *Educ. Technol. Soc.* **2014**, *17*, 133–149.
21. Cabero-Almenara, J.; Barroso-Osuna, J.; Llorente-Cejudo, C.; Martínez, M.M.F. Educational Uses of Augmented Reality (AR): Experiences in Educational Science. *Sustainability* **2019**, *11*, 4990. [CrossRef]
22. Fazel, A.; Izadi, A. An interactive augmented reality tool for constructing free-form modular surfaces. *Autom. Constr.* **2018**, *85*, 135–145. [CrossRef]
23. Wang, P.; Wu, P.; Wang, J.; Chi, H.L.; Wang, X.Y. A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training. *Int. J. Environ. Res. Public Health* **2018**, *15*, 1204. [CrossRef]
24. Diao, P.H.; Shih, N.J. Trends and Research Issues of Augmented Reality Studies in Architectural and Civil Engineering Education—A Review of Academic Journal Publications. *Appl. Sci.* **2019**, *9*, 1840. [CrossRef]
25. Soliman, M.; Pesyridis, A.; Dalaymani-Zad, D.; Gronfula, M.; Kourmpetis, M. The Application of Virtual Reality in Engineering Education. *Appl. Sci.* **2021**, *11*, 2879. [CrossRef]
26. Lanzo, J.A.; Valentine, A.; Sohel, F.; Yapp, A.Y.T.; Muparadzi, K.C.; Abdelmalek, M. A review of the uses of virtual reality in engineering education. *Comput. Appl. Eng. Educ.* **2020**, *28*, 748–763. [CrossRef]
27. Lin, S.S.; Shen, S.L.; Zhou, A.; Xu, Y.S. Risk assessment and management of excavation system based on fuzzy set theory and machine learning methods. *Autom. Constr.* **2021**, *122*, 103490. [CrossRef]
28. Rafols, I. Knowledge Integration and Diffusion: Measures and Mapping of Diversity and Coherence. In *Measuring Scholarly Impact*; Springer: Cham, Switzerland, 2014; pp. 169–190. [CrossRef]
29. Zinchenko, Y.P.; Khoroshikh, P.P.; Sergievich, A.A.; Smirnov, A.S.; Tumyalis, A.V.; Kovalev, A.I.; Gutnikov, S.A.; Golokhvast, K.S. Virtual reality is more efficient in learning human heart anatomy especially for subjects with low baseline knowledge. *New Ideas Psychol.* **2020**, *59*, 100786. [CrossRef]
30. Carmigniani, J.; Furht, B.; Anisetti, M.; Ceravolo, P.; Damiani, E.; Ivkovic, M. Augmented reality technologies, systems and applications. *Multimed. Tools Appl.* **2010**, *51*, 341–377. [CrossRef]
31. Kandi, V.R.; Brittle, P.; Castronovo, F.; Gaedicke, C. Application of a Virtual Reality Educational Game to Improve Design Review Skills. In *Construction Research Congress*; American Society of Civil Engineers: Reston, VA, USA, 2020; pp. 545–554.
32. Messner, J.I.; Yerrapathruni, S.C.M.; Baratta, A.J.; Whisker, V.E. Using Virtual Reality to Improve Construction Engineering Education. In Proceedings of the 2003 Annual Conference, Nashville, TN, USA, 22–25 June 2003; American Society for Engineering Education: Washington, DC, USA, 2003.

33. Behzadan, A.H.; Iqbal, A.; Kamat, V.R. A collaborative augmented reality based modeling environment for construction engineering and management education. In Proceedings of the 2011 Winter Simulation Conference, Phoenix, AZ, USA, 11–14 December 2011; pp. 3568–3576. [CrossRef]
34. Sampaio, A.Z.; Martins, O.P. The application of virtual reality technology in the construction of bridge: The cantilever and incremental launching methods. *Autom. Constr.* **2014**, *37*, 58–67. [CrossRef]
35. Ku, K.; Mahabaleshwarkar, P.S. Building interactive modeling for construction education in virtual worlds. *J. Inf. Technol. Constr.* **2011**, *16*, 189–208.
36. Vergara, D.; Rubio, M.P.; Lorenzo, M. New Approach for the Teaching of Concrete Compression Tests in Large Groups of Engineering Students. *J. Prof. Issues Eng. Educ. Pract.* **2017**, *143*. [CrossRef]
37. Goulding, J.; Nadim, W.; Petridis, P.; Alshawi, M. Construction industry offsite production: A virtual reality interactive training environment prototype. *Adv. Eng. Inform.* **2012**, *26*, 103–116. [CrossRef]
38. Li, X.; Yi, W.; Chi, H.L.; Wang, X.Y.; Chan, A.P.C. A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Autom. Constr.* **2018**, *86*, 150–162. [CrossRef]
39. Le, Q.T.; Pedro, A.; Lim, C.R.; Park, H.T.; Park, C.S.; Kim, H.K. A Framework for Using Mobile Based Virtual Reality and Augmented Reality for Experiential Construction Safety Education. *Int. J. Eng. Educ.* **2015**, *31*, 713–725.
40. Pham, H.C.; Dao, N.N.; Pedro, A.; Le, Q.T.; Hussain, R.; Cho, S.; Park, C.S. Virtual Field Trip for Mobile Construction Safety Education Using 360-Degree Panoramic Virtual Reality. *Int. J. Eng. Educ.* **2018**, *34*, 1174–1191.
41. Pedro, A.; Le, Q.T.; Park, C.S. Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality. *J. Prof. Issues Eng. Educ. Pract.* **2015**, *142*, 04015011. [CrossRef]
42. Clevenger, C.; Puerto, C.L.D.; Glick, S. Interactive BIM-enabled Safety Training Piloted in Construction Education. *Adv. Eng. Educ.* **2015**, *4*, n3.
43. Eiris, R.; John, B.; Gheisari, M.; Jain, E.; Wehle, A.; Memarian, B. *Hazard-Recognition Training Using Omnidirectional Cinemagraphs: Comparison between Virtual Reality and Lecture-Based Techniques, Construction Research Congress*; American Society of Civil Engineers: Reston, VA, USA, 2020; pp. 1117–1126. [CrossRef]
44. Bennett, V.G.; Harteveld, C.; Zastavker, Y.V.; Abdoun, T.; Hossein, M.; Omidvar, M.; Wen, K.J.; Wirth, X. A Mixed-Reality Pedagogical Innovation in the Reality of a New Normal. *Int. Found. Congr. Equip. Expo* **2021**, *2021*, 170–178. [CrossRef]
45. Mutis, I.; Issa, R. Enhancing Spatial and Temporal Cognitive Ability in Construction Education through Augmented Reality and Artificial Visualizations. *Comput. Civ. Build. Eng.* **2014**, *36*, 2079–2086. [CrossRef]
46. Behzadan, A.H.; Kamat, V.R. Enabling discovery-based learning in construction using telepresent augmented reality. *Autom. Constr.* **2013**, *33*, 3–10. [CrossRef]
47. Beh, H.J.; Rashidi, A.; Talei, A.; Lee, Y.S. Developing engineering students' capabilities through game-based virtual reality technology for building utility inspection. *Eng. Constr. Archit. Manag.* **2021**, *29*, 2854–2877. [CrossRef]
48. Wang, R.; Lowe, R.; Newton, S.; Kocaturk, T. Task complexity and learning styles in situated virtual learning environments for construction higher education. *Autom. Constr.* **2020**, *113*, 103148. [CrossRef]
49. Burcin, B.G.; Ku, K.; Jazizadeh, F. BIM-Enabled Virtual and Collaborative Construction Engineering and Management. *J. Prof. Issues Eng. Educ. Pract.* **2012**, *138*, 234–245. [CrossRef]
50. Dong, S.; Behzadan, A.H.; Chen, F.; Kamat, V.R. Collaborative visualization of engineering processes using tabletop augmented reality. *Adv. Eng. Softw.* **2013**, *55*, 45–55. [CrossRef]
51. Chou, C.; Hsu, H.L.; Yao, Y.S. Construction of a Virtual Reality Learning Environment for Teaching Structural Analysis. *Comput. Appl. Eng. Educ.* **1997**, *5*, 223–230. [CrossRef]
52. Guerrero-Mosquera, L.F.; Gómez, D.; Thomson, P. Development of a virtual earthquake engineering lab and its impact on education. *Dyna* **2018**, *85*, 9–17. [CrossRef]
53. Goedert, J.D.; Rokooei, S. Project-Based Construction Education with Simulations in a Gaming Environment. *Int. J. Constr. Educ. Res.* **2016**, *12*, 208–223. [CrossRef]
54. Weigel, T.A. A 21st Centuryclassroom—Improving teaching efficacy by combining real and virtual facilities. In Proceedings of the International Conference on Computing in Civil Engineering, Cancun, Mexico, 12–15 July 2005. [CrossRef]
55. Turkan, Y.; Radkowski, R.; Karabulut-Ilgu, A.; Behzadan, A.H.; Chen, A. Mobile augmented reality for teaching structural analysis. *Adv. Eng. Inform.* **2017**, *34*, 90–100. [CrossRef]
56. Setareh, M.; Bowman, D.A.; Kalita, A.; Gracey, M.; Lucas, J. Application of a Virtual Environment System in Building Sciences Education. *J. Archit. Eng.* **2004**, *11*, 165–172. [CrossRef]
57. Fogarty, J.; El-Tawil, S. Exploring Complex Spatial Arrangements and Deformations in Virtual Reality. In Proceedings of the Structures Congress, Boston, MA, USA, 3–5 April 2014; pp. 1089–1096.
58. Dib, H.N.; Adamo, N. An Augmented Reality Environment for Students' Learning of Steel Connection Behavior. In Proceedings of the ASCE International Workshop on Computing in Civil Engineering, Seattle, WA, USA, 25–27 June 2017; pp. 51–58. [CrossRef]
59. Sun, Q.; Gramol, K. Internet-based Simulation and Virtual City for Engineering Education. *Eng. Des. Graph. J.* **2004**, *68*, 13–21.
60. Moaveni, S.; Chou, K. An Interactive Steel Connection Teaching Tool—A Virtual Structure. In Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering, Orlando, FL, USA, 23–25 June 2014; pp. 2103–2110.
61. Martinez, P.; Al-Hussein, M.; Ahmad, R. A scientometric analysis and critical review of computer vision applications for construction. *Autom. Constr.* **2019**, *107*, 102947. [CrossRef]

62. Huang, J.M.; Ong, S.K.; Nee, A. Real-time finite element structural analysis in augmented reality. *Adv. Eng. Softw.* **2015**, *87*, 43–56. [CrossRef]
63. Fogarty, J.; McCormick, J.; El-Tawil, S. Improving Student Understanding of Complex Spatial Arrangements with Virtual Reality. *J. Prof. Issues Eng. Educ. Pract.* **2018**, *144*. [CrossRef]
64. Luo, X.W.; Cabico, C.D.M. Development and Evaluation of an Augmented Reality Learning Tool for Construction Engineering Education. In Proceedings of the Construction Research Congress, New Orleans, LA, USA, 2–4 April 2018; pp. 149–159. [CrossRef]
65. Try, S.; Panuwatwanich, K.; Tanapornraweekit, G.; Kaewmoracharoen, M. Virtual reality application to aid civil engineering laboratory course: A multicriteria comparative study. *Comput. Appl. Eng. Educ.* **2021**, *29*, 1771–1792. [CrossRef]
66. Louis, J.; Lather, J. Augmented Reality Sandboxes for Civil and Construction Engineering Education. In Proceedings of the 37th International Symposium on Automation and Robotics in Construction, Kitakyushu, Japan, 26–30 October 2020.
67. Ayer, S.K.; Messner, J.I.; Anumba, C.J. Augmented Reality Gaming in Sustainable Design Education. *J. Archit. Eng.* **2016**, *22*, 04015012. [CrossRef]
68. Shirazi, A.; Behzadan, A.H. Content delivery using augmented reality to enhance students' performance in a building design and assembly project. *Adv. Eng. Educ.* **2015**, *4*, n3.
69. Hartless, J.F.; Ayer, S.K.; London, J.S.; Wu, W. Comparison of Building Design Assessment Behaviors of Novices in Augmented- and Virtual-Reality Environments. *J. Archit. Eng.* **2020**, *26*, 04020002. [CrossRef]
70. Fonseca, D.; Valls, F.; Redondo, E.; Villagrasa, S. Informal interactions in 3D education: Citizenship participation and assessment of virtual urban proposals. *Comput. Hum. Behav.* **2016**, *55*, 504–518. [CrossRef]
71. Chang, Y.S.; Hu, K.J.; Chiang, C.W.; Lugmayr, A. Applying Mobile Augmented Reality (AR) to Teach Interior Design Students in Layout Plans: Evaluation of Learning Effectiveness Based on the ARCS Model of Learning Motivation Theory. *Sensors* **2019**, *20*, 105. [CrossRef]
72. Riera, A.S.; Redondo, E.; Fonseca, D. Geo-located teaching using handheld augmented reality: Good practices to improve the motivation and qualifications of architecture students. *Univers. Access Inf. Soc.* **2014**, *14*, 363–374. [CrossRef]
73. Joo, H.J.; Jeong, H.Y. A study on eye-tracking-based Interface for VR/AR education platform. *Multimed. Tools Appl.* **2019**, *79*, 16719–16730. [CrossRef]
74. Solmaz, S.; Gerven, T.V. Automated integration of extract-based CFD results with AR/VR in engineering education for practitioners. *Multimed. Tools Appl.* **2021**, *81*, 14869–14891. [CrossRef]
75. Huang, T.K.; Yang, C.H.; Hsieh, Y.H.; Wang, J.C.; Hung, C.C. Augmented reality (AR) and virtual reality (VR) applied in dentistry, Kaohsiung. *J. Med. Sci.* **2018**, *34*, 243–248. [CrossRef]
76. Martín-Gutiérrez, J.; Saorín, J.L.; Contero, M.; Alcañiz, M.; Pérez-López, D.C.; Ortega, M. Design and validation of an augmented book for spatial abilities development in engineering students. *Comput. Graph.* **2010**, *34*, 77–91. [CrossRef]
77. Shirazi, A.; Behzadan, A.H. Design and Assessment of a Mobile Augmented Reality-Based Information Delivery Tool for Construction and Civil Engineering Curriculum. *J. Prof. Issues Eng. Educ. Pract.* **2014**, *141*, 04014012. [CrossRef]
78. Chen, Y.C.; Chi, H.L.; Hung, W.H.; Kang, S.C. Use of Tangible and Augmented Reality Models in Engineering Graphics Courses. *J. Prof. Issues Eng. Educ. Pract.* **2011**, *137*, 267–276. [CrossRef]
79. Wen, J.; Gheisari, M.; Jain, S.; Zhang, Y.X.; Minchin, R.E. Using Cloud-Based Augmented Reality to 3D-Enable the 2D Drawings of AISC Steel Sculpture: A Plan-Reading Educational Experiment. *J. Civ. Eng. Educ.* **2021**, *147*, 04021006. [CrossRef]
80. Wu, W.; Sandoval, A.; Gunji, V.; Ayer, S.K.; London, J.; Perry, L.; Patil, K.; Smith, K. Comparing Traditional and Mixed Reality-Facilitated Apprenticeship Learning in a Wood-Frame Construction Lab. *J. Constr. Eng. Manag.* **2020**, *146*, 04020139. [CrossRef]
81. Chu, H.C.; Chen, J.M.; Hwang, G.J.; Chen, T.W. Effects of formative assessment in an augmented reality approach to conducting ubiquitous learning activities for architecture courses. *Univers. Access Inf. Soc.* **2017**, *18*, 221–230. [CrossRef]
82. Dunston, P.S.; Proctor, R.W.; Wang, X.Y. Challenges in evaluating skill transfer from construction equipment simulators. *Theor. Issues Ergon. Sci.* **2011**, *15*, 354–375. [CrossRef]
83. Wen, G.J.; Xu, L.H.; Chen, H.; Shang, X. Horizontal Directional Drill Rig Operating Training System based on Virtual Reality Technology. In Proceedings of the International Conference on Pipelines and Trenchless Technology (ICPTT), Shanghai, China, 18–21 October 2009; pp. 1093–1103. [CrossRef]
84. Irizarry, J.; Abraham, D.M. Application of virtual reality technology for the improvement of safety in the steel erection process. In Proceedings of the Computing in Civil Engineering, Cancun, Mexico, 12–15 July 2005; pp. 1–11. [CrossRef]
85. Su, X.; Dunston, P.S.; Proctor, R.W.; Wang, X.Y. Influence of training schedule on development of perceptual–motor control skills for construction equipment operators in a virtual training system. *Autom. Constr.* **2013**, *35*, 439–447. [CrossRef]
86. Mastli, M.; Zhang, J.S. Interactive Highway Construction Simulation Using Game Engine and Virtual Reality for Education and Training Purpose. In Proceedings of the ASCE International Workshop on Computing in Civil Engineering, Seattle, WA, USA, 25–27 June 2017; pp. 399–406. [CrossRef]
87. Wang, P.; Wu, P.; Chi, H.L.; Li, X. Adopting lean thinking in virtual reality-based personalized operation training using value stream mapping. *Autom. Constr.* **2020**, *119*, 103355. [CrossRef]
88. Teizer, J.; Cheng, T.; Fang, Y.H. Location tracking and data visualization technology to advance construction ironworkers' education and training in safety and productivity. *Autom. Constr.* **2013**, *35*, 53–68. [CrossRef]

89. Akbar, A.; Song, J.; Kwon, S.W. Remote Monitoring System and Controller for the Construction Machinery using AR Smart Glasses. In Proceedings of the International Symposium on Automation and Robotics in Construction, Dubai, United Arab Emirates, 2–4 November 2021; pp. 475–482.
90. Hou, L.; Wang, X.Y. A study on the benefits of augmented reality in retaining working memory in assembly tasks: A focus on differences in gender. *Autom. Constr.* **2013**, *32*, 38–45. [CrossRef]
91. Hoedt, S.; Claeys, A.; Landeghem, H.V.; Cottyn, J. The evaluation of an elementary virtual training system for manual assembly. *Int. J. Prod. Res.* **2017**, *55*, 7496–7508. [CrossRef]
92. Ojelade, A.E.; Paige, F. Virtual Reality Postural Training for Construction. In Proceedings of the Construction Research Congress, Tempe, Arizona, 8–10 March 2020. [CrossRef]
93. Bosché, F.; Abdel-Wahab, M.; Carozza, L. Towards a Mixed Reality System for Construction Trade Training. *J. Comput. Civ. Eng.* **2016**, *30*, 04015016. [CrossRef]
94. Lei, H.; Wang, X.Y.; Truijens, M. Using Augmented Reality to Facilitate Piping Assembly: An Experiment-Based Evaluation. *J. Comput. Civ. Eng.* **2015**, *29*, 05014007. [CrossRef]
95. Choudhry, R.M.; Fang, D.P.; Ahmed, S.M. Safety Management in Construction: Best Practices in Hong Kong. *J. Prof. Issues Eng. Educ. Pract.* **2008**, *134*, 20–32. [CrossRef]
96. Gupta, A.; Varghese, K. Scenario-Based Construction Safety Training Platform Using Virtual Reality. In Proceedings of the International Symposium on Automation and Robotics in Construction, Kitakyushu, Japan, 27–28 October 2020.
97. Assfalg, J.; Bimbo, A.D.; Vicario, E. Using 3D and Ancillary Media to Train Construction Workers. *IEEE* **2021**, *9*, 88–92. [CrossRef]
98. Chen, A.; GolparvarFard, M.; Kleiner, B. Design and Development of SAVES: A Construction Safety Training Augmented Virtuality Environment for Hazard Recognition and Severity Identification. In Proceedings of the Computing in Civil Engineering, Los Angeles, CA, USA, 23–25 June 2013. [CrossRef]
99. Jeelani, I.; Han, K.; Albert, A. Development of virtual reality and stereo-panoramic environments for construction safety training, Engineering. *Constr. Archit. Manag.* **2020**, *27*, 1853–1876. [CrossRef]
100. Perlman, A.; Sacks, R.; Barak, R. Hazard recognition and risk perception in construction. *Saf. Sci.* **2013**, *64*, 22–31. [CrossRef]
101. Sacks, R.; Perlman, A.; Barak, R. Construction safety training using immersive virtual reality. *Constr. Manag. Econ.* **2013**, *31*, 1005–1017. [CrossRef]
102. Li, H.; Chan, G.; Skitmore, M. Multiuser Virtual Safety Training System for Tower Crane Dismantlement. *J. Comput. Civ. Eng.* **2012**, *26*, 638–647. [CrossRef]
103. Zhang, H.; He, X.Q.; Mitri, H. Fuzzy comprehensive evaluation of virtual reality mine safety training system. *Saf. Sci.* **2019**, *120*, 341–351. [CrossRef]
104. Moore, H.F.; Eiris, R.; Gheisari, M.; Esmaeili, B. Hazard Identification Training Using 360-Degree Panorama vs. Virtual Reality Techniques: A Pilot Study. In Proceedings of the Computing in Civil Engineering, Atlanta, GA, USA, 17–19 June 2019; pp. 55–62. [CrossRef]
105. Pereira, R.E.; Gheisari, M.; Esmaeili, B. Using Panoramic Augmented Reality to Develop a Virtual Safety Training Environment. In Proceedings of the Construction Research Congress, New Orleans, LA, USA, 2–4 April 2018; pp. 29–39. [CrossRef]
106. Porta, M. *A Dictionary of Epidemiology*; Oxford University Press: Oxford, UK, 1983.
107. Chiang, F.K.; Shang, X.J.; Qiao, L. Augmented reality in vocational training: A systematic review of research and applications. *Comput. Hum. Behav.* **2021**, *129*, 107125. [CrossRef]
108. Hernandez, A.V.; Marti, K.M.; Roman, Y.M. Meta-Analysis. *Chest* **2020**, *158*, S97–S102. [CrossRef] [PubMed]
109. Higgins, J. Cochrane handbook for systematic reviews of interventions version 5.0.1. the cochrane collaboration. *Naunyn-Schmiedebergs Arch. Für Exp. Pathol. Pharmakol.* **2008**, *5*. [CrossRef]
110. Kenneth, F.S.; David, A.G. Blinding in randomised trials: Hiding who got what. *Lancet* **2002**, *359*, 696–700. [CrossRef]
111. Borenstein, M.; Hedges, L.V.; Higgins, J.P.; Rothstein, H.R. *Introduction to Meta-Analysis*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2009. [CrossRef]
112. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; Academic Press: Cambridge, MA, USA, 1977. [CrossRef]
113. Cheng, J.C.P.; Chen, K.Y.; Chen, W.W. State-of-the-Art Review on Mixed Reality Applications in the AECO Industry. *J. Constr. Eng. Manag.* **2020**, *146*, 03119009. [CrossRef]
114. Song, Y.; Wang, X.; Tan, Y.; Peng, W.; Monty, S.; Cheng, J.C.P.; Hampson, K. Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective. *ISPRS Int. J. Geo-Inf.* **2017**, *6*, 397. [CrossRef]
115. Hofmann-Wellenhof, B.; Lichtenegger, H.; Collins, J. *Global Positioning System: Theory and Practice*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 1997.
116. NOAA, GPS Accuracy. 2014. Available online: http://www.gps.gov/systems/gps/performance/accuracy/ (accessed on 6 October 2021).