CCC 2022
Proceedings of the Creative Construction e-Conference (2022) 037
Edited by: Miroslaw J. Skibniewski & Miklos Hajdu
https://doi.org/10.3311/CCC2022-037

Explore Challenges and Benefits of Virtual Reality in Construction Projects

Saeed Rokooei[1], Bahar Javan[2] and Ahad Nazari[2]

[1] *Building Construction Science, Mississippi State University, USA*
[2] *Shahid Beheshti University. Tehran, Iran*

Abstract

Today, the construction industry has undergone extensive changes, and with the introduction of new technologies, it has moved away from traditional project methods in different phases. One of these technologies is virtual reality technology (VR), which has more and more applications in different stages of the life cycle of construction projects, from design to delivery. One of the capabilities that this technology provides is that people can view the project's construction details virtually before completing the project, evaluate the project characteristics at the time of completion, and have a close-to-reality understanding of the final product. In this study, 57 experts in virtual reality were surveyed to examine the challenges and advantages of using virtual reality. The exploration was done through surveys and interviews. As a result, the most important challenges and benefits of using virtual reality in construction projects were identified and categorized.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2022.

Keywords: Construction, Training, Emerging Technologies, Virtual Reality

1. Introduction

In recent years, the development of digital concepts and technologies has made professionals involved in the construction industry familiar with various technologies, including building information modeling. However, there is still a long way to go to fully understand and utilize this process and related technologies. One of the tangible benefits of building-information modeling that some employers have experienced is the observation of a three-dimensional design model using virtual reality technologies. This has caused the various stakeholders of the project to have a better understanding of what is to be built before implementing the design and to announce the necessary changes to the design and construction department if necessary (Hirani and Patel, 2020).

1.1 Application of virtual reality in the construction industry

In 1996, Bushlagm et al. addressed the use of virtual reality in the UK construction industry and showed that this technology could be useful in both design and construction. In the design section landscaping, fire risk assessment, lighting design, interior design, and space modeling were areas to use VR. The VR technology in construction can be used to evaluate construction scenarios, planning and monitoring, and site planning and equipment (Thabet et al., 2002). Studies have shown that in the manufacturing industry, engineers tend to use virtual reality more to identify and understand engineering problems in large and complex projects and review the design (Goulding et al., 2014). In recent years, virtual and augmented reality technologies have taken their place in various industries such as computer games, education, medicine, and tourism. Rapid advances, especially in smartphones, have made these technologies cheaper, more pervasive, and usable in other industries (Hirani and Patel, 2020). The medical community strives to improve the health and protection of human lives. It has gained significant success in using this technology to train novice physicians in high-risk situations (Dawood, 2009). Virtual reality and related technologies have also been used in other industries to assist in designing, developing, and evaluating before the construction of costly physical samples (Thabet et al., 2002). In the construction industry, VR tools were first used in the design department (Kalhoub and Ayre, 2018). Wang et al., For example, believed that virtual environments enable designers to more easily articulate and evaluate what they have in mind. These technologies also increased interaction between the design team (Wang et al., 2018). Chen and Schneibel addressed the issue of "lost spaces" and showed that there were spaces in design as hidden spaces that allow virtual reality to explore, and thus architects can use those spaces better in their design (Chen and Schneibel, 2009). Recently, research has been conducted on the design of prototypes and architectural models in the virtual reality environment. Cassis et al. developed a floating environment for conceptual design modeling in which designers were able to edit three-dimensional models in a stereoscopic environment using body movements. In this environment, there were two communication spaces, one on a multi-touch screen and the other at the top, where users could select various tools and modeling techniques in this environment and use it to edit the model (De Araujo et al., 2013). In a study, Jackson and Keefe used a lift-off interface that allowed the user to create their own 3D models in a controlled, hand-crafted style over reference images. In this model, after the initial design, it was entered as images in the virtual reality environment, and then two-dimensional curves were extracted from images with image processing algorithms (Jackson and Kiev, 2016). In interaction with the virtual reality environment, the user could select these curves in space and give them a third dimension to create a three-dimensional curved network whose surfaces were designed to build a three-dimensional model. This interface is due to the use of the CAVE environment (a floating virtual reality environment in which projectors were placed between three to six cubic walls the size of a room) (Cruz-Neira et al., 1992). With four walls, it placed limitations on designers compared to the virtual reality open environment that used head-mounted devices (HDM). Clerk et al. also developed a virtual reality-based system for creating prototype architectures using the Minecraft idea to create digital environments. The system made designers tired for a long time (Clerk et al., 2019).

Comparing traditional non-floating and fully floating virtual reality architectural design platforms, Piez et al. presented research with quantitative criteria and statistical analysis based on participants' performance. This study showed that the use of a floating environment caused the user to provide a better understanding of space. Also, the floating environment increased the accuracy of estimating distances in users. But a better understanding of the spatial arrangement in the floating virtual model had no effect on improving the understanding of architectural design and its optimal design. This study also showed that a better understanding of the spatial arrangement of the virtual reality environment is directly related to age and education (Paes et al., 2017). Virtual reality and augmented reality are used in various areas of safety management, including safety planning, safety training, and safety inspection (Du et al., 2018).

Recently, most studies on the applications of augmented reality and virtual reality in construction safety have been conducted in the areas of hazard identification, safety training and practice, and safety inspection (Syamimi et al., 2020). The purpose of identifying risks is to analyze and extract potential hazards during construction (Du et al., 2018). Traditional desktop-focused risk identification methods and common sources in maps, accident cases, and exploratory knowledge are used to provide prevention of potential safety hazards through project meetings (Rankohi and Vogue, 2012). Using this approach to understand the danger for people involved in the construction process is difficult in the real-world situations. Modeling and visualizing in virtual reality environments enhance people's experiences and predict how they interact in real-world situations. To this end, various studies are conducted on the development of risk identification systems based on three-dimensional visualization and virtual and augmented reality systems. These inlcude design systems for safety processes (Hadicosumo and Rawlinson, 2002), augmented virtual systems (Ge, L., & Kuester, 2014), peripheral systems virtual automatic caves (Perlman et al., 2014), and display-based safety management systems (Park and Kim, 2013) (Li et al., 2018). The results of these studies show that most users in the virtual environment have assessed a higher level of risk and identified more risks than those who see photos and read documents. In addition, virtual reality systems can receive rapid feedback to understand the performance of individuals in risk identification (Liu et al., 2020). In the field of safety education, virtual reality and augmented reality provide new opportunities for effective training and practice for individuals and students with a higher level of knowledge and less risk (Liu et al., 2020). The use of these technologies as a complement to digital modeling can lead to better communication in the training of construction safety training professionals and increase student safety awareness (Liu et al., 2020). Lee et al. Showed that VR and AR increase students' interest in learning, improve their level of safety knowledge, and help develop realistic behaviors in safety training games.

Another application of virtual reality is safety inspection and building safety assessment (Li et al., 2018). Kamat and Al-Tawil discussed the identification of earthquake damage and the differences that occurred after the earthquake by adding previously-stored building information to the actual structure by augmented reality. For building fires, the time spent evacuating is a determining factor in rescuing people. Virtual reality-based emergency evacuation simulation and a navigation method can be a convenient approach to construction safety guidelines to shorten emergency evacuation time (Salem et al., 2020).

Another application of virtual reality technology in the manufacturing industry is project control and defect management. Many existing fault management systems, such as PDAs, RFIDs, and laser scanners, have responsive performance, meaning that they operate after the appearance of defects. The use of building information modeling technologies can lead to the development of dynamic, automated pre-fault inspection systems. Faults and errors inevitably and frequently occur in the construction process, increasing construction time and project costs. On the other hand, the responsiveness of many existing systems has made the project control and inspection process time-consuming, so project managers have to spend a lot of time controlling, and monitoring. The loss of shop plan information is another part of the problem. Re-entering this information into the systems is a process that requires a lot of time and effort. Thus, due to the existing problems, an automated system using building information model and augmented reality technologies and virtual reality along with image-matching technology can be effective in speeding up the process of identifying defects (Rakhsari-Talmi et al., 2020). Studies on some of these systems have shown that the proposed systems can be very useful in saving time and also reduce the cost of reprocessing (George et al., 2017).

Virtual reality and augmented reality applications are not limited to the construction sector. Other studies on augmented reality applications in the manufacturing industry include research by Zhou et al. In this study, Zhou et al. used augmented reality to quickly inspect the displacement of segments in tunnel construction. This technology enabled construction site quality inspectors to retrieve the basic model of virtual quality control built to quality standards and to adapt this model to actual displacements. Therefore, the safety of the structure could be assessed automatically by measuring the difference between the base model and what was built. The results showed that the augmented reality system responded to the accuracy required to inspect the displacement of segments and was suitable for further development in this field. However, this system needed improvements, such as increasing the scope of the tracking system and improving the calibration system. Since the size of the segments varied in different tunnels, an automated method for generating VRML files from building information model objects needed to be designed (Du et al., 2018).

In addition, virtual reality and augmented reality technology have rapidly found their ways into the training industry. The advantage of using these technologies in education is that people can react and react to the three-dimensional environment, and the virtual environment helps them to learn and understand visually. Individuals' minds become located (Haggard, 2017).

Virtual reality-related technologies in training in the manufacturing industry can be divided into five main types. Desktop-based virtual reality, floating virtual reality, 3D reality based on 3D games, virtual reality-based on building information models, and augmented reality. This division is based on both media presentation and platform. Desktop-based virtual reality is the most common type of technology in manufacturing education. In this type of technology, only one monitor without any tracking equipment is used to communicate with the virtual 3D environment. Some of the most popular of these types of training systems in the manufacturing industry are V-REALISM for engineering maintenance training and the Interactive Construction Management Learning System (ICMLS) developed by Sunny et al. (Wang et al., 2018). Sax et al. used a Powerwall (a large, high-resolution screen made from a matrix of other displays) to create a floating three-dimensional virtual reality environment for safety training purposes. The Powerwall consisted of three projector screens at the rear, an open configuration of a three-way CAVE that uses stereo 3D imaging with a pair of glasses. The trainees used an XBOX head tracking and control system that used eight cameras mounted on the screens. The results showed that VR-based training was effective in improving participants' concentration and perception of measuring environmental control. In this study, sixty-six people participated in construction safety training. Participants' safety knowledge and skills were evaluated before the test, immediately after the test, and one month after the test. Half of the participants were traditionally trained in the classroom with photos and videos, and the other half were mentioned in the floating virtual reality environment. Measuring general safety knowledge did not show significant difference (Hirani and Patel, 2020).

2. Research Approach

First, by studying and interviewing virtual reality experts, a list of advantages and challenges of using virtual reality in construction projects was prepared. Challenges were categorized into five categories and advantages into four categories. Then, this list was placed in the form of a questionnaire and was given to 57 experts in this field. They scored the challenges and advantages and based on the scores, the most important ones in each section were identified .

3. Results and Discussions

3.1 Challenges

Initially, 21 challenges were identified for the application of virtual reality in construction projects, which were divided into the following five categories. Table 1 shows the challenges associated with each category:

Table 1. Challenges of Virtual Reality Application in Construction Projects

	Categories	Challenges
1	Financing and costs	Support costs (network, data management, etc.)
		Software and hardware costs
		High cost for evaluation and implementation (Upgrading software-hardware - account preparation)
		Costs of learning and training to employees
		Initial costs, financing, and investment in this field
		Cost for consumers, companies, and organizations
		High cost of compensation in the event of a technology failure
2	Hardware	Hardware dependency
		Easier and more intuitive experiences provided by other software
3	Organizational Culture	Lack of trust and resistance to change
		High competition of startups
		Consumers and businesses are reluctant to use new technology such as VR
4	Rules and Regulations	Failure to disclose information and strengthen data security measures to reduce the risk of breach or hacking
		Legal rules and privileges
5	Knowledge and expertise	User experience (in terms of hardware and software)
		Insufficient knowledge and information in the field of virtual reality
		Lack of sufficient experts in this field

These challenges were then scored in terms of importance by 57 experts in the field of virtual reality, the average of which factor is provided in Figure 1.

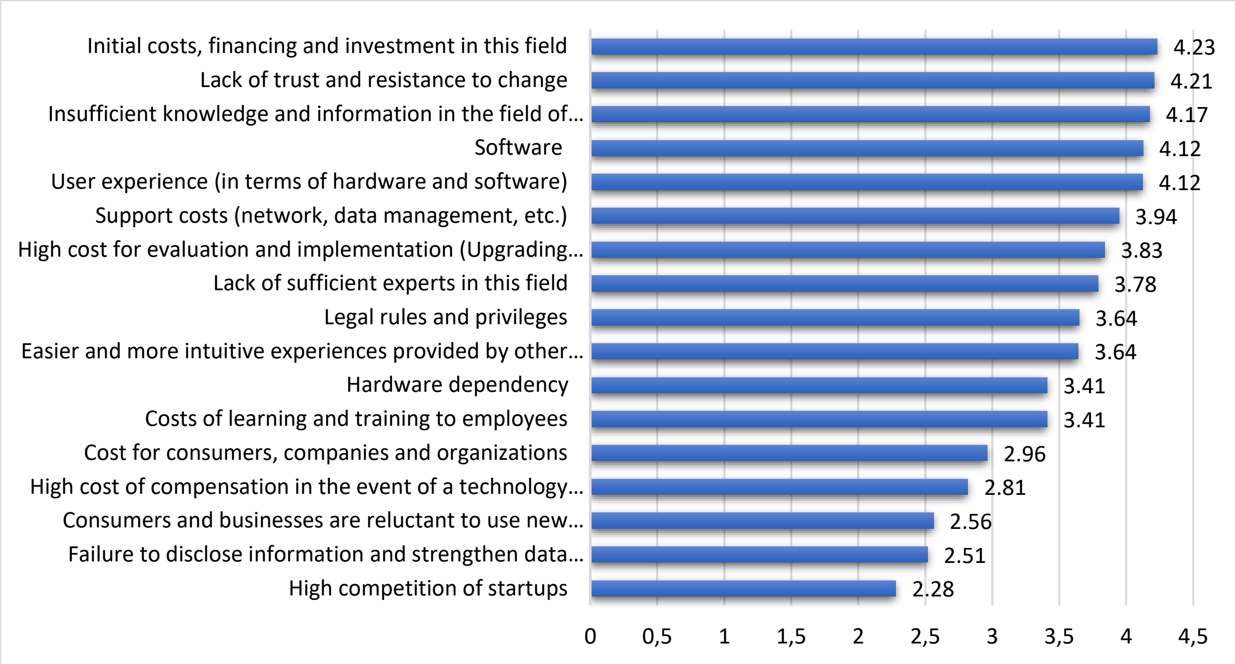

Fig. 1. Average Scores of Virtual Reality Application Challenges in Construction Projects

Also, according to the results, the most important challenges in each category are provided in Figure 2.

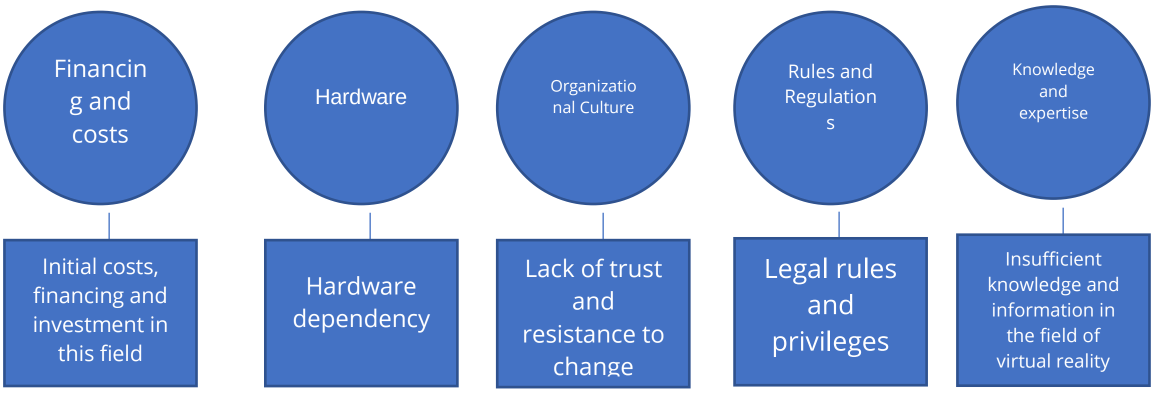

Fig. 2. The most important challenges of using virtual reality in construction projects in each category

3.2 Benefits

Initially, 23 advantages were identified for the use of virtual reality in construction projects, which were divided into the following four categories. Table 2 shows the advantages associated with each category:

Table 2. Benefits of using virtual reality in construction projects categorization

	Categories	Benefits
1	Project quality	Reduce rework Increase build safety Reduce project construction time Improving the final quality of the project Reduce construction and operating costs Ability to integrate systems Easy access to the model Ability to create more appropriate planning before starting work Increase the quality of decision making
2	Technology	Improved 3D design The flexibility of the visualization system Increase the level of confidence about the future of new technologies Increase the effectiveness of systems in the construction industry
3	Organizational Culture	Information sharing Improve information management Participate in achieving goals in the software environment Increase communication and development of information Improve the quality of information retention Possibility to create telecommuting (values participation and distance learning) Reduce the need to refer to paper manuals Increase coordination between employees while doing work
4	Knowledge and expertise	Increase the level of education and knowledge in the field of AR / VR Increasing experience and expertise in this field (gaining experience in related programs and software)

These advantages were then scored in terms of importance by experts in the field of virtual reality, and the average of each factor is shown in Figure 3.

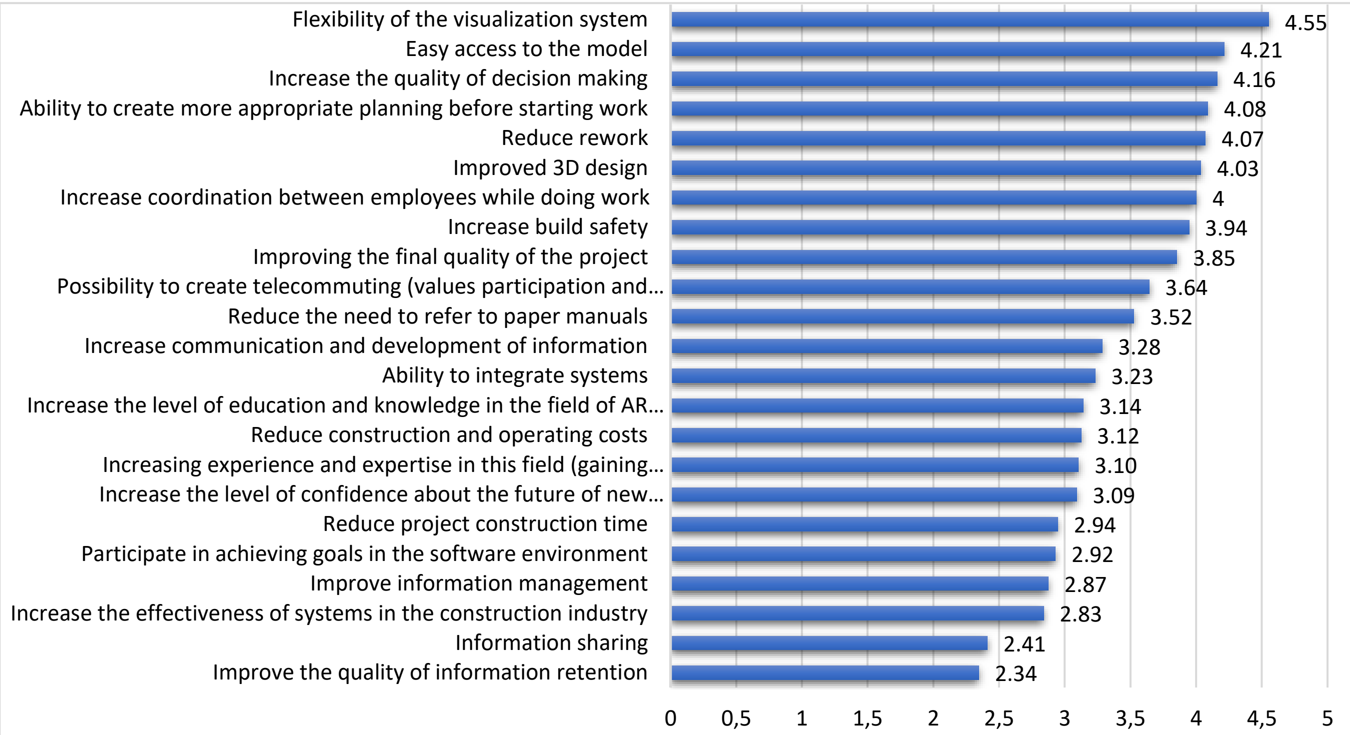

Fig. 3. Average Scores of Virtual Reality Application benefits in Construction Projects

Also, according to the results, the most important advantages are depicted in Figure 4.

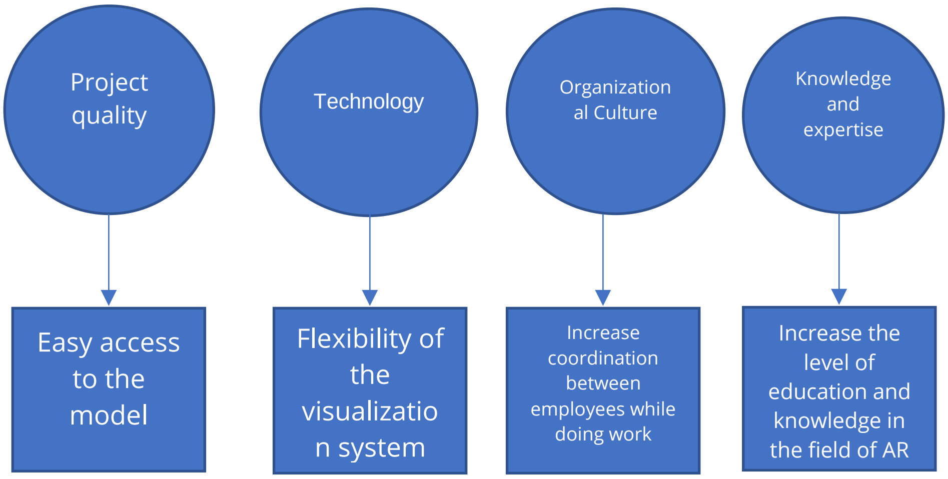

Fig. 4. The most important benefits of using virtual reality in construction projects in each category

4. Conclusion

In this study, the challenges and benefits of using virtual reality in construction projects were examined. Initially, 21 challenges and 23 advantages were identified through study and interviews with virtual reality experts.

Challenges were divided into the following five categories:

- Financing and costs
- Hardware
- Organizational culture
- Rules and regulations
- Knowledge and expertise

Advantages were also categorized into the following five categories:

- Project quality
- Technology
- Organizational culture
- Increase the level of education and knowledge in the field of AR / VR

These challenges and benefits were then placed in the form of a questionnaire and given to virtual reality experts so that they could score on these challenges and benefits. In this way, the most important advantages and the challenges were identified based on the order of the average points they gained. The most important challenges in the application of virtual reality in construction projects included initial costs, financing, and investment in this field, lack of trust and resistance to change, and insufficient knowledge and information in the field of virtual reality. Also, the most important benefits of using virtual reality in construction projects included the flexibility of the visualization system, easy access to the model, and an increase in the quality of decision making

References

[1] Hirani, M. D., & Patel, A. S. (2020). Issues and Future of Virtual Reality in Construction Project and Management.

[2] Thabet, W., Shiratuddin, M. F., & Bowman, D. (2002). Virtual reality in construction: a review. Engineering computational technology, 25-52.

[3] Goulding, J. S., Rahimian, F. P., & Wang, X. (2014). Virtual reality-based cloud BIM platform for integrated AEC projects. Journal of Information Technology in Construction, 19, 308-325.

[4] Dawood, N., Marasini, R., & Dean, J. (2009). 19 VR–Roadmap: A vision for 2030 in the built environment. Virtual Futures for Design, Construction and Procurement, 261.

[5] Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. International journal of environmental research and public health, 15(6), 1204.

[6] Chen, I. R., & Schnabel, M. A. (2009). Retrieving lost space with tangible augmented reality.

[7] De Araújo, B. R., Casiez, G., Jorge, J. A., & Hachet, M. (2013). Mockup builder: 3d modeling on and above the surface. Computers & Graphics, 37(3), 165-178.

[8] Jackson, B., & Keefe, D. F. (2016). Lift-off: Using reference imagery and freehand sketching to create 3d mode.

[9] Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. Communications of the ACM, 35(6), 64-73.

[10] Klerk, R., Duarte, A. M., Medeiros, D. P., Duarte, J. P., Jorge, J., & Lopes, D. S. (2019). Usability studies on building early stage architectural models in virtual reality. Automation in Construction, 103, 104-116.

[11] Paes, D., Arantes, E., & Irizarry, J. (2017). Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems. automation in Construction, 84, 292- 303.

[12] Du, J., Zou, Z., Shi, Y., & Zhao, D. (2018). Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making. Automation in Construction, 85, 51-64.

[13] Syamimi, A., Gong, Y., & Liew, R. (2020). VR industrial applications—A singapore perspective. *Virtual Reality & Intelligent Hardware*, *2*(5), 409-420.

[14] Rankohi, S., & Waugh, L. M. (2012). VIRTUAL REALITY IN THE AEC INDUSTRY: A LITERATURE REVIEW1. CONVR 2014, 89.

[15] Hadikusumo, B. H. W., & Rowlinson, S. (2002). Integration of virtually real construction model and design-for-safety-process database. Automation in Construction, 11(5), 501-509.

[16] Ge, L., & Kuester, F. (2014). Integrative simulation environment for conceptual structural analysis. Journal of Computing in Civil Engineering, 29(4), B4014004.

[17] Perlman, A., Sacks, R., & Barak, R. (2014). Hazard recognition and risk perception in construction. Safety science, 64, 22-31.

[18] Park, C. S., & Kim, H. J. (2013). A framework for construction safety management and visualization system. Automation in Construction, 33, 95-103.

[19] Li, X., Yi, W., Chi, H. L., Wang, X., & Chan, A. P. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. Automation in Construction, 86, 150-162.

[20] Liu, Y., Castronovo, F., Messner, J., & Leicht, R. (2020). Evaluating the impact of virtual reality on design review meetings. Journal of Computing in Civil Engineering, 34(1), 04019045.

[21] Salem, O., Samuel, I. J., & He, S. (2020). BIM and VR/AR Technologies: from Project Development to Lifecycle Asset Management.

[22] Rokhsaritalemi, S., Sadeghi-Niaraki, A., & Choi, S. M. (2020). A review on mixed reality: Current trends, challenges and prospects. Applied Sciences, 10(2), 636.

[23] George, B. H., Sleipness, O. R., & Quebbeman, A. (2017). Using virtual reality as a design input: Impacts on collaboration in a university design studio setting. Journal of Digital Landscape Architecture, 2, 252-259.

[24] Haggard, K. E. (2017). Case Study on Virtual Reality in Construction.

[25] Wang, X. (2007). Mutually augmented virtual environments for architectural design and collaboration. In Computer-Aided Architectural Design Futures (CAADFutures) 2007 (pp. 17-29). Springer, Dordrecht.

[26] Hirani, M. D., & Patel, A. S. (2020). Issues and Future of Virtual Reality in Construction Project and Management.