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# Swot Analysis of Virtual Reality Application in Architecture and Construction

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**Abstract:** Virtual reality has become more and more recognized and applied in architecture and construction during the past decade. Its ability to create simulated 3-dimensional environments significantly facilitates design, construction and construction management. Despite its numerous advantages, VR faces a number of challenges that limit the integration of VR technology into the architecture and construction sector. Issues such as motion sickness, high investment costs and difficulty of use significantly hinder the adoption of VR technology in this industry. The aim of this study is to explore in detail the advantages and challenges of applying virtual reality in the field of architecture and construction through six typical use cases: Stakeholder engagement, design support, design review, construction support, management and marketing and education and training. Each of these categories is treated in detail through the relevant scientific literature, in order to highlight specific examples of use and to identify challenges. A total of 39 articles from the "Google Scholar" were reviewed. Through the review of scientific papers, the various implications of the virtual reality application in architecture and construction were clearly formed and these implications were systematically analyzed through SWOT analysis. In order to achieve a wider adoption of VR technology in the field of architecture and construction, it is necessary to implement research programs aimed at overcoming the numerous challenges that this technology faces. Therefore, the purpose of this study is to identify and highlight obstacles so that they can be solved through research programs, in order to facilitate the adoption of VR technology in the AEC sector.

**Keywords:** Virtual Reality, Architecture, Construction, Swot, VR Systems

## Introduction

Virtual reality opens unexplored horizons in the field of architecture and construction, transforming aspects that seemed unattainable before its development. Its ability to shape every phase of the process, from initial design to final construction, is extremely significant. VR enables the recognition of errors at an early stage of design and the resolution of issues with construction and usability. Virtual presentations allow potential buyers to walk virtually through the object on a real scale.

This gives them a sense of real experience and provides a better understanding of the property, compared to traditional presentation methods, such as blueprints, photos, or videos. According to JMD Delagode and colleagues (2020), we distinguish six key categories of application of VR technology in the fields of architecture, engineering and construction. Those categories are:

1) The involvement of stakeholders becomes a powerful marketing tool for attracting potential clients and enables interactive communication with all participants in the design and construction process
2) Design support-VR enables architectural engineers, in the early stages of design, to evaluate their design decisions in order to achieve optimal results
3) Design participants in the design process can use VR to review their creations on a real scale, facilitating the development of alternative design solutions AND avoiding possible mistakes
4) Support during construction technology facilitates the planning and supervision of construction, ensures

the safety of the structure and provides practical support for construction works in risky environments
5) Management and marketing with the help of VR technology, remote management of objects within an immersive environment is possible, improving cooperation between field and office workers
6) Education and training technology provides realistic simulations that enable users to acquire knowledge and skills through practical activities, replacing traditional learning from books. The aim of this study is to investigate in detail the advantages and identify the challenges of applying virtual reality in the field of architecture and construction, using the relevant scientific literature that includes six key application categories (Delgado *et al*., 2020)

## Related Work

Six scientific papers were analyzed in this chapter, each of them focusing on one of the key categories of the application of Virtual Reality (VR) in architecture and construction. The main goal of the analysis was to investigate the potential and effectiveness of VR technology in each of the mentioned application categories and also to study the challenges that occur in the case of using it in these sectors.

### Involvement of Stakeholders

Juan *et al*. (2018) examine VR technology's application in pre-sale housing. They aim to develop a navigation system that allows potential buyers to virtually explore properties in the design phase. In an experiment with 30 participants, VR presentations were compared to traditional 2D drawings and visualizations. Results indicate VR provides more detailed property information, improving users' attitudes and intentions toward VR technology. Participants favored VR for its immersive experience but noted room for improvement in system usability and comfort. This indicates the need for further research and development of VR technology to ensure the best possible user experience. The study predicts increased VR usage in pre-sale housing, revolutionizing property presentation and sales methods (Juan *et al*., 2018).

### Design Support

Gomez-Tone *et al*. (2022) Assess Immersive Virtual Reality (IVR) in enhancing first-year architecture students' competencies. The study involves 12 students from the National University of San Augustin, Peru, exploring IVR's benefits and challenges in architectural design workshops. IVR aids spatial understanding and compositional skills, but issues like limited software familiarity and discomfort persist. The quantitative evaluation of the research shows that the use of IVR led to better results compared to the traditional design, especially in the evaluation of the quality of the space and the graphic representation of the design. The authors of this study conclude that IVR is a useful tool during all design phases. Despite drawbacks, IVR shows promise for improving architectural design efficiency (Gomez-Tone *et al*., 2022)

### Design Review

This study (Zaker and Coloma, 2018) examines the use of Virtual Reality (VR) for design review, collaboration and communication in BIM-supported projects. Through a real project case study, experts from construction, architecture and engineering collaborated with a software company to explore VR software features, including on-site project simulation. BIM models of the campus general building were created in Revit and transferred to the VR platform fuzor. Participants, equipped with HTC Vive devices and high-performance computers, reviewed models and assessed hardware and software correctness. VR sessions focused on examining MEP systems and architectural design, providing participants with enhanced spatial understanding compared to traditional methods. After the completion of the VR experiment, the authors of this study interviewed the participants via an online questionnaire. Participants were impressed by the immersive VR experience and recognized its potential for daily use, especially for client presentations and team collaborations. The main barrier to VR adoption in the AEC sector was software and hardware costs, while some participants highlighted staff and company resistance to change as an additional challenge. Participants also expressed interest in more advanced features such as simulation of building behavior in different conditions, which would further enrich the experience of using VR in the AEC sector. The conclusion of this research highlights the importance of VR technology in BIM collaboration processes in the Architecture, Engineering and Construction (AEC) sector. VR enables better visualization of 3D models, error detection and effective communication between project stakeholders. However, existing tools are not always suitable due to slow performance and model privacy issues. Also, the authors pointed out that investing in VR software and hardware is essential, but costs are an obstacle. Future works should improve the software for better performance and educate professionals about the potential of VR (Zaker and Coloma, 2018)

### Support During Construction

Researcher Dergi (2020) examines how VR technology improves site organization, contrasts 3D VR planning with conventional methods for a Cyprus university project and consults 102 experts. At the end of the comparison, the authors of this study pointed out that traditional 2D methods are quicker and easier to understand. They find that while 2D plans are inadequate, 3D plans offer advantages. Participants rate VR as challenging but recognize its potential for identifying construction issues. VR aids managers in visualizing site plans, pinpointing issues like crane collisions and improving productivity and risk management. The authors noted that the continuation of this research will focus on testing the various available VR technologies for construction site planning (Muhammad *et al*., 2019)

### *Management and Marketing*

Lorusso *et al*. (2022) explore virtual reality's role in simulating fire evacuations in school buildings, emphasizing its importance alongside numerical simulations and agent-based models. They integrate a VR platform with numerical simulation tools to replicate a fire evacuation scenario in a two-story school building near Milan, Italy. The simulation focuses on the main block with classrooms and considers life-risk profiles using a fire prevention algorithm. Four scenarios with different ignition points are analyzed to ensure redundancy according to the fire prevention code. The authors of this study presented VR as a useful tool for simulating and experiencing, from the first person, emergency fire situations (Lorusso *et al*., 2022).

### *Education and Training*

The study of authors (Na *et al*., 2022) The study evaluates the impact of BIM-VR technology on spatial perception skills among civil engineering students. BIM-VR integration into construction projects led to a significant 17% improvement in spatial perception skills, as measured by a roof plan drawing test. A survey revealed positive student perspectives and increased interest in BIM technology for future careers. However, the study's limitation of a small sample size (33 students) suggests the need for further investigation into BIM-VR's impact on skill development. (Na *et al*., 2022).

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## Materials and Methods

In this manuscript, we undertake a comprehensive analysis of extant research to distill and synthesize key findings and identify common themes within the domain. To facilitate a structured presentation of data, we have developed Tables 1-2, both of which are included in Appendix A. Table 1 provides a detailed overview of the application of Virtual Reality (VR) technologies in the fields of architecture and construction, highlighting practical use cases. Conversely, Table 2 delineates the challenges associated with the application of VR in these sectors.

These tables are instrumental in illustrating the principal components extracted from recent scholarly literature and offer a clear reference point for further academic inquiry. An explanation of the basic categories from Tables 1-2 is provided:

1. Stakeholder engagement: VR revolutionizes real estate marketing by providing realistic representations of unbuilt properties, surpassing traditional 2D and 3D visualizations. Multi-user VR platforms facilitate interactive communication among stakeholders throughout the design and construction process. Delgado *et al*. (2020); Juan *et al*. (2018) Multi-user VR platforms enable interactive communication in the design and construction process, as well as automatic updating of BIM models on VR glasses (Grudzewski *et al*., 2018) by applying VR to the CAD interface, creation becomes more intuitive and visualization becomes natural (Kini and Sunil, 2019)
2. Design support: VR technology can support architectural engineers in the early stages of building design to assess their design decisions and thereby improve the outcome (Delgado *et al*., 2020; Gomez-Tone *et al*., 2022) The VR system can be applied to visualize different types of sustainable construction techniques which are proposed to rural communities (Roach and Demirkiran, 2017) The VR system can be used for urban planning, which contributes to the creation of sustainable and functional cities (Nguyen *et al*., 2016)
3. Design review: With the help of VR technology, design analysis becomes more efficient as participants can review their design in virtual reality at a real scale and identify possible issues to address more easily. Delgado *et al*. (2020); Juan *et al*. (2018); Gomez-Tone *et al*. (2022); Zaker and Coloma (2018) Additionally, VR technology enables the development of alternative designs in the early stages of building design, avoiding potential errors and enabling better planning (Berg and Vance, 2017). The use of VR technology affects a better understanding of spatial relationships and also

encourages participants to actively participate in discussions and decision-making (Boton, 2018)

4. Construction support: The application of VR technology in construction can be grouped into four areas: Construction planning, construction monitoring, construction safety and operational support (Delgado *et al*., 2020) Construction planning the primary goal is to anticipate potential issues and improve the construction process (Delgado *et al*., 2020; Muhammad *et al*., 2019; Nguyen *et al*., 2016). With the help of BIM-VR technology, the cost sheet is updated in real-time, in accordance with the changes made by the user (Davidson *et al*., 2020)
5. Construction monitoring the progress of building construction in a virtual environment enables faster and more precise identification of possible delays in the project, which is crucial for completing the work within the specified time frames. Delgado *et al*. (2020). The VR system enables the monitoring of construction progress, using BIM data and real images from the construction site (Rahimian *et al*., 2020). Safety in construction technology helps to ensure construction safety through effective on-site safety education. It allows workers to experience simulated accident scenarios, enhancing awareness and proper procedure comprehension (Delgado *et al*., 2020). The main applications in this domain include hazard identification, safety training and education and safety inspection and guidelines (Li *et al*., 2018)
6. Application of VR technology in simulations of high-risk work situations to assess participants' reactions to different safety learning methods (Shi *et al*., 2019). Operational support-VR mainly focuses on the teleoperation of construction equipment so that, for example, construction machinery operators can control equipment from a safe and remote environment (Delgado *et al*., 2020; Tang *et al*., 2010; Kamezaki *et al*., 2013)
7. Management and marketing: In facility management, VR technology enables remote exploration and supervision of buildings by field workers (Delgado *et al*., 2020; El Ammari and Hammad, 2019; Carreira *et al*., 2018) It allows experts and staff to simulate evacuation strategies and assess exit effectiveness for emergency preparedness (Lorusso *et al*., 2022). The application of VR technology for facility management support enables better visualization of maintenance scheduling decisions and improved maintenance resource scheduling (Jiang *et al*., 2017)
8. Training and education: VR technology has significant potential in the field of training and education because it enables practical experience in controlled virtual environments. One of the key advantages of VR technology in this area is the reduction of training costs. Through VR simulations, users can train and acquire skills without the need for expensive real resources or equipment. Delgado *et al*. (2020) VR can help students to understand complex static structures in civil engineering (Fogarty *et al*., 2018) VR technology can positively influence student motivation and improve understanding of spatial concepts (Na *et al*., 2022; Wang *et al*., 2018) VR can reduce travel costs associated with training because users can access virtual lessons and education from any location (Sopher *et al*., 2022)

## Results and Discussion

In this study, 35 articles related to the application of VR technology in architecture and construction were reviewed. Articles are classified according to their primary application in the AEC industry: Stakeholder engagement, design support, design review, construction support, management and marketing and education and training.

Advantages: From the analysis of the mentioned scientific papers, we can conclude that Virtual Reality (VR) plays an increasingly important role in the field of architecture and construction. VR technology has significant potential for improving the way real estate is presented and sold, especially in the context of pre-sale apartments (Roach and Demirkiran, 2017). It can assist architectural engineers in the early stages of design in making design decisions (Gomez-Tone *et al*., 2022). The application of VR technology affects a better understanding of spatial relationships and encourages participants to actively participate and make better decisions (Zaker and Coloma, 2018). When planning and monitoring construction, the main goal is to predict possible problems and improve the construction process itself and VR technology can help us in this. Gomez-Tone *et al*. (2022); Nguyen *et al*. (2016) VR technology helps to ensure safety in construction through hazard identification and effective safety training and education (Li *et al*., 2018). By applying construction robots equipped with a VR system, it is possible to work in dangerous places. Tang *et al*. (2010); Kamezaki *et al*. (2013) VR technology has a positive effect on students' motivation, can help them understand complex static constructions and generally improve their understanding of spatial relationships (Na *et al*., 2022; Fogarty *et al*., 2018; Wang *et al*., 2018)

Limitations and disadvantages: With all its advantages, VR like any other technology has its limitations and disadvantages. To a lot of (users), VR is not easy enough to use and often requires experts (Juan *et al*., 2018; Kini and Sunil, 2019; Khan *et al*., 2021) Due to reduced social interaction, feelings of isolation may occur. (Delgado *et al*., 2020; Khan *et al*., 2021). Many users will not choose VR technology because of the high initial stakes (Delgado *et al*., 2020; Khan *et al*., 2021). After the VR experience, some users may experience nausea, dizziness and disorientation (Juan *et al*., 2018; Zaker and Coloma, 2018; Khan *et al*., 2021).

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The review of scientific research clearly outlines the diverse implications of the application of virtual reality in architecture and construction, which were systematically analyzed through a SWOT analysis. SWOT analysis is a business strategy tool used to assess the competitive position in the market. Combining internal (strengths and weaknesses) and external (threats and opportunities) factors, SWOT analysis provides a comprehensive overview of the company's current situation and helps identify key factors that may impact business success in the future (Teoli and Sanvictores, 2022). The general results of this research are given in an overall SWOT analysis inside Table 3, while each SWOT analysis factor is further described in individual paragraphs. A table of overall SWOT analysis is provided in Appendix A.

### *Strengths*

By reviewing scientific papers, it can be concluded that the application of virtual reality in architecture and construction has numerous strengths:

1. A powerful tool for stakeholder engagement: VR is used as a marketing communication tool to facilitate the presentation of real estate market offers and enable interactive communication with potential clients and stakeholders in the construction process. Delgado *et al.* (2020); Juan *et al.* (2018); Grudzewski *et al.* (2018)
2. Ability to provide project support: VR supports architectural engineers in the early stages of building design, allowing them to assess design decisions and improve final results. It also enables collaborative analysis of construction projects (Juan *et al*., 2018; Gomez-Tone *et al*., 2022; Kini and Sunil, 2019; Oke *et al*., 2023)
3. A powerful tool for design review: Through VR technology, it is possible to review designs on a real scale and develop design alternatives in the early stages of design to avoid potential errors (Delgado *et al*., 2020; Zaker and Coloma, 2018; Roach and Demirkiran, 2017; Safikhani *et al*., 2022)
4. A powerful tool for construction planning: VR technology allows the creation of immersive construction simulations during the planning phase, helping to predict potential issues, reduce risks and delays and optimize the construction process. (Delgado *et al*., 2020, Muhammad *et al*., 2019; Nguyen *et al*., 2016)
5. A powerful tool for construction monitoring: VR has the potential to monitor the progress of building construction in a virtual environment, which can be very useful in ensuring timely delivery of construction materials and reducing the possibility of construction delays (Delgado *et al*., 2020; Nguyen *et al*., 2016)
6. A powerful tool for ensuring safety in construction: VR enables hazard identification, provides safety education and training and is used for safety inspections and instructions, increasing safety at the construction site (Delgado *et al*., 2020; Li *et al*., 2018)
7. Ability to provide operational support: With the help of construction robots equipped with VR systems, it is possible to work in dangerous places, such as disaster sites and extreme environments and on demolition tasks (Delgado *et al*., 2020; Tang *et al*., 2010; Kamezaki *et al*., 2013)
8. Reduced risks and costs: The use of immersive techniques reduces the risk and costs of design and construction through a better understanding of project aspects (Delgado *et al*., 2020; Oke *et al*., 2023; Safikhani *et al*., 2022)
9. Timesaving on travel: Immersive techniques reduce the need for physical travel to present projects (Delgado *et al*., 2020; Tang *et al*., 2010)
10. Social and emotional experience: Immersive techniques create a social and emotional impact that strengthens the connection between project participants (Delgado *et al*., 2020)
11. Better feedback: Immersive techniques provide clients and stakeholders with a real building experience, resulting in more precise and detailed feedback. This improves the quality of design and construction (Delgado *et al*., 2020; Zaker and Coloma, 2018)
12. Knowledge of potential risks: VR enables the identification of potential issues and risks in the design before implementation, reducing the need for later corrections (Delgado *et al*., 2020; Zaker and Coloma, 2018; Berg and Vance, 2017)
13. Increase in worker competencies: VR allows for realistic simulation of different tasks and situations, enhancing the skills and competencies of workers (Delgado *et al*., 2020; Li *et al*., 2018)
14. Remote progress monitoring: Through VR, facility managers can remotely track the progress of construction and maintenance and make informed decisions (Delgado *et al*., 2020; Rahimian *et al*., 2020)

### *Weaknesses*

The application of VR technology in architecture and construction also comes with a number of weaknesses that can hinder the achievement of business goals:

1. Difficulty in use: For many users, the interface of VR technology is not simple enough for independent use and often requires an expert companion (Juan *et al*., 2018; Khan *et al*., 2021)
2. Feeling of isolation: Its use reduces social interaction and can cause a sense of isolation (Delgado *et al*., 2020; Khan *et al*., 2021)
3. High investments: Using VR technology requires equipped space and qualified personnel, resulting in

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high initial investments (Roach and Demirkiran, 2017; Khan *et al*., 2021)
4. Movement restriction: Movement using VR technology is limited to a predefined area (Khan *et al*., 2021)
5. Motion sickness: After a VR experience, some users may experience nausea, dizziness and disorientation (Berg and Vance, 2017; Zaker and Coloma, 2018; Khan *et al*., 2021)
6. Location errors: Improper location registration in virtual space can cause discrepancies between the real and virtual worlds (Khan *et al*., 2021)
7. Content creation difficulties: Creating high-quality virtual content can be challenging and may require specific skills (Delgado *et al*., 2020; Khan *et al*., 2021)
8. Lack of complete hardware equipment: The lack of fully integrated hardware equipment can affect the user experience (Delgado *et al*., 2020; Khan *et al*., 2021)
9. High expertise required: The lack of experts with the necessary qualifications in architecture, construction and VR technology complicates VR content production
10. File size limitations: The file size can prevent the loading of all materials and textures into models (Delgado *et al*., 2020; Zaker and Coloma, 2018; Khan *et al*., 2021)
11. Low resolution: Low resolution can further burden the user experience. (Delgado *et al*., 2020; Berg and Vance, 2017; Khan *et al*., 2021)
12. Short battery life: Insufficient device battery capacity is one of the main limitations of using VR technology in the field (Delgado *et al*., 2020; Khan *et al*., 2021)
13. Internet issues: Internet problems can result in limited movement and image lagging (Delgado *et al*., 2020; Khan *et al*., 2021)

### *Opportunities*

The application of VR technology in architecture and construction brings a range of drawbacks that require research and improvement to increase productivity. By addressing these drawbacks, new opportunities for future application of VR technology in these areas are opened:

1. Device comfort and safety: Current VR devices are not comfortable enough for prolonged use, but it is possible to improve the design through user studies to ensure greater comfort and safety, thereby increasing the time of VR device usage (Khan *et al*., 2021; Kim *et al*., 2022)
2. Ability to perceive space in real scale and proportions: VR technology enables the display of elements of architectural design in real scale and proportions, providing a unique way of spatial perception (Delgado *et al*., 2020; Zaker and Coloma, 2018; Roach and Demirkiran, 2017; Khan *et al*., 2021)
3. The ability for multiple users and devices: Multi-user immersive experiences allow better collaboration on the same model and shorten the time needed to identify anomalies and take effective actions. Delgado *et al*. (2020); Zaker and Coloma (2018); Grudzewski *et al*. (2018); Khan *et al*. (2021)
4. Long battery life: By solving battery capacity issues on VR devices, it is possible to perform more tasks in the field (Delgado *et al*., 2020; Khan *et al*., 2021)
5. Wireless technologies: Advancements in wireless technologies enable greater mobility and flexibility for users when using immersive techniques (Delgado *et al*., 2020; Khan *et al*., 2021)
6. Increased productivity: Immersive techniques can enhance productivity and efficiency in the processes of design, analysis and planning, leading to reduced time and resources. Kini and Sunil (2019); Roach and Demirkiran (2017); Nguyen *et al*. (2016); Berg and Vance (2017)
7. Enhancement of company reputation: The use of immersive techniques can improve the company's reputation as technologically advanced and innovative (Khan *et al*., 2021)
8. Spatial understanding: Immersive techniques provide users with a better understanding of spatial relationships and dimensions, facilitating informed decision-making. Zaker and Coloma (2018); Kini and Sunil (2019); Roach and Demirkiran (2017)
9. Business growth: Immersive techniques can stimulate business growth through better communication, increased engagement and attracting new clients (Khan *et al*., 2021)
10. Archiving VR content and experiences: Developing methods for recording and archiving user experiences enables sharing these experiences with other users and provides potential for learning and teaching (Delgado *et al*., 2020; Khan *et al*., 2021)
11. Integration of computer vision: Combining immersive techniques with computer vision allows for more precise monitoring and analysis of construction sites (Khan *et al*., 2021)
12. Integration of artificial intelligence: Integrating AI enhances data understanding and analysis, improving progress tracking and risk management (Khan *et al*., 2021)
13. Drone technology integration: Integrating drones with immersive techniques facilitates monitoring and analyzing construction sites from the air (Khan *et al*., 2021)
14. Motivation of new students: Introducing immersive techniques into the educational system attracts new students and stimulates their interest (Delgado *et al*., 2020; Li *et al*., 2018; Safikhani *et al*., 2022)
15. Learning through practical experience: Immersive techniques allow users to learn through practical experience, enhancing understanding and knowledge exchange (Na *et al*., 2022; Li *et al*., 2018; Safikhani *et al*., 2022)

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### *Threats*

Threats, or potential dangers of implementation, are as follows:

1. Content security and privacy: The use of VR technology may expose user data to cyber-attacks, with the possibility of stealing sensitive information about projects and designs (Khan *et al*., 2021; Kürtünlüoğlu *et al*., 2022)
2. Capital risk: Implementing immersive techniques entails financial risk in investing in a complex hardware and software infrastructure (Afolabi *et al*., 2022)
3. Licensing obligations: Introducing immersive techniques may require software and technology licensing, resulting in additional costs and restrictions (Khan *et al*., 2021)
4. Harmful health effects: Prolonged use of VR devices can cause potential health issues such as vision problems and nausea for some users (Delgado *et al*., 2020; Khan *et al*., 2021)
5. Rapid technological change: The rapid evolution of VR technology can lead to quick obsolescence of existing technology and the need for frequent upgrades (Delgado *et al*., 2020; Khan *et al*., 2021)
6. Intellectual property: Virtual models and designs may be sensitive to intellectual property infringement and unauthorized use (Khan *et al*., 2021)
7. Technical issues: Immersive techniques can become obsolete or less effective compared to new technologies (Vlahovic *et al*., 2022; Khan *et al*., 2021)
8. High costs of robotic teleoperation: Although remote work processes related to physical work significantly improve safety in the AEC industry, which often involves dangerous and risky environments, the costs of remote work via VR devices can be significantly high (Kim *et al*., 2022; Kürtünlüoğlu *et al*., 2022; Afolabi *et al*., 2022; Qin *et al*., 2023)
9. Risk of injuries: Immersed in the virtual world, users easily forget the real environment, which can lead to physical injuries (Khan *et al*., 2021; Jones-Dellaportas *et al*., 2023)
10. Job loss: Integrating VR for object management can lead to fear of job loss for people who traditionally performed those tasks (Khan *et al*., 2021)
11. Lack of multimodal senses: VR cannot always convey all the multimodal senses needed to understand the environment (Khan *et al*., 2021; Mills *et al*., 2022)
12. Unforeseen graphic changes: Sudden changes in graphics and visual display can cause disorientation and discomfort (Vlahovic *et al*., 2022)
13. Fragmented content: VR training content can be fragmented and disconnected, making learning and understanding difficult (Khan *et al*., 2021)
14. Lack of sensor inputs: VR may have limited ability to transfer all sensory information from the real construction site to the virtual environment (Khan *et al*., 2021)
15. Increased cognitive load: After a certain period of use, there is an increase in the cognitive load on users or workers, which can be uncomfortable for prolonged use (Vlahovic *et al*., 2022; Khan *et al*., 2021)

## Conclusion

During the last decade, architectural and civil engineers have recognized the potential of virtual reality in the AEC industry. Virtual reality opens up unexplored horizons in the field of architecture and construction, transforming aspects that seemed unattainable before its development. Its ability to shape every phase of the process, from initial design to final construction, is extremely significant. Six typical use cases of VR technology in the fields of architecture and construction make an exceptional contribution to these sectors. Through stakeholder engagement, VR becomes a powerful marketing tool for attracting potential clients and enables interactive communication with all process participants, while through design support, it provides support to architecture engineers in the early stages of design to better assess their design decisions and achieve optimal results. Furthermore, through design review the process participants can use VR to review their creations at a real scale, facilitating the development of alternative design solutions and avoiding possible errors. VR technology also facilitates construction planning and supervision, ensures construction safety and provides practical support for construction work in risky environments. On the other hand, with the help of VR technology, remote management of objects within an immersive environment is possible, improving collaboration between on-site and remote office workers. In today's dynamic business environment, leading architectural and construction companies have recognized the powerful potential offered by virtual reality technology. This technology has become a powerful tool in their business, enabling significant benefits in various aspects of operations. Along with all the advantages, VR has a number of technical limitations and disadvantages. Using VR technology is not intuitive and often requires expert help. High initial costs may also deter potential users from adopting this technology. After a virtual reality experience, some people may experience nausea, dizziness and disorientation, further limiting their enjoyment of VR content.

A review of scientific papers clearly outlines the diverse implications of virtual reality application in architecture and construction, systematically analyzed through a SWOT analysis. This analysis identifies key strengths, weaknesses, opportunities and threats associated with the use of VR technology in these sectors.

Although virtual reality has recently become an important tool for some leading companies in the field of architecture and construction, overall, its acceptance in the Architecture, Engineering and Construction (AEC) sector remains relatively low. The most common use case of this technology is stakeholder engagement, where it is used as a means of communication and interaction with potential clients and participants in the design process. However, there is a significant interest from numerous architectural and construction companies in investing in virtual reality technology. This interest suggests that there is potential for transformation and improvement of various aspects of business in the AEC sector. To achieve broader adoption of VR technology in the field of architecture and construction, additional research programs are necessary. These programs should explore and address the barriers that currently limit the acceptance of VR technology, such as usability challenges, the need for high expertise and technical and operational obstacles. Ultimately, the successful adoption of VR technology in the AEC sector also requires continuous training of staff. Office and field workers need to acquire the necessary skills and knowledge to effectively use this technology. Progress in the acceptance and implementation of virtual reality in architecture and construction will require collaboration, education and further research to realize its full potential.

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## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and that no ethical issues are involved. The authors declare no conflict of interest.

## Author's Contributions

**Genoveva Veble:** Conceptualization, methodology formal analysis, investigation, written original drafted preparation.

**Andrija Bernik:** Written and reviewed and edited, supervised and funded.

**Andrej Čep:** Written reviewed and edited.

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## Appendix

**Table 1:** Application of VR in architecture and construction - examples of use

| | |
|---|---|
| Stakeholder engagement<br>Delgado *et al*. (2020);<br>Juan *et al*. (2018);<br>Grudzewski *et al*. (2018);<br>Kini and Sunil (2019) | Real estate agents use VR for interactive virtual property tours, replacing 2D blueprints Juan and visuals<br>The VR system visualizes sustainable construction techniques in rural poor communities<br>Application of the BVRS multi-user VR platform, which enables all stakeholders in the design and construction process to communicate interactively in a virtual environment |
| Design support<br>Delgado *et al*. (2020);<br>Gomez-Tone *et al*. (2022);<br>Roach and Demirkiran (2017);<br>Nguyen *et al*. (2016) | Using software for 3D modeling with VR support-VR cad<br>Using a VR system for urban planning and object modeling that includes special communication protocols and gesture recognition techniques |
| Design review<br>Delgado *et al*. (2020);<br>Zaker and Coloma (2018);<br>Berg and Vance (2017);<br>Boton (2018) | Using virtual reality as a design tool with a focus on more effective decision making<br>Collaborative analysis when creating a construction project through the VR application BIM 4D<br>Application of VR technology to assess the comfort of different spaces and improve the design and planning of spaces |
| Construction support construction planning<br>Delgado *et al*. (2020);<br>Muhammad *et al*. (2019);<br>Nguyen *et al*. (2016);<br>Davidson *et al*. (2020) | Creation of cost estimates that are updated in real time in accordance with changes in the project<br>Simulation of complex construction works<br>The VR system helps in planning the routes of crane applications during highway construction, thus reducing traffic disruptions |
| Construction support-construction monitoring<br>Delgado *et al*. (2020);<br>Rahimian *et al*. (2020) | Track the progress of building construction in a virtual environment using bim data and real site images |
| Construction support-Constructionsafety<br>Delgado *et al*. (2020);<br>Li *et al*. (2018);<br>Shi *et al*. (2019) | A VR construction safety training system that is more effective than a traditional training system<br>A VR platform that helps assess risk perception and risk behavior of workers |
| Construction support-operational support<br>Delgado *et al*. (2020); | Application of construction robots with an implemented VR system working at disaster sites and extreme environments and on demolition tasks |

**Table 1:** Conutinue

| | |
|---|---|
| Tang *et al*. (2010); Kamezaki *et al*. (2013) | Remote object management using VR technology |
| Management and Marketing | Applying VR technology to simulate disaster scenarios to assess risks in advance and prepare for emergency situations |
| Delgado *et al*. (2020); Lorusso *et al*. (2022); | VR technology assesses building evacuation preparedness during earthquakes by prepare for emergency situations |
| El Ammari and Hammad (2019); Carreira *et al*. (2018); Jiang *et al*. (2017) | VR technology assesses building evacuation preparedness during earthquakes by simulating various scenarios |
| Training and education | Application of VR technology for training and acquisition of crane management skills |
| | VR simulations allow workers to acquire skills in maintenance and repair of construction |
| Delgado *et al*. (2020); | machinery |
| Na *et al*. (2022); Fogarty *et al*. (2018); | Application of VR system for safe training of workers in tasks involving electrical hazards |
| Wang *et al*. (2018); | The VR system helps in understanding the complex operations of bridge construction |
| Sopher *et al*. (2022) | VR technology helps students to understand the complex static constructions of buildings |

**Table 2:** Application of VR in architecture and construction - examples of challenges

| | |
|---|---|
| Stakeholder engagement Delgado *et al*. (2020); | The interface of VR technology is often not easy enough to use, so an expert companion is often needed |
| blueprints Juan *et al*. (2018); | The use of VR technology can cause the user to feel isolated |
| Grudzewski *et al*. (2018); Kini and Sunil (2019) | Difficulties in recording user experiences and discussions within a VR environment |
| Design support | Difficulties in converting VR models to BIM models |
| Delgado *et al*. (2020); | Inability to archive VR projects for later review or analysis |
| Gomez-Tone *et al*. (2022); Roach and Demirkiran (2017); Nguyen *et al*. (2016) | The need for high investment in space and qualified personnel |
| Design review | Difficulties in converting VR models to BIM models |
| Delgado *et al*. (2020); | Inability to archive VR projects for later review or analysis |
| Zaker and Coloma (2018); | Difficulties in recording user experiences and discussions within a VR environment. |
| Berg and Vance (2017); Boton (2018) | The need for high investment in space and qualified personnel |
| Construction support-construction planning Delgado *et al*. (2020); Muhammad *et al*. (2019) | Lack of interoperability between the BIM system and the VR model-loss of information or difficult data transfer from one system to another |
| Nguyen *et al*. (2016); Davidson *et al*. (2020) | Difficulties in automatically updating BIM models |
| Construction support-construction monitoring | Difficulties in managing different data sources and technologies used on the construction site and for visualization in a VR environment |
| Delgado *et al*. (2020); | Lack of integration of data standards |
| Muhammad *et al*. (2019) | Lack of a way to verify and confirm the accuracy of construction progress monitoring for visualization in a VR environment data |
| Construction support-construction safety | Lack of durable VR devices that can withstand harsh construction site conditions and provide a reliable experience for workers |
| Delgado *et al*. (2020); | Lack of interoperability between different systems |
| Davidson *et al*. (2020; | High investment in equipment and training of qualified personnel |
| Rahimian *et al*. (2020) | Lack of security-approved hardware-different certifications and security approvals required |
| Construction support-operational support | Limited internet access-in some remote and isolated areas it can be challenging to provides stable internet access |
| Delgado *et al*. (2020); | Difficulties in archiving output VR formats |
| Tang *et al*. (2010); Kamezaki *et al*. (2013) | VR teleoperation systems can reduce efficiency as operators need more time to perform tasks |
| Management and marketing Delgado *et al*. (2020); Lorusso *et al*. (2022); | Lack of integration with other facility management systems |
| El Ammari and Hammad (2019); Carreira *et al*. (2018); | Difficulties in archiving and analyzing the VR experience |

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**Table 2:** Countinue

| | |
|---|---|
| Jiang *et al*. (2017) | |
| Training and education<br>Delgado *et al*. (2020);<br>Na *et al*. (2022);<br>Fogarty *et al*. (2018);<br>Wang *et al*. (2018);<br>Teoli and Sanvictores (2022) | Lack of experts in the production of VR content-creating quality VR simulations for training requires expertise in the creation and development of VR content<br>Lack of integration with existing qualification standards-integration of VR technology into existing educational institutions can be challenging as it requires alignment with existing training and education programs |

**Table 3:** Table of overall SWOT analysis

| Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|
| A powerful tool for stakeholder engagement | Difficulties in use | Comfort and safety of the device | Content security and privacy |
| The possibility of providing project support | A feeling of isolation | The possibility of seeing the space in real scale and proportions | High costs of robotic telesurgery |
| A powerful design review tool | High investments | Possibility for multiple users and devices | Capital risk |
| A powerful tool for construction planning | Motion sickness | Longer battery life | License obligations |
| A powerful build tracking tool | Location errors | Wireless technologies | Adverse health effects |
| A powerful tool for ensuring safety in construction | Difficulty creating content | Increasing productivity | Rapidly changing technology |
| The possibility of providing operational support | Lack of complete hardware equipment | Improving the company's reputation | Intellectual property |
| Reduced risk and costs | High expertise required | Understanding space | Technical problem |
| Saving travel time | File size limits | Increase in business | Risk of injury |
| Better feedback | Low resolution | Archiving VR content and and experience | Loss of jobs |
| Increasing the competences of worker’s | Poor battery life | Computer vision integration | Lack of multimodal sensations |
| Remote progress check | Internet problems | Integration of artificial intelligence | Unforeseen graphics changes |
| | | Integration of drone technology | Fragmented content |
| | | Motivation of new students | Lack of sensor input |
| | | Learning through practical | Increasing cognitive load experience |