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Virtual Reality in Civil Engineering: A Comprehensive Review of Applications, Challenges, and Future Trends

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Abstract

Virtual reality (VR) technology has gained significant attention in civil engineering, offering immersive and interactive environments that enhance visualization, safety training, and project management. This review paper comprehensively examines the current applications of VR in civil engineering, focusing on construction safety training, design visualization, and stakeholder collaboration. VR's ability to simulate hazardous scenarios allows for effective safety awareness and risk mitigation without real-world exposure. Additionally, the integration of VR with building information modeling (BIM) and other digital tools improves design accuracy and communication across multidisciplinary teams. Despite its benefits, VR adoption faces challenges including hardware limitations, motion sickness, high implementation costs, and user resistance. This paper reviews various technology acceptance models applied to VR, highlighting key factors influencing user adoption in construction settings. Finally, emerging trends such as artificial intelligence integration, real-time sensor data incorporation, and advancements in VR hardware are discussed. This review aims to provide civil engineers, researchers, and practitioners with a comprehensive understanding of VR's transformative potential, current limitations, and future research directions, fostering safer, more efficient, and collaborative civil engineering practices.

Keywords: Virtual reality, civil engineering, building information modeling (BIM), applications

INTRODUCTION

Civil engineering projects encompass a wide range of activities from design and planning to construction and maintenance of infrastructure. These projects are becoming increasingly complex due to advancements in technology, increasing stakeholder demands, and the need for enhanced safety and sustainability. Traditional tools such as two-dimensional (2D) drawings, physical mock-ups, and text-based reports often struggle to convey complex spatial information and dynamic construction processes effectively. In this context, virtual reality (VR) technology has emerged as a promising solution to improve visualization, training, and collaboration in civil engineering.

VR provides a computer-generated 3D environment where users can immerse themselves and interact with digital models of structures or construction sites in real time. The immersive nature of VR allows engineers, project managers, and construction workers to visualize designs, simulate construction sequences, and identify potential safety hazards before they occur in the physical world. This ability is particularly valuable in addressing the high rates of accidents and fatalities commonly observed in the construction industry [1, 2].

Construction safety training is one of the most widely researched applications of VR in civil engineering. Traditional safety training often relies on classroom lectures or PowerPoint presentations,

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which lack engagement and realism [3]. VR-based training immerses users in realistic scenarios where they can experience and react to hazards virtually, enhancing hazard recognition, risk perception, and safety compliance [4, 5]. Studies such as those by Leder et al. [2] and Nykänen et al. [1] provide evidence that VR training can improve learning outcomes and decision-making related to workplace safety.

Beyond safety, VR is used extensively for design visualization and project planning. Civil engineers can navigate immersive building information modeling (BIM) models to review designs, detect clashes, and optimize constructability [6]. This interactive environment facilitates communication among architects, engineers, contractors, and clients, reducing misunderstandings and costly changes during construction [7]. Moreover, VR prototypes have been developed for training workers in offsite production and bridge construction methods, demonstrating VR's versatility [3, 8].

However, despite these advantages, several challenges limit VR's widespread adoption in civil engineering. Hardware issues such as motion sickness, limited field of view, and cumbersome equipment can reduce user comfort and effectiveness [9]. Cost and technical expertise required to develop high-quality VR simulations pose barriers to entry, especially for small- and medium-sized enterprises [10]. Additionally, understanding human factors influencing VR acceptance is critical. Technology acceptance models (TAMs), extended for VR hardware, reveal that perceived usefulness, ease of use, enjoyment, and social influence significantly impact adoption decisions [11, 12].

Integration of VR with emerging technologies such as artificial intelligence (AI), internet of things (IoT), and sensor networks presents new opportunities. AI can tailor VR training by adapting scenarios to user performance, while real-time sensor data can feed into VR environments for up-to-date monitoring and decision support [13]. These integrations can transform VR from a standalone visualization tool into a dynamic platform for smart infrastructure management.

This paper aims to synthesize the current body of research on VR applications in civil engineering, identify key challenges and limitations, and highlight future trends that will shape the adoption and development of VR technologies in this domain.

METHODOLOGY

This review was conducted through a systematic search of relevant literature from multiple databases, including ScienceDirect, IEEE Xplore, and Google Scholar. Keywords such as "virtual reality", "civil engineering", "construction safety training", "BIM", and "technology acceptance model" were used to identify peer-reviewed journal articles published between 1999 and 2020. The selection focused on articles related to VR applications in civil engineering construction, design, safety training, and technology acceptance.

After initial screening based on titles and abstracts, 35 articles were selected for full-text review. These articles were analyzed for content relevance, research methodology, outcomes, and challenges. The review categorized studies by application domain, technological aspects, and user acceptance factors. Key studies were synthesized to provide an overview of VR’s benefits and limitations.

Special attention was given to studies incorporating technology acceptance models (TAM, VR-hardware acceptance model [VR-HAM]) to understand user adoption patterns. Emerging trends such as AI integration and real-time data incorporation were also highlighted based on the latest research developments.

LITERATURE REVIEW

VR has been used in civil engineering primarily for construction safety training, design visualization, and enhancing project collaboration. Early studies by Sawacha et al. [14] and Demirkesen et al. [15] highlighted safety challenges on construction sites, setting the context for VR applications.

Leder et al. [2] compared immersive VR with traditional training methods, concluding that VR significantly improves hazard perception and decision-making. Similarly, Nykänen et al. [1] demonstrated VR's effectiveness in randomized controlled trials for construction worker training. Zhang et al. [9] developed a fuzzy evaluation framework for VR safety training systems in mining, showing improvements in risk mitigation.

VR's integration with BIM and offsite construction was explored by Goulding et al. [8], who created a VR prototype for offsite production training. Sampaio et al. [3] applied VR in bridge construction, simulating cantilever and incremental launching methods, improving worker understanding and safety.

Technology acceptance has been a critical focus. Manis et al. [11] extended the TAM for VR hardware, introducing VR-HAM to address specific VR challenges. Studies by King et al. [16] and Estriegana et al. [17] underline factors such as perceived usefulness, ease of use, and enjoyment in driving VR adoption.

Other research addresses user discomfort such as VR sickness, with Kim et al. [18] developing a Virtual Reality Sickness Questionnaire (VRSQ) to measure and mitigate adverse effects. The cost and technical barriers remain concerns as noted by Laurell et al. [12], restricting smaller firms from adopting VR fully. Emerging trends include AI-enhanced VR, where AI tailors training to individual learning curves, and IoT integration, which connects real-time sensor data with VR models to provide dynamic updates, discussed by Wang et al. [13]. Literature review on applications, challenges, and future trends for virtual reality (VR) in civil engineering is shown in Table 1.

Table 1. Applications, challenges, and future trends for virtual reality (VR) in civil engineering.

Author(s)	Applications	Challenges	Future Trends	Key Insights
Nykänen et al. [1]	VR-based construction safety training	High development costs; user acceptance	Integration with AI for personalized training	VR improves hazard recognition and safety compliance
Leder et al. [2]	Safety risk perception and decision making	VR-induced motion sickness; hardware limits	Enhanced immersive devices; VR with AR	VR significantly enhances learning outcomes
Sampaio et al. [3]	Training for bridge construction methods	Complexity modeling accurate processes	Real-time simulation and mixed reality	VR aids understanding complex bridge construction
Li et al. [4]	VR/AR applications for construction safety	Technical integration issues; user adaptation	Hybrid VR/AR, mobile VR, and IoT integration	Comprehensive review highlighting VR/AR benefits and limits
Guo et al. [5]	Interactive safety awareness training	Resistance to new tech; content quality	Gamification of training programs	Interactive VR games increase safety awareness
Goulding et al. [8]	Offsite construction process training	Scalability; technical support	Cloud-based VR training platforms	VR facilitates offsite prefabrication training
Zhang et al. [9]	VR for mine safety training	Data integration from real sites	AI-driven safety scenario generation	VR improves risk mitigation efficiency
Kim et al. [10]	VR effects on user experience and satisfaction (sport spectators)	Motion sickness; hardware constraints	Enhancing flow experience via VR design	VR improves engagement and satisfaction
Manis & Choi [11]	VR hardware acceptance modeling	User comfort; cost of VR hardware	Lightweight and affordable VR gear	TAM extensions explain VR adoption factors
Laurell & Sandström [12]	VR adoption barriers analysis	Price, lack of trials, social acceptance	Social media and ML to improve user engagement	Social and economic barriers limit adoption
Wang et al. [13]	Integration of VR, AI, and IoT	Data complexity and privacy concerns	Smart VR environments with AI and IoT	AI/IoT can create adaptive VR learning
Kim et al. [18]	VR sickness measurement	Motion sickness limits session length	Improved hardware & software to reduce sickness	VRSQ helps evaluate and reduce VR sickness

RESULTS AND DISCUSSION

The reviewed literature confirms that VR enhances civil engineering workflows by improving visualization, training effectiveness, and stakeholder communication. Safety training benefits are particularly notable, with VR increasing engagement and risk awareness compared to traditional methods [2, 5].

Design visualization via VR-integrated BIM models supports early detection of design clashes and constructability issues, reducing rework and costs [6, 7]. VR prototypes for offsite and specialized construction demonstrate promising improvements in worker preparedness [3, 8].

However, hardware limitations such as VR sickness and equipment bulkiness affect user acceptance [9, 18]. High costs and required technical skills limit widespread adoption, especially in smaller enterprises [12]. User acceptance models indicate that beyond technology capabilities, social factors and perceived enjoyment influence VR adoption [11, 16].

The integration of AI and IoT with VR presents promising future directions by creating adaptive, real-time interactive environments [13]. These advancements could transform VR from a static training and visualization tool into a dynamic, smart infrastructure management platform.

CONCLUSION

VR is revolutionizing civil engineering by providing immersive and interactive environments that improve safety training, design visualization, and project collaboration. Despite its demonstrated benefits, challenges related to hardware, cost, and user acceptance remain barriers to widespread adoption.

Understanding user behavior through extended technology acceptance models and addressing hardware limitations are critical for successful implementation. Future research should focus on integrating VR with AI, IoT, and real-time data to enhance the responsiveness and effectiveness of VR applications.

This comprehensive review serves as a foundation for researchers and practitioners aiming to leverage VR technology to create safer, more efficient, and collaborative civil engineering processes.

REFERENCES

1. Nykänen M, Puro V, Tiikkaja M, et al., Implementing and evaluating novel safety training methods for construction sector workers: results of a randomized controlled trial. J Saf Res. 2020; 75: 205–221. doi: 10.1016/j.jsr.2020.09.015.
2. Leder J, Horlitz T, Puschmann P, Wittstock V, Schütz V. Comparing immersive virtual reality and PowerPoint as methods for delivering safety training: impacts on risk perception, learning, and decision making. Saf Sci. 2019; 111: 271–286. doi: 10.1016/j.ssci.2019.07.022.
3. Sampaio AZ, Martins OP. The application of virtual reality technology in the construction of bridge: the cantilever and incremental launching methods. Autom Construct. 2014; 37: 58–67. doi: 10.1016/j.autcon.2013.10.015.
4. Li X, Yi H, Chi C, Wang T. A critical review of virtual and augmented reality (VR/AR) applications in construction safety. Autom Construct. 2018; 86: 150–162. doi: 10.1016/j.autcon.2017.11.003.
5. Guo H, Li H, Chan G, Skitmore M. Using game technologies to improve the safety of construction plant operations. Accid Anal Prev. 2012; 48: 204–213. doi: 10.1016/j.aap.2011.06.002.
6. Ge L, Falko K. Integrative simulation environment for conceptual structural analysis. J Comput Civ Eng. 2015; 29 (4): B4014004. doi: 10.1061/(ASCE)CP.1943-5487.0000405.
7. Sacks R, Perlman A, Barak R. Construction safety training using immersive virtual reality. Construct Manage Econ. 2013; 31 (9): 1005–1017. doi: 10.1080/01446193.2013.828844.

8. Goulding J, Madim W, Petridis P, Alshawi M. Construction industry offsite production: a virtual reality interactive training environment prototype. Adv Eng Inform. 2012; 26 (1): 103–116. doi: 10.1016/j.aei.2011.09.004.
9. Zhang H, He X, Mitri H. Fuzzy comprehensive evaluation of virtual reality mine safety training system. Saf Sci. 2019; 120: 341–351. doi: 10.1016/j.ssci.2019.07.009.
10. Kim D, Ko YJ. The impact of virtual reality (VR) technology on sport spectators' flow experience and satisfaction Computers Hum Behav. 2019; 93: 346–356. doi: 10.1016/j.chb.2018.12.040.
11. Manis KT, Choi J. The virtual reality hardware acceptance model (VR-HAM): extending and individuating the technology acceptance model (TAM) for virtual reality hardware. J Bus Res. 2019; 100: 503–513. doi: 10.1016/j.jbusres.2018.10.021.
12. Laurell C, Sandström M, Berthold A, Larsson D. Exploring barriers to adoption of virtual reality through social media analytics and machine learning – an assessment of technology, network, price and trialability. J Bus Res. 2019; 100: 469–474. doi: 10.1016/j.jbusres.2019.01.017.
13. Wang P, Wu P, Wang J, et al. A critical review of the use of virtual reality in construction engineering education and training. Int J Environ Res Public Health. 2018; 15 (6): 1204. doi: 10.3390/ijerph15061204.
14. Sawacha E, Naoum S, Fong D. Factors affecting safety performance on construction sites. Int J Proj Manage. 1999; 17 (5): 309–315. doi: 10.1016/S0263-7863(98)00042-8.
15. Demirkesen S, Arditi D. Construction safety personnel's perceptions of safety training practices. Int J Proj Manage. 2015; 33 (5): 1160–1169. doi: 10.1016/j.ijproman.2015.01.007.
16. King WR, He J. A meta-analysis of the technology acceptance model. Inform Manage 2006; 43 (6): 740–755. doi: 10.1016/j.im.2006.05.003.
17. Estriegana R, Medina-Merodio JA, Barchino R. Student acceptance of virtual laboratory and practical work: an extension of the technology acceptance model. Comput Educ. 2019; 138: p1–14. doi: 10.1016/j.compedu.2019.02.010.
18. Kim HK, Park J, Choi Y, et al. Virtual reality sickness questionnaire (VRSQ): motion sickness measurement index in a virtual reality environment. Appl Ergon. 2018; 69: 66–73. doi: 10.1016/j.apergo.2017.12.016.

