Immersive Virtual Reality in Construction Education

Subjects: Construction & Building Technology

Contributor: Muhammad Sami Ur Rehman , Narmin Abouelkhier , Muhammad Tariq Shafiq

The emergence of immersive technologies, such as virtual reality (VR) headsets, has revolutionized the way we experience the physical world by creating a virtual, interactive environment. In the field of education, this technology has immense potential to provide students with a safe and controlled environment in which to experience real-world scenarios that may be otherwise unfeasible or unsafe.

immersive technologies virtual reality technical education

1. Introduction

Engineering education amalgamates related research and technical education to foster technological and educational innovation, thereby enhancing problem-solving abilities and creativity among recent graduates entering the technical workforce. The 2019 Degree Survey by the Ministry of Education (MoE) in the United Arab Emirates (UAE) identified engineering as the most sought-after degree program. According to the Knowledge and Human Development Authority (KHDA)—MoE, over 9000 engineering students are currently enrolled in various institutions across the UAE, and this number is anticipated to significantly escalate [1]. These statistics underscore the criticality of a technically skilled workforce and the indispensability of quality engineering education in the UAE.

Conventional approaches to engineering instruction are limited in their ability to provide students with exposure to practical applications of their field-specific knowledge, as they are typically conducted in a classroom setting with minimal opportunities for hands-on learning [2]. This poses a challenge for students in understanding real-world situations, particularly in harsh weather conditions such as those experienced in the UAE [3]. Moreover, conventional engineering courses rely heavily on non-intuitive documentation, which can be problematic for students lacking industry experience, such as those in construction management programs. Such documentation, including two-dimensional drawings and project-related materials for activities such as project planning, activity sequencing, scheduling, safety planning, and cost estimates, can be difficult to comprehend and prone to error.

The emergence of building information modeling (BIM) has brought about numerous opportunities for both industry and academia to transition from traditional document-oriented practices to data-driven, 3D model-enabled engineering processes and workflows [4]. Additionally, the advent of immersive and reality-based technologies has given rise to highly effective tools such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). The construction sector has increasingly used applications of BIM and VR to enhance construction sequencing and planning, such as 4D BIM and virtual construction. VR technology offers users the ability to completely immerse themselves in a virtual environment through computer-generated simulations [5], providing a symbolic representation that helps them better visualize and understand the project [6]. As a result, decision-makers can use VR simulation to visualize, evaluate, and mitigate any errors that might obstruct the project's execution. The integration of BIM and immersive technologies has been studied, and various studies have used these integrations to enhance the construction management process [7][8][9]. This advanced visual communication can significantly improve students' ability to understand and learn by reviewing designs for constructability and planning the construction of building and infrastructure projects. Moreover, the utilization of advanced visualization techniques can promote active learning among students. However, limited studies have investigated the potential of these technologies in enhancing engineering education.

2. Immersive Virtual Reality (IVR)

IVR refers to a computer-generated environment that simulates an interactive experience and fully engages the user's senses, typically including sight, sound, and touch. IVR involves the use of wearable displays, such as head-mounted displays (HMDs), to track the movements of users and present virtual information based on their positions. This enables users to experience the virtual environment in 360 degrees, resulting in a fully immersive experience. It is this sense of immersion that is often associated with VR technology and is one of its most marketable features [10]. The history of IVR can be traced back to the 1960s when Ivan Sutherland introduced the first head-mounted display system. However, the technology was not advanced enough to garner widespread attention until the 1990s, when the reality-based system became a research field of its own [11]. Moreover, the idea of IVR began to gain traction with the advent of consumer-grade hardware such as virtuality headwear and Nintendo's Virtual Boy, which helped introduce the concept to the general public [12]. With advancements in computer processing and graphics technology, the CAVE (cave automatic virtual environment) was conceived by a team of scholars at the University of Illinois at Chicago in 1991 as a tool to advance scientific visualization. The CAVE system elicited a sense of immersion by enclosing the user within a physical space surrounded by projection screens that displayed images in a stereo format. The projected images were rear-projected onto the walls and down-projected onto the floor. To fully experience the stereoscopic visualization, the user required specialized three-dimensional shutter glasses [13]. In the 2000s, with the rise of the internet and advent of online gaming, IVR continued to evolve with the development of more sophisticated hardware such as HMDs and haptic feedback devices that allowed for greater sensory immersion [14]. IVR represents a significant advance in our ability to simulate and interact with the digital environment, opening up new possibilities for entertainment, education, and scientific research.

IVR technology has experienced significant advancements that have opened up various possibilities for exploring new dimensions in different fields, such as education, healthcare, gaming, entertainment, engineering, and beyond [10]. A literature review recently explored the impact of IVR on various fields, highlighting its current and potential applications along with the limitations of the technology. The study noted the potential of IVR in industrial applications such as driving simulation, as it allows the creation of realistic situations without risk to the driver or learner [15]. Additionally, IVR can be used in product design and prototyping by creating virtual design alternatives, thus saving significant time, money, and effort by reducing material wastage [16]. The study also identified the potential of IVR in education, specifically in fields such as medicine, engineering, and military training [17]. IVR technology can keep students more attentive and enable teachers to have one-on-one interactions with students, thereby enhancing the learning experience [18][19]. In addition, IVR-based medical training can be utilized to train surgeons to operate and practice in a virtual environment, reducing the chances of mistakes, while students can practice and experience real-life scenarios with virtual patients [20][21]. Moreover, IVR has great potential in public health and wellness. For instance, exergaming, fitness, and sports opportunities can be provided that improve the overall fitness of users, which contrasts with traditional sedentary techniques of gaming [22]. IVR technology is also utilized in therapy and meditation to provide immersive environments for overcoming traumas and other stress-related illnesses [23]. Furthermore, social interactions are one of the latest additions to the category, where IVR provides a realistic setting to interact, improving the social abilities of people with disabilities or allowing individuals to interact in various situations such as education, business, work, and community gatherings [23][24].

In recent years, IVR technology has made significant progress, thanks to continued technological advancements in both hardware and software [25]. These innovations have contributed to the enhancement of the VR experience, resulting in increased levels of immersion and interactivity for users. The integration of high-quality displays, wireless headsets, hand and body tracking, haptic feedback, and artificial intelligence (AI) works together to create a more realistic and engaging virtual environment [26][27]. High-quality headsets equipped with advanced features such as high resolution, high refresh rate, wide field of view, and precise tracking accuracy have greatly enhanced the IVR experience [28]. These features contribute to a more realistic and detailed visual representation of the virtual environment, providing users with a truly immersive experience. Furthermore, the introduction of wireless VR headsets has significantly improved the IVR experience by freeing users from the physical constraints of being tethered to a computer or console [29]. The integration of hand and body tracking in virtual reality technology has improved the overall immersive experience by enabling more natural and intuitive interactions with the virtual environment [30]. In addition, haptic feedback improves the immersive virtual reality experience by providing tactile sensations that simulate the feeling of touch and enhance the realism of interactions with virtual objects [31]. Artificial intelligence has also been used to create better virtual reality experiences by developing new techniques for improving 3D displays for virtual and augmented reality technologies. AI can also be used to interpret user input in a more natural way, allowing for more realistic and responsive interactions with virtual characters and environments [32]. These advancements have the potential to revolutionize the way we interact with virtual reality. Overall, the progress in IVR technology has the potential to disrupt almost every field imaginable in the near future and remarkably enhance the users' learning experiences across all domains.

3. IVR in Construction Education

The emergence of IVR has transformed the way students learn in many fields, including education. This technology provides an opportunity to engage learners in a highly interactive and immersive learning environment [33]. IVR has been shown to enhance the learning experience by providing a highly realistic and interactive setting where learners can visualize and experience complex concepts, ideas, and procedures [34]. The use of IVR in education offers several benefits, including increased engagement, better knowledge retention, and enhanced learning outcomes [35]. Furthermore, it offers the potential to overcome traditional classroom limitations by enabling students to learn at their own pace and in a way that best suits their learning style [36]. One of the key benefits of IVR in education is that it provides a safe and controlled environment for learners to experiment and practice without the risk of harm or damage to equipment [37]. For example, engineering students can simulate and explore different design solutions while construction management students can simulate and practice project management scenarios, leading to better decision-making and critical thinking [38]. Additionally, the use of IVR in education has the potential to address the challenge of providing practical experiences for students in fields such as medicine and healthcare, where the risks associated with real-world procedures are high [39]. By using IVR to simulate real-world scenarios, students can develop their skills and improve their confidence in a controlled and safe environment. Despite the many potential benefits of IVR in education, some limitations exist, such as the high cost of implementation, technological limitations, and the need for specialized training for both educators and learners [33][40]. Moreover, there is a lack of standardization in the field, making it difficult to evaluate the effectiveness of IVR in education [41]. Nonetheless, the potential of IVR in education is enormous, and with continued development and refinement, it could revolutionize the way students learn in the future.

The use of IVR technology has been implemented in various studies focused on construction management education, with positive results. A study reviewed the recent applications of VR in architecture, the construction industry, as well as in education and evaluated its potential to improve student learning. It found that using VR could enhance creativity, improve visualization of complex designs, and aid in understanding course concepts but may face obstacles related to cost and rapidly changing technology [42]. Another study developed and tested an augmented reality-based assessment tool for evaluating hazard recognition skills of construction management students, finding that it outperformed traditional paper and computer-based assessments in terms of effectiveness and student preference. The study highlighted the potential of immersive technologies to bridge the gap between classroom and real-world construction environments for improved safety training [43]. Furthermore, Whisker et al. [5] explored the use of 4D CAD modeling and immersive virtual reality in construction engineering education and found that these advanced visualization tools could improve students' understanding of construction projects and plans. The study suggested that using virtual reality could supplement actual construction site visits and allow students to experiment with different construction sequences, temporary facility locations, trade coordination, safety issue identification, and design improvements for constructability. In a similar realm, a recent study investigated the use of immersive videos (360, 180 3D, and flat) as an educational tool in construction management and found that students had a positive perception towards using this technology, with HMDs being their preferred delivery method. The study suggested that incorporating immersive videos could enhance construction management education, although further research with larger and more diverse samples was needed [44]. A class experiment found that the implementation of a 4D BIM schedule, along with virtual reality technology, could enhance the fabrication and assembly performance of modules. Most of the participants who experienced a 4D BIM schedule along with immersive virtual reality (4D/IVR) strongly agreed that it was an easy and straightforward way to visualize the project, understand the schedule, and find any errors. Moreover, almost all of them successfully sequenced the assembly with 4D/IVR, compared to only 42% with conventional 2D drawings and schedules [45]. In an effort towards implementation of VR-based techniques, a recent research study proposed a methodology for implementing VR-BIM technology in the construction management undergraduate curriculum to enhance students' understanding of building principles. The methodology included integrating VR-BIM into the existing courses and providing a new computer lab classroom, while overcoming challenges such as faculty training and availability of technology [46]. These studies have reported that the implementation of IVR-based techniques can enhance creativity, improve visualization of complex designs, aid in understanding course concepts, and supplement actual construction site visits. However, obstacles such as cost, limited exposure of both students and faculty to VR, lack of infrastructure, rigidity of traditional course content, and policies may impede the implementation of IVR in construction management education [47][48].

References

1. Ministry of Education Unveils Results of Its "Majors in Demand" Study. 2019. Available online: https://www.moe.gov.ae/En/MediaCenter/News/Pages/Training.aspx (accessed on 2 September 2022).
2. Hersam, M.C.; Luna, M.; Light, G. Implementation of Interdisciplinary Group Learning and Peer Assessment in a Nanotechnology Engineering Course. J. Eng. Educ. 2004, 93, 49–57.
3. Wang, M.T.; Degol, J.L. School Climate: A Review of the Construct, Measurement, and Impact on Student Outcomes. Educ. Psychol. Rev. 2015, 28, 315–352.
4. Russell, D.; Cho, Y.K.; Cylwik, E. Learning Opportunities and Career Implications of Experience with BIM/VDC. Pract. Period. Struct. Des. Constr. 2014, 19, 111–121.
5. Whisker, V.; Yerrapathruni, S.; Messner, J.; Baratta, A. Using Virtual Reality to Improve Construction Engineering Education. In Proceedings of the 2003 Annual Conference Proceedings, Boston, MA, USA, 18–21 May 2003; pp. 8.1266.1–8.1266.9.
6. 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.
7. Afzal, M.; Shafiq, M.T.; Al Jassmi, H. Improving construction safety with virtual-design construction technologies—A review. J. Inf. Technol. Constr. 2021, 26, 319–340.
8. Wang, C.; Li, H.; Kho, S.Y. VR-embedded BIM immersive system for QS engineering education. Comput. Appl. Eng. Educ. 2018, 26, 626–641.
9. Afzal, M.; Shafiq, M. Evaluating 4d-bim and vr for effective safety communication and training: A case study of multilingual construction job-site crew. Buildings 2021, 11, 319.
10. Hamad, A.; Jia, B. How Virtual Reality Technology Has Changed Our Lives: An Overview of the Current and Potential Applications and Limitations. Int. J. Environ. Res. Public Health 2022, 19,

11278.

11. Krevelen, D.W.F. Augmented Reality: Technologies, Applications, and Limitations. Res. Gate 2007, 1–25.
12. Berkman, M.I. History of Virtual Reality. Encycl. Comput. Graph. Games 2018, 1–9.
13. Manjrekar, S.; Sandilya, S.; Bhosale, D.; Kanchi, S.; Pitkar, A.; Gondhalekar, M. CAVE: An emerging immersive technology—A review. In Proceedings of the UKSim-AMSS 16th International Conference on Computer Modelling and Simulation, UKSim 2014, Cambridge, UK, 26–28 March 2014; pp. 131–136.
14. Wei, H.T.; Chen, M.H.; Huang, P.C.; Bai, Y.M. The association between online gaming, social phobia, and depression: An internet survey. BMC Psychiatry 2012, 12, 92.
15. Ihemedu-Steinke, Q.C.; Erbach, R.; Halady, P.; Meixner, G.; Weber, M. Virtual Reality Driving Simulator Based on Head-Mounted Displays. In Automotive User Interfaces; Springer: Berlin/Heidelberg, Germany, 2017; pp. 401–428.
16. Lutters, E.; van Houten, F.J.; Bernard, A.; Mermoz, E.; Schutte, C.S. Tools and techniques for product design. CIRP Ann. 2014, 63, 607–630.
17. Ely, D.; Shute, A.; Baldwin, S.; Bazar, L. Virtual reality as applied to the fields of education, transportation and exploration. Int. J. Stud. Proj. Report. 2022, 1, 123.
18. Alhalabi, W.S. Virtual reality systems enhance students' achievements in engineering education. Behav. Inf. Technol. 2016, 35, 919–925.
19. Lau, K.W.; Lee, P.Y. The use of virtual reality for creating unusual environmental stimulation to motivate students to explore creative ideas. Interact. Learn. Environ. 2012, 23, 3–18.
20. Izard, S.G.; Juanes, J.A.; García-Peñalvo, F.J.; Gonçalvez Estella, J.M.; Ledesma, M.J.S.; Ruisoto, P. Virtual Reality as an Educational and Training Tool for Medicine. J. Med. Syst. 2018, 42, 50.
21. Nickel, F.; Brzoska, J.A.; Gondan, M.; Rangnick, H.M.; Chu, J.; Kenngott, H.G.; Linke, G.R.; Kadmon, M.; Fischer, L.; Müller-Stich, B.P. Virtual Reality Training Versus Blended Learning of Laparoscopic Cholecystectomy: A Randomized Controlled Trial with Laparoscopic Novices. Medicine 2015, 94, e764.
22. Rizzo, A.S.; Lange, B.; Suma, E.A.; Bolas, M. Virtual reality and interactive digital game technology: New tools to address obesity and diabetes. J. Diabetes Sci. Technol. 2011, 5, 256–264.
23. Srivastava, K.; Chaudhury, S.; Das, R. Virtual reality applications in mental health: Challenges and perspectives. Ind. Psychiatry J. 2014, 23, 83–85.

24. Perry, T.S. Virtual reality goes social: Meeting people, not playing games, will be VR's killer app. IEEE Spectr. 2015, 53, 56–57.

25. Chan, C.-S.; Bogdanovic, J.; Kalivarapu, V. Applying immersive virtual reality for remote teaching architectural history. Educ. Inf. Technol. 2021, 27, 4365–4397.

26. Li, P.; Fang, Z.; Jiang, T. Research into improved Distance Learning Using VR Technology. Front. Educ. 2022, 7, 32.

27. Cipresso, P.; Giglioli, I.A.C.; Raya, M.A.; Riva, G. The past, present, and future of virtual and augmented reality research: A network and cluster analysis of the literature. Front. Psychol. 2018, 9, 2086.

28. Goh, G.S.; Lohre, R.; Parvizi, J.; Goel, D.P. Virtual and augmented reality for surgical training and simulation in knee arthroplasty. Arch. Orthop. Trauma Surg. 2021, 141, 2303–2312.

29. Kim, S.; Yun, J.-H. Motion-Aware Interplay between WiGig and WiFi for Wireless Virtual Reality. Sensors 2020, 20, 6782.

30. Schnack, A.; Wright, M.J.; Holdershaw, J.L. Immersive virtual reality technology in a three-dimensional virtual simulated store: Investigating telepresence and usability. Food Res. Int. 2019, 117, 40–49.

31. Han, P.-H.; Chen, Y.-S.; Lee, K.-C.; Wang, H.-C.; Hsieh, C.-E.; Hsiao, J.-C.; Chou, C.-H.; Hung, Y.-P. Haptic around: Multiple tactile sensations for immersive environment and interaction in virtual reality. Proc. ACM Symp. Virtual Real. Softw. Technol. 2018, 35, 1–10.

32. Zhang, Z.; Wen, F.; Sun, Z.; Guo, X.; He, T.; Lee, C. Artificial Intelligence-Enabled Sensing Technologies in the 5G/Internet of Things Era: From Virtual Reality/Augmented Reality to the Digital Twin. Adv. Intell. Syst. 2022, 4, 2100228.

33. Hamilton, D.; McKechnie, J.; Edgerton, E.; Wilson, C. Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. J. Comput. Educ. 2021, 8, 1–32.

34. Freina, L.; Ott, M. A literature review on immersive virtual reality in education: State of the art and perspectives. In Proceedings of the 11th International Conference eLearning and Software for Education, Bucharest, Romania, 23–24 April 2015; pp. 133–141.

35. Araiza-Alba, P.; Keane, T.; Chen, W.S.; Kaufman, J. Immersive virtual reality as a tool to learn problem-solving skills. Comput. Educ. 2021, 164, 104121.

36. Xenos, M. The Future of Virtual Classroom: Using Existing Features to Move beyond Traditional Classroom Limitations. Adv. Intell. Syst. Comput. 2018, 725, 944–951.

37. Sacks, R.; Perlman, A.; Barak, R. Construction safety training using immersive virtual reality. Constr. Manag. Econ. 2013, 31, 1005–1017.

38. Bande, L.; Ahmed, K.G.; Zaneldin, E.; Ahmed, W.; Ghazal, R. Virtual Reality Technology Trends Current and Future Applications, an Interdisciplinary Overview. Virtual Augment. Real. Archit. Design 2022, 17–55.
39. Li, L.; Yu, F.; Shi, D.; Shi, J.; Tian, Z.; Yang, J.; Wang, X.; Jiang, Q. Application of virtual reality technology in clinical medicine. Am. J. Transl. Res. 2017, 9, 3867–3880. Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5622235/ (accessed on 16 March 2023).
40. Häfner, P.; Häfner, V.; Ovtcharova, J. Teaching Methodology for Virtual Reality Practical Course in Engineering Education. Procedia Comput. Sci. 2013, 25, 251–260.
41. Zhao, J.; Xu, X.; Jiang, H.; Ding, Y. The effectiveness of virtual reality-based technology on anatomy teaching: A meta-analysis of randomized controlled studies. BMC Med. Educ. 2020, 20, 127.
42. Alizadehsalehi, S.; Hadavi, A.; Huang, J.C. Virtual Reality for Design and Construction Education Environment. In AEI 2019: Integrated Building Solutions—The National Agenda; American Society of Civil Engineers: Reston, VA, USA, 2019; pp. 193–203.
43. Kim, K.; Alshair, M.; Holtkamp, B.; Yun, C.; Khalafi, S.; Song, L.; Suh, M.J. Using Immersive Augmented Reality to Assess the Effectiveness of Construction Safety Training. J. Constr. Eng. Proj. Manag. 2019, 9, 16–33.
44. Shojaei, A.; Rokooei, S.; Mahdavian, A.; Carson, L.; Ford, G. Using immersive video technology for construction management content delivery: A pilot study. J. Inf. Technol. Constr. 2021, 26, 886–901.
45. Ghimire, R.; Lee, S.; Choi, J.O.; Lee, J.-Y.; Lee, Y.-C. Combined Application of 4D BIM Schedule and an Immersive Virtual Reality on a Modular Project: UNLV Solar Decathlon Case. Int. J. Ind. Constr. 2021, 2, 1–14.
46. Ghanem, S.Y. Implementing virtual reality—Building information modeling in the construction management curriculum. J. Inf. Technol. Constr. 2022, 27, 48–69.
47. Radhakrishnan, U.; Koumaditis, K.; Chinello, F. A systematic review of immersive virtual reality for industrial skills training. Behav. Inf. Technol. 2021, 40, 1310–1339.
48. Harknett, J.; Whitworth, M.; Rust, D.; Krokos, M.; Kearl, M.; Tibaldi, A.; Bonali, F.; Vries, B.V.W.D.; Antoniou, V.; Nomikou, P.; et al. The use of immersive virtual reality for teaching fieldwork skills in complex structural terrains. J. Struct. Geol. 2022, 163, 104681.