

Analysing Virtual Reality Applications in Built Environment Education: A Study of Existing Research

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Abstract: The application of Virtual Reality (VR) in built environment education has wide-ranging potential to enhance experiential learning through simulating accessible real-world scenarios for practical application of classroom concepts and providing a spatial scale for students. Relevant applications may have a transdisciplinary impact, with specific relevance to fields such as engineering, urban planning, and architectural studies. The continued diffusion of VR technology and applications may alter diverse sectoral value chains and production, necessitating educational responses in design, analysis, and management approaches. Evident is the importance of integrating related tools in tertiary education practices to enable the resilience, productivity, and competitiveness of built environment students. However, the lack of existing research restricts the development of best practice that is applicable to the diverse activities of built environment practitioners. This paper aims to investigate the existing body of knowledge to delineate lessons that inform tertiary sector stakeholders on the use of VR to support the development of graduate attributes in the process of teaching and learning. The research methodology applied is centred on a bibliometric review of current research. The VOSviewer (v1.6.20) software is utilized to identify relevant themes and trends among the publications. The latter is sourced from the Scopus database using keywords such as “virtual reality”, “built environment”, and “education”. The most cited papers are also qualitatively analyzed to interpret the findings of the review. Findings indicate that current research themes include the application of VR in education and pedagogy, user perception and experiences in this regard, and informing practical training and decision making toward sustainable development and applied practice. The qualitative content review indicates four categories of VR application in built environment education, including visualisation, participation, and collaboration, knowledge creation and transfer, and an integrated approach. Recommendations include institutions utilizing said findings to inform curriculum transformation, improving student and stakeholder participation, supporting evidence-based teaching.

Keywords: Virtual Reality; Built Environment; Knowledge Transfer; 4IR; Cross-reality Environment.

1. Introduction

Technological advancements, such as Artificial Intelligence (AI), the Internet of Things (IoT), and VR, have the potential to radically transform diverse sectors of society, including tertiary education (Matsika & Zhou, 2021). VR, through facilitating the creation of immersive real-world and imagined virtual environments, may be utilized to support a range of activities relevant to teaching and learning (Campos et al., 2022). This includes experiential learning, student exposure to simulated real-world scenarios, and collaborative content engagement (Dai et al., 2022). This is especially relevant to the disciplines in the built environment, where activities and industries are anchored in a specific spatial context and stakeholders engage and collaborate in complex environments where design, development, and analysis approaches are dynamic and flexible. VR and other emerging technology have already catalyzed related changes in the fields of engineering, urban planning, construction, and architecture (Kim et al., 2013). This underlines the motive for their holistic incorporation in tertiary education pedagogies to support the ongoing competitiveness of built environment students in contributing to practice, policymaking, and academia.

However, there is limited research to guide built environment education stakeholders in terms of possible VR applications in teaching and learning related activities. Current research is limited to context- and discipline-specific use cases and lack a holistic framework that delineates best practice in this regard. This inhibits the systematic integration of this potentially transformative tool into teaching practice. Accordingly, the aim of this paper is to delineate and broadly categorize applications of VR technology in this context. The related research objectives are to analyse existing research on this topic, identify the prominent research themes reflective of potential applications and the way they have changed over time, as well as a detailed investigation of application cases. Identifying and grouping potential VR use cases supports curriculum development and transformation initiatives, while enabling relevant stakeholders and institutions to strategically align teaching practices with emerging technology to support sustained and resilient outcomes. To achieve the research aim, a mixed method research approach is applied in the form of a bibliometric review of existing research on this topic, the findings of which are augmented by a qualitative review of select high impact publications. The structure includes a literature review of VR and education related themes, an overview of the research methodology, a findings and discussion section, followed by the conclusion.

2. Literature Review

The literature review is focused on providing an introductory overview to VR technology, in addition to broadly delineating potential educational applications for technology.

2.1 Introduction to VR Technology

VR is a virtual, computer-generated environment that may be reflective of an existing physical space or a unique digital space (Campos et al., 2022). User immersion and interaction are to core characteristics of VR. The former may be facilitated by wearable technology, including a VR headset, which creates the perception of physical presence in the virtual environment for the user. Interaction, on the other hand, is enabled through controllers and sensors that capture and reflect user movements and decisions within the virtual environment (De Fino et al., 2023). VR may be grouped with other advanced technologies that form part of the Fourth Industrial Revolution (4IR), the application of which has the potential to revolutionize production and consumption processes (Matsika & Zhou, 2021), including AI, IoT, automation, 3-dimensional (3D) printing, and cloud computing. De Amicis et al. (2019:339) delineate certain advantages associated with the use of VR technology within the specific context of education and learning environments, asserting that “dynamic visualizations outperform conventional, static instructional materials”. Student engagement is heightened through “technology-mediated” teaching approaches, reflecting greater motivation and learning satisfaction after use. More information can be incorporated into dynamic virtual environments, while also being able to integrate multimedia content and data visualizations (De Amicis et al., 2019). Students are also exposed to diverse environments that may be “otherwise [...] geographically unreachable”, while being able to analyse complex features of virtual sites in intricate detail. Disadvantages to VR use identified by Acevedo et al. (2024), on the other hand, include the high cost of hardware associated with the technology, and significant technical requirements needed to use related hardware and software, as well as creating and curating relevant content. Additional disadvantages include training requirements for first-time VR users for efficient application, uneven knowledge acquisition among users, and doubts regarding the transfer of skills from virtual to physical context (Acevedo et al., 2024).

2.2 Educational Applications for Technology

One aspect where technology may contribute to educational outcomes is knowledge transfer. This includes conveying the core theoretical and conceptual information on a specific theme to students (Jensen & Freeman, 2019), in line with the standards and competencies captured within a curriculum (Sahin, 2018). This is mostly done in a structured manner, where content and learning outcomes are communicated to students within the framework of predetermined objectives (Gunardi & Hartati, 2024). This initial prioritisation of transferring foundational knowledge to students is central to the teaching philosophy of essentialism (Kaminer, 2024). This is the building blocks in students comprehending and engaging with both basic and advanced themes in any discipline. The advantage of first focusing on core knowledge transfer is that it creates a predictable learning environment with clear expectations for the student (Strong et al., 2015). However, this approach may also reinforce “predetermined explanations for human interaction” (Kokkonen et al., 2022:1), which may limit critical thinking and problem-solving on the part of the student.

This highlights the importance of the second area in which technology, including VR, may affect outcomes in education, i.e. knowledge co-creation. In this aspect, as captured in the teaching philosophy of constructivism, students actively participate in knowledge creation through engaging with the taught content and the process of learning (Mimi et al., 2020). This is influenced by the personal context and perspective in which the student interprets the foundational knowledge, including social and cultural milieu. This catalyzes a nuanced and novel investigation of existing knowledge and culminates “learners actively constructing” new knowledge (Tan & Ng, 2021:1). For effective knowledge co-creation, students evaluate and analyse existing knowledge and related data through applying critical thinking (Sigalov & Cohen, 2025). In addition to reflecting on their own experiences, this is also done in collaboration and interaction with others. One advantage of knowledge co-creation is that students engage holistically with existing and new knowledge, while also increasing their social interaction and partnerships with other students (Siddique et al., 2024).

These two aspects, i.e. knowledge transfer and co-creation, form the basis of investigating potential VR applications in built environment education.

3. Research Methodology

To achieve the research objectives, this study applied a mixed method approach. Firstly, this includes a quantitative bibliometric review of research related to VR applications in built environment education. To identify relevant publications, the keywords “virtual reality”, “built environment” and “education” (including “teaching and learning”) were used as source concepts. Research analysed in this regard was limited to those found on the Scopus database due to the quality its indexed papers and ease of extraction from the database (Patel et al., 2023; Huston-Pretorius et al., 2024). The selected publications were limited to book chapters and journal publications due to access and impact considerations. Publication information, including authors, abstracts, keywords, and references, were downloaded from the database in comma-separated values (.csv) format. VOSviewer (v. 1.16.20) software was utilised to undertake the bibliometric review, with specific reference to generating the network and overlay visualisation (Van Eck & Waltman, 2018). The former depicts the primary keywords found in the publications, their linkages with other keywords, and research clusters that group the keywords that are linked to similar publications. This illustrates the prominent research themes among the publications. The overlay visualisation, on the other hand, depicts the average year of publication for each keyword, providing a visual guide on the manner in which research themes have changed over a delineated period.

The second component of the mixed method approach is a qualitative content review of the highest impact publications contained within the bibliometric review (Islam et al., 2021; Huston-Pretorius et al., 2024). Accordingly, the ten papers with the highest number of citations are utilized in this regard. Each full publication is downloaded and thematically analysed to identify the application of VR in its unique context to inform the findings of the paper. Artificial Intelligence (AI) software (i.e. ChatGPT from OpenAI) was utilised to provide an initial scoping of relevant publications. This select information was verified and expanded upon by the author within the delineated parameters of the study and analysis.

4. Findings and Discussion

This section incorporates an analysis of the keywords and publication trends inherent to the delineated research, in addition to the content review of the highest impact publications in line with the research aim and objectives.

4.1 Keywords and Publication Trends

Figure 1 illustrates the network visualisation of the different keywords included in the delineated publications. Related output includes the four prominent research clusters and the linkages between said clusters and individual keywords.

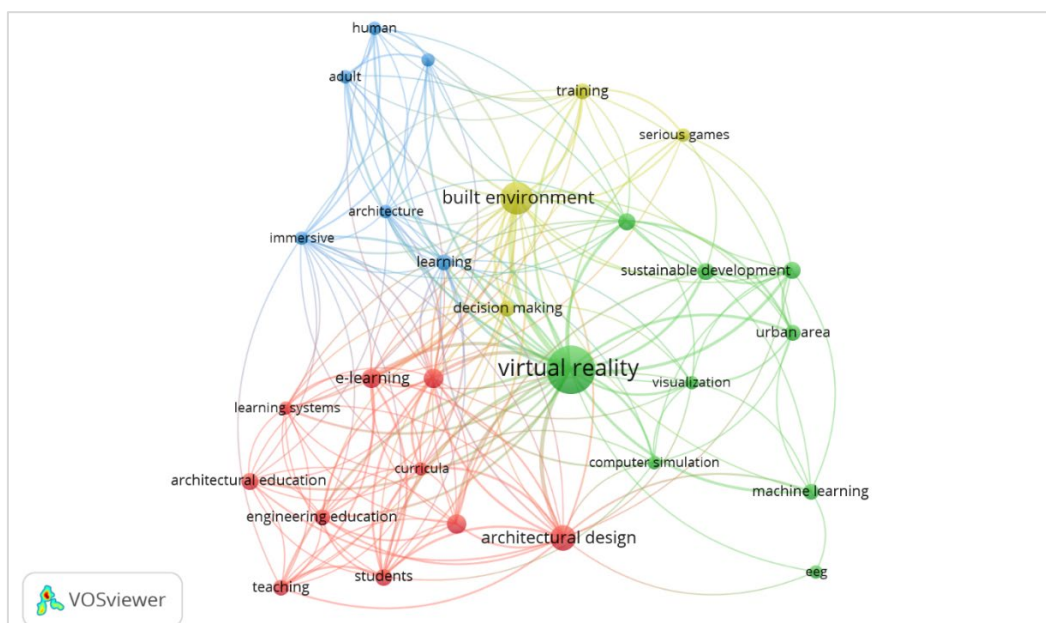


Figure 1: Network visualisation

Source: Authors (2025).

The red cluster captures keywords that are focused on education and pedagogy, with keywords that include *e-learning*, *learning systems*, *teaching*, and *curricula*. This may be indicative of the role of VR in formal education and curriculum development, with specific reference to *architectural* and *engineering education*. The green cluster incorporates keywords centred on technology and the urban context. Indicated keywords may indicate the application of VR and associated advanced technology within the specific spatial milieu of the built environment. The blue cluster connects keywords associated with the perceptual and experiential aspects of VR applications. This may be indicative of the connection between VR and engagement, individual learning experiences, and experiential learning. The yellow cluster integrates keywords with themes related to practical training and decision making. This is potentially indicative of the application of VR in professional skills development in diverse contexts. There are also linkages between these clusters and the keywords they represent. The education and pedagogy cluster illustrates significant linkages with the perceptual and experiential themes, potentially connecting VR and educational outcomes through student experiences, learning, and user perception. Another example is the linkages between research on the urban context cluster and practical training and decision making themes, alluding to the potential use of VR in connecting theoretical aspects inherent to sustainable development and applied practice.

Figure 2, on the other hand, illustrates the overlay visualisation.

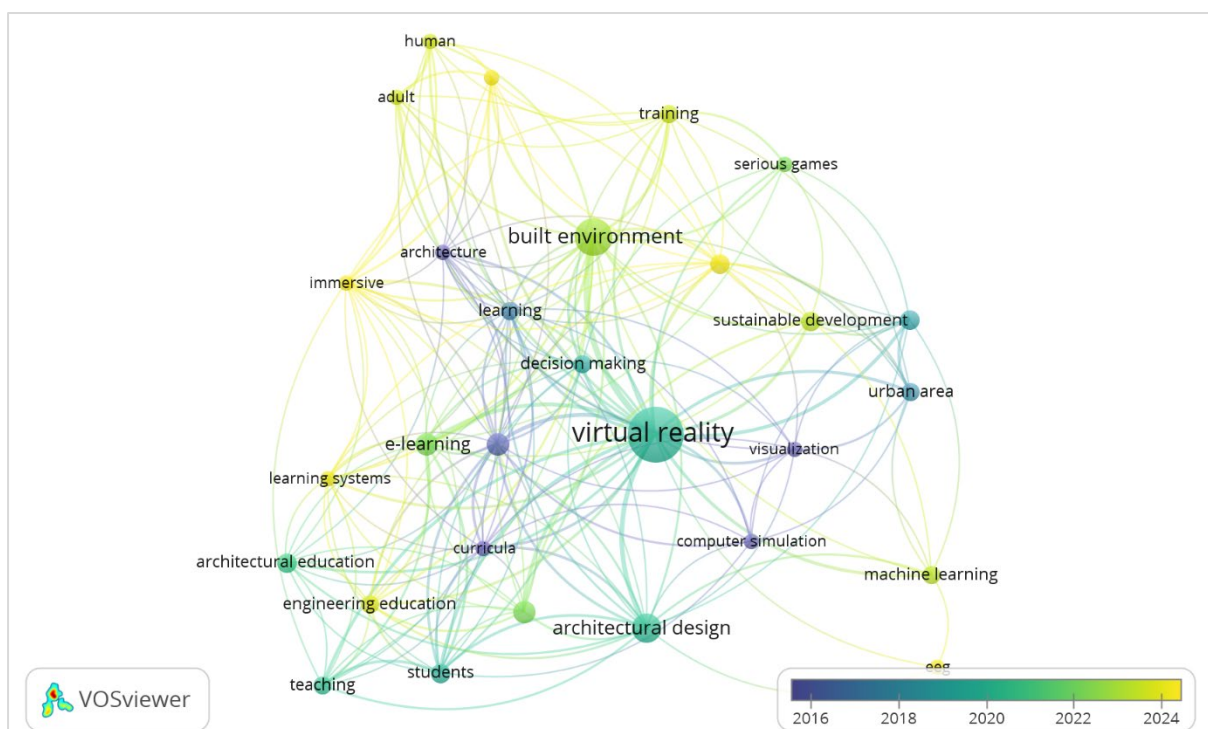


Figure 2: Overlay visualisation

Source: Authors (2025).

As illustrated in Figure 2, the established themes among existing research (published around 2016-2020) include *e-learning*, *curricula*, and *teaching*, i.e. the keywords predominantly that form part of the education and pedagogy cluster. Publications from 2020-2022 include keywords related to *architectural design*, *built environment*, *decision making*, and *visualization*. Emerging themes (2022-2024), on the other hand, are focused on keywords related to *sustainable development*, *serious games*, *machine learning*, *human*, *immersive*, and *training*. This is potentially indicative that the application of VR has changed from being used predominantly as an instrument in teaching and learning, with specific reference to the disciplines of architecture, engineering, and urban planning, toward a broader application linked to societal imperatives such as sustainability, practical skills development, and decision making. This wider scope is also supported by the emergent research focussed on VR integration with more advanced technology and data analysis (e.g. machine learning).

4.2 Qualitative Review

With reference to the qualitative content review, Table 1 indicates the 10 highest impact publications among the delineated research (in terms of citations). Indicated are the authors, the total citations, the disciplinary focus, and the application context.

Table 1: Ten most cited publications

Author(s)	Citations	Discipline Focus	Application Context
Lovreglio et al., 2021	114	Construction	Safety training
Doyle et al., 1998	110	Urban Planning	Urban modelling
Li et al., 2022	77	Urban Studies	Walkability perception
Pachouri et al., 2024	51	Built Environment	Sustainability
Ito et al., 2024	49	Urban Studies	Perception analysis
Jung et al., 2023	42	Healthcare Design	Hospital environments
Hong et al., 2016	39	Architecture Education	Design projects
De Amicis et al., 2019	26	STEM Education	Data literacy
Harrison et al., 2004	26	Accessibility	Wheelchair accessibility
De Fino et al., 2023	23	Urban Resilience	Disaster training

Source: Authors (2025).

As indicated in Table 1, the disciplinary focus of these publications ranges from construction management, urban planning, and architecture, with application contexts that include safety training, urban design, disaster risk management, and architectural design. The following discussion situates these publications in terms of their contribution in the application of VR in education.

4.2.1 Visualisation, Participation, Collaboration

In this sample, Doyle et al. (1998) provide the earliest investigation on the potential use of VR in education. This is centred on the modelling of virtual urban environments on web-based platforms. Applications include web mapping through 2-dimensional (2D) Geographic Information System (GIS) outputs where users could interact with different geospatial layers. Virtual Reality Modelling Language (VRML) is used to simplistically model urban environments which could be further explored by the user in a 3D format. These virtual worlds could be explored by multiple users using avatars in Virtual Internet Design Arenas, where participants are able to engage in designing and constructing their shared environment through text chat. Applications also included the integration of “photorealistic scenes” of real-world contexts captured by 360-degree photographs (Doyle et al., 1998:145). Interaction with these Virtual Streetscapes “is limited to the original location of the camera”, with users unable to move seamlessly between scenes (Doyle et al., 1998:146). The findings of the paper are directed toward improving planning practice through urban design and development control visualisation and modelling. Doyle et al. (1998:138) underline the participatory and collaborative potential of VR technology with the potential to “aid the decision making process, to democratise the planning process and to assist in the conveyance or dissemination of ideas”. This is applied in the context of innovation in education in related built environment fields. Environmental visualisation is the key contribution of the paper, despite the inherent limitations to the desktop screen-based VR experience. VR as an instrument for visualisation, participation, and collaboration is highlighted in this regard.

4.2.2 Knowledge Creation

Since the publication of Doyle et al. (1998), VR technology has seen significant development. This is illustrated by the use of VR headsets as presented by Li et al. (2022), which creates a sense of spatial presence in the virtual environment enabled by the user’s motor functions (i.e. head and neck movements). This provides a more

realistic and immersive user experience. While the user interface has improved, the virtual environments themselves are generated using similar tools. In the case of Li et al. (2022), users also interact with 360-degree street images, with the objective of analysing their experiences in a virtual urban environment in terms of street walkability. Gauging the user's perception of accessibility, safety, comfort, and pleasurability has the potential to directly inform theory and real-world decision making on "street walkability-oriented neighbourhood design" (Li et al., 2022:18). Increased VR technology and application development and integration may precipitate more nuanced educational outcomes: from the broad potential collaborative potential explained by Doyle et al. (1998), to the spatially targeted, field specific knowledge creation and decision making tool motivated by Li et al. (2022). The latter application is further illustrated in the meta-analysis undertaken by Ito et al. (2024:14), where it is concluded that VR technology enables stakeholders to "design experiments" to inform decision making in an exceedingly specific milieu (e.g. street design). Jung et al. (2023) use VR technology to investigate the neurophysiological response from participants to certain virtual building spaces, providing healthcare facility design insights prior to construction. Furthermore, Harrison et al. (2004) uses VR simulations of buildings to investigate wheelchair accessibility. One factor underlying this significant potential is the technology's effective simulation of real-world contexts that overcome the "limitations [of environmental audits] in terms of cost, time, and measurement scale" (Li et al., 2022:3).

4.2.3 Knowledge Transfer

VR applications may also support knowledge transfer within broad built environment contexts. De Fino et al. (2023) utilise VR headsets to immerse users in virtual training scenarios. This simulates hazardous situations in urban environments linked to disaster risks, including earthquakes and heat waves. Users are required to navigate said conditions and make appropriate risk-mitigating safety choices. This application, called a Virtual Reality-Serious Game (VR-SG), provides immediate corrective feedback on the validity of user input and decisions, allowing for step-by-step guidance to participants to increase their in-game and real-world awareness and preparedness to related scenarios. To enable active decision making, additional technology in the form of gesture controllers is required (De Fino et al., 2023). This training incorporates a "modular structure of self-contained learning units" to guide active knowledge transfer that is "engaging and authentic", as well as "scalable and flexible" to different disciplines (De Fino et al., 2023:9-10). This application presents a technical education tool that provides information from different contexts, while also effectively communicating strategies and influencing behaviour in line with broad objectives. A similar VR application is presented by Lovreglio et al. (2021), where simulations provide fire extinguishing training in different built environments. VR-enabled immersive knowledge transfer has catalysed "a significant increment [...] of knowledge acquisition [and] retention", indicating its educational value (Lovreglio et al. (2021:143). This application integrates an additional technology, i.e. sensors, to track headset and handheld controller movement.

4.2.4 Integrated Approach

Nuanced VR applications may also bridge the gap between knowledge creation and knowledge transfer, combining immersive educational experiences with data generation that provide the user with new insights. This is highlighted by the case study of Hong et al. (2016:2), in which students use VR to investigate how spatial design features affect virtual users ("VUsers") in a simulated built environment. This includes analysing human-environment interaction such as pedestrian movement through walkways. This enables real-time testing of the effects of different design approaches and elements, which supports evidence-based design and bridging theory and practice in this regard. This is done through screen-based simulations, rather than being experienced through VR headsets (Hong et al., 2016).

Furthermore, Pachouri et al., (2024) state successful use of VR technology and applications in the long term require holistic integration with other advanced technology, including Artificial Intelligence (AI), the Internet of Things (IoT), and digital twins. Accordingly, "to accomplish real-time analysis and give useful information" to be applied within a specific built environment context, "the data collected from multiple sources such as sensors, cameras, LIDAR and AR/VR has to be processed more quickly" (Pachouri et al., 2024:7). This will strengthen the existing visualisation, simulation, and communication capabilities of VR, while expanding the knowledge creating and transfer capabilities. De Amicis et al. (2019) provides an example application of holistic VR integration in this regard. VR headsets are used to visualise digital twins of urban features, enabling users to interact with said features in the real world while accessing and projecting supplementary sensor data (e.g. building heat) through augmented reality (AR) to enhance insights. This constitutes "cross-reality environments" (XR) (Amicis et al., 2019:331), where the interface between the virtual and the physical built environment "are combined with

sonified and visual data to create a more immersive environment for data analysis and exploration". Through its ability to combine the real and virtual world, supplemented by visualised real-time data, XR represents an advanced VR application that may support educational, practical, and policymaking outcomes. It integrates VR into a more holistic approach to built environment and data visualisation and analysis which fosters collaboration, participation, and knowledge creation and transfer.

5. Conclusion

This paper aimed to delineate and categorize potential applications of VR technology in the context of built environment education. Prominent research themes, as per the findings of the quantitative bibliometric review, include the application of VR in education and pedagogy, also with consideration of the urban context, investigating user perceptions and experiences, and informing practical training and decision making toward sustainable development and applied practice. The latter constitutes the emergent application of VR from its initial focus as a teaching and learning tool. The findings of the qualitative content analysis indicate that there are four potential areas of VR application in education. Firstly, *visualisation, participation, and collaboration* focus on engagement and communication through 2D (screen) or 3D (VR headset) visualisation of virtual built environments, which enables participatory and collaborative learning. Another application is *knowledge creation*, which enables novel research through user interaction with virtual environments via immersive VR headsets and real-time data analysis. This may inform decision making on diverse fronts, including theory and practice. VR may contribute to *knowledge transfer* where the focus is on training and skills development. This may be achieved through VR simulations and more advanced user interaction through sensors and gesture control. Continuous and real-time corrective feedback to the user is one way of transferring related knowledge. VR applications also include an integrated approach, where VR is combined with other advanced technology, including AR, machine learning, and digital twins, where users are able to interact, visualize, and analyse data in real-time, while being immersed in both a virtual and physical reality (XR). This has the potential to support diverse theoretical, practice, and policy outcomes, and bridges knowledge transfer and creation.

Evidently, VR applications range from basic screen-based visualizations to fully immersive and integrated platforms applicable to education and other sectors. This ought to be used in built environment education to guide curriculum development and transformation, while positioning institutions are the forefront of 4IR, the Scholarship of Teaching and Learning (SoTL), and sustainable education initiatives. VR applications ought to be applied to improve student and other stakeholder participation in built environment education, while supporting research-lead and evidence-based teaching where students interact with data and evaluating diverse planning and design interventions. Transdisciplinary collaboration is required for the development of advanced cross-reality (XR) environments. This would enable diverse built environment education stakeholders in engineering, urban planning, architecture, and construction, among others, to collaborate in the development of virtual environments that are meaningful on a technical, pedagogical, and contextual level. Institutions ought to also be capacitated to overcome potential challenges associated with VR application in teaching and learning, including high costs, technical and training requirements, transferability of skills, and potential uneven knowledge acquisition by students.

Limitations to the study include its focus on Scopus-indexed publications at the exclusion of papers in other journals and databases, in addition to the qualitative content analysis being centred on the highest impact publication at the exclusion of lower cited papers. Future research ought to focus on discipline-specific applications of VR technology and investigating the nuanced perspectives of teachers and students on the use of said technology within the education aspects delineated in this paper.

Ethics Declaration

No ethics clearance is required for this secondary data research.

AI Declaration

AI software (i.e. ChatGPT from OpenAI) was utilised to provide an initial scoping of relevant publications. This select information was verified and expanded upon by the author.

References

- Acevedo, P., Magana, A.J., Benes, B. and Mousas, C. (2024) 'A systematic review of immersive virtual reality in STEM education: advantages and disadvantages on learning and user experience', *IEEE Access*, 12, pp. 189359-189386.
- Campos, E., Hidrogo, I. and Zavala, G. (2022) 'Impact of virtual reality use on the teaching and learning of vectors', *Frontiers in Education*, 7, pp. 1-15.
- Dai, C., Ke, F., Dai, Z. and Pachman, M. (2022) 'Improving teaching practices via virtual reality-supported simulation-based learning: Scenario design and the duration of implementation', *British Journal of Educational Technology*, 54, pp. 836-856.
- De Amicis, R., Riggio, M., Badr, A.S., Fick, J., Sanchez, C.A. and Prather, E.A. (2019) 'Cross-reality environments in smart buildings to advance STEM cyberlearning', *International Journal on Interactive Design and Manufacturing*, 13, pp. 331-348.
- De Fino, M., Tavolare, R., Bernardini, G. and Quagliarini, E. (2023) 'Boosting urban community resilience to multi-hazard scenarios in open spaces: A virtual reality – serious game training prototype for heat wave protection and earthquake response', *Sustainable Cities and Society*, 99, pp. 1-14.
- Doyle, S., Dodge, M. and Smith, A. (1998) 'The potential of web-based mapping and virtual reality technologies for modelling urban environments', *Computers, Environment and Urban System*, 22(2), pp. 137-155.
- Gunardi, A. and Hartati, S. (2024) 'Essentialist educational philosophy (doctrine and its influence in the context of modern education', *Journal of Innovation in Teaching and Instructional Media*, 4(3), pp. 179-188.
- Harrison, C.S., Grant, M. and Conway, B.A. (2004) 'Haptic interfaces for wheelchair navigation in the built environment', 13(5), pp. 520-534.
- Hong, S.W., Schaumann, D. and Kalay, Y.E. (2016) 'Human behavior simulation in architectural design projects: An observational study in academic discourse', *Computers, Environment and Urban Systems*, 60, pp. 1-11.
- Huston-Pretorius, Engelbrecht, C. and Pretorius, O.R. (2024) 'Curriculum transformation in South African tertiary institutions: Current research on narratives of change', in Proceedings of the 1st International Conference on Education Research, Cape Town, November 2024, pp. 91-99.
- Islam, A., Hassini, S. and El-Dakhkhni, W. (2021) 'A systematic bibliometric review of optimization and resilience within low impact development stormwater management practices', *Journal of Hydrology*, 599, pp. 1-18.
- Ito, K., Kang, Y., Zhang, Y., Zhang, F. and Biljecki, F. (2024) 'Understanding urban perception with visual data: A systematic review', *Cities*, 152, pp. 1-30.
- Jensen, D. and Freeman, S. (2019) 'Stepping to center stage: the rise of higher education as a field of study', *The Journal of Educational Foundations*, 32(1-4), pp. 24-48.
- Jung, D., Kim, D.I. and Kim, N. (2023) 'Bringing nature into hospital architecture: Machine learning-based EEG analysis of biophilia effect in virtual reality', *Journal of Environmental Psychology*, 89, pp. 1-16.
- Kaminer, T. (2024) 'The subjugation to contingency: Popper, poststructuralism, and fear of the plan', *Planning Perspectives*, pp. 1-19.
- Kim, M.J., Wang, X., Love, P.E., Li, H. and Kang, S.C. (2013) 'Virtual reality for the built environment: a critical review of recent advances', *Journal of Information Technology in Construction*, 18(14), pp. 279-305.
- Kokkonen, L., Jager, R., Frame, A. and Raappana, M. (2022) 'Overcoming essentialism? Students' reflections on learning intercultural communication online', *Education Sciences*, 12(579), pp. 1-17.
- Li, Y., Yabuki, N. and Fukuda, T. (2022) 'Measuring visual walkability perception using panoramic street view images, virtual reality, and deep learning', *Sustainable Cities and Society*, 86, pp. 1-18.
- Lovreglio, R., Duan, X., Rahouti, A., Phipps, R. and Nilsson, D. (2021) 'Comparing the effectiveness of fire extinguisher virtual reality and video training', *Virtual Reality*, 25, pp. 133-145.
- Matsika, C. and Zhou, M. (2021) 'Factors affecting the adoption and use of AVR technology in higher and tertiary education', *Technology in Society*, 67, pp. 1-12.
- Mimi, A., Terver, A. and Awaan, W.I. (2020) 'Towards enhancing the teaching and learning of participatory theatre: perspectives from the constructivist approach', *Journal of Education Management*, 2(1), pp. 157-165.
- OpenAI. (2025) 'ChatGPT'. Available at: <https://chatgpt.com/> (Accessed: 10 September 2025).
- Pachouri, V., Singh, R., Gehlot, A., Pandey, S., Akram, S.V. and Abbas, M. (2024) 'Empowering sustainability in the built environment: A technological Lens on industry 4.0 Enablers', *Technology in Society*, 76, pp. 1-18.
- Patel, A. K., Singh, M., Singh, K., Patel, A. K., Varma, A. K. and Kuri, R. (2021) 'Visualizing publication trends in Webology Journal: a bibliometric review based on the SCOPUS database (2006-2020)', *Library Philosophy and Practice (eJournal)*, 5995, pp. 1-24.
- Sahin, M. (2018) 'Essentialism in philosophy, psychology, education, social and scientific scopes', *Journal of Innovation in Psychology, Education and Didactics*, 22(2), pp. 193-204.
- Siddique, M., Jabeen, R. and Bhutto, A. (2024) 'Interdependence of critical thinking and active participation in constructivist learning for public secondary students', *International Journal of Trends and Innovations in Business & Social Sciences*, 2(3), pp. 423-432.
- Sigalov, S.E. and Cohen, A. (2025) 'Leveraging Wikipedia for educational innovation: a higher education course model for enhancing students' competencies and collaborative knowledge creation', *International Journal of Educational Technology in Higher Education*, 22(27), pp. 1-28.

- Strong, A.C., Watson, M.K. and Llewellyn, D.C. (2015) 'What makes an undergraduate course impactful? An examination of students' perceptions of instructional environments', in Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition, Seattle, Washington, June 2025.
- Tan, C. and Ng, C.S.L. (2021) 'Constructivism in education'. Available at: <https://oxfordre.com/education/display/10.1093/acrefore/9780190264093.001.0001/acrefore-9780190264093-e-92> (Accessed: 03 June 2025).
- Van Eck, N.J. and Waltman, L. (2018) 'VOSviewer manual'. Available at: https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.8.pdf (Accessed: 10 September 2025).