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A Comprehensive Review of the Benefits of Virtual Reality Application for Facilities Management in the Construction Industry †

Oluwaseun Raimi *, Babatunde Ogunbayo and Clinton Aigbavboa

cidb Centre of Excellence & Sustainable Human Settlement and Construction Research Centre, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg 2006, South Africa; tundeogunbayo7@gmail.com (B.O.); caigbavboa@uj.ac.za (C.A.)

* Correspondence: raimioluwaseun66@gmail.com; Tel.: +2348133430392

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Abstract: Facilities management (FM) is pivotal in ensuring the efficient operation of built environments essential for organisational functions. However, buildings' operation and maintenance stages often incur significant costs, emphasising the importance of effective FM practices. Digital technology, particularly Virtual Reality (VR), offers innovative solutions to enhance FM in the construction industry. Despite its potential benefits, VR adoption faces various barriers, such as financial constraints and a lack of standardisation, expertise, and awareness. This study aims to explore the application benefits of VR in FM within the South African construction industry, addressing the knowledge gap in the existing literature. A comprehensive literature review identifies key benefits of VR application for FM. Strategies to improve VR implementation include the development of cost-effective solutions, extensive training programs, and collaborative initiatives with stakeholders and government agencies. By leveraging VR technology, FM practices can be revolutionised, improving safety, communication, and project optimisation. This study provides insights into overcoming challenges and harnessing the transformative potential of VR in FM, paving the way for a more efficient, safe, and sustainable built environment in the South African construction industry.

Keywords: virtual reality; facilities; management; construction; industry; benefits

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1. Introduction

Facilities management (FM) is a multidisciplinary field dedicated to establishing and maintaining an efficiently built environment crucial for organisational operations. In the lifecycle of a building, the operation and maintenance stages emerge as the foremost contributors to its overall costs, as highlighted by [1]. Ref. [2] emphasises that 50% to 70% of a facility's annual operating expenses are allocated to operations and maintenance, while [3] underscores that a substantial 85% of the entire lifecycle costs are devoted to facilities management (FM). The crucial daily management of properties revolves around maintenance management and energy consumption, as noted by [4]. Effective decision making in building maintenance necessitates the adept analysis and integration of diverse information and knowledge sources, including maintenance records and insights into the causes and consequences of failures generated by various stakeholders within the project team [5]. Ref. [1] noted that failure to capture and utilise this valuable information and knowledge can lead to ineffective decisions and significant costs, stressing the importance of proficiently managing information exchange and collaboration within the project team.

Digital technology in construction encompasses the scientific or engineering knowledge that deals with establishing and applying computerised or digital devices, methods, and systems with the potential to enhance the immediacy, accuracy, and flexibility of

construction processes [6]. This technological progression has revolutionised numerous individuals' daily routines and reshaped numerous traditional industry practices [7]. The construction sector remains marked by inefficiencies in its operations, alongside persistent challenges. Refs. [8,9] observed that among the challenges of adopting digital technologies for the construction industry are the financial cost of implementing new digital technologies, the maintenance cost of these digital technologies, and the personnel training required to use them. Furthermore, ref. [10] stated that the barriers facing the adoption of new technological innovations by construction professionals are centered on enough power supply (infrastructure), the price of digital technologies being high and not being accessible to all sizes of enterprises, cyber-security, the expense of employing information technology staff, and fear of technology cutting on professional jobs. Despite dedicated efforts to address these issues over time, progress in mitigating these challenges has been limited [11]. Integrating digital technologies in construction has yielded significant advantages, including process optimisation, improved service delivery, expedited job completion schedules, and cost savings [11,12].

Virtual reality (VR) represents a revolutionary visualisation technology that fundamentally alters how individuals engage with visual information. With its increasing prevalence, VR technology is poised to impact every sector as it continues to be rapidly adopted. Notably, VR was recognised as one of the top 10 strategic technology trends for 2019 by Gartner [13], underscoring its significance in shaping the technological landscape. The application of virtual reality (VR) for FM practices in the construction industry leverages its attributes, which include realism, interactivity, and visualisation capabilities [14]. However, there have been limited studies on the application possibilities of Virtual Reality as a digital tool in the South African construction industry for facilities management, thereby creating a knowledge gap that this study seeks to explore. Therefore, this study examines the benefits of virtual reality application for facilities management to enrich its application in the South African construction industry.

2. Literature Review

Despite its potential, the adoption of VR in the construction industry faces obstacles. Challenges include the significant cost of VR equipment, financial constraints, maintenance expenses, and adequate staff training, emphasising the multifaceted nature of financial barriers hindering VR adoption [8,9,15]. Another challenge is the lack of standardisation, with obstacles such as inadequate training, high costs, poor adaptability of standards, and interoperability issues hindering effective VR implementation in FM [16,17]. Additionally, the need for specialised skills poses a pivotal challenge, encompassing a lack of expertise, resistance to cultural change, the cost of VR implementation, application development complexity, and a broader technological immaturity [18,19]. Furthermore, a lack of awareness among facilities managers regarding VR compound challenges necessitates focused efforts on enhancing awareness and understanding among key stakeholders [18]. Addressing these multifaceted challenges is crucial for unlocking the full potential of VR in facilities management within the construction industry.

2.1. Benefits of VR Application for Facilities Management

Applying VR for facilities management (FM) within the South African construction industry offers multifaceted benefits. Ref. [20] emphasises VR's versatility, spanning simulation training, facilities simulation prototyping, designing, and testing, providing a risk-free environment for training against dangerous circumstances. Ref. [21] highlighted VR's prowess in enhancing performance and safety stimulation for complex operations. Ref. [13] described several benefits, including better impact assessment, technician risk reduction, real-time visual asset information, 3D simulation of large-scale operations, increased inclusivity, and easy understanding of simulation results. The adoption of VR in FM marks a paradigm shift, streamlining communication, enhancing safety planning, optimising project execution, and propelling the construction industry toward sustainability [22,23].

VR enables proactive FM through immersive 3D environments, facilitating observation and rehearsal of construction processes, increasing awareness, reducing delays, and improving project outcomes [24]. The identified VR applications in the South African context, including 3D model visualisation, remote inspection, maintenance training, and asset tracking, contribute to improved communication, enhanced spatial awareness, increased efficiency, and heightened safety, highlighting the substantial benefits of VR in facilities management within the South African construction sector.

VR applications for FM span various transformative solutions, encompassing asset visualisation, space planning, training, maintenance, remote monitoring, collaboration, and data visualisation [25]. This integration, marked by fully computer-generated environments, empowers professionals to manipulate, interact, and navigate in real time, optimising diverse facets of the built environment [26]. According to Ref. [27] these applications extend to construction safety training and cover various FM areas such as space modelling, interior design, lighting, fire risk assessment, landscaping, site layout, and construction process planning). Table 1., below, summarises the benefits of VR application for FM in the construction industry.

Table 1. Benefits of VR Application for Facilities Management.

S/N Benefits of VR Application for Facilities Management	Source(s)
1. Facilities Design and Testing	[17]
2. Safety Simulation	[18]
3. Better impact assessment	[19]
4. Enhancing safety planning	[19,20]
5. Better communication among stakeholders	[19,20]
6. Increased awareness	[21]
7. Reduced Delays	[21]

2.2. Strategies to Improve VR Application for FM in the Construction Industry

Several crucial steps and recommendations must be considered to propel the revolution of virtual reality (VR) in facilities management practices within the South African construction industry. Concurrently, there is a demand for developing cost-effective VR solutions, exploring alternative access models like cloud-based platforms, and implementing comprehensive training programs to upskill the workforce in VR technology and applications. Collaborative efforts with government agencies and industry stakeholders are essential to create supportive policies and infrastructure for widespread VR adoption. Strategies for VR application in construction management encompass educating relevant parties, skill development workshops, seminars on technology, awareness campaigns, training programs, government enforcement, regulation of VR systems, and policy development [28]. Ref. [29] emphasised the need for an innovative framework for VR in facilities management, describing a real-world pilot project that applied state-of-the-art VR-enabled strategies and tools, leading to a successful handover of FM-enabled VR. Additionally, ref. [30] advocates for integrating emerging technologies like VR into FM, offering valuable insights for construction industry stakeholders, thus contributing to the understanding and improvement of infrastructural FM, especially in developing countries. By addressing these recommendations and fostering continuous research and development, VR holds the potential to revolutionise facilities management practices, paving the way for a more efficient, safe, and sustainable built environment in the South African construction industry.

3. Research Methodology

This study employed bibliometrics to pinpoint critical areas in applying virtual reality for facilities management, utilising Scopus for data collection, renowned for its extensive coverage [31]. We focused on Scopus literature, widely recognised among scientific

researchers [32], concentrating our literature search on journal articles, conference proceedings, and books in domains like engineering, construction, and facilities management. These sources were chosen for their reputation as reliable knowledge repositories known for offering detailed information [33]. Our study spanned twenty-eight years, from 1995 to 2023, aiming to capture the latest practices in sustainable construction and resilient building practices. In March 2024, our search initially yielded 150 papers, refined meticulously to select 138 articles relevant to the construction field and in the English language. Visual representation of co-occurrence networks was generated using VOSviewer (version 1.6.19), known for its selective display of nodes and distance-based visualisations [34]. Figure 1, below, shows the research framework.

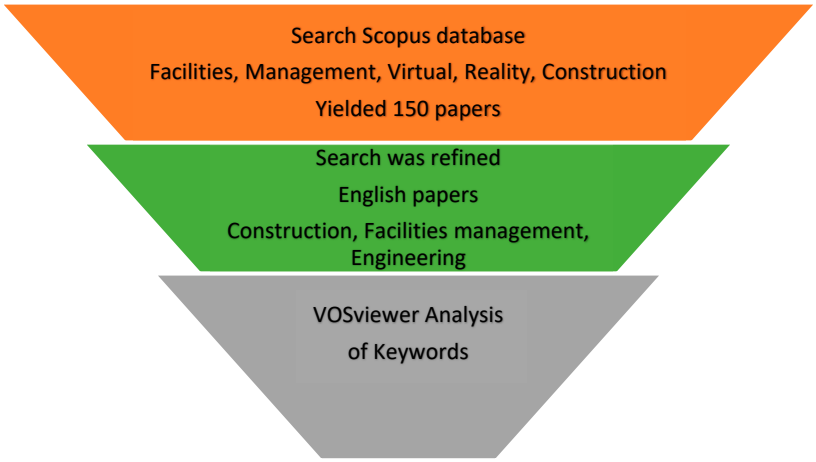

Figure 1. Research Framework.

4. Results and Discussion

The data in Table 2 reveals that conference papers dominate the publications, with 77 documents recorded, indicating a significant focus on disseminating research findings through conference presentations within the academic community. Following closely are articles, representing the next most common type of publication, with 36 documents identified, serving as a vital medium for in-depth exploration and analysis of virtual reality applications in facilities management within the construction industry. Additionally, conference reviews and reviews collectively contribute 24 documents, signifying a notable interest in summarising and evaluating the existing literature in this domain. Notably, there is a relatively lower number of book chapters, with only one document recorded, suggesting a lesser emphasis on comprehensive book-length treatments of the subject matter. The distribution of publication types reflects a dynamic and evolving research landscape, with a strong focus on conference presentations and scholarly articles as primary avenues for knowledge dissemination and exchange.

Table 2. Publication per document type.

Document Type	Number of Publications
Conference Paper	77
Article	36
Conference Review	24
Book chapter	1

Analysis of Co-Occurrence of Keywords

When constructing a co-occurrence map based on collected bibliographic data, it is crucial to determine the minimum number of co-occurrences required for extracting keywords. This is necessary for effectively categorising keywords into themes highlighting

previous studies' main areas. This investigation used a minimum of seven co-occurrences for the VOSviewer analysis, justified by the growing application of digital twins in the construction industry. The decision to deviate from VOSviewer's predefined minimum of five co-occurring keywords is supported by the work of [35], who previously employed a minimum of five co-occurrences. This approach reflects the suitability of a more adaptable threshold, especially in an emerging research area where a higher minimum may result in limited keyword outputs. Such an approach enables a nuanced analysis that captures relevant connections within a dynamic and evolving field. The study revealed a total of 1217 keywords across all 138 extracted publications. Among these keywords, 45 met the criterion of at least five co-occurrences and were subsequently organised into four clusters, as shown in Figure 2. Regarding the importance of keyword proximity for higher co-occurrence, perspectives from [33,36] argue that the outcomes generated in VOSviewer software may vary depending on the specific keywords used, and this variability is not necessarily linked to the topic's novelty or the keywords.

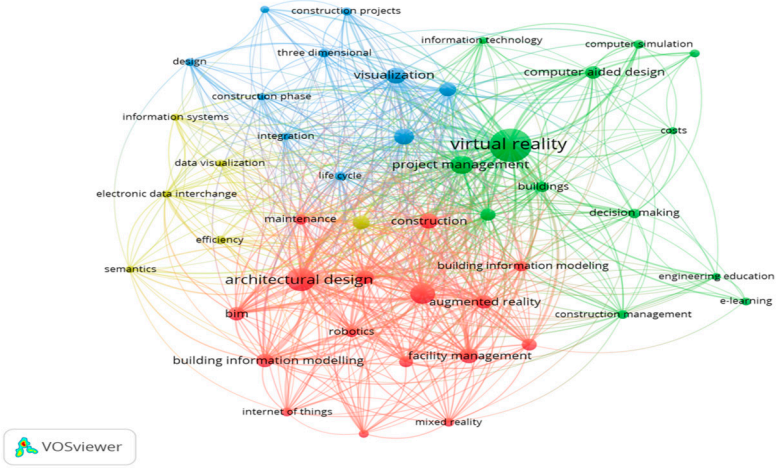

Figure 2. Network Visualisation Map.

Cluster 1 (red): Smart construction utilises innovative tech for efficiency, safety, and sustainability.
Cluster 2 (green): Digital construction leverages VR for design, simulation, project management, and education.
Cluster 3 (blue): Built environment benefits from VR in project visualisation, management, and spatial awareness.
Cluster 4 (Yellow): Data efficiency improves with VR's data visualisation, communication, collaboration, and information management capabilities.

5. Conclusions

In conclusion, this review highlights the transformative potential of virtual reality (VR) applications for facilities management in the construction industry. Through the examination of benefits and strategies surrounding VR implementation, it becomes evident that while VR presents significant opportunities, several challenges persist. Financial constraints and a lack of standardisation, expertise, and awareness emerge as critical hurdles to realising the full potential of VR in facilities management. However, the benefits of VR, including enhanced safety, communication, and project optimisation, underscore its value as a game-changing technology for the construction sector. Concerted efforts are necessary to address these challenges through innovative solutions, comprehensive training programs, and collaborative initiatives involving industry stakeholders and government agencies. By overcoming these obstacles, VR promises to revolutionise facilities management practices and drive efficiency, safety, and sustainability in the construction industry.

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References

1. Wong, J.K.W.; Ge, J.; He, S.X. Digitisation in facilities management: A literature review and future research directions. *Auto Const.* **2018**, *92*, 312–326. [CrossRef]
2. Rondeau, E.P.; Brown, R.K.; Lapides, P.D. *Facility Management*; John Wiley & Sons: Hoboken, NJ, USA, 2012.
3. Teicholz, P. (Ed.) *BIM for Facility Managers*; John Wiley & Sons: Hoboken, NJ, USA, 2013.
4. Lewis, A.; Elmualim, A.; Riley, D. Linking energy and maintenance management for sustainability through three American case studies. *Facilities* **2011**, *29*, 243–254. [CrossRef]
5. Ogunbayo, B.F.; Aigbavboa, C.O.; Thwala, W.; Akinradewo, O.; Ikuabe, M.; Adekunle, S.A. Review of culture in maintenance management of public buildings in developing countries. *Buildings* **2022**, *12*, 677. [CrossRef]
6. Bamgbose, O.A.; Ogunbayo, B.F.; Aigbavboa, C.O. Barriers to Building Information Modelling Adoption in Small and Medium Enterprises: Nigerian Construction Industry Perspectives. *Buildings* **2024**, *14*, 538. [CrossRef]
7. Copeland, D. Digital Technology. 2013. Available online: https://www.defence.lk/upload/ebooks/Costas%20M.%20Constantinou,%20Pauline%20Kerr,%20Paul%20Sharp-The%20SAGE%20Handbook%20of%20Diplomacy-SAGE%20Publications%20Ltd%20(2016).pdf#page=667 (accessed on 20 October 2024).
8. El-Mashaleh, M.S.; Edward Minchin, R., Jr.; O'Brien, W.J. Management of construction firm performance using benchmarking. *J. Manag. Eng.* **2007**, *23*, 10–17. [CrossRef]
9. Ogunbayo, B.F.; Abina, O.G.; Aigbavboa, C.O. Enabling Technologies of Health and Safety Practices in The Fourth Industrial Revolution: Nigerian Construction Industry Perspective. *Front. Built Environ.* **2023**, *9*, 1233028.
10. Oladapo, A.A. A quantitative assessment of the cost and time impact of variation orders on construction projects. Journal of Engineering. *J. Eng. Des. Technol.* **2007**, *5*, 35–48.
11. Ikuabe, M.O.; Aghimien, D.O.; Aigbavboa, C.O.; Oke, A.E. Inhibiting factors to the adoption of digital technologies in the South African construction industry. In Proceedings of the 5th Research Conference of the NIQS (RECON5) 2020, Lagos, Nigeria, 9–10 November 2020; Nigerian Institute of Quantity of Surveyors: Abuja, Nigeria, 2020; pp. 455–461.
12. Aghimien, D.; Aigbavboa, C.; Oke, A.; Koloko, N. Digitalisation in the construction industry: Construction professionals perspective. In Proceedings of the Fourth Australasia and South-East Asia Structural Engineering and Construction Conference, Brisbane, Australia, 3–5 December 2018; pp. 3–5.
13. Delgado, J.M.D.; Oyedele, L.; Beach, T.; Demian, P. Augmented and virtual reality in construction: Drivers and limitations for industry adoption. *J. Constr. Eng. Manag.* **2020**, *146*, 04020079. [CrossRef]
14. Maher, M.L.; Rosenman, M.; Merrick, K.; Marchant, D. Designworld: A multidisciplinary collaborative design environment using agents in a virtual world. In *Design Computing and Cognition*; Gero, J.S., Ed.; Springer: Berlin/Heidelberg, Germany, 2006; pp. 695–710.
15. Oke, A.E.; Aliu, J.; Onajite, S.; Simeon, M. Success factors of digital technologies (DT) tools adoption for sustainable construction in a developing economy. *Constr. Innov.* 2022; *ahead-of-print*.
16. Oke, E.A.; Omoregie, A.D.; Koloko, A.C.O. Challenges of digital collaboration in the South African construction industry. In Proceedings of the International Conference on Industrial Engineering and Operations Management Bandung, Bandung, Indonesia, 6–8 March 2018; pp. 6–18.
17. Lapierre, A.; Cote, P. *Using Open Web Services for Urban Data Management: A Test Bed Resulting from an OGC Initiative for Offering Standard CAD/GIS/BIM Services, Urban and Regional Data Management: UDMS Annual 2007*; Taylor and Francis: London, UK, 2008; pp. 381–395.
18. Badamasi, A.A.; Aryal, K.R.; Makarfi, U.U.; Dodo, M. Drivers and barriers of virtual reality adoption in UK AEC industry. *Eng. Constr. Archit. Manag.* **2022**, *29*, 1307–1318. [CrossRef]
19. Hampson, K.; Kraatz, J.A.; Sanchez, A.X. *R&D Investment and Impactin the Global Construction Industry*; Routlege: Oxford, UK, 2014.
20. Lele, A. Virtual Reality and Its Military Utility. 2013. Available online: https://link.springer.com/article/10.1007/s12652-011-0052-4#Sec2 (accessed on 12 December 2022).

21. 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. [CrossRef]
22. Getuli, V.; Capone, P.; Bruttini, A.; Isaac, S. BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach. *Auto Constr.* **2020**, *114*, 103160. [CrossRef]
23. Lew, Y.L.; Toh, T.C.; Lim, K.L.; Yan, F.Y.Y.; Yow, L.P. A study on the constraints of implementing Information and Communication Technology (ICT) in Malaysian Construction Industry. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *385*, 012005. [CrossRef]
24. Nassereddine, H.; Hanna, A.S.; Veeramani, D.; Lotfallah, W. Augmented Reality in the Construction Industry: Use-Cases, Benefits, Obstacles, and Future Trends. *Front. Built Environ.* **2022**, *8*, 730094. [CrossRef]
25. Shamsudin, N.M.; Mahmood, N.H.N.; Rahim, A.R.A.; Mohamad, S.F.; Masrom, M. Virtual reality training approach for occupational safety and health: A pilot study. *Adv. Sci. Lett.* **2018**, *24*, 2447–2450. [CrossRef]
26. Sacks, R.; Perlman, A.; Barak, R. Construction safety training using immersive virtual reality. *Constr. Manag. Econ.* **2013**, *31*, 1005–1017. [CrossRef]
27. Bouchlaghem, N.M.; Liyanage, I.G. Virtual reality applications in the UK's construction industry. In *Construction on the Information Highway, Proceedings of CIB W78 Workshop, Bled, Slovenia, 10–12 June 1994*; Turk, Z., Ed.; University of Ljubljana: Ljubljana, Slovenia, 1996.
28. Malomane, R. *The Impact of Fourth Industrial Revolution Technologies in Managing Health and Safety within the Construction Industry*; University of Johannesburg: Johannesburg, South Africa, 2022.
29. Pishdad-Bozorgi, P.; Gao, X.; Eastman, C.; Self, A.P. Planning and developing facility management-enabled building information model (FM-enabled BIM). *Auto Constr.* **2018**, *87*, 22–38. [CrossRef]
30. Okwe, E.I.; Olanrewaju, O.I.; Heckman, M.; Chileshe, N. Barriers to building information modelling and facility management practices integration in Nigeria. *J. Facil. Manag.* **2023**, *21*, 845–865. [CrossRef]
31. Zhu, J.; Liu, W. A tale of two databases: The use of Web of Science and Scopus in academic papers. *Scientometrics* **2020**, *123*, 321–335. [CrossRef]
32. Singh, P.; Piryani, R.; Singh, V.K.; Pinto, D. Revisiting subject classification in academic databases: A comparison of the classification accuracy of web of science, Scopus& dimensions. *J. Intell. Fuzzy Syst.* **2020**, *39*, 2471–2476.
33. Aghimien, D.O.; Aigbavboa, C.O.; Oke, A.E.; Thwala, W.D. Mapping out research focus for robotics and automation research in construction-related studies: A bibliometric approach. *J. Eng. Des. Technol.* **2020**, *18*, 1063–1079. [CrossRef]
34. Oladinrin, O.T.; Arif, M.; Rana, M.Q.; Gyoh, L. Interrelations between construction ethics and innovation: A bibliometric analysis using VOSviewer. *Constr. Inv.* **2023**, *23*, 505–523. [CrossRef]
35. Babalola, A.; Musa, S.; Akinlolu, M.T.; Haupt, T.C. A bibliometric review of advances in building information modeling (BIM) research. *J. Eng. Des. Technol.* **2023**, *21*, 690–710. [CrossRef]
36. Eshima, S.; Imai, K.; Sasaki, T. Keyword-assisted topic models. *Am. J. Pol. Sci.* **2024**, *68*, 730–750. [CrossRef]