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Investigating the Research Landscape of Virtual Reality in Built Environment Education on the African Continent: a Bibliometric Review

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1 ABSTRACT

The Fourth Industrial Revolution brought disruptive changes that profoundly impacted all industries, promising revolutionary progress in ideologies and processes. Although this revolution casts a shadow of uncertainty, it brings great potential to improve how humanity will live, learn, work, and play in the future. Industry 4.0, like previous revolutions, significantly impacts the often-sluggish Construction Industry and, equally, the education of future construction professionals. Disruptions by technologies such as Building Information Modelling (BIM), Virtual Reality (VR), Augmented Reality (AR), 3D Printing, Artificial Intelligence (AI) in various automated derivatives and other technologies have shown a significant impact on the design and creation of the Built Environment (BE). Consequently, education and training in Industry 4.0 systems are crucial for smooth progress in articulating the development of future professionals. In this research, the authors investigate the research landscape of virtual reality and BE education in an African context. An appropriately curated bibliometric review process is utilised to examine the current trends in this niche body of knowledge. The review process utilises exported data from Scopus using the terms ‘virtual reality’, ‘education’, ‘built environment’ and ‘Africa’ between 1998 and 2024. The exported data was then analysed using Vos Viewer software to illustrate the main keywords around the study area through network maps. Preliminary results reveal that VR technology in BE education is severely under-researched in Africa and globally. However, a steady incline in VR technology research reveals an increase of 719.73%. With due consideration of the importance of VR in an educational setting, the lack of research reveals not only an under-researched field but also an underutilised resource that has the potential to be incredibly impactful. Therefore, a recommendation is made to conduct empirical studies in educational settings using VR technology as part of the pedagogical approach to training future BE professionals.

Keywords: 4IR, biuilt environment, virtual reality, pedagogy, Africa

2 INTRODUCTION

The progress of humanity is a testament to the remarkable ingenuity of our species. Human beings have an inherent ability to progress rapidly and, at the same time, consciously reflect and implement corrective actions for their perceived benefits. At various historical moments, human beings have left evidence of their development. The unravelling of history between the Stone Age and the Modern era illustrates the humanitarian progress that had sudden peaks of rapid development. A critical peak in development that marks the modern era is recorded as the move from an agrarian society to an industrial mass production model, which trades globally rather than locally. Although the first industrial revolution is a reminder of the tragedies committed in Africa, the rapid development of human beings is well documented, consequently leaving the world unrecognisable over a short period (Oliver & Oliver, 2017; Christopher, 2023).

Humanity actively participates in the fourth industrial revolution, which has recently become a pivotal topic in various knowledge bodies. The rapid development of artificial intelligence and machine learning and a firm reliance on digital technologies to advance everyday processes are keyframes of significant change. Unlike other industrial revolutions, the Fourth has impacted human processes beyond physical tasks, challenging human intelligence and bridging the gap between the biological mind and machine (Schwab, 2016; Marwala, 2021; Mazibuko-Makena & Kraemer-Mbula, 2021). This sudden change has threatened various industries, removing the need for humans in specific processes. For example, tasks that require higher-order thinking to complete will be challenging to replace compared to functions that require simple or routine outputs (Dahlin, 2019; Webb, 2019). Consequently, this argument has been a point of heated discussion on the purpose of humans and our developmental trajectory as active citizens in the economy.

Although the rapid change in the job market is seen as a challenge, Marwala (2021) asserts that the growth of future economies relies heavily on the lifelong learning of citizens who are resilient to an actively changing environment. Continual improvement and upskilling concretise humans‘ importance in the industrial process. Johannessen (2023) states that human competence in digital technologies is the key to augmenting old competence into skills required for the labour market 4.0. In this sense, high competency in these digital technology skills becomes the currency of the future in the rapidly changing capitalist world. Although arguments are on either end of the spectrum, an agreement is that this revolution is significantly disruptive and requires human capital to embrace change.

Drawing from the premise of 4IR technology as an assistive principle in humanitarian processes and the need for upskilling, the authors use this rationale to explore technologies critical to developing future BE professionals. Furthermore, as a note, the BE industries are often categorised as digitally adverse (Abioye et al., 2021) and sluggish or resistant to change (Letsoko & Pillay, 2019). It is, therefore, a crucial departure point to explore the various 4IR digital technologies and the relevant usages within the BE. For the scope of this study, the authors focus on exploring the research landscape of Virtual Reality Technologies within the BE disciplines, explicitly focusing on implementation within the BE education sector in Africa. This approach is curated as a step in exploring a field lacking research output and potentially contains gaps in knowledge which will require further investigation.

3 REVIEW OF LITERATURE

The literature review for this study aims to reinforce the rationale, support the investigation of the research question, and locate the study's variables within the existing body of knowledge. Critical to this approach, the authors curate a review of the literature to unpack the concept of Virtual Reality and explore the perceived benefits of the technology within BE education.

3.1 Virtual Reality

Virtual Reality (VR) technology has been introduced previously; however, it was used before mass digitisation and the advent of the 4IR. Slater (2018:433) professes that contemporary VR technology has a 30-year development history and "did not suddenly appear out of nowhere in 2012". The technology dates back to 1916 when the first head-mounted periscope was patented by Albert B. Pratt (Sherman & Craig, 2018). As early as 1931, the first flight simulators were developed and patented by Edward Link, using simple mechanical technologies to simulate flight virtually (Paro, Hersh & Bulsara, 2022). Although VR is conceptualised as a visual technology, it encompasses all senses to create immersion. In the 1950s, Martin Heilig, the father of virtual reality, experimented with multi-sensory experiences that engaged all the senses (Kapoor & Kalia, 2023). The technology was further developed by Ivan Sutherland in the 1960s using a head-mounted display (HMD) named Sword of Damocles, contemporarily known as a VR headset (Wohlgenannt, Simons & Stieglitz, 2020). At this point, most developments in VR were for professional and industrial uses. In the early 1990s, attention was turned to computer gaming used by companies such as W-Industries, Attari, Nintendo, Sega, and others (Sherman & Craig, 2018). From here on, the trajectory of VR technology changed to commercialisation and civilian uses. The years leading up to the current technologies were developmental, and the introduction of other supporting technologies now allows VR technology to be used for various purposes (Sherman & Craig, 2018; Slater, 2018; Wohlgenannt, Simons & Stieglitz, 2020; Paro, Hersh & Bulsara, 2022; Kapoor & Kalia, 2023).

Notwithstanding the digital age, eighteenth-century philosopher Immanuel Kant coined the term Virtual Reality to describe the reality in one‘s mind (LaValle, 2023). In this sense, reality was virtual (mind) and was separate from the physical world. Jaron Lanier later coined Virtual Reality, placing it in a modern setting by including digital technology as a complexity layer. Henceforth, the authors refer to the Lanier term as a basis for defining Virtual Reality. Many modern understandings of Virtual Reality tend to focus on visual perceptions; however, the Heilig approach of multi-sensory immersion is a robust benchmark from which the premise of the technology shows the potential power and abilities to simulate the real world. Zhang & Xue (2023) observe that VR technology utilises image processing and other hardware technologies to allow a sensory experience through sight, smell, sound and touch. Lv (2020) argues that although visual, auditory, and tactile senses are well developed, researchers must do more work to create true immersion to develop olfactory, taste and mechanical perception in VR systems. By using techniques to replicate the natural world through the senses, users of VR technology can be completely immersed in the Virtual Environment (VE), which may result in an indistinguishable experience.

Beyond sense immersion, VR technology requires five key elements: Participants, Creators, Virtual world, Immersion, and Interaction (Sherman & Craig, 2018). For any VR system to work, it requires a participant to engage with the virtual environment. Various examples of this application define distinct participants and creators, such as in sports (Neumann et al., 2018), education (Radianti et al., 2020), arts (Zhang & Xue, 2023), medicine (Rantamaa et al., 2023), and several others. Creating a virtual environment that elevates the participant experience is critical to successful interdependence. With it, the perceived experience is likely to stay strong. VR technology focuses on creating a world that either mimics the physical world (captured) or creates a world using computer-generated graphics (synthetic), often termed the virtual world or virtual environment (LaValle, 2023). Therefore, prioritising the development of a virtual environment is crucial to guarantee a successful outcome.

The virtual environment must be immersive to engage a participant fully, simulating or elevating a natural experience. A study conducted by Zhang & Xue (2023) on the use of VR technology in museums to simulate a visit shows evidence of enhancing user experience by creating digital maps of exhibitions to navigate through large spaces and better interaction in a dynamic environment as opposed to standing in a static position and overall greater experience without the distraction of large crowds. Geraets et al. (2021) acknowledge the potential power of VR technology in psychological cases, where patients experience the same or better results through immersion in treatment practices and outcomes; moreover, this approach was more cost-effective, and the reach was greater. Although these are only two examples, the body of knowledge comprises several studies illustrating robust use cases where immersion through VR technologies has significantly impacted respective cases.

Interactivity, the fifth key element in VR technology, elevates the user experience to simulate the real world entirely. Sherman & Craig (2018:12) profess that the simulation must respond to user actions for VR technology to seem authentic. An experimental study conducted by Lyu et al. (2023) presents a case in which multi-sensory stimuli incorporated into virtual reality to experience an outdoor space increased the sense of immersion and presence, uplifting the interaction between human-built environments. Methodologies such as those proposed by Lyu et al. are critical, especially in the construction industry, where environmental design conditions can be simulated to assist designers in providing pre-tested solutions before implementation. Thus, VR technology shows incredible promise as a source of experimentation to enhance final implementable solutions.

3.2 VR in the Built Environment

As a base, the physical Built Environment is often used as a virtual environment to create immersion for the participant. However, the Built Environment can be created virtually for several different requirements. Virtual reality can inherently mimic real-world situations and opens the stage for experimentation before implementation (Sherman & Craig, 2018; LaValle, 2023). In this sense, Built Environmental professionals can use this tool to enhance their primary duties by adding a layer of complexity in the form of big data and Virtual Reality in their processes.

The design disciplines in the context of the Bult Environment have always relied on visual methodologies to represent, experiment, and execute projects in the grandest of scales. For example, architects and planners often use physical models to represent large urban spaces, individual buildings and even minute details. The introduction of CAD and BIM enhanced these methodologies by creating digital models of existing and future developments (Pillay, Gumbo & Musonda, 2019). Although these technologies have proven robust, the lack of immersion and interaction with space and environmental conditions has been an age-old issue; VR technology bridges this gap and offers an additional medium of experiencing space before it is physically constructed (Davila Delgado et al., 2020).

As a point of departure, the professional disciplines of architecture, planning and engineering are perceived to benefit significantly from VR technology as an assistive layer for problem-solving in the design process and a medium of representation. Beyond the prospects of a medium of representation, VR technology can be used to simulate real-world- buildings with various levels of outcomes, resulting in buildings that meet or surpass the requirements of sustainable design (Suryawinata, 2021). Ahmed (2019) posits that VR technology effectively visualises sector planning, communication, and safety. Regarding physical construction, VR technology can effectively work on various safety methodologies and processes ((Zhang et al., 2022; Luo et al., 2023). VR impacts the construction industry as a technology with multiple uses, especially regarding cost savings, quality, safety, and the ability to virtually experience built infrastructure.

3.3 VR in Education

The built environment education (architectural design and construction) looks to implement more commercially available VR technologies into the curriculum as VR was previously perceived to be expensive, difficult to attain, and requiring specialized facilities and facilitators. In 2006, 'Virtualsite' (a virtual reality multi-media) created virtual construction site tours for students. This enhanced student experiences in teaching and learning as it could mimic sites through visualisation (Horne & Thompson, 2008). VR has been implemented in built environment education for around two decades. With VR being more accessible, students can create several simulations and make adjustments that may have been expensive or dangerous to replicate in the real world. Through these simulations, students can even make impulsive creative designs and get instant results on the feasibility of it. VR facilitators in built environment education find that students better understand when viewing multifaceted designs and structures spatially(Alizadehsalehi, Hadavi & Huang, 2019).

4 METHODOLOGY

For this study, a bibliometric analysis approach was utilised. This methodology has proved to be rigorous as a quantitative approach to analyse large data sets. It has proved helpful in various research domains to map a field's current state and observe nuances and development (Donthu et al., 2021). The authors use this methodology to explore the knowledge structure and visually map and analyse the field of "Virtual Reality" in the domain of "Built Environment Education" on the continent of "Africa". Data using the term "Virtual Reality" between 1994-2024 was exported using Scopus. Figure 1 represents the searching, screening, and inclusion procedure.

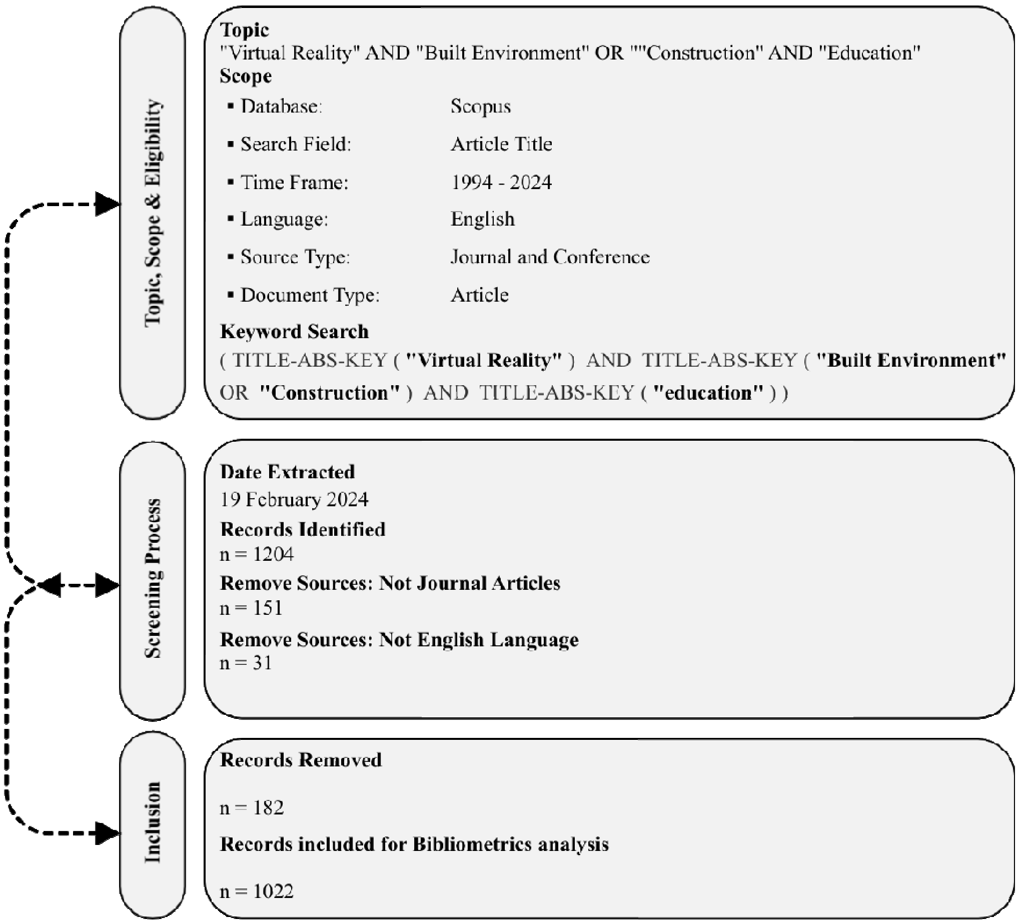

Figure 1: Methodological workflow of the Bibliometric analysis.

The main aim of this research is to investigate the research landscape of virtual reality in built environment education in Africa. Therefore, the study has been designed to unpack the knowledge structure of the field by using the following research questions:

- What is the conceptual knowledge structure of the field?
- What is the intellectual knowledge structure of the field?
- What is the social structure of the field?
- How does Africa fit into the body of knowledge?

Following the collection of data from the Scopus database, it was imported into Bibliometrix to conduct the analysis (Aria & Cuccurullo, 2017). Concluding the analysis, data was exported to VOS Viewer for graphical representation. Responding to the research questions, the authors mapped its knowledge structure. To achieve this, conceptual, intellectual, and social frameworks were used to explore the body of knowledge (Samiee & Chabowski, 2012). A keyword co-occurrence analysis was used to map the conceptual structure of the field, a document and author co-citation analysis was used to map the intellectual structure and a document co-authorship was used to map the social structure. Each technique discovered deep patterns, which are usually missed without this approach. The investigation methodology of these structures is detailed in the analysis section of this research. To conclude the research, the analysis of the knowledge structure revealed elements of how Africa, as a contributor of knowledge, fits into the network.

5 RESULTS, ANALYSIS AND DISCUSSION

5.1 Analysis of Annual Publications

It is critical to understand the publication trend over several years to determine the level of interest within that given domain. For this study, the researchers used bibliometric data over 30 years between 1994 and 2024. Referencing Figure 2, between the period 1994 to 2016, the publication rate in this field was relatively slow. Although the trend is upward, during this period, the general norm was a peak followed by a trough. A significant increase in publications from 21 documents in 2016 to 47 papers in 2017, representing 4,60% of the cumulative total of publications in this area of research over the 30 years. This upward spike in research is due to the launch of consumer-orientated VR systems by companies such as Oculus, HTC, and Valve (Sherman & Craig, 2018). VR products' commercial availability meant that they were readily available in the market and could be used by anyone. The trajectory forward shows a significant increase in publications between 2020 and 2021, almost doubling publication documents. Considering the COVID-19 pandemic in this temporal scope, evidence suggests that researchers were looking at remote teaching, especially in fields requiring immersion. In 2023, the research interest in this field tapered off. This could be for many reasons, including the end of pandemic measures or no significant technological development to report. Overall, the publication trend indicates substantial growth in this area of research.

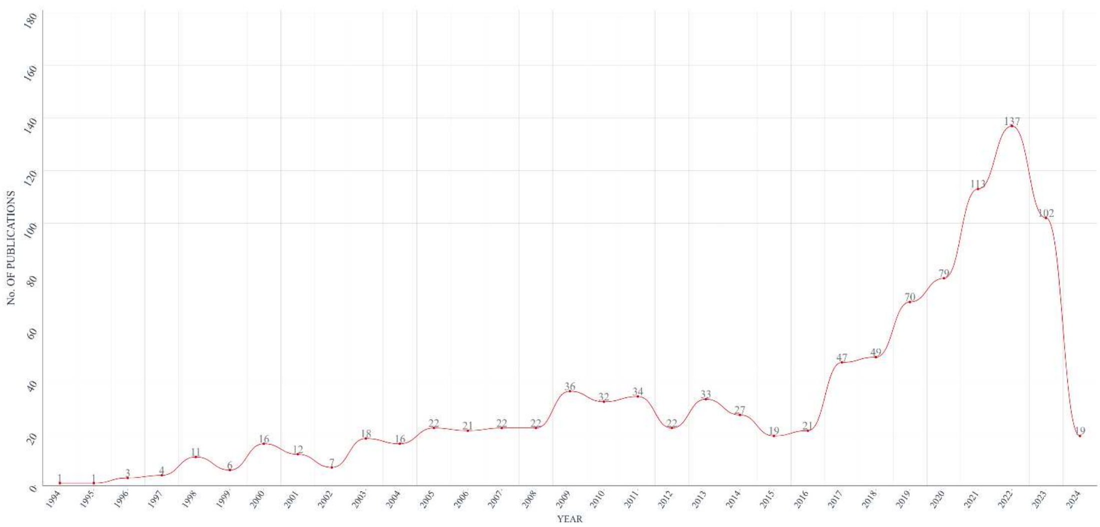

Figure 2: Graph depicting the publication trend of the topic area between 1994 and 2024.

5.2 Intellectual Knowledge Structure of the Field

In this research segment, the authors use science mapping to represent the intellectual structure of the field. In direct response to the first three research questions and the development of the overall research aim. The conceptual, intellectual, and social structures will be analysed to conduct this procedure. The global body of knowledge must be represented before distilling down to the specific focus of this research. Therefore, the intellectual knowledge structure is created and represented as a base of analysis.

5.2.1 Conceptual Structure

The second set of data analysed for this study consisted of a keyword co-occurrence network analysis. Drawing from the upward trend in research publications from the first data set, it is critical to analyse which research areas are in high demand within the keyword variables, answering the first research question. During the sorting of data, 6,281 keywords were exported from the Scopus database, and a minimum of 5 co-occurrences, of which 399 words met the threshold. This created 8 clusters and a total of 12670 links with a link strength of 31512.

The top 10 preferred keywords from the data are listed in Table 2. Compared to the total publications exported, an undeniable link between Virtual Reality and E-learning, Engineering Education and Students is present. This data reveals a strong focus on using Electronic Learning Technologies such as VR in education, especially engineering education. To further investigate the pertinent topics in this field, a network map was created in VOS Viewer with a temporal overlay (2014-2024) to understand the research trend. The research areas that move between orange and red are new or emerging research areas. Although Engineering Education features highly in several publications, the research interest in this field has slightly tapered away. E-learning remains high on the agenda with strong links to curricula, virtual reality technology, learning systems, students, and education computing. This relationship shows that E-learning is closely related to those fields, and the relationship between these keywords is evidence of educational disciplinary collaboration. Emerging research in this area comes from themes such as Metaverse, Virtual Simulations, 3D Modelling, Simulation Platforms, and E-learning. Representation of these areas appears smaller, represented as darker orange and red. However, this is evidence of a research gap.

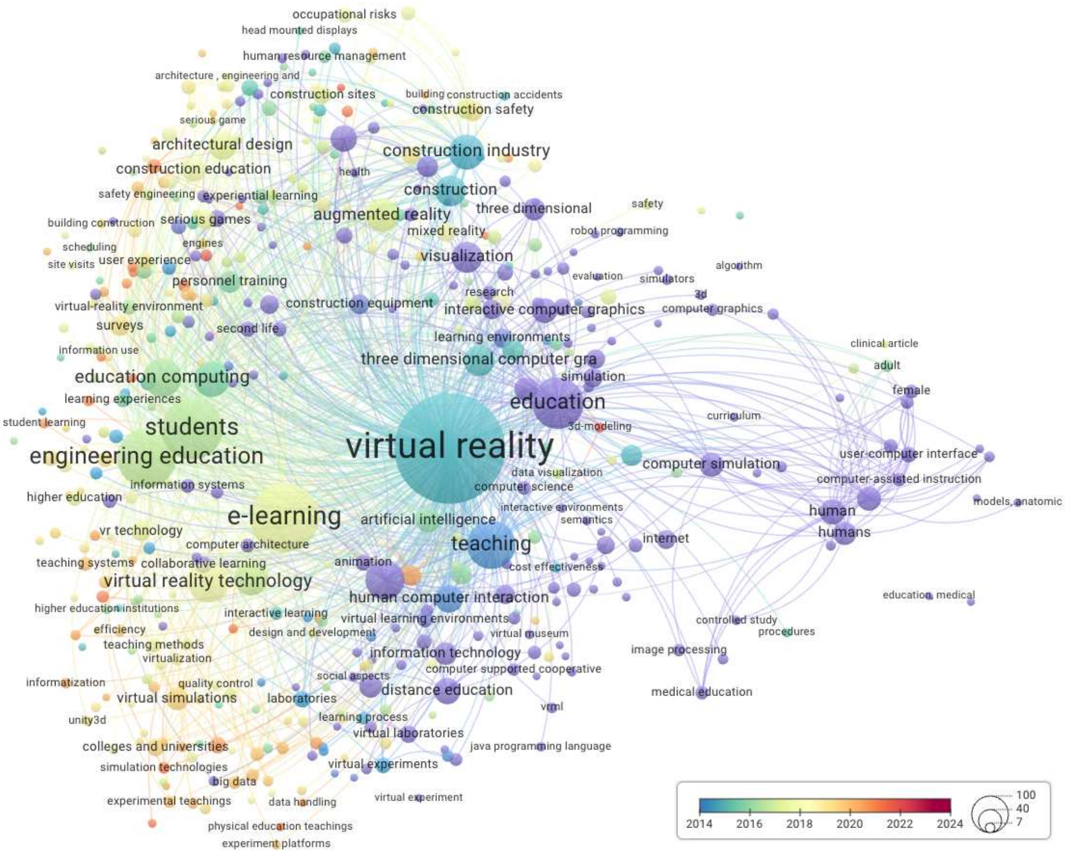

Figure 3: Visualised network map of research themes, overlay between 2014 and 2024 (10-year period) to understand the trajectory of research themes.

Author Keywords	Occurrences	Percentage (%)	Link Strength
Virtual reality	803	14,50%	5922
E-Learning	326	5,89%	2765
Engineering Education	265	4,79%	2317
Students	260	4,69%	2353
Education	190	3,43%	1560
Teaching	163	2,94%	1578
Virtual Reality Technology	118	2,13%	961
Education Computing	109	1,97%	1062
Computer Aided Instruction	96	1,73%	869
Construction Industry	87	1,57%	881

Table 1: The top 10 Keywords in the research network.

5.2.2 Intellectual Structure

In data set three, the focus is moved to the intellectual structure of the field. Therefore, a co-citation analysis utilised document and author coupling to determine the intellectual knowledge structure. Co-citation analysis, developed by Henry G. Small, advocates that a citation symbolises an idea or concept (Small, 1978). Co-citation analysis is a powerful method where citing authors is central to the metric. A set of two identical articles is termed co-cited when it appears in the reference list of a new article; the frequency at which this occurs over some time results in a count of co-citation occurrence. Small (1973) interprets the idea of larger co-citation count as a measure of similarity or co-occurrence of ideas. Furthermore, he advocates that co-citation is a powerful measure because, over time, new documents or authors with new ideas become central to the focus and are co-cited; thus, it is possible to track knowledge development (Small, 1973).

Document Co-citation Analysis.

To determine the formation of the body of knowledge, the authors opted for a document co-citation analysis to reveal the underlying concepts and theories used to create this niche topic. The ten largest nodes are used to determine the centrality of knowledge and network formation. Each node represents a highly cited document, the size of the document is the normalised citation count, the thickness of the link line represents the frequency of co-citation, and the proximity of the two nodes represents the thematic relationship. The addition of a temporal scope helps in understanding the development of the field over time.

As the pedagogical foundation for this research, Node 6 and Node 2 are essential in the network and represent the underlying theories and concepts of experiential learning and situated learning. Kolb (1984) articulates that through life experience, great learning occurs due to direct sense experience and in-context action. Lave & Wenger (199:14) compound that learning is inextricably linked to actional contexts and not self-contained structures, which they term legitimate peripheral participation. The two authors clearly state that learning in a realistic environment allows students to gain experience without total responsibility. It is clear why these authors are critical in forming this knowledge area; the theories are central to learning and act as a support structure for using Virtual Reality technology in a learning environment. Furthermore, VR technology can allow students to be immersed in a real-world environment while participating in skill development without risk and responsibility.

Building upon the ideas of Node 2 and 6, Node 10 unpacks the idea of presence. Steuer (1995) reveals that virtual reality in various bodies of knowledge is defined by the idea of technology but devoid of the human experience. He argues that virtual reality is a communication medium through which a human can experience presence in a mediated environment and uses this telepresence(Steuer, 1995). The author's ideas give rise to the need to create an environment that allows the human being to be aware of the virtual environment by stimulating the senses to create a lifelike experience. Node 4 builds upon the experience of the environment and unpacks the ideas of immersive environments. A study by Paes, Arantes & Irizarry (2017) reveals that immersion in a virtual-environment results in a better spatial understanding. Therefore, virtual reality technology must always be able to interact with the senses and immerse the user to take full advantage of the experience. Node 5 introduces the concept of simulation within the VR environment.

Node 9 is a pivotal piece of literature in the context of Virtual Reality in the Built Environment. Considering the temporal location of the book, the author introduces the use of VR in the planning, design, and construction process (Whyte, 2003). Therefore, the literature is seminal in introducing the built environment fields to VR technology. (Zyda et al., 2005) advocate for the need to introduce gamification to Virtual Reality simulations so users can interact well with it linked to an outcome.

Node 8 is a critical juncture in the field of education. Although this paper is not the first to introduce the VR concept to education, the document reviews findings from several other papers over ten years (1999-2009). Therefore, it is likely that several authors in the field use this document as a source to study the state of the art. Node 3 moves the discussion into the construction profession to build on the findings in an educational context. (Wang et al., 2018)e the most studied areas in VR-integrated construction education.

At the centre of the network, Node 1 acts as the main bridge in knowledge flow in the fields. This indicates that the paper by Sacks, Perlman & Barak (2013) integrates a large body of knowledge in various areas. On closer inspection, the study integrates the various knowledge areas to conduct an empirical study with rich results. One is creating a virtual construction site where safety training can occur. Although the paper's title is focused on construction safety, the content is central to the greater knowledge body, integrating several concepts. Node 7 moves the discussion to the practical implications of the technology and the need to improve or enhance the current methodologies and, therefore, enhance their position in the knowledge body(Eiris, Gheisari & Esmaeili, 2020).

Year	Article	Node	Key Themes	Betweenness Centrality
1984	Kolb, D.A., 1984. Experiential learning. Experience as the Source of Learning and Development, 41.	6 Pink	Experiential Learning	236.06
1991	Lave, J. and Wenger, E., 1991. . Cambridge University Press.	2 Grey Blue	Situated Learning	595.52
1995	Steuer, J., Biocca, F. and Levy, M.R., 1995. Defining virtual reality: Dimensions determining telepresence. *Communication in the age of virtual reality*, *33*, pp.37-39.	10 Light Orange	Virtual Reality	144.24
2003	Whyte, J., 2003. Virtual reality and the built environment. *Presence*, *12*(5), pp.550-552.	9 Dark Blue	Virtual Reality in the Built Environment	156.97
2005	Zyda, M., Mayberry, A., McCree, J. and Davis, M., 2005. How We Built a Hit Game-based Simulation.	5 Light Pink	Game Based Simulation	339.09
2011	Mikropoulos, T.A. and Natsis, A., 2011. Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education*, *56*(3), pp.769-780.	8 Grey	Virtual Reality in Education	163.33
2013	Sacks, R., Perlman, A. and Barak, R., 2013. Construction safety training using immersive virtual reality. *Construction Management and Economics*, *31*(9), pp.1005-1017.	1 Orange	Virtual Reality in Construction safety training	978.94
2017	Paes, D., Arantes, E. and Irizarry, J., 2017. Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems. *automation in Construction*, *84*, pp.292-303.	4 Yellow	Immersive Environments	381.16
2018	Wang, P., Wu, P., Wang, J., Chi, H.L. and Wang, X., 2018. A critical review of the use of virtual reality in construction engineering education and training. *International journal of environmental research and public health*, *15*(6), p.1204.	3 Cyan	Virtual Reality in Construction Education	390.14
2020	Eiris, R., Gheisari, M. and Esmaeili, B., 2020. Desktop-based safety training using 360-degree panorama and static virtual reality techniques: A comparative experimental study. *Automation in construction*, *109*, p.102969.	7 Light Brown	Virtual reality and Safety training	182.57

Table 2: Top Ten documents creating the knowledge flow in the document co-citation network.

Author Co-citation Analysis

To further map the research field, the authors opted to conduct an author co-citation analysis to identify the main authors in the field and their research directions. This is critical in understanding the intellectual knowledge structure and which authors influence and create connections within the field (Song, Wu & Ma, 2021). To conduct the analysis, the authors used the entire cohort of authors and then applied a minimum of 30 citations as a cut-off, of which 68 authors met the threshold. Results revealed that author Wang X is a central part of the network; the high number of citations evidence this. The work of Wang X is central to robotics in the construction industry, therefore placing them at the centre of this research network. Gheisari M appears to be the second most cited researcher in the network; their work in construction education using VR technologies places them as a large node in the network, evidenced by 148 citations. Li H comes in third with 113 citations; their work is concentrated within digital technologies in construction, making them a vital node connecting academia and industry. Sampaio AZ's work focuses on pedagogical approaches to VR, especially in civil engineering education. Therefore, their work forms an integral node, moving knowledge and acting as a bridge to focused areas of construction education. Jalal A sits on the periphery of the network. Studying the works of Jalal A, the author’s works are in computer science; however, the technology discussed within the author’s oeuvre supports new developments and integration within this network.

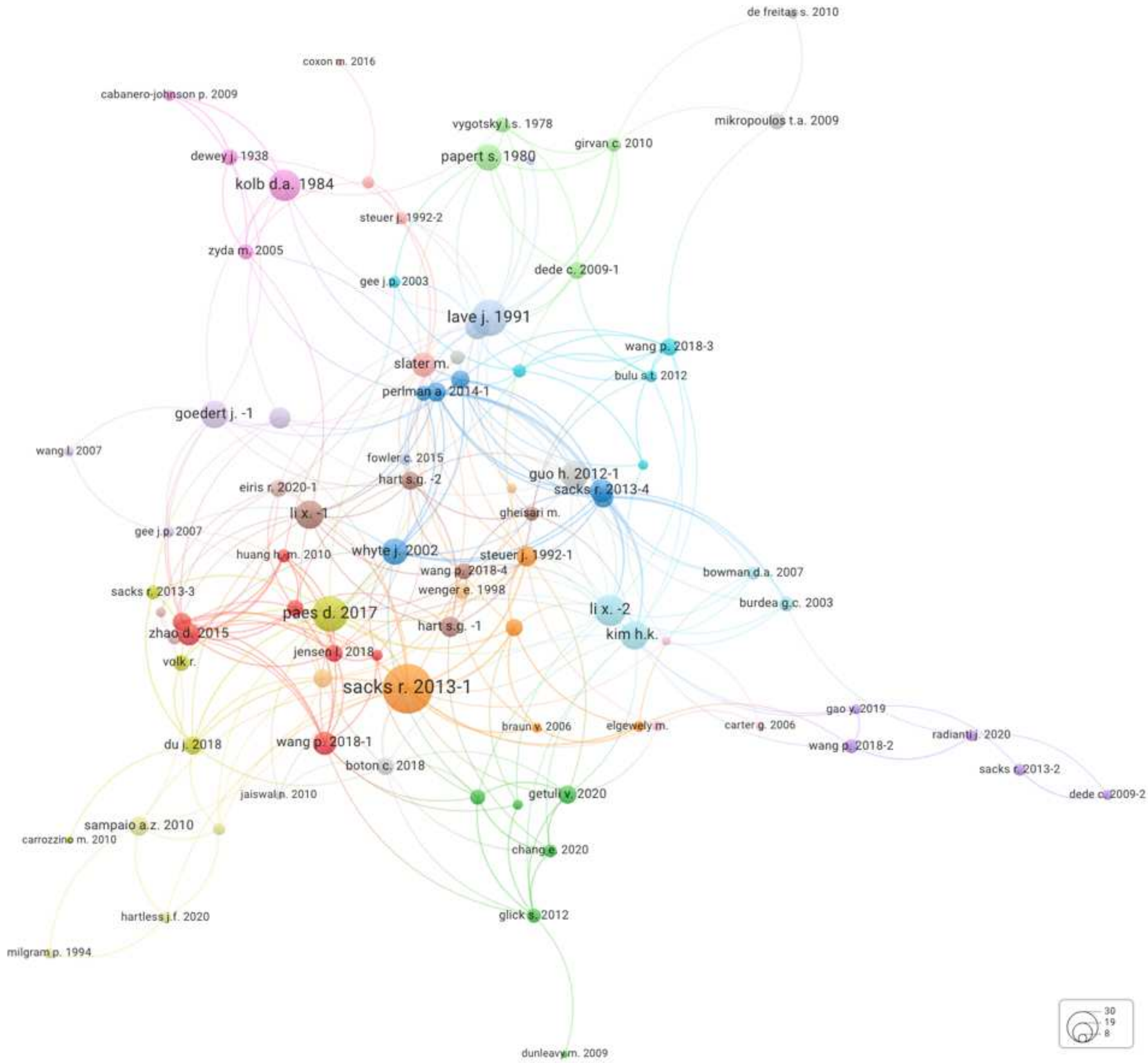

Figure 4: Visualised document co-citation network map of Virtual Reality in Built Environment Education.

No.	Author	Speciality	Citations	No. of Publications
#1	Wang X.	Construction Science	174	6
#2	Gheisari M.	Construction Management	148	12
#3	Li H.	Construction Informatics	113	5
#4	Sampaio AZ.	Civil Engineering	99	21
#5	Jalal A.	Computer Science	82	1

Table 3: Author co-citation analysis indicating the main authors within the network.

5.2.3 Social Structure

In the final data set, the authors mapped the social structure of the field. This approach explored how authors within the network and countries collaborate towards the knowledge body. Two methods represent the social structure of the network to understand the collaboration patterns. First, Co-author links are mapped to understand the collaboration groups and their links to the network. The respective countries are mapped to understand collaborations in the research network.

Co-authorship Analysis.

Scientific collaboration is a critical part of the nature and development of knowledge for the greater good. The need for collaboration occurs when opportunities such as new knowledge, specialisation, equipment, and skill sets exist. However, other reasons may create the need for collaboration, such as institutional or country goals. The authors used a co-authorship analysis to explore the social construct of the intellectuals that form the research network. This study discusses the largest collaborator in the five largest nodes. Gheisari M has the largest number of collaborations in their node, with a link strength of 22. Gheisari's network's top five interests are virtual reality, construction education, 360-degree panoramas, and drones. Teizer J holds the second-largest network, and its interests revolve around training, virtual reality, education, construction safety, and health. In the third largest network, central around Lin Y, topics including virtual reality, intelligent manufacturing, campus navigation, Chinese culture, and developed flow are commonplace. The fourth largest network is represented by Chen Y, and focus areas are central to adaptive education systems, digital intelligence technology, film art creation, virtual reality, and AR technology. Nikolic D, the central node of the fifth group, focuses on construction education, construction management, 4D simulation and development frameworks.

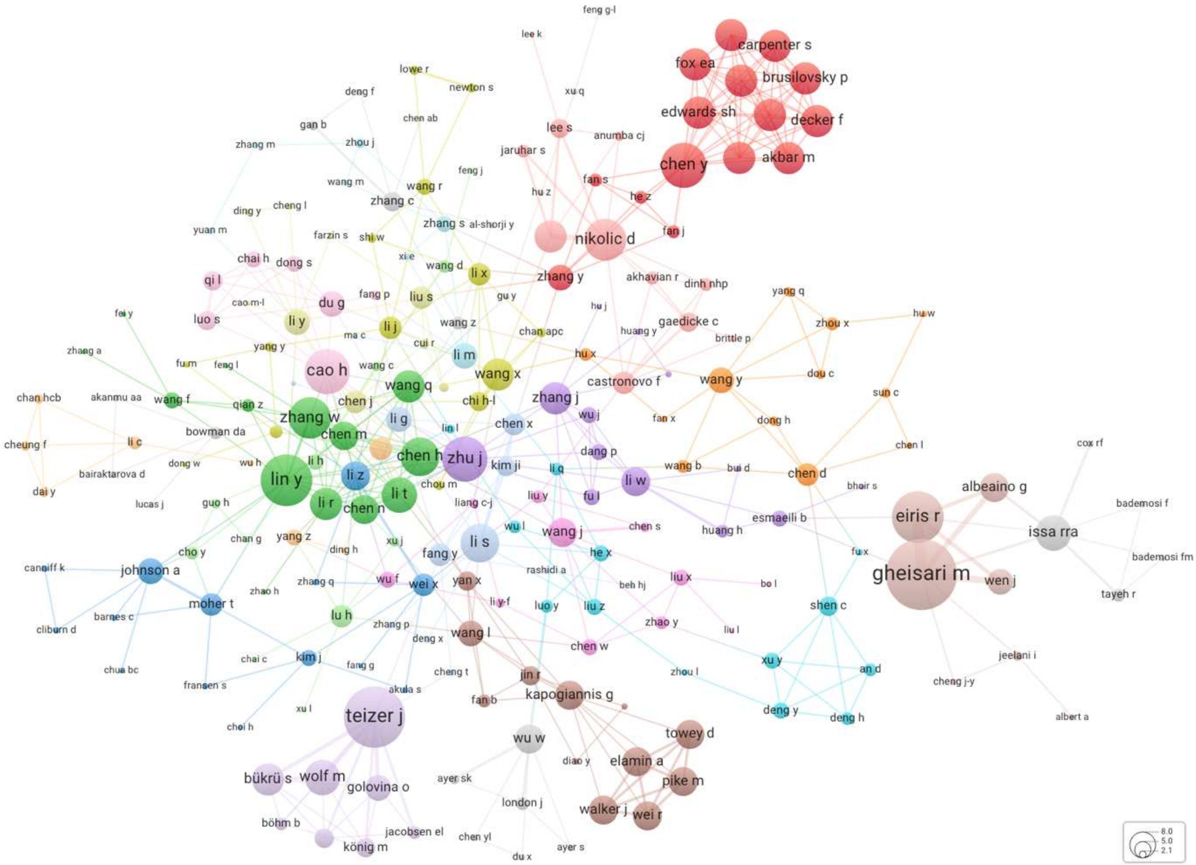

Figure 5: Visualisation of co-author network.

Country Collaboration Analysis.

Within the global knowledge society, it is critical to understand the collaboration of countries to unpack where the influential authors emanate from as well as their global ties. By conducting this analysis, patterns of collaboration reveal themselves. In this segment of the research, the top five collaborators are discussed. The biggest collaboration in the research network is between China and the USA, with 11 joint publications. In the second place, collaborations between China and Hong Kong sum up to 10. In third place, five publications exist between the USA and the United Kingdom. The USA and Egypt have four joint publications in fourth place. In fifth place are China and Japan, where there are three publications. The USA dominates collaborations with 22 connections to other countries, followed by China with 16 and the United Kingdom with 15.

5.2.4 Africa in the Knowledge Network

The data analysis throughout this study is a fair indicator of the amount of research carried out globally; consequently, it reveals a paucity of research within the African context. Throughout the study, none of the authors or publications linked to Africa show up within the top ten metrics. This result is an indication of various structural challenges. Only 18 articles have emanated from the entire African continent, with 62 citations. Contribution from the continent is low, with 18 papers, but some impactful articles have been produced. Nine papers are journal articles, of which six were published in journals with an impact factor greater than 3,5. Considering that the 14 publications were from the past five years, the citation count is reasonable for the time.

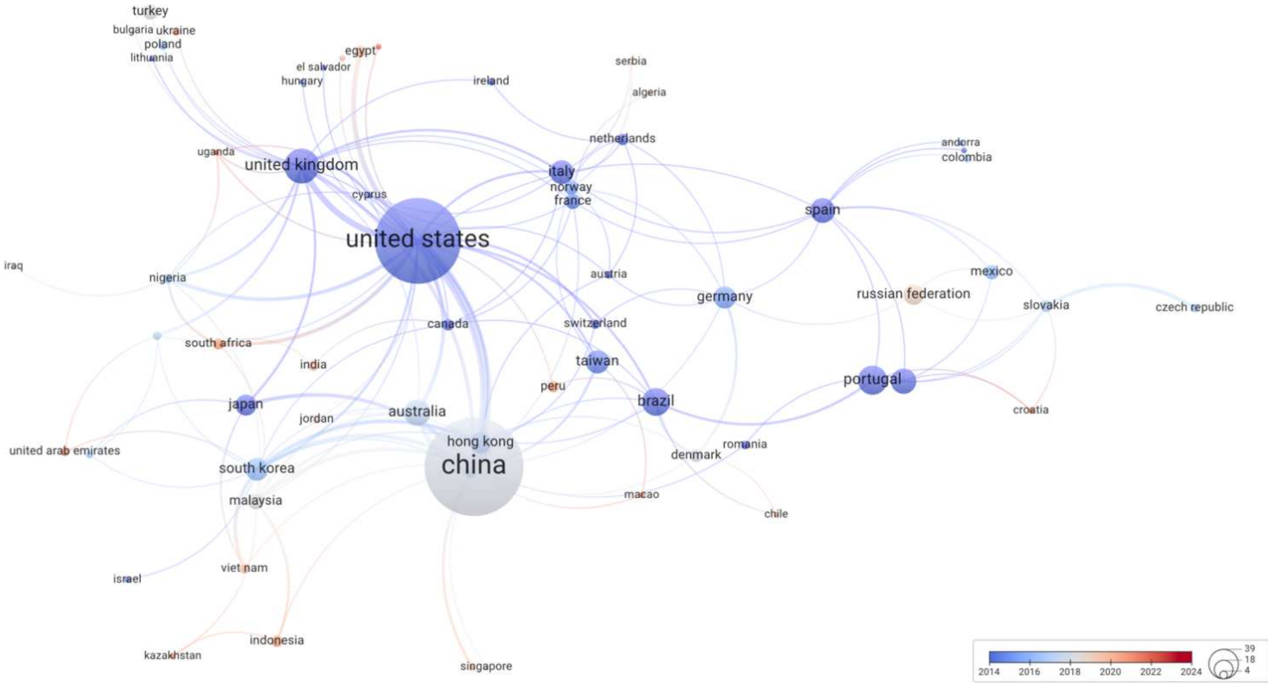

Figure 6: Visualisation of country collaboration network.

Regarding contribution to a similar set of keywords, the papers follow the same trend as their international counterparts. Some additional keyword co-occurrences, such as construction education, construction sites, building information modelling, construction, and performance, enter the debate. These words also appeared within the global keyword occurrence. However, some nuanced research areas seem more prevalent in Africa.

Running a co-citation analysis on the data set at present will result in skewed results. Due consideration is taken for the age and number of publications. Although, at present, the research emanating from Africa is low, a great need to investigate certain niche areas can be severely beneficial. For example, VR is a low-cost means to visit international construction works virtually for students and professionals alike. In terms of co-authorship, none of the authors within this study has formed strong co-authorship networks, locally or within the global body. Only eight links have been created on the continent, two of which are between African countries.

6 CONCLUSION

The study set out to investigate the research landscape of Virtual Reality in Built Environment Education through a Bibliometric methodology. Data exported from Scopus was analysed using Bibliometrix and visualised using VOS Viewer. The analysis revealed that the fourth industrial revolution increasingly significantly influenced publications in the network. The keyword co-occurrence revealed that Virtual Reality technology has significant ties to education and the built environment and is becoming a popular medium of representation, training and education. Future directions include Metaverse, Virtual Simulations, 3D Modelling, Simulation Platforms, and E-learning. These topics are new, and a paucity of research exists within this network. New empirical studies can bridge several gaps within the network.

The document co-citation analysis revealed the intellectual structure of the network. Education and psychology theories and concepts assist in creating a strong foundation for the use of VR in the setting of construction education. Equally, the seminal papers advocate for the environment to be central to the learning experience. VR technology bears this weight, especially if the intention is to immerse the user. The idea of VR technology being a rewarding experience is also important; some gamification frameworks are critical in the entire network development. Although several papers exist in the body of knowledge, few have recorded how students of construction. use and experience the technology. There is a gap in exploring this idea through a longitudinal study.

Analysing the authors' profile, a large amount of research is carried out by professionals from the construction management discipline, followed by civil engineering. There is some evidence of research in architectural education; however, more effort is required to streamline the technology and pedagogical approach. Professions such as Urban planning and design, quantity surveying, and landscape architecture are almost non-evident, leaving a gap in the overall network.

The collaboration patterns show that some internal country clusters have developed, and knowledge is generated within the group. International connections exist; however, these ties are weak between authors. More effort on international joint efforts is required to move this area of research forward. African researchers must create international connections, especially with the USA, China, and the UK. The current construction processes within Africa can be impacted severely by collaborating with international partners. However, other countries may benefit more from lessons from Africa.

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