Prospects of Digital Technologies for Teaching and Learning of the Built Environment Profession

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Abstract. The built environment (BE) profession, encompassing disciplines such as architecture, urban planning, civil engineering, and construction management, plays a pivotal role in shaping the physical spaces we inhabit and enhancing the socio-economic status of the people. As the BE continues to grow in complexity and faces the challenges of increased urbanisation and the need to embrace sustainability concepts, it becomes imperative to equip future professionals with the necessary knowledge and skills to navigate this dynamic sector. In this context, the integration of digital technologies (DTs) into the teaching and learning (T&L) process has emerged as a transformative approach with immense potential. Therefore, this study aims to explore the prospects and significance of DTs for T&L within the BE profession. This study aims to shed light on the transformative role that DTs can play in the education of future professionals. An extant review of the literature was conducted on DTs with the capacity to enhance the pedagogical processes and experiences of BE students. The findings revealed that DTs offer numerous advantages, such as the promotion of collaborative learning and communication, enhancement of visualisation and simulation capabilities, promotion of immersive experiences facilitated by virtual and augmented reality, and access to a wide range of resources. In conclusion, the integration of DTs into the T&L of the built environment profession holds immense promise. By enhancing visualisation, promoting collaboration, providing access to resources, facilitating personalised learning experiences, and bridging the gap between theory and practice, DTs have the potential to equip BE students with the necessary skills to thrive in this rapidly evolving world.

Keywords: Construction Industry, Digital Technologies, Quality Education, Pedagogy, South Africa, Teaching and Learning.

1 Introduction

Despite the unclear concept of the built environment (BE) globally [1], it has been identified to be vital for human mobility and an essential element of tourism [2]. The

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BE constitutes the physical manifestation of human civilisation, encompassing the design, construction, and management of buildings, infrastructure, and urban spaces. This has shown that the sustenance of the whole society is dependent on the sustainable state of the BE, especially in this present-day world [3]. According to Chynoweth [4], BE also constitutes an applied discipline, yet maintains theoretical coherence, serving as an interdisciplinary field grounded in a shared epistemological axiomatic. As our cities grow more complex and interconnected, the demand for skilled professionals in architecture, urban planning, and construction rises in tandem. Hence, embracing digital technologies (DTs) for T&L becomes imperative to empower the next generation of professionals with the requisite technological proficiency, skills, and knowledge.

Considering the rapidly evolving landscape of the 21st century, DTs have become pervasive, fundamentally transforming the way we live, work, and learn. The digital revolution which has disrupted traditional educational paradigms and now more proliferated post-COVID-19 pandemic era, offers unprecedented opportunities to enhance learning experiences [5]. As the world progresses into the fourth industrial revolution (4IR) era, these innovative tools have gained significant traction across diverse disciplines, and the realm of education is no exception. Through a myriad of digital tools, educators can now seamlessly and in real-time engage learners on a personalised level, attend to diverse learning styles, and facilitate interactive and immersive experiences. In particular, the BE profession (encompassing architecture, engineering, urban planning, construction, and related fields), is witnessing a profound shift as DTs reshape its pedagogies, discourses, and practices. This revolution holds the promise of revamping the way urban spaces are mapped out, construction processes are optimised, and architectural concepts are visualised. Also, DTs present exciting prospects for T&L in the BE profession as they enable both learners and educators to collaborate, create, and adapt in exceptional ways. These technologies have therefore shown the potential to drive cutting-edge advancements for T&L in the BE profession.

Several key technologies that characterised the 4IR era are transforming T&L, especially in the BE profession. Examples include building information modelling (BIM), virtual reality (VR), augmented reality (AR), machine learning, digital twins, big data and data analytics, metaverse, machine learning, and artificial intelligence, digital trust and cyber security technologies, robotics, internet of things (IoT), blockchain, exoskeletons, and wearable technologies, drones/unmanned aerial vehicles (UAVs), and additive manufacturing (AM) or 3D printing. While most of these technologies have been adopted and implemented in other fields, their integration for T&L is beginning to transform the landscape of education. Foremost among the DTs is BIM which is believed will potentially cause the largest scale impact when effectively implemented [6]. BIM is regarded as a powerful DT that enables the creation, management, and visualisation of dimensional models representing building designs and construction projects [7]. This technology facilitates collaboration among architects, engineers, and other construction professionals by providing a centralised platform to share information, make real-time updates, and optimise the entire building life cycle. Similarly, BIM enhances students' understanding of complex architectural concepts, construction processes, and sustainable design practices.

Another example of DTs at the forefront for T&L in the BE profession is AR & VR. These technologies offer immersive and interactive learning experiences in the BE profession making the process of understanding likable and easier for the learners [8]. Through VR simulations, students can explore architectural designs and urban spaces in a virtual environment, enabling them to visualise spatial concepts and interact with different dimensional models. AR overlays digital information onto physical spaces, allowing students to observe architectural elements in real time, making the T&L experience a more engaging and tangible process [9]. Also, 3D printing, or AM, allows students to transform digital designs into physical models and prototypes. In the built environment profession, this technology facilitates rapid prototyping, enabling students to test architectural concepts and experiment with innovative designs. 3D printing nurtures students' creativity, problem-solving skills, and understanding of material properties [10]. Another DT is the geographic information system (GIS) which enables the collection, analysis, and visualisation of geographic data to inform urban planning and decision-making processes [11,12]. In the BE profession, GIS enhances students' understanding of urban development strategies, land use patterns, and spatial relationships, land use patterns. It enables the learners to identify optimal locations for infrastructure projects, design sustainable cities, and assess the environmental impacts of projects. Robotics and automation for educational purposes are increasingly being used to support T&L activities. These robots can assist in teaching coding, problem-solving, and hands-on science experiments [13]. Additionally, robotic process automation (RPA) can streamline administrative tasks, freeing up educators' time to focus on instructional activities. IoT is another popular DT that connects devices and objects to the internet, creating smart T&L environments. In education, IoT can enable smart classrooms with connected devices, such as interactive whiteboards, smart projectors, and wearable devices, enhancing student engagement and enabling real-time data collection for analysis [14,15]. By embracing a participatory pedagogical approach and integrating formal and informal learning, DTs can enhance learning experiences, fostering a more dynamic and flexible learning environment [16]. While there is an array of DTs for T&L in construction-related professions, it is imperative to assess the trends and identify and reveal the research cynosure. Hence, the objective of this study is to appraise, understand, map out, and present the state of DTs for T&L in the BE profession. While pinpointing key areas of interest for future research and policymaking, the study aims to offer a comprehensive overview of the status quo.

2 Research Methodology

To understand and map out the DTs for T&L in the BE profession, the study employed the triple approach of bibliometric analysis, scientometric analysis, and discussion. Science mapping was used to analyse scholarly works on the subject published from the year 2019 when the COVID-19 pandemic broke out to date (2023).

According to Moral-Muñoz et al. [17], science mapping is a quantitative method that utilises bibliometric tools to mine and analyses research publication outputs, quality, and productivity. The review process through the bibliometric search was the first step taken. The bibliographic data collected from the Scopus database was adopted for this study. Despite the availability of other rich and popular databases such as the Web of Science, the choice of Scopus was made due to certain reasons. Since its inception sometime around 2004, the Scopus database has been regarded as a search choice for publications [18]. It is also one of the largest citations and abstract collections of peer-reviewed scholarly articles. The study search was limited to conference proceedings, journal articles, book chapters, and books published within all subject areas available on the Scopus database. The subject areas include engineering, social sciences, environmental science, arts and humanities, energy, computer science, earth and planetary sciences, materials science, medicine, business, management, and accounting, decision sciences, physics and astronomy, economics, econometrics and finance, nursing, veterinary, mathematics, chemistry, and health professions. Considering all subject areas is for the study to capture scholarly works on the study subject that are published in non-subject areas specific to the study.

The key search words adopted are "Digital technology" OR "Digital technologies" AND "Built environment". These terms were employed to search and retrieve the bibliometric datasets for the study. The language selection was limited to "English" while the year in focus was from 2019 to July 2023 (post-COVID-19 era). The search conducted revealed a total of 90 articles after a careful refining process using the earlier-mentioned factors. Results are presented based on the number of publications per year, number of publications per country, number of publications per document source, top-cited publications, number of publications per author, co-authorship network, and keywords co-occurrence network. The VOSviewer software was employed to develop the bibliometric networks of the datasets owing to its user-friendliness and simplicity. The results presented and discussed are the trend in publication output per year, per country, per document source, per co-occurring keywords, per author and co-authorship networks, and most cited publications.

3 Results and Discussion

3.1 Trend in Publications Per Year

A total of 90 articles were extracted, 54 of which were journal articles, 22 were conference papers, 11 were book chapters and the remaining 3 were books. Based on the number of publications per year, the result in Figure 1 shows a steady rise in the number of publications on DT in the built environment from 2019 to 2022 with 14 articles in 2019 rising to 26 articles in 2022. However, there are 16 publications to date in 2023. The low number recorded so far for the year can be attributed to the fact that the bibliometric dataset was extracted in July 2023. It is envisaged that by the end of the year, the number will have risen to surpass the 26 publications recorded in 2022. The findings are in tandem with the study of Ibem and Laryea [19] which reported increasing patronage and use of DTs. This is related to the understanding that DT use establishes the basis for digital transformation across disciplines [20]. It can therefore be predicted that the adoption and utilisation of DTs for T&L will continue to increase within the BE as long as global digitalisation persists.

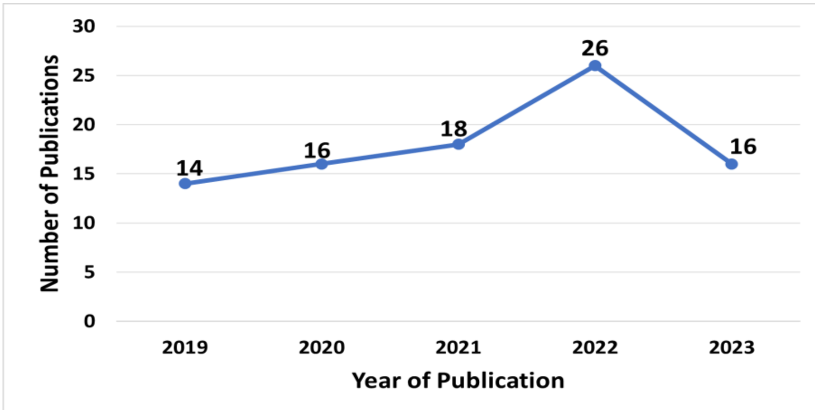

Fig. 1. Number of publications per year

3.2 Trend in Publications Per Country

Considering the trend in publications per country, the result showed that few documents are affiliated with more than one country thereby causing some overlap. To overcome this, the study considered only countries with a minimum of four articles with at least five citations. Publications per country are shown in Figure 2 with the United Kingdom topping the list with 20 articles generating 196 citations. This is followed by Italy (11 articles with 28 citations), USA (11 articles with 9 citations), South Africa (7 articles with 69 citations), Netherlands (6 articles with 107 citations), Australia (6 articles with 13 citations), Nigeria (4 articles with 10 citations), and China (4 articles with 7 citations). It is not surprising that the top three countries in this category are regarded as high-income and developed. This is because the developed countries have embraced digitalisation to fully maximise its positive impacts such as improved service delivery, expanded opportunities, and boosted growth [21,22]. However, it is encouraging to see two African countries (South Africa and Nigeria) represented in the eight-country list. This shows that the adoption and implementation of DTs are growing on the African continent.

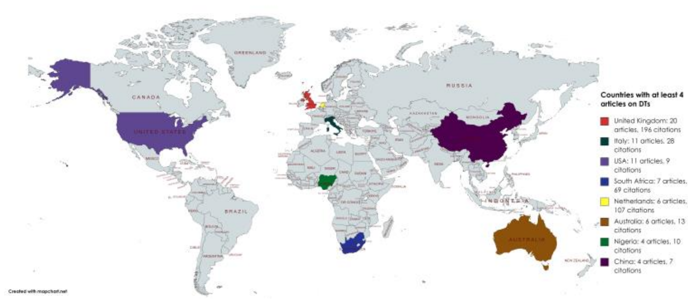

Fig. 2. Number of publications and citations per country

3.3 Trend in Publications Per Document Source

The number of extracted articles per source title was assessed showing that the 90 articles that constitute the bibliometric datasets were published in 72 different sources. Table 1 presents the result showing only the source titles with a minimum of two published articles and one citation on DTs for teaching and learning in the BE profession. Out of the seven document sources that met the threshold, IOP Conference Series: Earth and Environmental Science topped the table with 5 articles and 10 citations. However, Sustainability by MDPI followed with 4 articles generating a whopping 124 citations. Likewise, the IOP Conference Series: Materials Science and Engineering is third on the table with 4 articles and 10 citations. It is important to note that the top three source titles are open-access publication sources thereby making the articles accessible to researchers, and subsequently enhancing the citation index.

Table 1. Number of publications per document source.

Source Title	Documents	Citations
IOP Conference Series: Earth and Environmental Science	5	10
Sustainability (Switzerland)	4	124
IOP Conference Series: Materials Science and Engineering	4	10
Smart and Sustainable Built Environment	3	2
International Journal of Environmental Research and Public Health	2	36
Engineering, Construction and Architectural Management	2	8
Structural Integrity	2	1

3.4 Most Cited Publications

Considering the authorship of the scholarly articles that constituted the bibliometric dataset, the assessed 90 documents had 279 authors attributed to them. This number includes the corresponding/lead authors, co-authors, and collaborators. However, the result indicated that none of the authors published more than one article out of the 90 documents evaluated. To therefore identify the authors regarded as more impactful, the value for the least number of documents was left as one while the minimum number of citations of an author was set at 13. The number of times an article is cited is adjudged as a major means of evaluating its impact [23,24]. Therefore, this bibliometric dataset is analysed to identify the most cited publications on DTs. As shown in Table 2, only 13 articles have at least 10 citations. The first article titled “Circular Digital Built Environment: An Emerging Framework” was authored by Çetin et al. [25] generating a total of 55 citations. This is followed by the article titled “Material Passports and Circular Economy” authored by Hoosain et al. [26] with a total of 54 citations. The third on the table is titled “Digital Twins in Built Environments: An Investigation of the Characteristics, Applications, and Challenges” authored by Shahzad et al. [27] with a total of 41 citations. It is noteworthy that a staunch similarity in the top three publication outputs entails the application of DTs to further optimise and enhance the performance of the built environment. While the first two address the subject of circular economy which is a major sustainability concept in the built environment, the third publication evaluates a type of DT to understand its attributes, challenges, and applications in the sector.

Table 2. Most cited publications on DT.

Title	Citations	Authors
Circular digital built environment: An emerging framework	55	[25]
Material Passports and Circular Economy	54	[26]
Digital Twins in Built Environments: An Investigation of the Characteristics, Applications, and Challenges	41	[27]
Valuing Urban Heritage Through Participatory Heritage Websites: Citizen Perceptions of Historic Urban Landscapes	32	[28]
How Innovation Champions Frame the Future: Three Visions for Digital Transformation of Construction	31	[29]
How does a (Smart) age-friendly ecosystem look in a post-pandemic society?	30	[30]
Built environment of Britain in 2040: Scenarios and strategies	23	[31]
A systemic framework for addressing cybersecurity in construction	16	[32]
Segmentation, classification, and determinants of In-Store shopping activity and travel behaviour in the digitalisation era: The context of a developing country	15	[33]
Effective use of blockchain technology for facilities management procurement process	13	[34]
Digitalization for a circular economy in the building industry: Multiple-case study of Dutch social housing organizations	13	[35]
The urban digital lifestyle: An analytical framework for placing digital practices in a spatial context and for developing applicable policy	12	[36]
Digital Technologies in Built Environment Projects: Review and Future Directions	10	[37]

3.5 Publications Per Co-occurring Keywords

Keywords are considered significant in aiding the indexing of scholarly articles in databases [38]. This is because keywords reflect the themes and major highlights of the research articles. Hence, the inclusion of between three to seven keywords in scholarly publications is identified as a global practice by mere perusing calls for abstract and paper submissions. Where two or more keywords are occurring together at a time, a co-occurring keyword network is used to examine such instances. Systematic reviews of scientific publications can also be promoted by keyword co-occurrence networks [39]. Understanding the focus area of previous studies on a particular subject can therefore be made possible through properly clustered keywords into themes [18]. They also help in improving the accuracy of clustering and querying processes [40]. The VOSviewer software was used to create the keywords co-occurrence network for the study. The analysis identified 771 keywords from the 90 scholarly publications. Using the threshold of 5 co-occurring keywords (full counting) as predefined by the software, 19 items are revealed as presented in Table 3. These 19 co-occurring keywords were further grouped into three clusters. Figure 3 shows the VOSviewer co-occurrence network visualisation map of the 19 keywords that met the threshold.

Table 3. Summary of main co-occurring keywords.

Keywords	Occurrences	Total link strength
Built Environment	27	88
Digital Technologies	24	70
Architectural Design	16	41
Construction Industry	14	45
Sustainable Development	12	44
Digital Technology	10	35
Building Information Modelling	8	19
Smart City	7	25
Smart Cities	7	22
Covid-19	6	23
Circular Economy	6	20
BIM	6	15
Human	6	27
Digitization	6	15
Information Management	6	10
Article	5	26
Artificial Intelligence	5	21
Digital Devices	5	21
Digital Transformation	5	17

Figure 3 presents the co-occurrence network visualisation map of the 19 keywords revealing three clusters. At the centre of the map is the "built environment" keyword which is linked to other keywords. Cluster One (the red network of the map) contains 10 keywords namely smart city, smart cities, human, digitization, digital technology, COVID-19, circular economy, built environment, artificial intelligence, and article. This cluster can be described as keywords related to *Digital Technologies for Smart Cities and Circular Economy*. To ensure the modern, competitive, functional, and livable attributes of a smart city, the role of DTs in promoting knowledge management and innovation cannot be overemphasised [41]. Implementing and embracing DTs in the BE to make a smart one is, therefore, the future of urbanisation [42]. The earlier the teaching and learning of these technologies begin, the better the built environment profession will be prepared for the future which will be largely driven by technology. Cluster Two (the green network of the map) contains sustainable development, digital transformation, digital technologies, construction industry, and digital devices. This cluster can be described as keywords related to *Digital Technologies for Sustainable Development*. It is general knowledge that the built environment is largely responsible for the negative environmental impacts threatening the sustenance of the human and natural environment. Achieving sustainable development to address these challenges is therefore largely dependent on DT infusion and use [43]. Educating the learners on the use of these technologies can be a tool in addressing the challenges of sustainable development [44]. Cluster Three (the blue network of the map) contains BIM, architectural design, information management, and building information modelling. This cluster can be described as keywords related to *Digital Technologies for Building Information Management*. Considering the constituting keywords in this cluster, it can be inferred that a major part of the built environment that has seen the use and interoperability of DTs is building design and management. BIM is described as a process and a technology that can be employed to plan, design, construct, and operate a facility [45,46]. It is regarded as the most important tool in the BE [47]. This led credence to the suggestion that BIM education should be a major subject in undergraduate curricula [48]. Similarly, teaching and learning BIM also has the potential to improve student employability as it empowers them with competitive skills for the future [49]. To this end, the BE should be collaboratively empowered to be an epicenter of DT to optimise and enhance its performance.

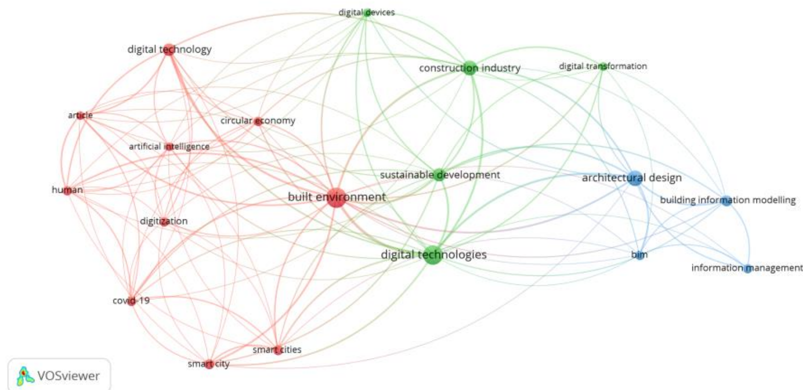

Fig. 3. Network visualisation map of co-occurring keywords

4 Conclusion and Recommendation

The study set out to appraise, understand, map out, and present the state of digital technologies (DTs) for teaching and learning (T&L) in the built environment profession. Based on the available dataset (scholarly publications on DTs from 2019 to 2023) extracted from the Scopus database, the study has been able to reveal the vital DTs and their imperativeness in the post-COVID-19 era. The study also showed that there has been a steady upward trajectory of DT-related publications since the outbreak of the pandemic. While the developed and high-income countries remain ahead with the adoption and use of DTs, it is important to note that the two foremost African nations (South Africa and Nigeria) are embracing technology, especially for T&L. Similarly, the study revealed that most of the research outputs on the subject emanated from open access sources. This supported the clamour by educators and other relevant stakeholders on the need to decolonise knowledge by ensuring unrestricted access to scholarly publications, especially in developing and underdeveloped nations. Furthermore, the most cited publication outputs on the subject focused on the implementation of DTs for a circular economy. This is to show that technology adoption to ensure the sustainability agenda of the BE is at play and highly explored globally. Out of the 771 keywords from the 90 scholarly publications that make up the bibliometric dataset of this study, three major clusters were revealed through the keyword co-occurrence network analysis. This showed that DTs can be employed to enhance T&L in the BE profession for smart cities and circular economy, sustainable development, and building information management. These themes constitute the major aspects of the BE where the professionals of the future must be vast and equipped with the technological proficiency to optimise the sector. It is therefore recommended that higher education institutions, government agencies, professional bodies, and other relevant stakeholders embrace and implement DTs collaboratively. Also, necessary financial support and investment from the government and private sector are key to ensuring these technologies (hardware and software) are proliferated and accessible to educators and learners.

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