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Systematic Review

A Systematic Review of the Impact of Emerging Technologies on Student Learning, Engagement, and Employability in Built Environment Education

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Abstract: This paper presents a systematic literature review of the impact of emerging technologies such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and gamification on student engagement, learning outcomes, and employability in Built Environment (BE) education. This review covers studies conducted between 2013 and 2023, utilizing the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework. From an initial pool of 626 studies, 61 were identified and rigorously analyzed. The findings reveal that these technologies significantly enhance student engagement by providing immersive and interactive learning experiences that bridge the gap between theoretical knowledge and practical application. Furthermore, their use is shown to improve learning outcomes by facilitating a deeper understanding of complex concepts and increasing student motivation. In terms of employability, the integration of digital tools into BE education equips students with the requisite skills that are increasingly demanded in the modern workplace. However, the study also identifies several challenges, including high costs, limited resources, and the need for extensive faculty training, which act as barriers to the effective implementation of these technologies. Despite these challenges, this review underscores the transformative potential of digital technologies in BE education. This study is significant as it synthesizes recent evidence to highlight the critical role of digital technologies in reshaping BE education. It offers practical recommendations for educators and policymakers to enhance teaching and learning practices. Providing pathways for integrating these technologies into BE curricula, this study aims to inform future research and pedagogical strategies, ultimately contributing to the development of a highly skilled and adaptable workforce.

Keywords: built environment education; immersive technology; student engagement; learning outcomes; employability

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Citation: Ghanbaripour, A.N.; Talebian, N.; Miller, D.; Tumpa, R.J.; Zhang, W.; Golmoradi, M.; Skitmore, M. A Systematic Review of the Impact of Emerging Technologies on Student Learning, Engagement, and Employability in Built Environment Education. *Buildings* **2024**, *14*, 2769. https://doi.org/10.3390/buildings14092769

Academic Editor: Saeed Banihashemi

Received: 28 June 2024
Revised: 10 August 2024
Accepted: 13 August 2024
Published: 3 September 2024

1. Introduction

Current Built Environment (BE) education focuses on equipping students with foundational knowledge and basic technical skills to prepare them for roles in infrastructure development, sustainability, and disaster resilience [1,2]. BE education significantly impacts socio-economic advancement through its influence on infrastructure development. Trained professionals in the BE field are key to constructing resilient and efficient cities, thereby enhancing both the quality of life and economic growth. Infrastructure development, bolstered by the expertise of BE graduates, can help mitigate the effects of natural disasters, leading to reduced economic losses and faster recovery. Furthermore, BE education supports sustainable development goals by fostering innovative construction and urban planning practices that are sustainable and environmentally conscious. Studies highlight BE education's role in promoting ecological and economic awareness among professionals and fostering sustainable practices within the construction industry [3,4]. Additionally, continuous skill development in disaster management is emphasized, underlining the socio-economic benefits of a disaster-resilient Built Environment [5]. It also integrates both theoretical knowledge and practical skills across various disciplines, including architecture, urban planning, civil engineering, and construction management. The curriculum is designed to impart a deep understanding of infrastructure development, sustainability, and disaster resilience. It also emphasizes the development of 21st-century skills such as critical thinking, communication, teamwork, and digital fluency, which are crucial for the employability of graduates [6].

Emerging technologies such as Augmented Reality (AR) and Virtual Reality (VR) are increasingly being introduced into BE education [7,8]. These technologies offer new ways to enhance student learning by creating immersive, interactive environments that engage students in practical experiences [9]. Student learning in this context refers to the acquisition of knowledge, skills, and competencies through various educational activities, which is increasingly supported by digital tools and innovative methods. Engagement refers to students' involvement and active participation in the learning process, which is crucial for their academic success [10]. In BE education, engaging students often involves hands-on, experiential learning that helps them connect theoretical knowledge with real-world applications [11]. Employability relates to the readiness of graduates to enter the workforce, equipped with the necessary skills and knowledge to meet industry demands. In BE education, employability is enhanced by integrating industry-relevant skills and technologies into the curriculum, preparing students for future careers [12].

Efforts have been made to introduce such emerging technologies as Augmented Reality (AR) and Virtual Reality (VR) into BE education, aiming to enhance learning outcomes and engage students in interactive, hands-on experiences [13]. Overall, the current approach emphasizes foundational knowledge and skills while acknowledging the importance of integrating emerging technologies and preparing graduates for the demands of the modern workforce.

However, in practice, many BE education programs still rely heavily on traditional lecture-focused teaching methods, which may not effectively impart the 21st-century skills and digital fluency needed [14]. While there is recognition of the importance of integrating such emerging technologies as AR and VR into BE education, their actual adoption and implementation remain limited [13]. As a result, students may not have sufficient exposure to the technologies, potentially leaving them ill-prepared to meet the evolving demands of the industry. Despite the intention to enhance learning outcomes and engagement through technology-based learning, the gap between current practices and the ideal implementation of emerging technologies persists in many BE education programs.

Educational practices have been considerably affected by the COVID-19 epidemic, leading to the need for swift transitions towards digital technologies. This is especially pertinent in the field of BE education, where the acquisition of practical, experiential knowledge is crucial. This paper evaluates how technologies have supported BE education's shift to remote learning during the pandemic, focusing on their role in maintaining engagement and educational outcomes.

Various studies have investigated the implementation of technology in BE education to enhance Building Information Modeling (BIM) competencies, integrate VR-based pedagogical frameworks, explore sustainable education, teach building regulations, and leverage BIM-enabled virtual projects for soft employability skills [7,15–18]. These studies offer valuable insights into the potential benefits of technology integration in BE education. However, there is a need for a systematic literature review (SLR) to synthesize these findings and address the current gaps in the research landscape.

In response, the present study aims to address the following research questions:

(1) What are the publication trends and prominent journals that feature research regarding technology integration in BE education?
(2) What are the research hotspots (critical themes) in using state-of-the-art technology to facilitate BE education?

This study is part of an ongoing project based on longitudinal and cross-disciplinary studies, which aim to explore how technology can effectively engage BE students, improve their learning experiences, and polish their employability skills to prepare them for the world of work. It provides a thorough analysis of the current extent to which technology is being incorporated into BE education, highlighting important areas where research has not been adequately evaluated in terms of how specific technologies, such as VR, AR, and gamification, impact learning outcomes and employability. Although increasing evidence supports the effectiveness of these technologies, there is a lack of long-term studies and comprehensive pedagogical frameworks specifically designed for BE education. Therefore, this review aims to resolve these disparities by consolidating recent studies and suggesting avenues for future research. It seeks to provide a thorough review of the effects of emerging technologies on critical aspects of BE education to address the gaps in the literature. Our primary areas of attention include the following: (i) enhancing student engagement, (ii) improving learning outcomes, (iii) equipping students with employability skills, and (iv) identifying and overcoming challenges in technology implementation. The paper provides an extensive literature review on the use of technology in enhancing BE education, which acts as a steppingstone towards an in-depth understanding of the role of technology in improving BE students' learning experience and employability skills.

2. Technology in Education

The boom and emergence of technologies have resulted in the fourth industrial revolution (4IR). In the fourth industrial revolution (4IR), students should be competent, knowledgeable, and technically sound to improve their employability skills and readiness for the challenges in the contemporary workplace [19]. The evolution of various technologies such as artificial intelligence, blockchain, robotics, cloud computing, data science, Virtual Reality, and 3D printing has changed the landscape of the workplace. The onus is on higher education institutions (HEIs) to develop these technological skills in future generations [20]. HEIs need to respond to this challenge by upgrading their programs and exposing students to technologies so that they can cope with the 4IR era [21]. Universities should offer education and training programs that are closely aligned with the 4IR, aiming to improve students' employability skills [22]. While digital technologies are diffusing into the education sector at an exponential rate, their pedagogical implications are questionable in the era of the 4IR [23]. Scholars are constantly exploring how students can be better equipped with digital technologies in the 4IR. For instance, Al-Maskari et al. [19] investigated higher students' readiness level and preparedness for the 4IR. The readiness of students influenced by their personal characteristics and HEIs' efforts to redesign their programs, educators' training, and technological infrastructure. Similarly, Oke and Fernandes [23] aimed to explore the education sector's readiness for the 4IR. The education sector needs to significantly improve the curricula to stay aligned with the requirements of the 4IR.

The integration of technologies in BE education has become increasingly valuable in recent years with the manifestation of the 4IR. Garzón et al. [24], for example, highlight the remarkable effectiveness of AR in fields closely related to BE, such as engineering and construction. This highlights the potential of AR to enhance learning experiences within BE education. Moreover, Solnosky et al. [25] observed rapid growth in the integration of digital technologies and the 4th Industrial Revolution (IR) in BE projects, indicating a shift towards more technologically advanced practices in the industry. Additionally, the literature suggests a proliferation of various technologies such as VR, AR, Mixed Reality (MR), and tools such as 3D scanning and drones in BE education [26–28], signifying a broader acceptance and adoption of digital tools to enhance learning outcomes in BE programs.

2.1. Enhancing Teaching Methods and Learning Experience

Hajirasouli and Banihashemi [29] emphasize the importance of integrating technology into Built Environment (BE) education to enhance graduates' soft and technical skills. Contrastingly, Shirazi and Behzadan [14] critique traditional lecture-focused BE education, suggesting it may be inadequate for imparting necessary skills for modern workplaces.

A recent study by Hussein [30] highlights a significant shift in BE education from traditional didactic lectures to collaborative and self-directed learning. Ibáñez et al. [31] find that technology-based learning methods are more effective than traditional approaches in enhancing students' subject-related skills. Supporting this, Thompson [32] observes that today's students prefer 'learning by doing' over passive methods. Moreover, Sánchez et al. [33] argue that technology bridges the gap between conventional and novel teaching practices.

Diao and Shih [34] critique traditional teaching methods in BE education, noting their monotonous and disengaging nature. Ayer et al. [35] advocate for transforming conventional teaching into a more visualized and engaging format using technology. Aguayo et al. [36] strongly correlate technology-based learning and improved student engagement in BE education. Additionally, Sepasgozar [37] highlights the positive impact of technology on student motivation and engagement levels.

Patil et al. [38] emphasize the role of technology in enhancing student satisfaction and overall learning experiences. Kim and Irizarry [39] suggest that by simulating real-life environments, technology provides students with a more realistic understanding, thus making them more engaged and motivated. Noghabaei et al. [40] further support this notion by demonstrating the enhancement of students' learning outcomes through technology.

Cochrane et al. [41] propose the adoption of computer-based games as a means of engaging students in BE education. Vasilevski and Birt [28] argue that gamification not only improves students' technical skills but also brings enjoyment to the classroom environment. Ebekozien et al. [42] advocate for the inclusion of technology skills in learning outcomes to enhance job performance in the workplace. Moghayedi et al. [43] highlight the potential of digital technologies to facilitate student innovation. Rennie [44] suggests that digital technologies can introduce self-directed learning through two-way communication between students and educators.

Ku and Mahabaleshwarkar [45] emphasize the development of interactive learning environments through VR in BE education. Keenaghan and Horvath [46] propose the integration of VR and AR to bring real-life scenarios into the classroom. Tumpa et al. [47] demonstrate the effectiveness of computer-based simulation games in transferring knowledge and improving students' performance in BE education. Wang et al. [48] highlight the positive impact of simulation games on students' learning experiences. Li et al. [49] discuss the utilization of VR for practicing construction activities without negative consequences.

Zhang et al. [50] critique traditional teaching methods in BE education, noting their requirement for significant effort from students to grasp complex concepts. Skaik and Tumpa [51] argue that the integration of interactive technology will break the passive learning attitudes of BE students. Sampaio et al. [52] discuss the facilitation of discussions on construction-related technical material through digital technologies. Repetto et al. [53] demonstrate the positive impact of VR on memory retention of BE students. Okada et al. [54] present the development of VR models for interactive learning in BE education. Young et al. [55] emphasize the enhancement of attention and learning through 3D visualization in BE education. Han [56] suggests the engagement of students through virtual field trips in BE education.

Lin and Wang [57] highlight the potential of digital technologies to boost student motivation and facilitate the exchange of ideas among peers. Finally, Rahimian and Ibrahim [58] discuss the transformation of classroom environments through digital simulations and role play in BE education.

To summarize, the transformative role of technology in BE education involves a shift away from traditional teaching methods towards collaborative and self-directed learning to the integration of such immersive technologies as VR and AR, the evidence suggesting that technology has the potential to enhance student engagement, motivation, and learning outcomes. Moreover, the inclusion of digital technologies in the curriculum prepares students with the technical skills required in the workplace and encourages innovation and critical thinking. As BE education continues to evolve, embracing technology-driven pedagogical approaches appears to be necessary to meet the demands of the 21st-century learning environment and equip graduates with the skills needed to thrive in the global economy.

2.2. Addressing Industry Demands and Real-World Applications

Addressing industry demands and real-world applications is a critical theme in BE education, emphasizing the necessity for curricula to align with industry practices and real-world applications. For instance, Bhoir and Esmaeili [13] noted the adoption of state-of-the-art technologies in the BE industry, advocating for integrating AR technologies into BE curricula to better prepare students for industry challenges. Moreover, Diao and Shih [34] stress the importance of BE education reflecting industry practices, with such technologies as VR and AR providing students with a perception of real-world environments.

Universities bear the responsibility of ensuring graduates are industry-ready [59,60], addressing challenges where education may not seamlessly translate into real-world project environments [46]. To bridge this gap, Balogun [61] and Underwood and Shelbourn [62] emphasize the need for curriculum revisions integrating digital technologies, important for addressing skill gaps in the construction industry [61]. Leon et al. [63] further highlight the importance of graduates possessing digital skills, echoing the industry's expectations. Despite this, there remains a significant disparity between employer expectations and graduate skills [61].

Alongside technical skills, such interpersonal competencies as teamwork and problem-solving are critical for employability [64], necessitating BE curricula transformation to embrace digital technologies and develop 4IR competencies [65]. Significantly, BIM, AR, VR, Internet of Things (IoT), cloud computing, and big data emerge as prominent technologies shaping students' skills for construction employers [66], highlighting the importance of integrating both generic and digital technological skills into BE education [42].

In summary, addressing industry demands and real-world applications in BE education is critical for preparing graduates for the challenges of the BE industry. This theme highlights the need for curricula revisions integrating such state-of-the-art technologies as AR and VR, ensuring graduates possess the digital skills required by employers. Universities need to bridge the gap between education and industry expectations, emphasizing both technical and interpersonal competencies needed for employability in the modern construction landscape.

2.3. Improving Employability and Soft Skills Development

Improving employability and soft skills development is a significant theme in BE education, emphasizing the pivotal role of technology in enhancing graduates' employability and nurturing their soft skills. Diao and Shih [34] and Spitzer et al. [27], for example, emphasize the necessity of adopting technology in teaching BE to engage students and cultivate their employability skills. This necessitates a shift in teaching approaches toward digitization [67].

While technology enhances students' engagement and technical skills, it also develops soft skills such as communication and teamwork [29]. The exponential rise of technology in BE education has led to studies exploring its implementation in various aspects, from enhancing BIM competencies to integrating VR-based pedagogical frameworks [7,15]. Additionally, technology plays a significant role in sustainable education and teaching building regulations, further contributing to soft employability skills [16–18].

The globalization of higher education and the demand for improved graduate employability highlight the need for skilled employees in the industry [68]. This highlights the importance of leveraging technology in BE education to equip graduates with the necessary skills and competencies for success in the global job market.

This literature review of the integration of technology in BE education reveals a significant shift towards innovative teaching methods and immersive technologies such as VR and AR. Studies emphasize the potential of these technologies to enhance learning experiences and prepare students for industry challenges. However, weaknesses in the current literature include a lack of comprehensive studies on the long-term impact of technology integration and varying levels of adoption by educational institutions. The present paper addresses these gaps by providing a comprehensive analysis of the role of technology in BE education, examining its impact on teaching methods, learning outcomes, and graduates' employability. By synthesizing extant research findings and identifying areas for further investigation, this study contributes to a deeper understanding of how technology can be effectively integrated into BE curricula to meet the demands of the modern workforce and encourage the development of necessary graduate skills.

2.4. Research Gaps

Prior to conducting the systematic literature review, a scoping review was conducted to explore the landscape of digital technologies in the context of BE education. The initial research suggests that scholars have been exploring various aspects of technologies for improving BE students' employability and enhancing learning outcomes and experiences [7,27,37,69–72]. However, the studies are scattered and lack a comprehensive analysis of the phenomena with a notable absence of a systematic literature review of the existing literature. The lack of a systematic literature review with an extensive coverage of the available literature acted as a motivator to undertake this study. A systematic literature review is considered a powerful tool to highlight prominent and emerging trends and patterns of the current literature [73]. Therefore, this research aims to address this research gap, highlight critical themes, and propose future research avenues for investigating new insights.

3. Research Method

3.1. The Review Process

This study aims to identify the role of technology in BE education using an SLR. This is a process of identifying, selecting, evaluating, and analyzing previous studies through a comprehensive review process [74]. The SLR method has been utilized in previous studies of technology in the architecture, engineering, and construction (AEC) sector and construction sector [75–77]. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) is adopted to report the findings of the SLR, selected due to its widespread use in reporting research findings. PRISMA uses a 27-item checklist to enhance transparency [78,79].

3.2. Database and Keywords

In the first stage, relevant studies were identified through the use of a database search. The widely adopted databases for conducting systematic literature reviews in higher education research are Scopus, Web of Science, Google Scholar, and ScienceDirect [80,81]. Scopus was the primary search engine to identify relevant studies for this search. This is commonly used to locate, retrieve, and select relevant studies for construction, BE, and multidisciplinary studies [82]. It is one of the most trusted and largest databases as it makes the search process easier [83]. It is a citation database that encompasses over 50 million documents from around 5000 publishers [84]. Although Scopus was regarded as the primary database, ProQuest and Google Scholar were also used to locate any additional studies.

Three different kinds of search strings were used to ensure the capture of all relevant publications:

("Built Environment Education" OR "Built Environment Teaching" OR "Architecture Education" OR "Urban Planning Education" OR "Construction Management Education") AND ("Technology" OR "Digital Tools" OR "Online Learning" OR "E-Learning" OR

"Virtual Reality" OR "Augmented Reality") AND ("Student Engagement" OR "Student Participation" OR "Student Involvement")

("Built Environment Education" OR "Built Environment Teaching" OR "Architecture Education" OR "Urban Planning Education" OR "Construction Management Education") AND ("Technology" OR "Digital Tools" OR "Online Learning" OR "E-Learning" OR "Virtual Reality" OR "Augmented Reality") AND ("Learning Outcomes" OR "Academic Performance" OR "Knowledge Retention" OR "Skill Development")

("Built Environment Education" OR "Built Environment Teaching" OR "Architecture Education" OR "Urban Planning Education" OR "Construction Management Education") AND ("Technology" OR "Digital Tools" OR "Online Learning" OR "E-Learning" OR "Virtual Reality" OR "Augmented Reality") AND ("Employability" OR "Career Readiness" OR "Job Preparedness" OR "Employment Opportunities").

3.3. Study Selection Process with Inclusion and Exclusion Criteria

The initial search identified 626 documents, with 219 in Scopus, 31 in ProQuest, and 376 in Google Scholar. These were screened to identify the relevant studies in the next stage: screening.

In the screening stage, the studies were filtered through such inclusion criteria as studies published in peer-reviewed journals, available in full text, written in English, and published in the last 10 years. The duplicates in these databases were also removed at this stage. This stage resulted in 281 articles.

In the eligibility stage, the titles and abstracts of the 281 articles were read to confirm their eligibility to be included in the review. A total of 47 articles were deemed inappropriate at this stage and were excluded from further consideration, thus resulting in 108 articles. Many studies were excluded at this stage as they did not discuss the use of technology in educational settings, and research was not conducted in the BE context.

In the final stage, these 108 articles were downloaded and read thoroughly to ensure that the information presented in the articles met the study's objectives. At this stage, another 47 articles were excluded as they failed to meet the inclusion criteria. Finally, 61 articles were included. Figure 1 summarizes the research method used.

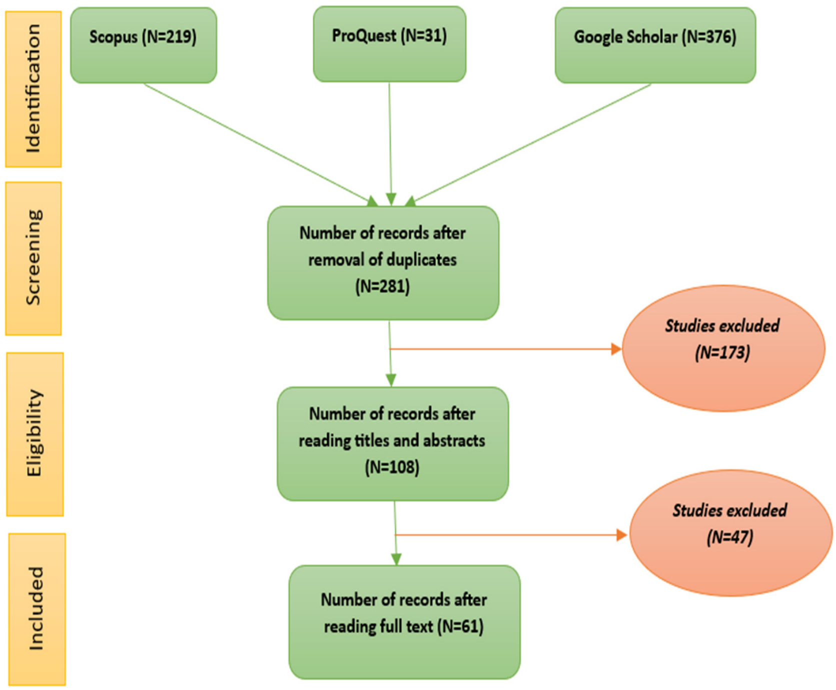

Figure 1. Research method following the PRISMA strategy (prepared by the authors).

The focus on literature published between 2013 and 2023 was chosen to reflect the most significant recent advancements and shifts in educational technology within the BE sector. This period is characterized by the rapid evolution of immersive technologies such as VR, AR, and MR, which have seen increased adoption in educational settings. Additionally, the onset of the COVID-19 pandemic in early 2020 significantly influenced educational methodologies worldwide, accelerating the shift towards digital and hybrid learning models. This specific timeframe ensures that the review captures pivotal technological and methodological shifts that are most relevant to current and emerging practices in BE education.

3.4. Data Analysis

Descriptive and thematic analyses are carried out on the finally selected 61 articles. Descriptive information such as the articles' publication year and journal is accumulated on an Excel spreadsheet for further analysis. Subsequently, an inductive thematic analysis is performed to identify the themes from the selected articles. Many previous systematic reviews adopted an inductive thematic analysis approach when undertaking a systematic review [50,60,85]. The thematic analysis utilized for identifying themes regarding the integration of technologies in BE education is based on Braun and Clarke [86]. NVivo, a qualitative data analysis tool [87], is used to analyze the data from the 61 articles to address the second research question. The process commences by reading the full text of the article to help the researchers become familiar with the data, followed by generating codes on NVivo. The codes are then consolidated to develop themes that address the second research question. Finally, the codes are reviewed to ensure that the codes represent the themes accurately.

In order to address the second research question, four themes emerge from the 61 reviewed studies. These include technology and student engagement, technology and learning outcomes, technology and employability, and challenges in implementing technologies in BE education. Table 1 illustrates the identified themes and the corresponding codes of the 61 reviewed articles, which explain how emerging technologies can benefit BE students and educators.

Table 1. Themes and corresponding codes with the reviewed articles.

Themes	Codes	Articles	Frequency
Technology and Student Engagement in BE Education	Improved students' understanding, engagement, interests, and comprehension	[27,69,72,75,88–91]	9
	Increased students' motivation	[7,28,75,92–94]	6
	Better engagement in the design process	[37,70,71,92,95]	5
	Providing real-time experiences in safe settings	[37,72,91,96]	4
	Interaction with virtual architectural details and understand spatial linkages	[29,70,92,95]	4
	Facilitation of active learning	[7,28,97]	3
	Improved critical thinking	[7,98,99]	3
	Improved collaborative learning and teamwork	[89,98,99]	3
	Improved engagement with equipment	[37,91,93]	3
	Providing interesting and realistic learning settings	[29,39]	2
	Improved comprehension and practical abilities	[71]	1
	Dynamic interaction with information	[95]	1

Table 1. *Cont.*

Themes	Codes	Articles	Frequency
Technology and Learning Outcomes in BE Education	Improved immersive and interactive learning experiences	[7,28,37,69–71,90,92,95]	9
	Increased knowledge and skills	[7,8,27,28,88,89,97,100]	8
	Improved learning experiences and environment	[7,28,37,70,71,92,95]	7
	Enhanced learning outcomes	[69,90,101–103]	5
	Improved visualization and understanding of construction processes and complex concepts	[8,27,77,104]	5
	Increased safety training and education	[72,89,91,94,105]	5
	Enhanced students' comprehension of structural elements	[37,70,71,92,95]	5
	Facilitation of construction methodologies	[37,70,71,92,95]	5
	Improved hazard identification	[72,89,105]	3
	Improved students' academic performance and decision-making	[26,77,106]	3
	Self-directed learning resources and problem-based learning	[101,103]	2
	Improved understanding of subjects, grades, and educational experiences	[101,103]	2
	Improved both hard and soft skills	[98,99]	2
	Ability to carry out a virtual exploration of construction sites	[37,91]	2
	Improved spatial and graphical skills	[29,39]	2
	Comprehension of challenging assembly processes	[29,39]	2
	Integrating in-class demonstration	[101,103]	2
	Ability to test ideas and receive immediate feedback	[95]	1
Technology and Employability in BE Education	By equipping students with necessary knowledge and competencies, and more competitive in the job market by expanding their knowledge of cutting-edge technologies	[9,70,98–100,107]	6
Challenges in Implementing Technologies in BE Education	Restricted access to resources, high costs, need for training, and requirement for a foundational understanding of usage	[8,27,69,88,90,92,98,103,108–110]	11
	Complexity of implementation	[27,103,111]	3
	Poor integration with other design methodologies	[28,69,95]	3
	Faculty reluctance	[27,103]	2
	Motion sickness	[88]	1

4. Review Results

4.1. Descriptive Analysis

The descriptive analysis examines the annual publication trends and distribution of the reviewed studies across journals. This systematic review is based on 61 studies published between 2014 and 2023, inclusive, focusing on the role of technology in BE education. Figure 2 shows the annual publication of the reviewed studies involved. The annual research trend shows that more than 80% were published in the last five years, with the highest number (18) published in 2022. The average number of studies over the previous five years (2019–2023) has increased exponentially to 9.8% from 2.4% in the preceding five years (2014–2018). This can be attributed to various reasons, such as the ubiquitous adoption of online teaching during COVID-19, increased awareness of improving student engagement in learning, and proliferation of technology in construction/BE-related tasks.

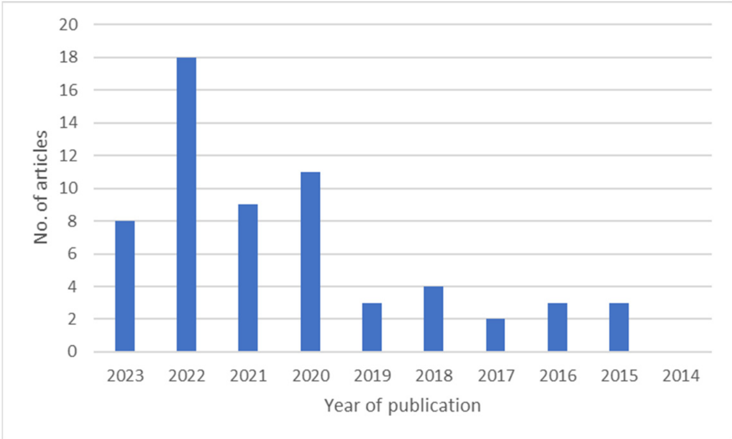

Figure 2. Annual publication trends between 2014 and 2023.

The reviewed 61 studies were published in 41 different journals worldwide. This shows the growing interest of studies and journals in the inclusion of technology in BE education. The top five journals where approximately 36% of the studies were published are the Journal of Information Technology in Construction (6), Buildings (5), Sustainability (4), Journal of Professional Issues in Engineering Education and Practice (3), and International Journal of Construction Education and Research (3). Construction Innovation, International Journal of Engineering Education, Research in Learning Technology, and Applied Sciences published two articles each in the last decade. The other 32 studies were published in 32 different journals. Figure 3 shows the journal-wise distribution.

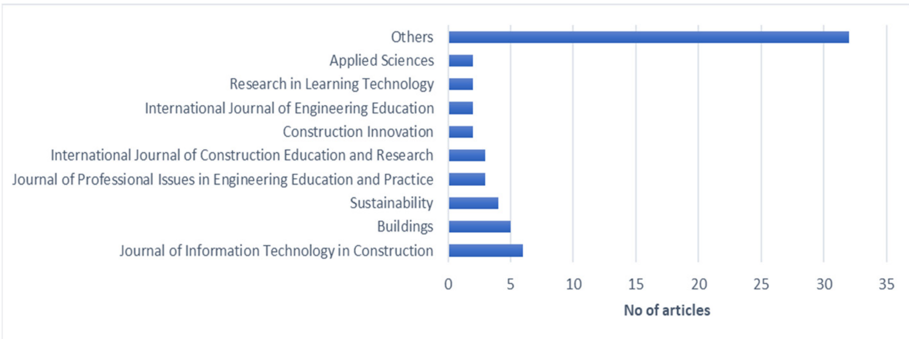

Figure 3. Distribution of studies across different journals.

4.2. Thematic Analysis

4.2.1. Commonly Used Technologies in BE Education

Based on the 61 peer-reviewed journal articles, this section outlines the list of technologies that are frequently used by BE educators in higher education. Highlighting these technologies is significant as educators can benefit from this list in a number of ways. Higher education academics can be aware of the most frequently used technologies and how they have been integrated and implemented in pedagogy. These technologies provide students with hands-on learning experiences and practical approaches to real-world problems. BE students can experience improved learning, develop relevant skills, align with industry needs, foster innovation and problem-solving skills, and stay competitive globally.

Synthesizing the most broadly used technologies will help BE educators select the most appropriate technologies for widespread application.

Table 2 presents the most extensively used technologies, with VR, AR, and BIM appearing in 38%, 21%, and 13% of the reviewed papers, respectively. Less frequently used technologies include gamification, Extended Reality (XR), Mixed Reality (MR), 3D scanning, drones, Interactive Voice Response (IVR), computer-aided technologies (CATs), Enhanced Virtuality (EV), and laser scanning.

Table 2. Most widely used technology in BE education.

Emerging Technologies in BE Education	Articles	Frequency
Virtual Reality (VR)	[7,26–29,37,69–72,88,89,91–93,95,96,100,103,105,106,112,113]	23
Augmented Reality (AR)	[26–29,72,93,100,103–105,107,110,113]	13
Building Information Modeling (BIM)	[7,26,98–100,105,109,110]	8
Gamification	[29,37,70,92,95,97,105]	7
Extended Reality (XR)	[8,27,69,90,103]	6
Mixed Reality (MR)	[26–28]	4
3D scanning	[26–28]	3
Drones	[26–28]	3
Interactive Voice Response (IVR)	[8,27]	2
Computer-aided technologies (CATs)	[75]	1
Enhanced virtuality (EV)	[94]	1
Laser scanning	[109]	1

4.2.2. Enhancing Student Engagement through Technology in BE Education

The use of technologies in BE education has improved student engagement and contributed significantly to raising student enthusiasm and satisfaction. The integration of technologies creates an exciting learning environment in the classroom rather than the traditional one-way didactic learning environment. Generation Z students show extreme interest in the use of technology [47].

VR technology, for example, has been shown to positively impact student motivation in architecture education by allowing them to interact with virtual architectural details and understand spatial linkages [29,70,92,95]. VR simulations enable students to explore construction sites and engage with equipment safely, providing real-world experiences [37,91]. Kuncoro [96] highlighted how VR simulations of earthquake-resistant structures enhanced student understanding through experiential learning. This immersive approach aligns with Pedro et al. [102], who found that VR-based frameworks significantly augment engagement in construction safety education.

Similarly, AR technology aids the visualization and understanding of construction processes by providing access to 3D images. Students find AR interesting due to its mobile accessibility and interactive simulations [104]. AR improves motivation and investigative skills while enhancing interactive learning in building and architecture education [93]. The design of complex teaching scenarios is made possible by AR-supported teaching platforms that bridge the gap between AR and open BIM [110].

Pedagogy frameworks incorporating VR and AR technologies emphasize active learning and knowledge construction processes. These frameworks enable students to construct knowledge and improve critical thinking skills [7]. They also facilitate hazard identification and safety training [72,105].

XR technologies, including VR, AR, and MR, create immersive and interactive learning experiences that enhance student understanding and engagement. These technologies reduce cognitive load and facilitate digital prototyping, improving learning outcomes [69,90].

Gamification also improves student involvement and attitudes towards learning [97]. ICT and digital education support collaborative learning and effective information retrieval [99].

Mixed mobile reality using AR and VR creates an improved learning environment [28]. Construction safety training using EV enhances learner motivation [94]. Immersive videos such as 360-degree and 180-degree formats engage technologically inclined students [114]. Ummihusna and Zairul [77] found that immersive learning technologies, including games, improve performance, decision-making, and visualization. CATs simulate real-world work environments, boosting user interest [75]. Social VR systems with cooperative learning and hazard inspection modules enhance construction safety education by improving engagement and emotional impact [89].

By incorporating these technologies, educators can provide dynamic and exciting learning environments to teach students BE challenges. Student comprehension and practical abilities are improved by the immersive, interactive, and personalized learning experiences created by the technologies [71]. These innovations stimulate active learning, provide immersive learning environments, and give students access to robust tools and resources. By leveraging these technologies in the BE area, educators can improve student motivation, happiness, and learning outcomes.

4.2.3. Improving Learning Outcomes with Technology in BE Education

Technology integration has significantly enhanced educational outcomes in BE. Students can visualize complex engineering designs, virtually explore construction sites, analyze datasets, and obtain real-time data from sites. These technologies collectively enhance learning outcomes in BE education.

For instance, VR technology offers an interactive and immersive environment that improves comprehension of structural elements and construction methodologies [37,70,71,92,95]. VR improves student performance compared to traditional methods and enhances construction safety education by mimicking real-world sites [72,91,106].

AR technology enhances spatial and graphical skills, critical thinking, and comprehension of complex assembly processes, creating engaging and realistic learning settings [29,39]. AR and VR integration in BE education leads to higher levels of learning and content knowledge [113]. A 4D construction learning environment improves subject understanding, grades, and educational experiences [101,103]. XR and IVR technologies promote knowledge retention and visualization of complex concepts [8,27].

According to Mahat et al. [97], game-based learning promotes knowledge creation and strengthens fundamental skills. Additionally, VR games have been proven to help students achieve greater knowledge evaluation results [112]. Le et al. [89] found that incorporating VR into online social VR systems creates immersive experiences that help students retain knowledge. By supporting knowledge creation and motivation, active learning frameworks based on VR pedagogy and digital technologies improve the learning experience [7,28]. In a fascinating study by King et al. [88], it was demonstrated that VR systems with AI enhancements boost skill development and teacher–student engagement.

Integrating BIM and ICT into BE education, as highlighted by Lucas [98] and Xu et al. [99], encourages students to work together, think critically, and develop hard and soft skills. Students can use digital tools for effective information retrieval and to understand how BIM affects construction processes. Student performance improves when BIM is included in VR as a teaching aid [26]. Furthermore, laser scanning technology assists in documenting and modeling existing buildings in BIM, improving students' comprehension of BIM procedures and their comfort level with the technology [109].

BIM, gaming, VR, and AR are just a few examples of virtual environments that have been proven to improve safety learning and shorten learners' time to become proficient in their field of work [105]. Personalized education, self-education, and increased knowledge and skills are made possible by combining VR, cloud-based education systems, digital textbooks, multimedia training courses, and BIM technology [100].

In short, these technologies help improve learning outcomes, such as increased retention of the subject content, higher student performance, and improved safety and subject-matter expertise. The immersive and interactive features of these tools increase engagement, support efficient learning processes, and close the gap between theory and practice, putting students in a strong position for BE employment.

4.2.4. Enhancing Employability Skills through Technology in BE Education

Integrating technology in BE education can significantly enhance students' employability skills by equipping them with the necessary knowledge and competencies demanded by the industry [9]. The construction and building industry is heavily reliant on such technologies as Digital Twin, artificial intelligence (AI), IoT, BIM, and Smart Vision (SV) to improve the efficiency, accuracy, and productivity of building work [115]. The industry is striving to adopt Industry 4.0 by adopting digital technologies. To keep pace with the rapidly evolving industry, BE students need to shape their skills to meet the industry's criteria. The use, integration, and implementation of technologies in BE education will make students employable as technologies are being implemented in most of the construction- and building-related work. Lacking skills in the use of technologies may jeopardize students' ability to remain competitive on a global scale.

Several studies have examined how different technologies affect employability in BE education, highlighting the function and efficacy of various technology tools. Lu's [70] exploration of the use of VR technology in teaching architectural technology claims that it improves students' job market competitiveness by enhancing their understanding of advanced technologies.

ICT and digital education have also shown promise in enhancing employability in BE education. The advantages of digital education for engineering students' abilities and employability are highlighted by Xu et al. [99]. Educators can monitor student progress, encourage collaborative learning, and improve information retrieval skills by incorporating digital training. To better prepare students for the digitalized economy and increase their employability, Lasheen et al. [107] also emphasize the significance of incorporating such digital technologies as blockchain, IoT, AR, and BIM into BE education curricula. Additionally, Pugacheva et al. [100] highlight the importance of integrating different technologies into professional skill development training, which offers a whole educational process that leads to acquiring the requisite knowledge and abilities. Abidoye et al. [9] emphasize the importance of technology-related skills such as data science analysis techniques, machine learning, AI, and blockchain for students' employability in the construction sector. According to Lucas [98], BIM benefits students' employment in the construction sector since employers' value relevant BIM knowledge. Shanbari et al. [109] highlight the importance of understanding BIM practices and technologies, including laser scanning, in the construction industry. Integrating these technologies into work processes increases efficiency and competitiveness in the job market.

Studies show that using technologies such as VR, digital learning, BIM, and laser scanning promotes crucial skill development, immersive learning opportunities, and industry alignment for students in the BE sector. While the findings from the reviewed studies provide valuable insights into the impact of technology on employability in BE education, it is important to note the need for further research. For instance, more empirical evidence is needed to determine how VR technology affects students' employability when teaching architectural technology [70]. Similarly, Hajirasouli et al.'s study [7] suggests a VR-based instructional framework for architectural design studios but does not offer any concrete proof of the framework's effect on employability. Therefore, more investigation is needed to examine the precise effects of various technologies on students' employability and to improve existing pedagogical frameworks or develop novel approaches that adequately prepare students for the industry's changing needs [29,116].

4.2.5. Challenges in Implementing Technologies in BE Education

Technology integration in BE education has positively affected student engagement, learning outcomes, and employability skills. According to several studies [69,90,92,95,106,108], these technologies have been shown to improve visual and spatial recognition, student motivation, spatial perception, imagination, and technical abilities. However, studies emphasize the need to evaluate the application of the technologies and determine a suitable practical framework to maximize the benefits and advantages they offer [93,116]. The implementation of technologies also faces several difficulties, including restricted access to resources, high costs, lack of empirical evidence, potential restrictions on creativity, the need for training, and the requirement for a foundational understanding of how to use them [69,90,92,108–110].

According to [70], better VR tools that align with architectural technology knowledge are required. Existing VR and AR applications need to address issues such as user-friendliness, screen size limitations, site accessibility, and the provision of sufficient spatial learning experiences [29,93,103]. Integrating AR into construction technology courses also demands sufficient resources and addresses the challenges of understanding 2D drawings [104]. The requirement for specific educational objectives, lack of case studies, rapid technological improvements, the cost and complexity of implementation, faculty reluctance, and lack of assessment tools are additional difficulties associated with XR technologies [27,103].

Implementing BIM in the classroom involves such difficulties as training and balancing technical skill development with conceptual-based discussions [98]. IVR technology faces issues related to standardization, cost, and the knowledge–experience gap [8]. Digital transformation is also hampered by the industry's reluctance to change and a lack of technical expertise [111]. Additional hurdles include various tools, hardware compatibility, integration with other design methodologies, and aligning VR implementation with learning theories [28,69,95]. In addition to these drawbacks, VR also has training needs, and some users experience motion sickness while using this technology [88]. A lack of lectures or exercises on drawing 2D representations of 3D phenomena and having insufficient site visits hinder teaching building specifics [117].

The COVID-19 pandemic also increased the need for digital transformation in the AEC sector. It prompted businesses to prioritize digital transformations and obliged quick improvements [111]. According to Mahat et al. [97], the pandemic raised the demand for creative methods in BE education to involve students in an active environment. The COVID-19 pandemic brought further attention to the drawbacks of in-person visits and the value of online resources [90,95]. Additionally, it raised the demand for online resources and underlined the importance of cutting-edge technologies in remote learning [37] and the necessity for innovative and adaptable educational paradigms [103].

To realize these technologies' potential fully, issues such as the need for better tools, developments required in educational institutions, cost, standardization, and industry adoption need to be resolved. Construction site visits and interactive virtual teaching spaces are examples of helpful, practical learning experiences in BE education. Educators should invest in assessment tools and acquire digital skills. Students will be more prepared for the workplace if solutions to overcome these obstacles are found. The pedagogic potential of these technologies should be investigated, and their application should align with learning theories [100]. The relevance of technologies for distant learning and overcoming physical limitations was highlighted by the COVID-19 pandemic [37,63]. By addressing these challenges, technologies can dramatically improve student engagement, learning results, and employability skills in BE education.

5. Conclusions

This systematic review explores the evolving landscape of technology integration in BE education from 2013 to 2023. The literature reveals a compelling narrative of how emerging technologies, including VR, AR, MR, and diverse digital tools, are reshaping pedagogical practices and enhancing learning experiences.

Throughout this review, it has become evident that technology integration in BE education is not merely a trend, but a necessity driven by the demands of the modern workforce and the dynamic nature of the BE industry. The integration of digital technologies addresses critical challenges traditional teaching methods face, offering immersive, interactive, and experiential learning environments that better prepare students for the complexities of real-world projects.

From the foundational role of BE education in socio-economic development to the imperative for digital transformation accelerated by the COVID-19 pandemic, each section of this review underlines the significance of technology integration in advancing educational outcomes and equipping graduates with the skills needed to thrive in the industry. Addressing the research gaps and challenges identified in this review will help educational institutions and policymakers leverage technology to drive meaningful advancements in BE education, ultimately contributing to socio-economic development and global prosperity.

6. Future Research

Based on the findings of this review, several key future research directions are identified that warrant further exploration:

Empirical Evaluation of Technology Integration: Future research should prioritize empirical studies that evaluate the specific effects of different technologies on student learning outcomes and employability skills. Longitudinal studies are particularly needed to provide deeper insights into the long-term impact of technology on educational outcomes and job readiness. This will help in quantifying the benefits and identifying any potential drawbacks associated with the use of emerging technologies in BE education.

Development and Evaluation of Pedagogical Frameworks: There is a need for research focused on developing and testing pedagogical frameworks that effectively incorporate technology into BE education. This includes optimizing and incorporating the use of digital tools within the curriculum, creating appropriate and authentic assessment methods for technology-enhanced learning, and training educators to use these tools effectively. Understanding the best practices for technology integration will help in standardizing its use across BE programs globally.

Implementation Challenges: Despite the evident benefits, the implementation of technology in BE education faces several challenges, including resource limitations, cost barriers, change fatigue among the educators, and faculty reluctance. Future research should explore strategies to overcome these challenges, such as developing cost-effective, user-friendly tools and promoting industry-wide adoption of technology-driven approaches. Investigating ways to provide adequate support and training for educators will also be crucial in ensuring successful implementation.

Promoting Global Equity in BE Education: The disparity in educational resources between developed and underdeveloped regions presents a significant challenge. Research should focus on how technology can be leveraged to bridge these gaps, ensuring that students in all regions have access to high-quality BE education. This includes exploring the role of open access digital tools, online learning platforms, and global partnerships in enhancing educational equity and promoting socio-economic development worldwide.

Adapting to Rapid Technological Advancements: As technology continues to evolve, BE education must adapt by incorporating emerging technologies such as VR, AR, and gamification. Future research should examine how these advancements can be integrated effectively into the curriculum to enhance student engagement, learning outcomes, and employability skills. Additionally, research should explore the implications of future technological trends, such as artificial intelligence (AI) and machine learning (ML), on BE education and how they can be utilized to further enhance the learning experience.

7. Theoretical and Practical Implications

This research provides significant theoretical and practical implications for higher education policymakers, academics, and future researchers exploring digital technologies in educational settings.

Theoretical Implications: This research addresses a notable gap in the literature by examining the role of digital technologies in Built Environment (BE) education. As higher education increasingly embraces digital advancements, understanding their impact is crucial. This study identifies critical themes in the existing literature, offering a comprehensive understanding of how digital technologies enhance students' learning experiences in BE education. By synthesizing these findings, the research provides a foundation for academics to explore digital technologies' prominent uses and benefits. Furthermore, it outlines future research avenues, serving as a toolkit for advancing the body of knowledge in this field.

Practical Implications and Recommendations: Academics and Educators in BE Education: Academics should integrate emerging digital technologies, such as VR and AR, into their teaching practices to enhance student engagement, learning outcomes, and employability skills. This study's findings underscore the importance of moving beyond traditional lecture-based methods to adopt interactive and experiential learning tools. Therefore, educators can better prepare students for the demands of the modern workforce, equipping them with the digital fluency and critical thinking skills that employers increasingly seek.

Higher Education Policymakers: Policymakers should support the seamless integration of digital technologies across BE education curricula by providing the necessary resources, training, and institutional support. This will ensure that educational programs remain competitive and relevant in a technology-driven global economy, ultimately leading to the production of highly skilled graduates ready to contribute to industry innovation and sustainability.

Employers in the Built Environment Sector: Employers should collaborate with higher education institutions to define the specific digital competencies required in the industry and support initiatives that align educational outcomes with these needs. This is to ensure that graduates entering the workforce are proficient in the latest digital tools and practices, reducing the skill gap and enhancing overall industry productivity.

Students in BE Education: Students should actively engage with digital learning tools and resources provided in their courses to develop the skills and knowledge necessary for success in a rapidly evolving industry. Hence, students can enhance their learning experience and improve their employability, making them more competitive in the job market.

Author Contributions: Conceptualization, A.N.G., N.T. and D.M.; methodology, N.T., D.M., R.J.T., W.Z., M.G. and M.S.; software, M.G.; validation, A.N.G. and R.J.T.; formal analysis, R.J.T., W.Z. and M.G.; investigation, A.N.G. and M.G.; resources, A.N.G.; data curation, R.J.T.; writing—original draft preparation, All; writing—review and editing, All; visualization, R.J.T.; supervision, A.N.G.; project administration, A.N.G. All authors have read and agreed to the published version of the manuscript.

Funding: This study received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

Nomenclature

AEC	architecture, engineering, and construction
AI	artificial intelligence
AR	Augmented Reality
BIM	Building Information Modelling
BE	Built Environment
CATs	computer-aided technologies
DT	Digital Twin
EV	Enhanced Virtuality

GBL	gamification-based learning
ICTs	information and communication technologies
IoT	Internet of Things
IVR	Interactive Voice Response
MR	Mixed Reality
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
SLR	systematic literature review
SV	Smart Vision
VR	Virtual Reality
XR	Extended Reality

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