

ADVANCING CONSTRUCTION ENGINEERING EDUCATION THROUGH EXTENDED REALITY TECHNOLOGY: A SYSTEMATIC REVIEW

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ABSTRACT: The growing complexity of construction engineering education calls for innovative methods to connect theory with practice. Extended reality (XR) offers transformative opportunities, yet its adoption in construction education lags behind other fields. Therefore, this study systematically reviews XR applications in construction engineering education through a three-step methodology: identify review strategies, conduct bibliometric analysis, and synthesize key research elements. Using Boolean operators and wildcard searches in Scopus, 59 studies were selected from an initial 320 papers based on strict inclusion and exclusion criteria. The bibliometric analysis revealed that United States and China lead XR research output, accounting for more than 50% of the total studies. Moreover, the analysis of target groups revealed that approximately 88% of the studies focused on individuals within the educational sector, including students, teachers, and researchers, while only 11% targeted professionals and engineers. BIM tools were the most frequently used software, appearing in 29% of the total studies, while Navisworks® was less commonly used, accounting for 14%. The review also identified the top objective, which was to enhance student engagement, emphasized in 25.4% of the reviewed studies. The most notable outcome was improved 3D visualization, reported in 22% of studies, which enhances students' comprehension of complex engineering concepts through immersive digital environments. Finally, the primary future recommendation was further BIM integration and training programs to ensure seamless adoption of XR technologies. However, the most significant challenge identified was the high cost and accessibility issues, which hinder widespread implementation.

1. INTRODUCTION

The primary goal of pedagogy and education is to equip students with the necessary knowledge, skills, and competencies to thrive as future professionals, leaders, and innovators. Traditionally, construction engineering education has relied on lectures, textbook-based learning, and standardized assessments. However, these conventional approaches often fail to address the dynamic and evolving demands of the modern construction industry. Studies indicate that passive lecture-based learning results in low retention rates, with students retaining only about 5% of the information presented in lectures, compared to 75% from hands-on practice or experiential learning methods (Ho 2023). Despite significant investments in educational infrastructure globally, student satisfaction and learning outcomes often fall short of expectations. For example, the United States invests over \$600 billion annually in higher education, yet many graduates report feeling underprepared for the complexities of real-world construction challenges (Irwin et al. 2021). In the United Kingdom, over 30% of students believe their tuition fees do not provide adequate value, citing outdated teaching methods as a key concern (Naves & Hewitt 2022). These findings highlight a growing dissatisfaction with traditional educational methodologies, which often lack engagement,

critical thinking stimulation, and practical problem-solving opportunities necessary for tackling real-world construction challenges. In response to these issues, educational institutions are increasingly adopting innovative pedagogical strategies such as project-based learning, adaptive AI-driven tools, and immersive technologies to create more interactive, personalized, and compelling learning experiences. These advancements not only enhance student engagement but also align closely with industry requirements, equipping future construction engineers with the technical and practical skills necessary for success (Wang et al. 2024). Among these technological advancements, extended reality (XR) stands out as a transformative approach, offering immersive and interactive environments that bridge the gap between theoretical knowledge and practical application, particularly in construction engineering education (Hosny et al. 2025). XR encompasses a range of technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), which provide students with realistic, interactive experiences that enhance comprehension, retention, and engagement, as shown in Figure 1. VR is a fully immersive digital environment that replicates real-world or imagined scenarios through computer-generated simulations (Ogrizović et al. 2021). By wearing specialized VR headsets, users are completely isolated from their physical surroundings and placed in an entirely virtual space (Radianti et al. 2020). AR, on the other hand, overlays digital information onto the physical world, allowing users to interact with digital models and their surroundings simultaneously (Arena et al. 2022). AR is typically delivered via mobile devices, tablets, or wearable technologies like smart glasses (Dong et al. 2013). MR merges VR and AR technologies, enabling users to interact with both digital and physical elements simultaneously (Rokhsaritalemi et al. 2020). MR devices, such as HoloLens, allow users to manipulate digital models in real-world contexts, creating a seamless integration of the two environments (Wang et al. 2023). Moreover, the downward arrow in the figure represents a continuum from the virtual world on the left to the real world on the right. VR occupies the far left, creating a fully immersive digital environment with no connection to the physical world. AR resides on the far right, overlaying digital elements onto the real world without deep interaction. MR lies in between, enabling real-time interaction between digital and physical objects. The potential of XR technologies in education extends beyond improving theoretical understanding; they also foster increased motivation and active participation among students. One of the significant challenges in construction engineering education is sustaining student interest, especially in complex subjects such as cost estimation, progress monitoring, and dispute resolution. XR addresses this challenge by transforming passive learning into an interactive and engaging experience, enabling students to visualize construction processes, collaborate on digital models, and simulate real-world scenarios. Moreover, XR technologies facilitate collaborative learning by allowing multiple users to interact within the same virtual or augmented environment, making it particularly valuable for construction engineering disciplines where teamwork and coordination are crucial.

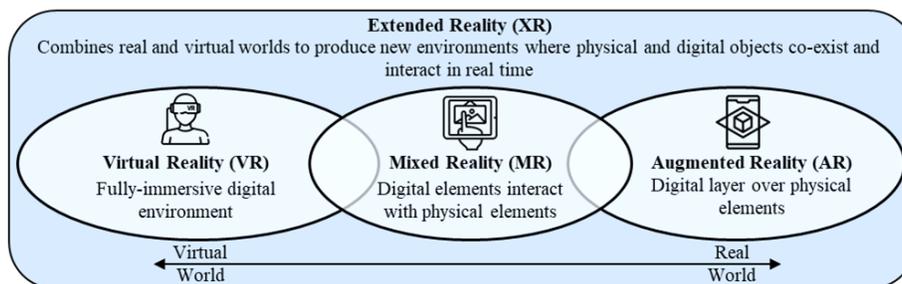


Figure 1: Overview of XR technology

Table 1 shows a summary of the five selected review studies focused on XR technologies in construction engineering education, drawn from an analysis of multiple studies within the broader domain of XR applications in education. These studies are categorized based on their scope, AR, VR, and XR, highlighting their specific contributions to the construction engineering education landscape. The primary objective of this review is to compare and contrast the findings from these studies to identify trends, strengths, and gaps specific to construction engineering education. From the summarized data, it is evident that XR technologies have been extensively applied in general education and training contexts; however, their focused implementation within construction engineering education remains relatively underexplored. Recent research has explored the use of XR technologies across various educational domains, including architecture (Casañas et al. 2021), engineering (Espinoza et al. 2021), and construction management

(Bartels & Hahne 2023). However, a critical gap persists in understanding the long-term impact of XR integration on learning outcomes and professional readiness in construction engineering disciplines. For example, Tan et al. (2022) conducted a review of 82 studies from a pool of 36,612 published between 2012 and 2021, focusing on AR/VR applications in education and training. The study found significant improvements in student engagement and learning retention but highlighted barriers such as technological infrastructure limitations and financial constraints. Similarly, Spitzer et al. (2022) reviewed 82 studies out of 337, covering the period from 2011 to 2021, emphasizing the broad adoption of XR technologies in general education but noting a lack of specialized construction-related applications. Specific applications of XR technologies, such as VR-based construction site simulations and AR overlays for real-time project assessments, have shown promise in enhancing practical skill development. For instance, Li et al. (2020) conducted a bibliometric review of 630 VR-related studies spanning from 2006 to 2019, underscoring the growing role of VR in construction engineering research and education. However, challenges such as cognitive overload and accessibility for resource-limited institutions were identified as significant barriers.

Table 1: Sample of review work related to XR in construction engineering education

#	Year	Scope of Study	No. of Studies Reviewed	Type of review	Period of Study	Purpose	Reference
1	2022	AR/VR	82 out of 36,612	Systematic Review	2012-2021	Education & training	(Tan et al. 2022)
2	2022	XR	82 out of 337	Comprehensive literature review	2011-2021	Education	(Spitzer et al. 2022)
3	2022	AR	39 out of 200	State-of-the-art	2010-2020	Education	(Hajirasouli & Banihashemi 2022)
4	2020	VR	630	Bibliometric analysis	2006-2019	Education & research	(Li et al. 2020)
5	2017	VR	28 out of 331	Bibliometric analysis	2000-2015	Education & training	(Obeidallah et al. 2023)

Despite the increasing interest in integrating immersive technologies into educational frameworks, the specific application of XR technologies in construction engineering education remains significantly underexplored. A critical gap exists in the methodological approaches that effectively integrate XR technologies into construction engineering education. Current studies primarily focus on isolated applications of XR, such as VR-based simulations for construction training or AR-enhanced visualization of building models. However, a holistic understanding of how XR can transform traditional pedagogical models, enhance experiential learning, and address real-world construction challenges is still lacking. This gap is particularly prominent in construction engineering education, where XR has the potential to address enduring challenges, such as improving spatial understanding of complex structures, enhancing safety training, and simulating real-world construction site scenarios in a risk-free environment. Therefore, this study aims to conduct a structured, systematic, and comprehensive analysis of multiple XR technologies in construction engineering education. The main objectives of this study are to:

1. Conduct a bibliometric analysis of existing studies, to evaluate trends such as publication distribution, global distribution, target groups, and software and tools used.
2. Collect and summarize the key elements from the reviewed studies, including research objectives, findings and outcomes, future recommendations, and challenges.

2. METHODOLOGY

This review follows a structured three-step methodology to effectively achieve the research objectives and provide a comprehensive analysis of XR technologies in construction engineering education. The methodology ensures a systematic approach to examining existing literature. The first step involves identifying the review strategy and selection process, which includes defining keywords related to XR applications through categorization and thematic clustering. This process enables a targeted exploration of relevant studies by strategically combining keywords and exclusion criteria. In this review, the keyword strategy focuses on three main aspects. The first aspect covers terms synonymous with or related to XR technologies, ensuring comprehensive coverage of various XR applications. The second aspect focuses

on the educational context, narrowing the search to studies that explore teaching and learning practices. The third aspect refines the scope of civil engineering disciplines, ensuring the literature aligns with the specific focus of construction engineering education. Once the search strategy was developed, Boolean operators and wildcard searches were used in the Scopus database to retrieve relevant literature. Scopus was chosen due to its extensive coverage of peer-reviewed journals and conference proceedings. To optimize the search process, specific criteria were defined to ensure the retrieval of the most relevant studies. Table 2 outlines the detailed search criteria, and the rationale behind these selections is as follows. Once the search strategy was refined and the Scopus database was selected, a literature search was conducted to gather relevant studies aligned with the review’s objectives.

Followed by the application of rigorous inclusion and exclusion criteria to ensure the selection of relevant and high-quality studies. Figure 2 outlines the process, starting from the initial search and concluding with the final selection of related research. Inclusion criteria 1 involved searching for papers published between 2014 and 2023 using the defined keyword strategy, limiting the results to articles and conference papers. This phase yielded an initial set of 320 papers. The papers were then subjected to three phases of exclusion criteria based on their relevance, empirical scope, and alignment with the research topic. In exclusion phase 1, papers were excluded based on a review of their title and abstract. A total of 134 papers were excluded for being unrelated to the topic, 57 for being theoretical rather than empirical, 29 for focusing on the wrong population (e.g., non-student or clinical groups), and 4 for being impossible to retrieve. After this phase, 96 papers remained. Exclusion phase 2 involved a detailed screening of the papers to check their relevance to the scope of the review. Here, 17 papers were excluded for not focusing on civil engineering education, and another 6 were excluded for being theoretical. This left 73 papers for the final phase. In exclusion phase 3, a full-text review was conducted. Papers were excluded if they did not involve CAR (5 papers), if they focused on unrelated outcomes like usability or user experience (4 papers), or if they were theoretical (3 papers). Additionally, two papers were excluded for not addressing the correct educational subject. After the final exclusion phase, a total of 59 papers were retained and included in the review for detailed analysis.

Table 2: Summary of search characteristics

Criteria	Option
Search type	Advanced search
Languages	English
Document type	Articles and conferences
Timespan	2014 – 2023
Booleans used	AND - OR
Advanced search tool used	Wildcard (*)
Searches within	TITLE-ABS-KEY (Article title, abstract, and keywords)

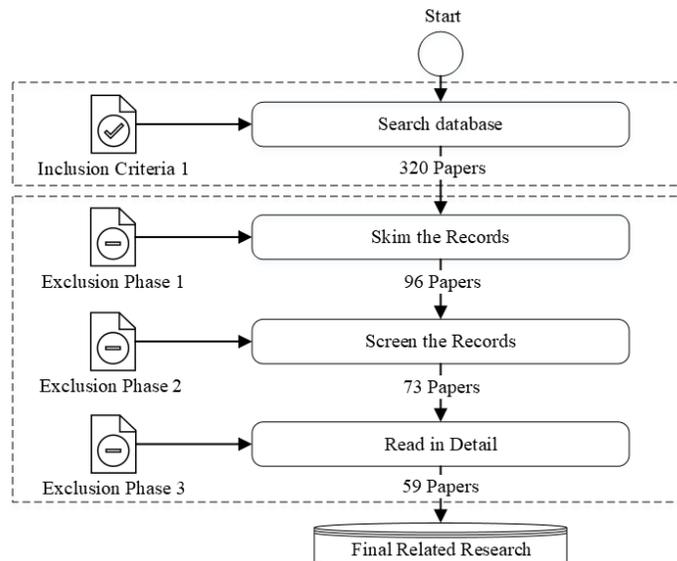


Figure 2: “Include and Exclude Studies” process

The second step is to conduct a bibliometric analysis that applies quantitative analysis techniques such as publication trends assessment (Section 3.1). This step helps identify influential research clusters, emerging trends, and geographical distribution patterns of XR technology adoption in construction engineering education. Additionally, statistical evaluations of research impact and focus areas provide further insights into the evolution of XR applications. The third and final step is to perform review synthesis and interpretation, which involves an in-depth synthesis of the selected studies to extract meaningful insights (Section 3.2). This phase focuses on evaluating the primary objectives of the reviewed studies, interpreting key findings on XR's effectiveness in enhancing student learning and engagement, and identifying the challenges associated with XR adoption. Furthermore, the study consolidates future recommendations provided in the reviewed literature to guide the development and practical implementation of XR technologies.

3. RESULTS

3.1 Conduct Bibliometric Analysis

A statistical analysis was conducted to evaluate the scope, distribution, and impact of the retrieved literature. This step was designed to both summarize the dataset and provide deeper insights into the relationships, patterns, and trends within the themes identified. The analysis was conducted in four phases: 1) distribution between conferences and journals, 2) global distribution, 3) distribution of target groups involved, and 4) types of software and tools. The first analysis, which is the distribution of publication types across the reviewed studies, reveals that 63% of the publications are journal articles, while 37% are conference papers. This distribution indicates a stronger emphasis on publishing in peer-reviewed journals, which suggests a preference for more rigorous, in-depth, and well-reviewed research contributions in the field of XR technologies in construction engineering education. On the other hand, the 37% representation of conference papers highlights the importance of conferences as a platform for disseminating emerging trends preliminary findings, and engaging with industry stakeholders. Figure 3 presents the global distribution of reviewed studies on XR technologies in construction engineering education over the past decade (2014–2023). Three key observations can be drawn from the data. The United States (20 studies) and China (10 studies) collectively account for a significant portion accounting for more than 50% of the total reviewed publications, underscoring their leading roles in XR research within education. The prominence of these countries can be attributed to factors such as substantial investment in research and development (R&D), strong industry-academia collaborations, and government initiatives aimed at advancing STEM education and immersive learning technologies. While the global distribution of XR research is concentrated mainly in developed economies, emerging contributions from countries such as India (3 studies) and Brazil (1 study) indicate growing interest in the adoption of immersive technologies. India's efforts can be linked to initiatives such as Digital India and the National Education Policy (NEP) 2020, which promote the integration of digital tools in education to enhance learning outcomes. However, despite these efforts, developing countries still face challenges such as limited funding, infrastructure gaps, and a focus on more fundamental educational priorities, which hinder broader adoption and research efforts in XR technologies. European countries, including Germany (4 studies) and the United Kingdom (2 studies), show a notable presence in XR research, emphasizing their strong academic research ecosystems and government support for educational technology innovations. Similarly, Australia (2 studies) demonstrates a growing commitment to XR integration in education, driven by national policies aimed at enhancing digital capabilities in engineering disciplines. However, regions such as Africa and parts of South America continue to exhibit lower levels of research output, highlighting disparities in access to resources and technological adoption across the globe.

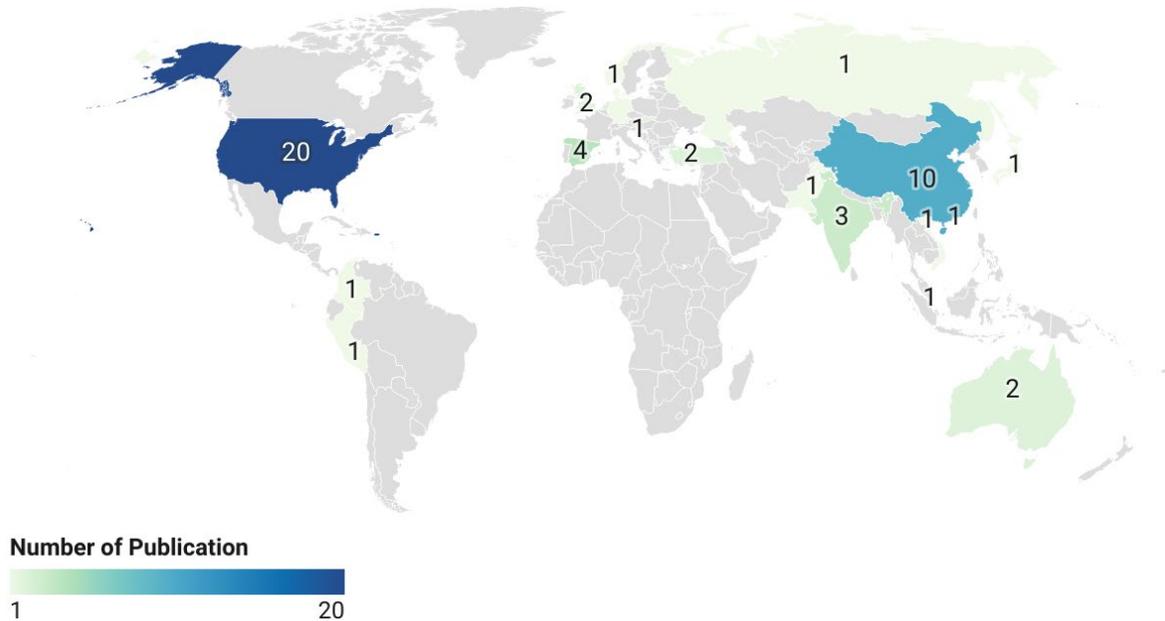


Figure 3: Global distribution of the publications on XR technologies in construction engineering education (Total of 59 studies)

Figure 4 illustrates the distribution of target groups involved in studies utilizing XR technologies in construction engineering education based on a total of 59 related studies. The analysis highlights the primary beneficiaries of these technological advancements, emphasizing their impact on various stakeholders within the educational ecosystem. The data indicates that students represent the largest target group, with 45 studies focusing on their learning experiences. This significant proportion underscores the strategic emphasis on enhancing student engagement through interactive and immersive learning environments. By leveraging immersive technologies such as VR and AR, educational institutions aim to bridge the gap between theoretical knowledge and practical application, providing students with hands-on experiences that better prepare them for real-world challenges in the construction industry. Teachers involved in 21 studies play a crucial role in implementing immersive technologies within the curriculum. Their participation highlights the importance of faculty training and the adaptation of new teaching methodologies that leverage XR tools to improve instructional delivery and learning outcomes. Researchers cited in 5 studies focus on evaluating the effectiveness and impact of immersive technologies in construction education. Their work is essential for developing best practices, exploring new pedagogical approaches, and identifying challenges associated with the adoption of XR technologies. Professionals and engineers featured in 7 studies represent another critical group benefiting from immersive technologies. The use of XR in professional development programs highlights the industry's recognition of these tools for ongoing training, skill enhancement, and competency building in a risk-free virtual setting.

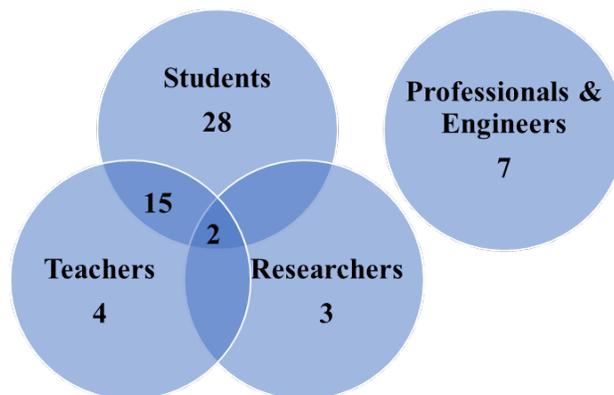


Figure 4: Distribution of target groups involved in studies utilizing XR technologies (Total of 59 studies)

Figure 5 presents an overview of the types of software utilized in research studies focusing on XR technologies in construction engineering education. The data, derived from a total of 59 related studies, highlights the diverse range of software tools employed to enhance both theoretical and practical aspects of construction education. The analysis reveals that building information modeling (BIM) tools are the most frequently utilized software, appearing in 17 studies. This distinction highlights the increasing reliance on BIM for digital visualization, project management, and collaboration within construction education. The widespread adoption of BIM tools reflects their critical role in bridging the gap between design concepts and real-world construction processes. Autodesk Revit®, utilized in 12 studies, is another widely used tool, emphasizing its importance in creating detailed architectural and engineering models. Similarly, AR simulators, mentioned in 11 studies, demonstrate the growing interest in overlaying digital information onto physical environments to enhance student understanding and interaction with complex construction concepts. Navisworks® and VR simulators are also frequently used, with 8 and 7 references, respectively. Navisworks® is valued for its capabilities in project review and clash detection, while VR simulators offer immersive experiences that allow students to explore construction environments in a risk-free setting. On the lower end of the spectrum, VSM and SketchUp® are each cited in 2 studies, indicating their role applications in educational settings. SketchUp® is primarily used for 3D modeling and visualization, while VSM supports lean construction education by visualizing process workflows.

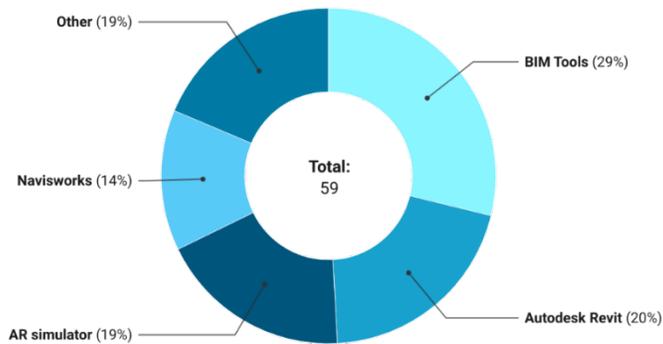


Figure 5: Types of software used and the corresponding number of research

3.2 Summarize Key Elements

This section summarizes the research objectives, findings and outcomes, future recommendations, and research challenges of the 59 studies integrating XR technologies in construction engineering education. The analysis of the reviewed studies reveals five primary objectives driving the integration of XR technologies in construction engineering education, as summarized in Table 3. These objectives highlight the role of XR in enhancing student engagement, improving construction management skills, supporting safety training, enriching teaching methodologies, and advancing design visualization.

Table 3: Summary of top five of the key objectives

Objectives	# of studies out 59	Example reference
Implement XR technology in civil engineering education to improve student engagement and understanding	15	(Chen et al. 2023; Walker et al. 2020; Wang et al. 2022)
Integrate XR with BIM in civil engineering and construction management	9	(Bew 2014; Li 2022; Yakshina et al. 2019)
Develop safety and health training system using XR for construction projects to reduce accidents	8	(Casañas et al. 2021; Spisakova et al. 2020)
Enhance design visualization for better comprehension of spatial relationships and design coordination	6	(Dong et al. 2013; Wen et al. 2021)
Use XR technology in teaching system to enhance the learning experience in construction engineering education	4	(Hu & Chen 2022; Wang et al. 2022)

The implementation of XR technologies has yielded significant positive findings and outcomes across various aspects of student learning and professional readiness. One of the most notable outcomes is the improvement in 3D visualization, allowing students to better comprehend complex architectural and engineering concepts through immersive digital environments (Behzadan & Kamat 2013; Dong et al. 2013;

Turkan et al. 2017). Another significant finding is the increase in student engagement and motivation, as the interactive nature of XR fosters active participation, enhancing focus and retention of construction-related concepts (Behzadan & Kamat 2013; Li 2022; Sepasgozar et al. 2020; Turkan et al. 2017). Studies also highlight that XR technologies enhance decision-making processes, enabling students to simulate real-world construction scenarios, evaluate design alternatives, and assess project risks in a controlled environment (Vasenev et al. 2014). Additionally, XR-based safety training has proven effective in improving hazard recognition and developing critical safety protocols, reducing workplace risks before students enter real-world job sites (Casañas et al. 2021; Clevenger et al. 2014; Ye et al. 2022). Finally, XR contributes to real-world readiness, equipping students with industry-standard tools, digital skills, and construction management workflows, ensuring they are better prepared for professional careers in the construction industry (Song et al. 2021; Yakshina et al. 2019; Zhang et al. 2018). Finally, the analysis identifies key future recommendations and challenges associated with the implementation of XR technologies in construction engineering education, as summarized in Table 4.

Table 4: Summary of top five future recommendations and challenges

Future recommendations	# of studies	Example reference	Challenges	# of studies out 59	Example reference
Further BIM integration and training programs	7	(Han et al. 2021)	High cost and accessibility challenges	7	(Wang et al. 2022)
Expand adoption and accessibility of XR technologies	5	(Wang et al. 2020)	Limited scope and sample size in studies	7	(Alizadehsalehi et al. 2019)
Enhance collaboration and real-world testing	3	(Dong et al. 2013)	Need for better integration of BIM and XR technologies	6	(Han et al. 2021)
Develop more cost-effective solutions for education	3	(Wang et al. 2022)	Technical limitations in implementation	4	(Spisakova et al. 2020)
Broaden research scope and diverse applications	3	(Turkan et al. 2017)	Challenges in adoption and learning barriers	4	(Delmastro & Chen 2023)

4. DISCUSSION

While the review indicates the growing potential of XR technologies in construction engineering education, a critical evaluation of the reviewed literature reveals several methodological and practical limitations that warrant closer scrutiny. First, a significant portion of the studies suffers from methodological weaknesses, particularly in the form of limited sample sizes, lack of control groups, and absence of longitudinal data. Many investigations rely heavily on qualitative measures, such as student surveys and self-reported experiences, without validating these findings through objective assessments of learning outcomes or skill acquisition. This raises concerns about the generalizability and reliability of the reported benefits of XR technologies. Second, the inconsistency in evaluation frameworks across studies makes cross-comparison challenging. While some studies focus on student engagement or motivation, others assess technical skill development or conceptual understanding, yet few employ standardized assessment criteria. This variation not only affects the comparability of outcomes but also obscures which XR applications are most effective in achieving specific educational goals. Furthermore, despite recognizing implementation barriers such as high costs and steep learning curves, relatively few studies offer actionable solutions or scalability strategies. For instance, while the need for faculty training is commonly noted, comprehensive models for training or institutional integration are seldom proposed. Finally, the limited scope of XR integration, often restricted to isolated modules or pilot programs, raises concerns about its sustainability and impact on broader curricula. Few studies investigate how XR technologies can be embedded into long-term educational strategies or how they align with accreditation requirements and industry standards.

5. CONCLUSIONS

This study addressed the key challenge of the limited adoption of XR in construction education through a structured, systematic, and comprehensive analysis of XR technologies in construction engineering education. Some of the key objectives were to conduct a bibliometric analysis of existing studies and

evaluate trends such as publication distribution, global distribution, target groups, and software and tools used. Furthermore, collect and summarize the key elements from the reviewed studies, including research objectives, findings and outcomes, future recommendations, and challenges. The study employed a three-step methodology to analyze XR technologies in construction engineering education systematically. First, review strategy and selection process were defined using Boolean operators and wildcard searches in Scopus to retrieve relevant literature. After the application of inclusion and exclusion criteria, 59 studies were selected from an initial 320 papers for final analysis. The second step focused on bibliometric analysis, which included publication distribution, global distribution, target groups, and software and tools used. The study examined publication trends, revealing that 63% of the reviewed studies were journal articles, indicating a preference for peer-reviewed, in-depth research, while 37% were conference papers, highlighting the importance of conferences in disseminating emerging trends. The analysis also revealed that the United States and China lead in XR research publications accounting for more than 50% of the total studies, with notable contributions from European countries like Spain and Germany. However, contributions from developing regions remain low, highlighting disparities in technological access and adoption. The analysis of target groups found that approximately 88% of the studies focused on individuals within the educational sector, while only 11% targeted professionals and engineers. Specifically, students were observed to be the primary beneficiaries (45 studies), followed by teachers (21 studies), researchers (5 studies), and professionals (7 studies). This distribution underscores the role of XR in enhancing student engagement, improving instructional methodologies, and supporting industry training programs. Additionally, the review of software utilization identified BIM tools as the most frequently used (17 studies), followed by Autodesk Revit® (12 studies), AR simulators (11 studies), Navisworks® (8 studies), and VR simulators (7 studies). These tools play a crucial role in digital visualization, project management, and immersive learning experiences, reinforcing the integration of XR technologies into construction engineering curricula. The third step involved evaluation of research objectives, summarization of outcomes and findings, and identification of challenges and future recommendations to support the development and implementation of XR technologies. The analysis of 59 reviewed studies identified five primary objectives for integrating XR technologies in construction engineering education, including enhancing student engagement, integrating XR with BIM, improving safety training, enriching teaching methodologies, and advancing design visualization. The findings highlight five key outcomes of XR adoption: enhanced 3D visualization, increased student engagement and motivation, improved decision-making, better safety training, and greater real-world readiness through industry-standard tools and digital workflows. These outcomes reinforce the practical benefits of XR technologies in bridging the gap between theoretical knowledge and real-world construction applications. Despite these advantages, studies identified several challenges and future recommendations. Key challenges include high implementation costs, accessibility issues, technical limitations, and the need for better integration of XR with BIM and other industry tools. The limited scope and sample size of current studies further highlights the need for broader research applications and interdisciplinary collaboration to enhance XR's impact on construction education. To address these challenges, future research should focus on expanding accessibility, developing cost-effective XR solutions, enhancing real-world testing scenarios, and improving adoption strategies through standardized frameworks. These improvements will strengthen the integration of XR technologies in construction engineering education, ensuring long-term effectiveness and industry relevance.

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