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# Integration of Augmented Reality (AR) in Construction Management (CM) Education: Bibliometric Literature Review

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# Integration of Augmented Reality (AR) in Construction Management (CM) Education: Bibliometric Literature Review


## Abstract

The objective of this review paper is to identify the state of the art in the use of Augmented Reality (AR) for construction management (CM) student education and highlight areas for future research. A literature search was conducted within the Web of Science, Education Resources Information Center (ERIC (EBSCO)), Compendex, and American Society of Civil Engineers (ASCE) databases, and International Journal of Construction Education and Research (IJCER). A keyword string including 'Augmented Reality', AND 'Construction Management' AND 'Education', was used to search for articles published from 2013 to 2023. In addition to using inclusion and exclusion criteria, a manual review of paper abstracts was performed to select the articles for the final analysis. Bibliometric analysis of the papers was utilized to determine the frequency of articles published during the 2013-2023 period, the journals in which the most papers were published, and the most cited papers. Analysis of the co-occurrence of the keywords used in these papers was performed to identify the previous research focus areas and propose future research directions related to the use of AR in CM education. Current state of the art of the AR use in CM education includes virtual site inspections, simulating construction sites, three-dimensional (3D) construction project visualization, collaborative learning environments, and interactive training programs.  Future research on AR-based CM education should investigate the impact of AR on students' performance and knowledge retention; the effectiveness of using AR applications in a user-friendly environment where all students feel supported and engaged; using different building assemblies to create an authentic experience for the students through AR by overlaying digital models on physical assemblies; and creating an adaptive learning approach with AR integration to meet individual students' needs and foster their learning. The contribution of this review study lies in providing the current state of the art in AR applications in CM education as well as future research directions for the integration of AR into CM education.



**Keywords:** Augmented Reality, Construction Management, Higher Education, Bibliometric Literature Review


## Introduction

In today's world, many nations are turning to technological innovations to boost their economies. Globalization reshaping development [1] underscores the imperative for nations to enhance their education systems, emphasizing both quality and practicality. Effectiveness and efficiency in Science, Technology, Engineering and Mathematics (STEM) courses play a pivotal role in enabling full participation in this global transformation. STEM courses would be effective and efficient in producing positive student learning outcomes when practical hands-on activities are incorporated to illustrate theoretical concepts through lab exercises [2], experiments and projects [3] and, thus, to enhance student understanding. Moreover, the integration of technologies, simulations and software tools help students relate concepts to authentic scenarios [4]. The primary educational challenge faced by CM students often revolves around bridging the educational disparity in understanding the spatial and temporal constraints inherent in construction procedures because CM students are not exposed to these processes as they are being taught concrete concepts with abstract teaching methods in the classroom. Augmented Reality (AR) is a promising way to improve education by bringing virtual site visits into the classroom [5]. According to Rankohi and Waugh [6], this approach enhances students' understanding by using the real-life examples in the course material delivery. Due to its ability to prepare students for real-world applications as they develop transferable skills, AR in CM education is gaining attention [7]. When AR-based learning methodologies are used, students' practical skills are developed, their information retention is increased, understanding of difficult ideas is improved, and course material delivery is made simpler [8]. AR technology has the potential to boost students' visual comprehension and their engagement with ideas [9]. Use of AR enables students to actively and independently participate in the process of developing concepts and learning how to apply what they have learned in a typical lecture setting [10].

There is a need to identify maturing and developing patterns in the integration of AR into CM, which supports the need for performing this review study. This review paper outlined the state of the art in the research on AR use in CM education. Additionally, the review findings could serve as a road map for further studies on the application of AR to CM teaching methods. The aim of this review paper was to perform bibliometric analysis to accomplish the following objectives: 1) Explore frequency of articles published during the 2013-2023 period**,** identify the journals and conference proceedings that published the highest number of articles, and identify the most cited articles, 2) Identify the state of the art in the research on using AR for CM students' education, and 3) Highlight areas for future research.

## Literature Review

Many information technology tools are being employed to improve architectural, engineering, and construction education at the tertiary level. For example, building information modeling (BIM) has consistently been explored in educational research alongside other research topics because of its significance in guaranteeing that students and graduates are equipped for the industry [11]. More attention has recently been paid to AR, a relatively new technology that is quickly developing into a helpful teaching tool in the classroom. AR technology is being used in education to complement traditional teaching methods and enhance student learning outcomes. Traditional teaching methods typically encompass in-person instruction, direct communication between teachers and students, and reliance on textbooks and lectures, often incorporating use of video or visuals [12]. While these methods are foundational, there is a growing shift toward more interactive and technology-driven approaches [4].

AR is a contemporary technological development that has the potential to improve instructional strategies. The integration of computer-generated information or digital content with real-world aspects enhances students' perceptions of reality. AR technology uses computer-generated sensory input to improve the real, physical world. AR superimposes digital information created by computers over images of the real environment [6]. AR works by sensing the real-world using sensors like cameras, global positioning system (GPS), or accelerometer to understand users' surroundings [7], [13] and to enhance the human's perception of reality [4]. The data collected from the sensors in real-time by software algorithms is processed and overlaid as digital content through AR. The augmented view is then presented to users through a display, which could be a smartphone screen, heads-up display, or AR glasses. This enables users to see both the real world and virtual objects simultaneously and enhances their interactions with the augmented elements [14].

Hajirasouli and Banihashemi [8] conducted a study to determine what the shortcomings of the conventional approaches to teaching architecture, engineering, and construction are as well as how they fail to address the ideas of Industry 4.0. They also investigated how AR-based technologies can address these shortcomings in the context of higher education. Utilizing immersive three-dimensional (3D) virtual information, according to the study, improved students' experience, and knowledge-acquisition process, leading to more persistent learning, deep and lasting knowledge, and developed in-depth perception and spatial representation. Their research found that using AR improves students' learning and performance in the classroom overall, both the short- and long-term. Diao and Shih [15] emphasized that the use of AR technology can assist in creating a connection between students' virtual and real-world learning. According to their research, AR can increase students' motivation, interest in learning, and performance. AR technology is one approach that complements traditional teaching methods through interactive and immersive elements, seamlessly integrating with traditional methods [16]. This augmentation has the potential to elevate the overall educational environment, making learning more dynamic and relevant. Akçayır and Akçayır [17] posit that AR provides interaction opportunities between students, enhancing their learning achievement and enabling visualization of invisible concepts, events, and abstract concepts. Students' attitudes about education are improving because of their motivation to embrace AR technology for exploration and learning. AR's interactive nature may motivate students more effectively than traditional teaching methods. This helps students to be more focused and interested in the concepts being taught [18].

Liu et al. [19] reported that AR enhances the capacity to explore and absorb new knowledge, facilitating problem-solving. This suggests that AR can promote student-centered learning by empowering students to autonomously explore information and solve problems [19]. Diegmann et al. [20] stated that AR has the potential to empower students, fostering proactivity and cultivating the willpower to sustain knowledge beyond class lectures. Wu et al. [21] found that through the organization, search, and evaluation of data and information, AR mobile games helped learners strengthen their navigational skills for both primary and secondary data. AR aids students in visualizing and comprehending intricate project design and construction ideas [9], [12], [22]. With its distinctive user interface, AR is useful for finishing projects, presentations, and reports that use both real building models and 3D virtual models.

Shanbari et al. [23] used AR video to enhance CM students' comprehension of masonry and roof components. During both masonry and roofing exercises, AR technology helped students better comprehend and identify some detailed elements involved in the assemblies. The research findings suggested that integrating AR technology with traditional lecture method enhances efficiency, providing students with greater impact and exposure to comprehend masonry and roof components through AR videos, surpassing the effectiveness of using AR technology alone.

AR can assist students in developing the abilities and knowledge required to succeed in the construction profession by offering a secure and regulated setting in which they can learn and practice building tasks [24]. As students gain abilities that are applicable in the construction industry, AR offers an opportunity to prepare them for real-world applications in CM. The application of AR-based learning methodologies leads to greater information retention, easier access to course materials, better understanding of difficult ideas, and the development of students' practical abilities [25]. AR applications can adapt to individual students' needs, helping them to learn at their pace to achieve better learning outcomes [26]. Use of AR enables students to visualize complex concepts enhancing their understanding and making long-term recall of the concept easier [27].

Although there is much promise for using AR technology as an effective pedagogical tool, there are drawbacks as well. To optimize AR's benefits and reduce any potential drawbacks, AR should be carefully incorporated into teaching and learning while considering any hindrances. For instance, due to their high implementation costs, AR technologies are not accessible to all students and educational institutions. Additionally, with a large number of students, AR can get highly expensive [17]. Since AR is still a developing technology, there may be initial start-up and development costs. Widespread adoption is hampered by issues including inadequate administrative and financial support, even if it has the potential to improve education [28], [29]. This leads to difficulties such as slow adoption and teachers' incapacity to use AR in the classroom [30].

Another issue to consider in an AR learning environment is that students may lose time due to usability issues and, thus, there is a need for excessively longer class periods. In Gavish et al. [31] study, the AR-user group needed noticeably longer mean training times than the non-AR-user group. They suggested that the novelty of AR technology might have had a role in this. Complex assignments with a vast amount of material to understand could put students under more cognitive strain and reduce their learning [32]. According to Chen and Tsai [33], the quantity of information and difficulty of the activities in an AR learning environment may cause cognitive overload in the students. Chiang et al. [18] suggested that teachers should give students immediate indications or learning aids to avoid problems with AR usage.

Overall, the previous literature indicates the potential value of AR as a tool for enhancing CM education and the strategies to address the challenges of the AR implementation. AR has the potential to effectively improve students' comprehension of complex concepts, honing problem-solving abilities, and fostering teamwork skills. As AR technology advances and becomes more cost-effective, we can anticipate witnessing further innovation and increased efficacy in its application within CM education.

## Research Methodology

A literature search was conducted within the Web of Science, Education Resources Information Center (ERIC)/EBSCO, Compendex, and ASCE databases, and International Journal of Construction Education and Research (IJCER). The concepts used to develop the keyword search string were Augmented Reality, Construction Management, and Education. The four databases and IJCER journal were searched using the following keyword search string:

(“Augmented Reality” OR “AR” OR “Mixed Reality” OR “MR” OR “Immersive tech*” OR “Extended Reality” OR “Spatial Skill” OR “Spatio-temporal constraints” OR “Three-dimensional 3D models”) **AND (“**Construction management” OR **“**Construction assemblies” OR “Construction processes” OR “Construction industry” OR “Construction technology” OR “Quantity take-off” OR “Estimating” OR “Plan reading”) **AND (“**Student Learning” OR “Active Learning” OR “Teaching” OR “Pedagogy*” OR “Education” OR “Construction management education” OR “Student performance”).

Figure 1 shows the search and screening methodology used in this study.

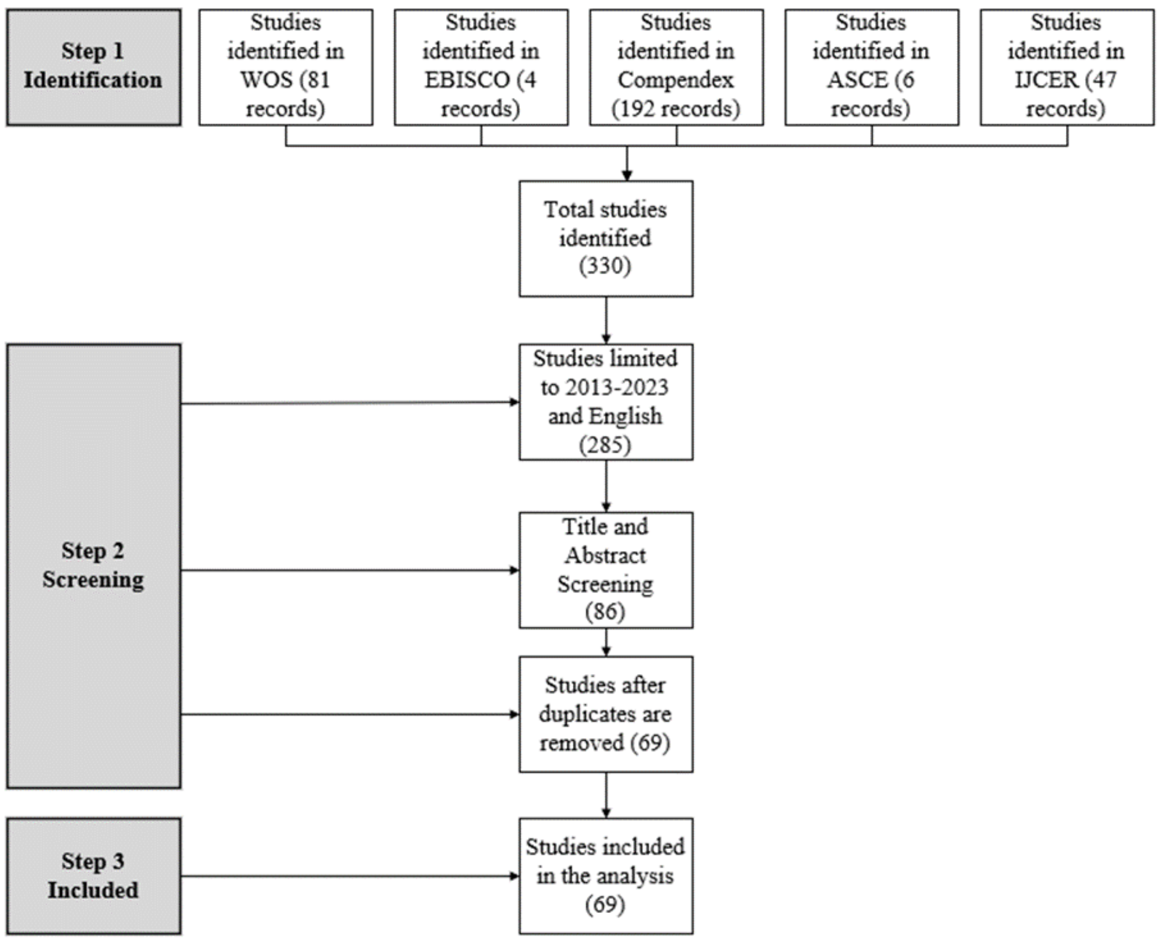


**Figure 1**. Methodology used for Article Search and Screening (Adapted from Costa et al. [34])

Data retrieval was carried out in the four databases, and IJCER. In Step 1, the documents were searched using the keyword search string in each of the databases and journal which resulted in 330 records. In Step 2, the study was limited to technical papers, journal articles, and conference proceedings written in English during a 10-year period from 2013 to 2023 which resulted in 285 records. Publications including early access, book chapters, editorials, and dissertations were excluded from the analysis. Technical papers, journal articles, and conference proceedings published before 2013 were also excluded. Moreover, papers written in languages other than

English (e.g.  Spanish, Russian, Czech, Chinese, and Portuguese) were excluded. Then, the publications for the final analysis were chosen through a manual assessment of paper title and abstracts which resulted in 86 records. Subsequently, the SR Accelerator was used to eliminate duplicates from all of the search results that were acquired in Step 2. In Step 3, 69 publications were included in the analysis in the bibliometric study.

**Results**

Sixty-nine papers identified for the bibliometric study were analysed to determine the frequency of articles published during the 2013-2023 period, the journals and conference proceedings in which the most papers were published, and the number of times papers were cited. Additionally, analysis of co-occurrence of the keywords used in these 69 papers was performed.

***Frequency of articles published during the 2013-2023 period***

The distribution of the publications during the investigated timeframe (2013– 2023) shows the largest number of papers were published in 2023, followed by 2022 and then 2019, before the onset of COVID-19 (see Fig. 2). Technological innovation in education systems has gained more significance than it did in the past according to the steady increase in the number of published articles. The increasing awareness of AR's potential to transform the construction industry caused a spike in published articles about the technology earlier in 2013, as Fig. 2 illustrates. The majority of the articles from that time period examined how AR might stimulate interest and conversation among professionals in the construction industry and how AR can enhance learning in construction education [35], [36], [37].

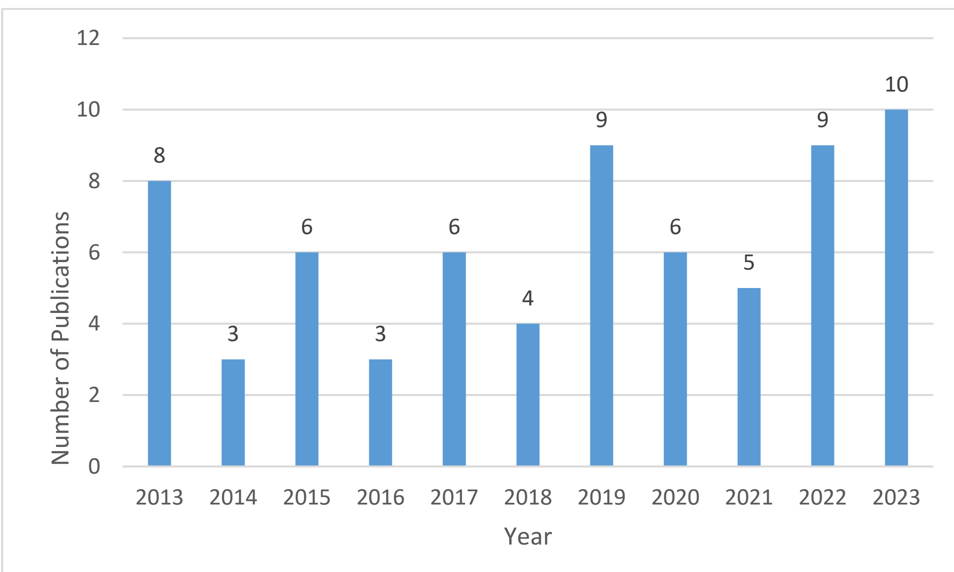


**Figure 2.** Number of Publications per Year

AR is being used increasingly in educational teaching and learning processes to keep up with the trend of integrating technology into education and getting students ready for a technologically advanced world. This growth is due to the increasing development of specific content in AR such as: simulation in a gaming environment [38], [39], use of AR videos to improve CM students' understanding of masonry and roof components [23], visualizing BIM via AR technology [40], visualization pedagogy for design communication [41], use of AR to perform rebar inspection tasks [42], and combining practical instruction with Virtual Reality (VR) or Augmented Reality (AR) in a single learning task to enhance comprehension, visualization, and communication of the subject matter [43].

### *Journals and conference proceedings with the most published articles*

The journals and conference proceedings that published the largest number of articles in the final sample are presented in Table 1. Automation in Construction (10) accounted for 14% of the publications, followed by Journal of Computing in Civil Engineering (4), International Journal of Construction Education and Research (4), and Institute of Electrical and Electronics Engineers (IEEE) conference proceeding (4), each accounting for 6% of the publications. Thirteen articles were published in the journals/conference proceedings ranked 5 to 10 as shown in Table 1. During the 2013-2023 time period, the largest number of journal articles (10, 14%) related to integration of AR in CM education was published in Automation in Construction. Approximately one fourth (26%) of the papers were published in the top three ranked journals.

**Table 1.** Top Ten Journals/Conference Proceedings with the Most Published Articles

| Rank | Journals/Conference Proceedings | Articles | |
|---|---|---|---|
| | | Number | Percentage |
| 1 | Automation in Construction | 10 | 14% |
| 2 | Journal of Computing in Civil Engineering | 4 | 6% |
| 3 | International Journal of Construction Education and Research | 4 | 6% |
| 4 | Institute of Electrical and Electronics Engineers (IEEE) Conference | 4 | 6% |
| 5 | International Symposium on Automation and Robotics in Construction | 3 | 4% |
| 6 | Journal of Architectural Engineering | 2 | 3% |
| 7 | Journal of Information Technology in Construction | 2 | 3% |
| 8 | Construction Innovation | 2 | 3% |
| 9 | Journal of Professional Issues in Engineering Education and Practice | 2 | 3% |
| 10 | Buildings | 2 | 3% |

### *Most cited articles*

The top ten most cited articles in the analyzed literature are shown in Table 2. In this case, the citation for each article was obtained from the publication page. With 1156 citations, the most cited work was written by Akçayır and Akçayır [17] and provides a methodical overview of the benefits and drawbacks of AR in education. As a result of AR special benefits, like "combination of virtual and real objects in a real setting," the authors concluded that AR has the potential to enhance learning and teaching. However, there are several issues to consider when utilizing AR, similar to other technologies. Notably, there are a number of pedagogical challenges that need to be resolved, including the need for longer class periods, unsuitability in crowded classrooms, and teachers' lack of technological competence, in addition to technical difficulties with AR technology. These difficulties are thought to be minimal, though, and they should not stop educators and students from using AR. Research trends and opportunities for AR applications in architecture, engineering, and construction by Chi et al. [36] and conceptual framework for integrating building information modeling with AR by Wang et al. [29] were cited 329 and 200 times respectively. Both articles focused on the opportunities for integrating AR into construction education. Furthermore, articles on integrating mobile BIM and AR systems by Chu et al. [44] and framework for using mobile-based VR and AR for experiential construction by Le et al. [45] were cited 137 and 127 times respectively. Both articles focused on the integration of AR with BIM and VR.

**Table 2.** Ten Most Cited Papers on Integration of AR Into CM Education

| Rank | Title | Reference | Total Citations |
|---|---|---|---|
| 1 | Advantages and challenges associated with augmented reality for education: A systematic review of the literature. | Akçayır & Akçayır [17] | 1156 |
| 2 | Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. | Chi et al. [36] | 329 |
| 3 | A conceptual framework for integrating building information modeling with Augmented Reality. | Wang et al. [29] | 200 |
| 4 | Integrating mobile building information modelling and augmented reality systems: an experimental study. | Chu et al. [44] | 137 |
| 5 | A Framework for Using Mobile Based VR and AR for Experiential Construction Safety Education. | Le et al. [45] | 127 |
| 6 | Benefits of Augmented reality in retaining working memory in assembly tasks: A focus on differences in gender. | Hou & Wang [46] | 92 |
| 7 | Enabling discovery-based learning in construction using telepresent augmented reality. | Behzadan & Kamat [35] | 82 |
| 8 | Trends and Research Issues of AR Studies in Architectural and Civil Engineering Education. | Diao & Shih [15] | 71 |
| 9 | Future development of Augmented reality for measurements applications. | Daponte et al. [47] | 70 |
| 10 | Gaming in sustainable design education | Ayer et al. [38] | 51 |

### *Analysis of keyword co-occurrence*

Analysis of co-occurrence of the keywords used in the 69 selected papers was performed using the VOSviewer tool version 1.6.20 to determine the previous research focus areas and propose future research directions related to the use of AR in CM education. Keyword synonyms were merged and replaced by a single keyword. The minimum number of occurrences of keywords was set to three and, based on that, 15 keywords met the threshold and were selected for the analysis of keyword co-occurrence (See Fig. 3). The size of each keyword's circle represents how frequently the keyword occurs in the sample; bigger circles denote more occurrences. According to the size of their circles, the top four keywords with a high frequency of occurrence were AR (40 occurrences), education (34 occurrences), construction industry (17 occurrences) and information technology (17 occurrences). The highest occurrence frequency of the AR keyword suggests that technological advancement with the use of AR has received more attention of researchers and that the application of AR specifically in education and construction industry is also receiving increased research interest.

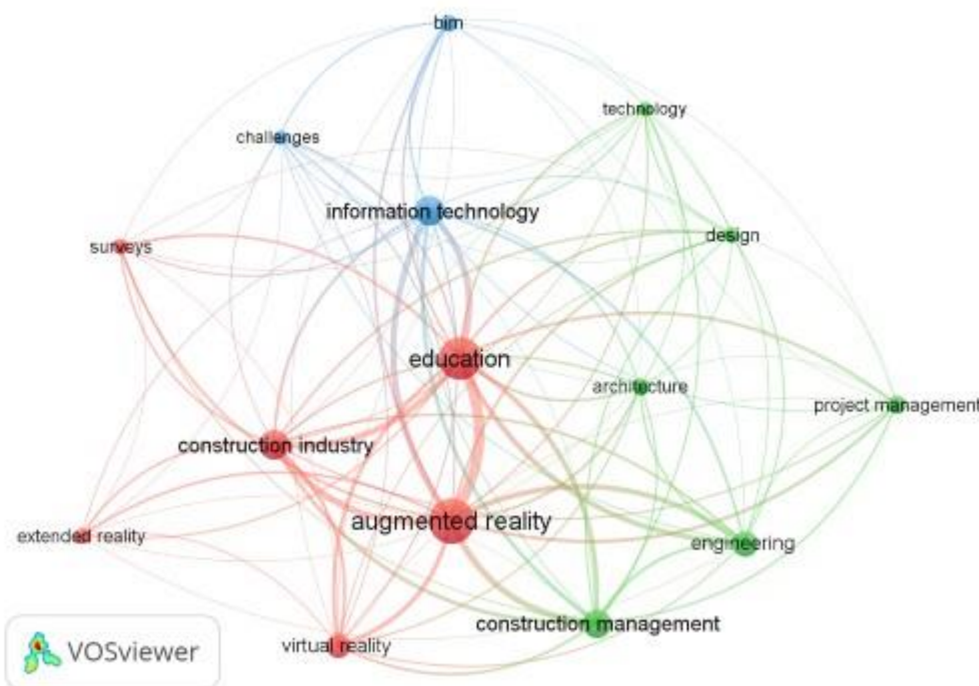


**Figure 3**. Keyword Analysis in VOSviewer.

The three clusters of keywords in the network visualization are colored differently. The terms that belong to the same cluster represent subjects that are related. Red cluster focuses on the use of Extended Reality (XR) in CM education and includes AR, VR, and XR, green cluster focuses on AEC which includes architecture, engineering, construction, and project management, and blue cluster comprises Information Technology and BIM. AR belongs to the red cluster along with education, construction industry, VR and XR. This suggests that according to the sample, more research has been performed in the areas related to integration of various XR technologies into CM education and industry.

The densest lines are found in the red cluster associated with AR. This demonstrates the close relationship between the research on AR and education, construction industry, VR and XR, respectively. The lines between AR, education, and construction industry in the red cluster are more distinct and pronounced than those between CM, engineering, architecture, project management, design and technology in the green cluster in this sample. This suggests that compared to CM, engineering, architecture, project management, design and technology, there is greater research interaction between AR, education, construction industry, VR and XR.

## Current State of the Art

As revealed in the keyword analysis performed in VOSviewer, more research has been conducted in education, construction industry, VR, and XR relating to AR. In order to keep up with the trend of integrating AR technology into education and prepare students for a technologically advanced future, AR is being increasingly employed in educational teaching and learning processes. The creation of specialized AR content is the cause of this expansion. The most cited article in this review [17], offers a thorough analysis of the advantages and disadvantages of AR in the classroom. AR has the potential to improve teaching and learning because of its unique advantages, such as its "combination of virtual and real objects in a real setting," according to the authors. Based on the articles analyzed in this review, the most advanced uses of AR in CM education at the moment include virtual site inspections [44], [45], simulated construction sites [29], 3D construction project visualization [36], collaborative learning environments [26], and interactive training programs [35]. There is also a strong connection between the use of AR and other Information Technologies (such as serious games) in education. In order to incorporate construction topics as necessary within a project-focused approach, Goedert and Rokooei [39] used simulation in an educational game environment while Ayer et al. [38] employed AR and simulation gaming technologies to help students learn how to create, visualize, and evaluate external wall designs for the purpose of retrofitting an existing facility and enhancing its sustainability performance.

## Future Research Directions

The findings of this review study revealed strongest links between research on the use of AR in education, construction industry and information technology, respectively. This suggests that more research on AR has been performed in these areas. The link between AR and technology, architecture, engineering and construction management (such as plan reading, assembly, construction processes, materials and methods) in this sample is thin. This indicates a need for more research on utilization of AR in technology, architecture, engineering and construction management. Areas for future research on AR in CM education could include identifying more effective pedagogical approaches for integrating AR into CM education, and exploring how AR can enhance hands-on learning experiences and skill development in construction-related tasks. Future research on AR-based CM education should investigate the impact of AR on students' performance and knowledge retention. High-quality AR content specific to CM education should be developed with relevant AR learning materials for diverse construction topics [48]. For example, learning modules using different building assemblies to create an authentic experience for the students through AR by overlaying digital models on physical assemblies should be developed. Future studies should explore the effectiveness of using AR applications in a user-friendly environment where all students feel supported and engaged. Strategies for seamless integration of AR into existing CM curricula should be examined and potential challenges and solutions related to incorporating AR without disrupting the overall educational framework should be explored. There also is a need to investigate the accessibility of AR technologies for students with diverse backgrounds and abilities [49]. Strategies to ensure equitable access to AR tools and content in CM education should be explored.

Moreover, seeing that the use of AR is more visible in the construction industry, there should be collaboration between academia and industry to align AR applications with authentic CM practices. Course instructors should explore how they can collaborate with industry professionals to contribute to a more practical and industry-relevant educational experience [50]. Additionally, it is important to investigate how AR integration affects students' performance in real-world construction settings and what long-term effects it has on their career readiness and success in the field.

## Conclusions

This study reviewed the research articles on AR in CM education published during the past decade. The analysis of article frequency from 2013-2023 uncovers a rising research interest and increased investment in AR applications within the field. The state-of-the-art assessment provides valuable insights into current practices and innovations, showcasing the diverse ways of using AR to educate CM students. The following limitations were encountered during this study. Our study was limited to these four databases and one additional journal: Web of Science, Education Resources Information Center (ERIC)/EBSCO, Compendex, and ASCE, and International Journal of Construction Education and Research (IJCER) respectively. However, this number of databases is not a concern since searching at least two databases reduces the chance of missing relevant papers [51]. Since the four databases used different search platforms, search input varied among them, which might have led to exclusion of some articles. The review was limited to the 69 publications; therefore, not all relevant articles might have been included. The review’s timeframe might overlook early developments in the integration of AR into construction management education, that is, research completed prior to 2013. Additionally, the study did not account for regional variations in research focus. Keyword synonyms were merged to avoid duplication of the terminology. This approach is typically used in the keyword occurrence analysis but could have included the bias and, therefore, presents the limitation of our study. Looking ahead, the identified gaps and areas for future research signify promising advancements in pedagogical strategies and technological applications for both scholars and practitioners. This encourages continued exploration and development of AR-based educational strategies in CM. Future research endeavors should contribute to expanding AR applications to ensure that students are well prepared for the challenges of the construction industry. Refining pedagogical approaches and seamlessly integrating AR into existing CM curricula should be the focus of future studies. As educators and researchers navigate this evolving field, addressing these research gaps becomes crucial to harnessing the full potential of using AR in CM education.

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