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Applications of augmented reality for construction productivity improvement: a systematic review

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Abstract

Purpose – Despite the significance of the construction industry to the nation's economic growth, there is empirical evidence that the sector is lagging behind other industries in terms of productivity growth. The need for improvements inspired the industry's stakeholders to consider using emerging technologies that support the enhancement. This research aims to report augmented reality applications essential for contractors' productivity improvement.

Design/methodology/approach – This study systematically reviewed academic journals. The selection of journal articles entailed searching Scopus and Web of Science databases. Relevant articles for reviews were identified and screened. Content analysis was used to classify key applications into six categories. The research results were limited to journal articles published between 2010 and 2021.

Findings – Augmented reality can improve construction productivity through its applications in assembly, training and education, monitoring and controlling, interdisciplinary function, health and safety and design information.

Originality/value – The research provides a direction for contractors on key augmented reality applications they can leverage to improve their organisations' productivity.

Keywords Applications, Augmented reality, Construction, Labour productivity, Systematic review, Technology

Paper type Literature review

1. Introduction

Compared to other sectors, the construction sector is experiencing slower productivity growth globally (El Asmar *et al.*, 2021). Due to the sector's substantial contribution to economic growth, stakeholders and policymakers in the construction industry are placing a greater emphasis on productivity growth.

Several studies have been conducted to enhance the level of construction productivity. These studies have made significant contributions to the field of construction productivity, but evidence suggests that many construction organisations continue to struggle with low

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productivity (Toan *et al.*, 2020). Organisations from diverse sectors are beginning to adopt emerging technologies to gain a competitive edge (Delgado *et al.*, 2020). The importance of productivity improvement in the construction sector necessitates exploring the benefits of emerging technologies for the desired enhancements. Consequently, the industry has started to employ technologies such as building information modelling (BIM), the Internet of things (IoT), virtual reality (VR), augmented reality (AR), and other innovative technologies for its operations.

AR originated from marker-based tracking toolkits that allow users to view virtual objects overlaid on their view of the physical environment (Wang *et al.*, 2013). It is a visualisation technology used primarily in the gaming and entertainment industries (Wang *et al.*, 2013; Delgado *et al.*, 2020). AR applications have recently extended to the manufacturing, tourism, education, marketing, sports, training and construction sectors to deliver a better quality of life (Fazel and Izadi, 2018). The technology provides an experience where virtual contents, including information and graphics, can be presented in their physical context (El Asmar *et al.*, 2021). Its usage combines the real world and computer-generated data. With AR, a user can work in a real-world environment while visually receiving additional computer-generated information to support the tasks at hand. Its application comprises three elements: data, computing, and presentation. The purpose of the data phase is to collect and organize data that will be used to augment reality. During work-intensive phases, computing combines virtual and natural environments and is viewed from a hardware standpoint. It can take place on mobile devices or remote servers.

Two general approaches are usually used to present AR (1) mobile hand-held devices such as smartphones and tablet computers and (2) head-mounted devices such as Google Glass (Meza *et al.*, 2014). Although the technology is not new to construction (Irizarry *et al.*, 2013), exploring its application is essential, which is critical to construction productivity improvement. Delgado *et al.* (2020) report the adoption of AR in construction as central to a long-term productivity boost. According to the Massachusetts Institute of Technology Review (2021), the construction sector can improve productivity and ensure sustainable growth by leveraging innovations in augmented reality.

AR applications in construction have been growing with attendant publications in the research field. The existing research develops applications that contribute to some improvements in construction. Some applications are useful for productivity improvement, while others cannot be directly associated with productivity. This research considers the prevalence of poor productivity in construction organisations (Enshassi *et al.*, 2007; Dai and Goodrum, 2011; Jarkas and Bitar, 2012; Akogbe *et al.*, 2015; Alaghbari *et al.*, 2019; El Asmar *et al.*, 2021), which contributes to the sector's slower productivity growth.

Adebowale and Agumba (2022) identified emerging knowledge areas for academics in the research field based on a scientific mapping of the construction labour productivity literature. One of the knowledge areas the research established is innovations in construction. The study suggested that the construction industry should incorporate more innovations. This research focuses on industry-level productivity due to the empirical evidence of the construction industry's low productivity. AR, one of the innovations in construction, is investigated in this study through a systematic review to determine its applications relevant for productivity improvement. The study directs contractors to adopt AR applications to enhance their organisations' productivity. The insights would bring to the awareness of contractors and aspects of their projects they can deploy AR technology. This would contribute to increased innovations and profitability of construction organisations and ultimately translates to productivity growth at the industry level.

2. Literature review

2.1 Construction productivity

The performance of any economy is dependent on the productivity of its constituent parts (Abdel-Wahab and Vogl, 2011). Operations of construction organisations constitute a significant part of any economy and contribute 3–8% of the gross domestic product (Arditi *et al.*, 2013). Most contractors, especially those in developing economies, are confronted with poor productivity (Jarkas *et al.*, 2015), while their competitiveness considerably depends on their productivity performance (Kazaz and Ulubeyli, 2007). Cost and time overruns that are becoming too frequent in construction are evidence of productivity challenges (Muya *et al.*, 2013). Poor productivity in construction organisations further impacts other organisations because, to some extent, their business depends on construction (Chia *et al.*, 2012). Consequently, the current state of construction productivity has given rise to broader criticism of the sector (Akogbe *et al.*, 2015).

Many research works have been undertaken to improve construction productivity in developing countries (Enshassi *et al.*, 2007; Alinaitwe *et al.*, 2007; Thomas and Sudhakumar, 2013; Odesola and Idoro, 2014; Jarkas *et al.*, 2015; Hiyassat *et al.*, 2016). These studies have resulted in various interventions to boost construction productivity in developing countries. For instance, Thomas and Sudhakumar (2013) emphasise the importance of understanding construction project stakeholders' perceptions of construction productivity. Similarly, Enshassi *et al.* (2007) argue that it is necessary to identify and control the positive and negative factors affecting construction productivity.

Some studies have also been conducted in developed economies (Chan and Kaka, 2007; Dai *et al.*, 2009). Durdyev and Ismail (2016) recognise the significance of establishing site productivity constraints to attain the desired improvement. Dai *et al.* (2009) suggest that craft workers should be integrated into strategies for improving construction productivity. Despite the abundance of research conducted to improve construction productivity, most contractors continue to experience either simple or complex forms of low productivity (Adebowale and Agumba, 2021; Sweis *et al.*, 2008). This situation is detrimental to project success and stakeholder satisfaction (Muya *et al.*, 2013). Disputes and litigations are becoming commonplace in the construction industry as a result of the dissatisfaction of project stakeholders resulting from poor productivity (Adebowale and Agumba, 2022).

Construction operations are not yet fully automated, but there have been remarkable technological advancements in the industry. Some existing studies have highlighted the role of technology in expanding construction productivity (Jarkas and Bitar, 2012; Nasirzadeh and Nojedehi, 2013; Durdyev and Ismail, 2016). Recently, innovations associated with advanced technologies are being considered to achieve sustainable growth (De Soto *et al.*, 2018). Among the widely acknowledged technologies is building information modelling, a multifaceted computer software data model that applies augmented reality and virtual reality to solve contemporary issues in construction (Enshassi *et al.*, 2016; Chen *et al.*, 2019; Lu *et al.*, 2021; Marefat *et al.*, 2019). These technologies can be deployed to improve projects' performance in the construction sector.

2.2 Digital technologies

The world is witnessing considerable transformations in the types and varieties of construction projects (Li *et al.*, 2018). This development has led to notable advancements in the global construction sector. The sector continues to modernise its approaches, methods, techniques, and strategies to meet the demands of the construction market (Rankohi and Waugh, 2013; Ahmed, 2019). In order to overcome certain limitations such as shortage of skilled workers, schedule overruns, and defective work, the construction industry has begun utilising advanced technologies such as augmented reality and virtual reality to improve the delivery of construction projects (Park *et al.*, 2013). VR creates an immersive environment

(Wang *et al.*, 2018), whereas AR is an enhancement of the existing surroundings created by overlaying digital information (Hou *et al.*, 2015).

AR is utilised in the field of architecture, particularly for design and planning (Fazel and Izadi, 2018). Virtual reality (VR) is a computer-generated environment in which a person can explore and interact (Ahmed, 2019). It presents a simulation of a three-dimensional image or environment generated by a computer. An individual using a unique digital system, which includes a helmet with an internal display screen or gloves equipped with sensors, can interact within a seemingly real or physical environment (Park *et al.*, 2013). AR and VR share the same theory. Rather than interacting in a non-existent environment (using digital facts), AR uses an existing environment while implementing virtual features that appear as though both are together. AR is an interactive, reality-based display environment that uses computer-generated display, sound, textual content and effects to enhance the user's real-world experience (Kwon *et al.*, 2014). Real and computer-based scenes and images are combined to deliver a unified but enhanced view of the world (Ahmed, 2019).

Diverse applications of AR and VR are reported in architecture, engineering and construction (Wang, 2009; Sampaio *et al.*, 2010; Dunston and Wang, 2011; Park *et al.*, 2013; Li *et al.*, 2018). Early studies have made significant contributions to AR and VR applications in construction. Their application has, however, sometimes been challenging (Ahmed, 2019), which gave rise to the increased efforts of scholars and practitioners. Consequently, their applications in recent years have been more successful than in the earlier years (Tavares *et al.*, 2019).

Results from previous successful implementations of AR and VR have been demonstrated in different areas of construction (Tavares *et al.*, 2019; Chen and Xue, 2020). The growing application of these technologies suggests their importance to the future of construction (Chowdhury *et al.*, 2019). According to El Asmar *et al.* (2021), AR and VR technologies can be employed to facilitate design development, construction stakeholders' communication, and cost-effectiveness. Ahmed (2019) states the usefulness of the technologies in workers' safety training, defects management, quality management, project scheduling, information collection, safety management, logistics management, and project progress evaluation, among others. AR makes it easier to identify and fix project errors in a safe and hazard-free environment in real time (Lin *et al.*, 2013). AR and VR applications have tremendously increased in recent years, but their potential has not been fully explored (Rankohi and Waugh, 2013; Sidani *et al.*, 2021).

2.3 AR applications for productivity improvement

AR implementation in the construction sector is currently low compared to other industries, but it has the potential to improve the productivity of the sector (Delgado *et al.*, 2020). The technology is useful in projects' pre-construction, construction, and post-construction phases (Lee *et al.*, 2020). Kwiatek *et al.* (2019) studied AR application for pipe fitting and spool inspection to increase productivity and reduce rework. Experiments were conducted with 21 professional pipe fitters and 40 engineering students. After the pipe spool assembly by experienced pipe fitters and engineering students, Kwiatek *et al.* (2019) report the time-saving benefits of the technology over conventional methods.

Hou *et al.* (2015) investigated the impact of gender factors on assemblers' effectiveness. The research reports AR applications as being helpful to both male and female trainees to learn the assembly routine faster. The technology was reportedly more effective for the participant assemblers than the 3D manual method. Tavares *et al.* (2019) propose a collaborative welding system using BIM for robotic reprogramming and spatial AR. The spatial AR system projects alignment information into the environment to help an operator to tack weld the beam attachments that will be seam welded later by the industrial robot. Maximum flexibility is ensured during the beam assembly stage, as the operator receives tasks through an immersive interface (Tavares *et al.*, 2019). It prevents relying on error-prone measurement procedures and analysis of complex manufacturing design specifications, which affect overall productivity and product quality.

Boeing (2018) reports that the productivity of electrical wiring installation tasks has increased by 40% due to the use of AR head-mounted displays to assist construction beginners and professionals. The application was deemed effective for novice assemblers with a substantial cognitive load (Fazel and Izadi, 2018; Kwiatek *et al.*, 2019; Chen and Xue, 2020). It provides exposure to a project before its physical existence, providing experienced and inexperienced construction practitioners with a unique learning opportunity (Kwon *et al.*, 2014).

Zhou *et al.* (2017) describe how augmented reality enabled engineers to complete their tasks after a brief training session, reducing their learning time (El Asmar *et al.*, 2021). In addition to saving time during training, the application has been shown to reduce stress compared to traditional training methods (Chalhoub *et al.*, 2021). The reduced training time contributes to decreased employee training costs, which justifies the technology's up-front cost (El Asmar *et al.*, 2021).

Engineering teaching instruction has mainly been lecture-based, making classrooms a passive learning environment (Kim and Irizarry, 2021). Liarokapis and Anderson (2010) applied AR in classrooms to provide students in architecture, engineering and construction supplemental digital information and assist them in understanding highly abstract and complex construction assemblies (Schwald and De Laval, 2003). The application assisted the students in better achieving their learning objectives than using the conventional approach. An immersive experience offering interactive 3D visualisation features in a classroom environment contributed to the student's understanding of structural analysis (Turkan *et al.*, 2017). The technology was used to enhance the understanding of three-dimensional objects among construction students and teach them about the relationship between 3D objects and their 2D projections in engineering graphics classes (Chen *et al.*, 2011). Behzadan and Kamat (2013) similarly used AR as an innovative pedagogical tool to bring live videos of remote construction job sites to the classroom. An intuitive interface was created for students to interact with the objects in the video scenes. The application also facilitated location-aware instructional materials visually delivered to the students.

Kwon *et al.* (2014) identify challenges preventing site managers from performing quality management efficiently. Quality management through visual senses engenders faulty construction and necessitates reworks. Kwon *et al.* (2014) utilised AR to develop two defect management systems, which include an image-matching system that enables quality inspection without visiting the actual work site. The authors also utilised mobile AR applications that automatically enabled workers and managers to detect dimension errors and omissions on jobsites. Park *et al.* (2013) investigated the issues with current defects management practices in construction. They propose a conceptual system framework for construction defects management using defects data collection template, defects domain ontology, and AR-based defects inspection system. The framework can assist in reducing the occurrence of construction defects.

Given that prefabrication and construction processes are interdependent, coordination between the two is crucial (Chowdhury *et al.*, 2019). When a production facility fails to provide sufficient materials promptly, significant delays may result, while early delivery to the job site may cause storage issues. A balance can be maintained by monitoring on-site status using AR and project documentation integrated with a prefabrication plant (Babic *et al.*, 2010). This can address possible construction delays, lower material buffering demand, improve logistics efficiency, on-site material handling and overall project progress tracking. AR visualises the difference between 'as-planned and as-built progress, enhancing progress monitoring and facilitating appropriate and prompt decision-making.

The construction sector is inherently multidisciplinary. The multidisciplinary nature of construction increases the challenges of effective interactions among diverse construction practitioners. AR is beneficial for multidisciplinary engagements and suitable for information communication in construction (Wang *et al.*, 2020). During the construction process, AR can be effectively applied to monitor progress and coordinate the activities of construction practitioners (Chen and Xue, 2020). Engineers can annotate AR visualisations of existing cables and pipes, allowing technicians to know the locations and other details before determining whether additional pipes and cables are required (Olbrich *et al.*, 2013).

The construction sector is primarily characterised by severe accidents and death rates (Kukoyi and Adebowale, 2021). AR has been applied to promote health and safety in construction (Li *et al.*, 2018). Harikrishnan *et al.* (2021) note the significance of AR in improving communication between the design and construction teams. Compared to VR, AR is a safer option for hazardous construction sites. It retains the user's awareness of their physical environment and allows them to maintain pride in their work (Irizarry *et al.*, 2013). Such experience allows an individual to interact with real-world projects and deal with the risks of accidents before their actual occurrence (Jiao *et al.*, 2013).

Kim *et al.* (2017) propose a vision-based hazard avoidance system that proactively informs workers of potentially dangerous situations. The system enables workers to recognise and consequently avoid dangers before accidents occur. The system displays augmented hazard information on a wearable device. It includes a vision-based site monitoring module that employs an image capture device and wearable devices to detect site hazards. The application offers a safety management system that provides actionable data, including hazard orientation, distance, and safety level.

AR has the potential to increase productivity when used as a design communication tool in construction (Chalhoub and Ayer, 2019). Design changes, errors and omissions, which often result in rework, are some factors contributing to construction schedule overruns (Love *et al.*, 2011). Recognising changes from the initial design in the BIM would significantly reduce the need for rework. Regrettably, there is currently no method for updating the BIM model to reflect such changes made during construction (Gu and London, 2010).

Chalhoub *et al.* (2021) demonstrated how AR supports design comprehension among untrained participants to allow them to accurately complete construction tasks that traditionally required professional training. AR is useful to map the as-built and as-planned data in a single digital environment with each component allocated with status such as: ordered, procured, delivered, checked, installed, completed, commissioned, and fixed (Wang *et al.*, 2013). The application makes design information easier to interpret and provides frequent feedback on completed or partially completed assemblies. This facilitates the process of completing assemblies correctly the first time, thereby reducing reworks and boosting productivity. AR has been used during the design phase to evaluate designs or models in the physical environment and to communicate design concepts to construction stakeholders (Jiao *et al.*, 2013).

3. Methodology

3.1 Research method

The research adopted a systematic review of published documents. A systematic review is a scientific research approach that is useful for appraising, summarising, and communicating the findings of a large number of research publications in a particular field of study. It is evident in the literature that a plethora of research has used systematic reviews to investigate different fields of construction (Babalola *et al.*, 2019; Gharbia *et al.*, 2020; Chen *et al.*, 2021). The processes considered essential to conducting a systematic review include: formulating the research question, determining relevant published documents, assessing the quality of the papers, and summarising of evidence. The research was guided by the question, “What augmented reality (AR) applications can construction companies leverage to increase their productivity?” The question focuses on augmented reality (AR) applications that could improve contractors’ productivity.

3.2 Database search

Through a search of the Scopus and Web of Science (WoS) databases, relevant published documents were identified. Scopus and WoS were chosen due to their extensive coverage of architecture, engineering, and construction articles. They are comprehensive online databases of peer-reviewed and non-peer-reviewed documents (Babalola *et al.*, 2019). “Augmented reality” AND "Construction” were used as search strings to identify AR articles relevant to the construction sector. These keywords were used to search journal article titles in databases for relevant papers. Initially, productivity was included in the list of keywords, but the number of articles generated was insufficient for reviews. The primary objective of this research is not to extract productivity articles but to identify AR applications that contractors can adopt to improve their productivity. Productivity was therefore excluded from the list of keywords. The databases subsequently yielded more articles for review. The search was limited to documents published between 2010 and 2021. Articles related to AR in construction included conference papers, journal articles, book chapters, review papers, and editorials. The databases yielded a total of 277 documents–Scopus (178) and WoS (99). Figure 1 presents the research process.

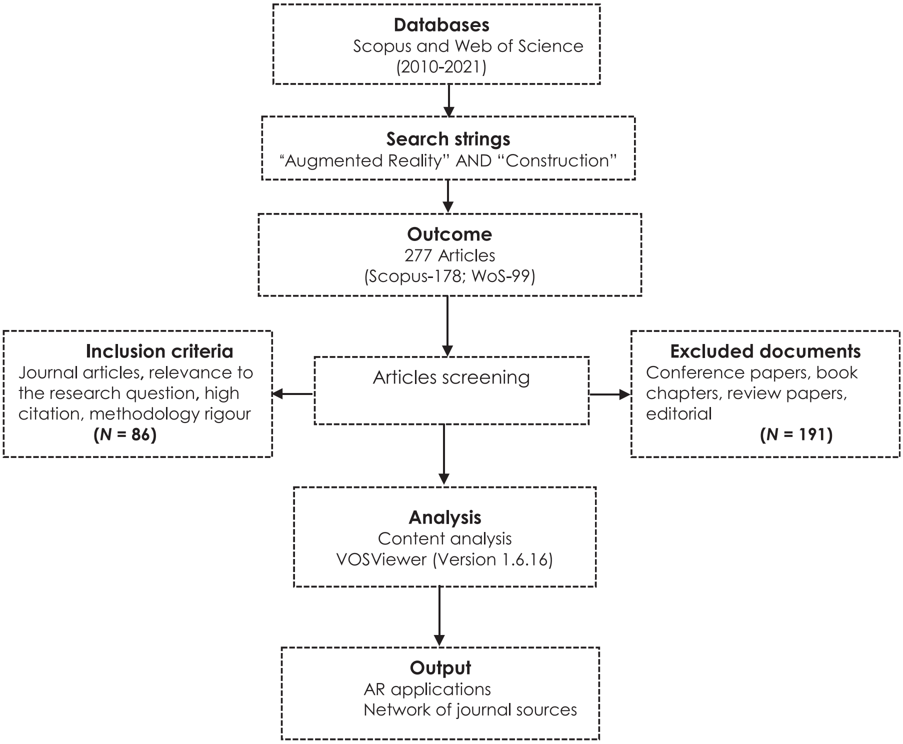

Figure 1.
Research process

3.3 Articles screening

It was necessary to choose publications with more substantive information and empirical evidence. Conference papers, book chapters, review papers, and editorials were excluded from the list, while journal articles were retained. Journal articles usually contain more information than other academic literature (Hosseini *et al.*, 2018). After the initial screening, 105 journal articles were found to be satisfactory. The abstracts of the articles were then read to determine which articles were relevant to the research question. The inclusion and exclusion criteria used by Babalola *et al.* (2019) were adopted. The articles were chosen in accordance with their relevance to the research question.

The rating scale consisted of the numbers "1" for low relevance, "2" for medium relevance, and "3" for high relevance. The significance of the articles was determined by analysing their methodologies and findings for rigour. Articles that addressed research topics outside the scope of this study were eliminated. For instance, Gomes *et al.* (2017) discussed the construction of augmented reality as opposed to AR applications in the construction industry.

Prioritising articles with multiple citations was the next criterion for screening. Kim *et al.* (2017), Wang *et al.* (2013), Behzadan and Kamat (2013), Lin *et al.* (2013), Zhou *et al.* (2017), and Kwiatek *et al.* (2019) were among scholars who had articles published in the two databases. Therefore, one of the articles published in the two databases was deleted. The 86 articles that satisfied the screening criteria were reviewed by examining their abstracts, discussions, and conclusions.

As shown in Table 1, 86 journal articles were reviewed, including 52 articles from the Scopus database and 34 papers from WoS. The reported augmented reality (AR) applications for each journal article were identified by analysing the articles' contents.

Database	Articles before filtering	Articles after filtering
Scopus	178	52
Web of science	99	34
Total	277	86

Table 1.
Number of articles

The applications were evaluated and recorded. After further review, applications not directly related to construction productivity were disregarded. Those deemed useful for the productivity enhancement of construction organisations were categorised into six relevant themes, as shown in Table 2. The categorisation of applications in the literature into key focus areas for construction organisations was aided by content analysis.

Applications	Sources
Components assembly	Boeing (2018), Chalhoub *et al.* (2021), Chen and Xue (2020), Danker and Jones (2014), Hou *et al.* (2015), Kwiatek *et al.* (2019), Nee *et al.* (2012), Tavares *et al.* (2019)
Training and education	Behzadan and Kamat (2013), Chalhoub *et al.* (2021), Chen *et al.* (2011), Kim and Irizarry (2021), Kwon *et al.* (2014), Liarokapis and Anderson (2010), Li *et al.* (2018), Lin *et al.* (2013), Park *et al.* (2013), Pereira *et al.* (2019), Schwald and De Laval (2003), Shanbari *et al.* (2016), Shirazi and Behzadan (2015), Turkan *et al.* (2017), Wang *et al.* (2020), Zhou *et al.* (2017)
Monitoring and controlling	Babic *et al.* (2010), Chen and Xue (2020), Chowdhury *et al.* (2019), Danker and Jones (2014), Dunston (2009), Hammad *et al.* (2009), Harikrishnan *et al.* (2021), Jiao *et al.* (2013), Kwon *et al.* (2014), Lin *et al.* (2015), Park *et al.* (2013), Wang and Dunston (2008), Zhou *et al.* (2017), Zollmann *et al.* (2014)
Interdisciplinary function	Dong *et al.* (2013), Hammad *et al.* (2009), Harikrishnan *et al.* (2021), Olbrich *et al.* (2013), Wang *et al.* (2020)
Health and safety	Kim *et al.* (2017), Jiao *et al.* (2013), Li *et al.* (2018), Pereira *et al.* (2019)
Designs information	Dong *et al.* (2013), Dunston (2009), Schubert *et al.* (2015), Wang and Dunston (2008)

Table 2.
Augmented reality applications

3.4 Articles sources

After database filtering, the leading journals in the field of AR in construction include automation in construction, the journal of computing in civil engineering, the journal of information technology in construction, and the electronic journal of information technology in construction. Figure 2 illustrates the network of sources for articles. The network's nodes represent journals, while the connections between them show their citation relationships. The clustering of journal node size and font is based on the number of published articles. Larger nodes and font sizes were used to represent periodicals with numerous articles.

4. Discussion

The construction industry has increasingly adopted innovative technologies to enhance its performance. There is sufficient evidence in the literature to support AR's ability to improve construction productivity. Various research studies have reported several AR applications that can help with different aspects of the construction industry. However, this study focuses on applications critical to improving productivity performance in the construction industry. Based upon the systematic review of existing research, AR can be leveraged to improve construction productivity by applying the technology in construction components assembly, training and education, monitoring and controlling, interdisciplinary function, health and safety, and design information.

AR, an innovative technology, helps to facilitate task assembly procedures by overlaying BIM data information directly on construction sites. The application improves the efficiency of assemblers and contributes to the faster assembly of construction components. The technology has proven effective for saving time in prefabrication, pipe spool, and electrical wiring. Prefabrications can be done in advance without the anxiety of issues with misaligning or miscalculations. It supports novice workers and professionals alike. For example, Boeing (2018) reports a 40%-time savings in electrical wiring installation for experienced and inexperienced augmented reality users.

Skill shortage has significantly affected the construction industry's decreased productivity (Adebowale and Agumba, 2021, 2022). AR can be useful in addressing this

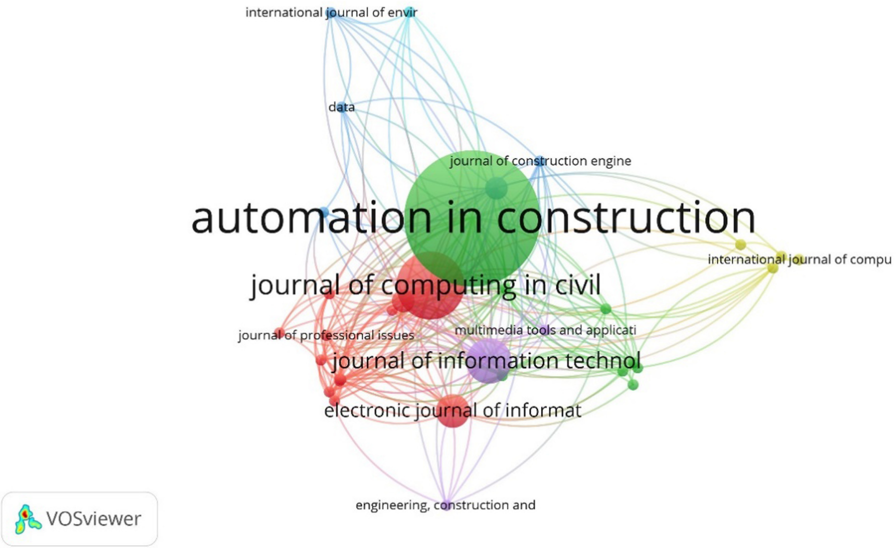

Figure 2.
Network of sources

deficit by training construction professionals and educating construction undergraduate students. To develop the skills and competence of the industry’s workforce, improved training for construction professionals and innovative methods of teaching construction students are essential. By presenting a 3D model to consumers, a series of learning experiences that contribute to skill development can be initiated (Chalhoub and Ayer, 2019). This helps to create exposure to a project before it physically exists and allows a knowledge-gaining opportunity for inexperienced and construction-savvy people. Construction practitioners are presented with the opportunity to locate and fix project flaws in a safe and hazard-free environment in real time. At the same time, engineers can improve the delivery of their tasks after a short training session.

AR helps to facilitate training in construction operations. For instance, using AR for training has an advantage over traditional training systems as it reduces the time and stress associated with training. AR can be utilised to enhance students’ understanding of structural analysis and complex construction assemblies, in addition to its utility for construction professionals. It enables students to better comprehend construction sites by simulating site conditions in the classroom. Such application would eventually enhance the proficiency of construction graduates.

With AR, a project manager responsible for several projects can obtain information about activities from different locations. Variances between the ’as-built’ and ’as-planned’ progress can be obtained and displayed, providing site managers with the intuitive representation of deviations. In such instances, ’behind schedule’, ’on schedule’, and ’ahead of schedule’ can be indicated. More problems can be uncovered and solved faster without paper blueprint hassle and communication delays.

The increasing prevalence and context-awareness of augmented reality, coupled with tracking and sensing technologies, will improve the efficiency of construction project deliveries. With the aid of an AR application, a building inspector can discover errors early by comparing what is being built to the building information model, making monitoring and controlling projects using information sharing more effective. Interdisciplinary interactions are a notable benefit of AR applications in construction and are well suited for communication effectiveness (Wang *et al.*, 2020).

The effectiveness of interactions among construction multi-stakeholders can influence the timeliness of construction project delivery. AR allows real-time collaboration and field-to-office communication across all stages of construction. The on-site real-time communication benefit of AR provides the opportunity to save time in resolving issues before constituting delays in construction operations. Site managers can share progress in real-time with the project’s team, which can contribute to expediting decision-making on matters that hinder progress on site. AR enables the site inspector to share any error uncovered with multiple team members, making problem areas easier to recognise and correct. Field workers can also share video feeds from the AR glasses and receive real-time advice or instructions from a remote expert. These give room to address defects, risks, and accidents before they occur.

AR provides the benefit of a visual-based hazard prevention system that proactively notifies workers of potentially dangerous situations. The system allows workers to identify hazards before an accident occurs and, as a result, avoid them by displaying comprehensive hazard information on their mobile devices. The AR-based visualisation of information contained in a database such as BIM can provide those on-site with an improved understanding of their work and thus increase productivity. One of the difficulties encountered in construction, especially among less-experienced practitioners, is design interpretation issues. Craftspersons are usually confronted with the difficulty of understanding engineering designs (Dai and Goodrum, 2011). AR aids a better understanding of design even by untrained participants. It enhances practitioners’ ability to interpret designs and accurately deliver construction operations more efficiently. Errors and omissions in designs are other challenges that constitute a barrier to productivity growth in construction (Jarkas *et al.*, 2015). AR can help to accurately determine potential errors in designs documentations as it enables workers and managers to automatically detect dimension errors and omissions on the Jobsite, which would ultimately mitigate the rate of reworks in construction. Conventionally, an inspection of design documentation is done manually. Documenting and disseminating the information to the other construction team members requires considerable time. AR applications can be implemented for expeditious delivery through visualisation that allows architects to interact with virtual spatial data and features of a proposed design in its final context.

5. Conclusion

Considering the importance of AR applications to construction project performance, it is expected that the technology will continue to gain wider acceptance in the construction sector. Through a systematic review of literature, key AR applications beneficial to construction productivity growth were identified in this study. BIM and AR have been widely integrated into construction operations. AR serves as a mechanism to enhance the information extraction process from building information models, thereby improving effectiveness and efficiency. Leveraging BIM, the adoption of AR has been used in different stages of construction production through improved information handling.

This study reported that augmented reality is an innovative technology that can be deployed to improve construction productivity through its applications in construction components assembly, training and education, monitoring and controlling, interdisciplinary function, health and safety, and designs information. Some of the benefits the industry would derive from using AR are the effective and efficient assembly of construction tasks, skill improvement for practitioners and construction students, and effective monitoring and controlling of project progress. AR is also advantageous for the early identification of potential hazards and accidents, real-time information sharing among project participants, early discovery of design errors, and improved interpretation of designs, which will help to mitigate non-value-adding activities. As augmented reality (AR) technology advances, construction organisations must continue to evolve and seize new opportunities for its application in order to increase construction productivity. This research is significant because it provides contractors with information on crucial areas of project delivery where their organisations can implement augmented reality technology.

Although augmented reality (AR) technology is useful for increasing construction productivity, two significant factors may prevent contractors from implementing it. These include the costs associated with augmented reality (AR) and the lack of functional information technology (IT) departments in some construction companies. Over the years, only large enterprises have been able to afford the technology's substantial up-front investments due to its high price. With the introduction of open-source mobile toolkits, costs have recently decreased. Therefore, its application is expected to continue to expand to small-to-medium contractors. IT departments are either absent or ineffective in some construction organisations, particularly small-to-medium enterprises in developing countries. Therefore, it is currently unrealistic for most contractors in the industry to adopt augmented reality technology.

This research has provided a foundation for future research examining the cost implications of construction companies employing the reported applications. If the impact of these organisations on the construction industry in terms of productivity growth will be significant, a large proportion of construction organisations should have access to these applications. Such a development will have far-reaching effects on practice and society regarding contractors' acceptability and overall contribution to economic growth. Future research should consider the reported applications to develop more AR devices affordable to small contractors considering initial and operating costs.

The results of this research are limited to journal articles published in the Scopus and WoS databases. The interventions provided in this study are based on reviews of articles retrieved from the two databases, which constitutes a limitation to the research. Future research should investigate additional databases containing journal articles and other documents to gain a deeper understanding of the subject matter.

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