Advanced Engineering Informatics 62 (2024) 102798

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Review article

Augmented reality applications in construction productivity: A systematic literature review

Zhidong Xu [a,*], Zhenan Feng [a], Mostafa Babaeian Jelodar [a], Brian H.W. Guo [b]

[a] School of Built Environment, Massey University, Auckland, New Zealand
[b] Department of Civil & Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand

ARTICLE INFO

Keywords:
Augmented reality
Mixed reality
Construction productivity
Civil engineering
Digital technology

ABSTRACT

Augmented reality (AR) has been extensively researched for its applications in the construction industry. However, there is limited focus on its effects on productivity. This paper aims to bridge the gap by using a systematic literature review to investigate AR applications in the planning, design, and construction phases, focusing on their mechanisms for enhancing productivity. The paper classifies AR applications by their target construction tasks, features, and factors contributing to improved productivity. Additionally, it proposes a framework for prototyping AR applications and evaluating their effects on productivity. Key findings reveal several contributions: the need for further investigation of AR for positioning and hazard notification tasks; the utilisation of different augmentation methods, display tools, and tracking methods based on specific construction tasks; AR's positive impact on productivity in design review, discrepancy check, assembly, and hazard notification, while future research on evaluating productivity in progress management, planning simulation, and positioning.

1. Introduction

Poor productivity has constantly plagued the construction industry [105]. McKinsey's report indicates that the global labour productivity in the construction industry has grown by 1 percent a year on average over the last two decades, while the world economy had a labour productivity growth of 2.8 percent [65]. Innovation is urgently needed to overcome this issue. Over the past decade, the rapid development of information and communication technology (ICT) has become a spur to the arrival of the Fourth Industrial Revolution (Industry 4.0). The essential feature of Industry 4.0 is the cyber-physical system [58], with augmented reality (AR) being one of the emerging technologies to facilitate the cyber-physical system. AR is a technology that superimposes virtual objects into the real world, enabling interaction with virtual objects and improving users' perception of reality [7].

The research on AR applications has attracted significant interest since the mid-1990s, owing to the development of key enabling technologies, such as tracking, display, and interaction [7,12,31]. Nowadays, more advanced wireless technologies and mobile devices have enabled researchers to see the industrial adoption of AR. In the context of Industry 4.0, AR techniques have a wide range of use cases with the potential to shift industry productivity. DHL has tested that AR can improve the picking process in the warehouse [28]. Airbus and Boeing also used AR in their aircraft factories to overlay virtual plans and images onto actual parts to aid with quality control [2,92]. Another popular AR application domain is healthcare, as AR can be integrated into the healthcare data system to visualise data [4]. Although the construction industry is behind other industries in adopting AR solutions, many studies have focused on utilising this technology in construction tasks [73]. This interest is driven by the complex nature of construction projects, which require extensive collaboration among various groups including architects, engineers, contractors, suppliers, and clients. AR offers a promising tool for facilitating the flow and exchange of vast amounts of information throughout a project's life cycle.

Over the past five years, several literature review studies have analysed AR applications in the construction industry with different focuses. Li et al. [59] reviewed several AR prototypes to assist in construction safety management. The authors categorised AR prototypes according to their application domains, safety enhancement mechanisms, and safety evaluation methods. They found that safety inspection and hazard

---

* Corresponding author.
E-mail addresses: zxu1@massey.ac.nz (Z. Xu), z.feng1@massey.ac.nz (Z. Feng), m.b.jelodar@massey.ac.nz (M. Babaeian Jelodar), brian.guo@canterbury.ac.nz (B.H.W. Guo).

https://doi.org/10.1016/j.aei.2024.102798
Received 9 October 2023; Received in revised form 3 June 2024; Accepted 29 August 2024

identification were the major domains utilising AR. In another study, Xu and Moreu [109] analysed AR use cases in civil infrastructure construction and found that underground utilities, structure health detection and discrepancy check were the main research areas. Muthalif et al. [71] also identified major technical barriers, such as 3D model registration accuracy and real-world object occlusion. A recent literature review conducted by Kolaei et al. [53] covered several construction tasks during the construction phase of a project. The authors classified AR applications based on technical details and compared the advantages of different AR implementation tools. The authors discovered that most AR applications in the construction industry had been implemented through mobile devices and tablets due to their benefits of cost-effectiveness. In summary, these studies have proved that AR could be applied to various domains in the construction industry.

AR was considered a part of the digital transformation in Construction 4.0 [111]. However, the current maturity of the technology does not yet meet the practical needs of the construction industry [25]. Also, there is little evidence demonstrating whether AR can improve productivity in the construction industry based on the current AR solutions in the market, which leaves the construction industry uncertain about the practicality and effectiveness of AR [26,84]. Analysing existing literature can identify the construction tasks that might benefit from AR and indicate the primary research domains on AR applications in the construction industry. Furthermore, the shortcomings of AR in facilitating construction tasks can be identified so that future research can design and develop more effective AR solutions for construction tasks. Given together, a framework for developing and evaluating AR applications in the construction industry is needed.

This paper aims to bridge these knowledge gaps by conducting a systematic literature review. The systematic literature review aims to investigate AR's impact on construction productivity based on existing literature. The first objective is to identify the construction tasks that may benefit from AR. The second objective is to study AR's effect on construction tasks. Based on these objectives, three research questions were raised encompassing the role of AR in enhancing construction productivity: RQ1: What construction tasks have been facilitated with AR applications? RQ2: How do AR applications function in those construction tasks? RQ3: How can AR applications impact the productivity of those construction tasks? By answering the research questions, this paper classifies AR applications based on their features and uses cases (i.e., construction tasks). This paper also reveals the impact of AR applications on the productivity of construction tasks and the mechanisms for enhancing productivity. The mechanisms offer an insight into AR's practical value and contribute to the practical implementation of AR in the construction industry. Based on the findings, this paper establishes a framework to develop and evaluate AR applications, which can be used to guide the development and evolution of AR applications to improve productivity.

2. Methods

This study employed the systematic literature review methodology proposed by [48], including the following steps: formulating the research problems, identifying relevant work, assessing the quality of studies, summarising the evidence, and interpreting the finding (Fig. 1). In the first step, research questions were formulated, as shown in Section 1.

Following that, Scopus and Web of Science were selected as the databases for searching. Both journal articles and conference papers were included in the review to ensure comprehensive coverage of relevant studies. The search keywords were divided into two parts. The first part included "augmented reality" OR "mixed reality" OR "AR". Mixed reality was included due to its similar meaning to augmented reality and its frequent use alongside augmented reality in the literature. The second part of the search keywords included "construction industry" OR "AEC" OR "civil engineering". To maximise the literature coverage pertaining to AR and the construction industry, no further keywords (e.g., "productivity") were used to narrow down the results. The "AND" operator combined the search keywords, and the search fields were restricted to titles, abstracts, and keywords. The search was conducted in January 2023, with a total of 352 results obtained from Scopus and 624 from Web of Science.

This study used the Preferred Reporting Items for Systematic Literature Reviews and Meta-Analyses (PRISMA) approach [74] to screen and filter the search results (Fig. 1). First, 127 duplicated search results from Scopus and Web of Science were removed. Second, articles were removed if they met the following exclusion criteria: (1) The article has no relation to augmented reality; (2) The article does not use AR in a construction task; and (3) The proposed prototype is not designed to assist in construction tasks. This step excluded 752 articles and kept 54 articles from Scopus and 43 from Web of Science. The full-text review was conducted on these remaining 97 articles with the following inclusion criteria: (1) The proposed prototype was applied in the planning, design, or construction stage. Post-construction stages, such as facility management and maintenance, were not considered; and (2) The proposed prototype was tested or validated using case studies, experiments, or surveys. Training and education AR applications were out of the scope because they were not designed to assist in completing construction tasks and further provide insights into the effects on productivity.

This review finally included 51 eligible papers that demonstrated the empirical evidence of AR applications on construction productivity. The number of eligible papers is aligned with other systematic literature review papers [53,91], where deep understandings of the subject were extracted and synthesised to generate new knowledge. The eligible papers contain 40 journal articles and eleven conference papers published between October 2007 and January 2023 (Fig. 2). There has been a growing trend in investigating AR applications in the construction industry since 2018.

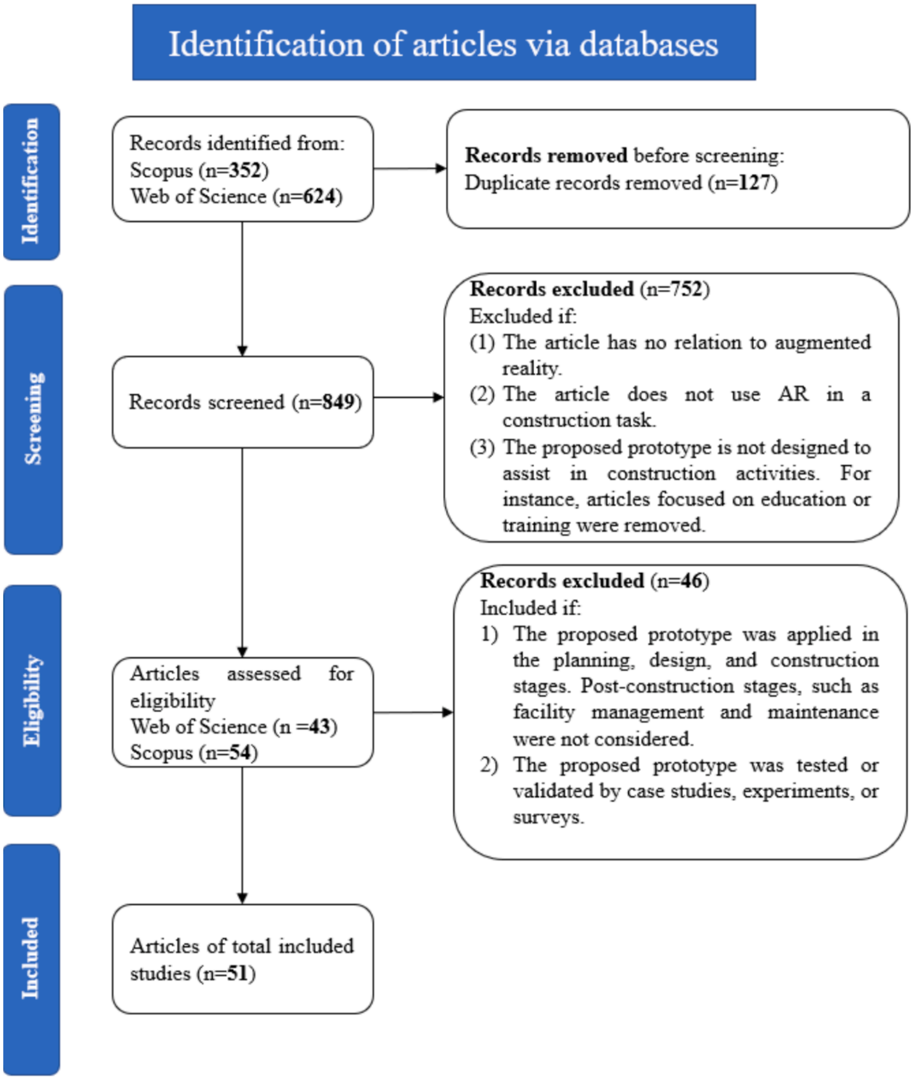
After identifying eligible papers, this literature review conducts a quality assessment for each eligible paper by scoring them based on their relevance to research questions. The quality assessment for the eligible papers is one of the steps to conduct a systematic literature review [108]. The purpose is to ensure the eligible papers in this systematic literature review achieve an overall high quality to answer research questions. The scoring process followed the method adopted by Feng et al. [33] and Connolly et al. [20]. The criteria were developed focusing on two aspects: (1) the details of AR prototype and development (to answer RQ1 and RQ2); (2) the findings of the impact on construction tasks productivity (to answer research questions 3). Based on the relevance to the criteria, the authors scored all eligible papers subjectively. The scoring was cross-checked by two authors to ensure a high level of validity. Each aspect was scored between 1 and 3, where 1 meant low relevance and 3 meant high relevance. The author scores all the articles based on subjective thoughts The scores for the two aspects were added up to achieve the final score for each paper (Fig. 3). The mean score was 4.04, with a standard deviation of 1.03. The result shows that 42 papers obtained a score greater than or equal to 4, which was highly relevant to the research questions in this review.

3. Result

This section outlines the findings extracted from the 51 eligible papers to answer the three research questions (Section 1).

3.1. Construction tasks

The first research question focuses on the construction tasks facilitated by AR. Shin and Dunston [88] proposed a construction activity classification framework which recognises seven construction activities to be benefitted from AR: layout, excavation, positioning, inspection, coordination, supervision, commenting and strategising. Based on this, this review discovered seven constriction tasks facilitated by AR, as



Records identified from:
Scopus (n=**352**)
Web of Science (n=**624**)

Records removed before screening:
Duplicate records removed (n=**127**)

Records screened (n=**849**)

Records excluded (n=752)
Excluded if:
(1) The article has no relation to augmented reality.
(2) The article does not use AR in a construction task.
(3) The proposed prototype is not designed to assist in construction activities. For instance, articles focused on education or training were removed.

Articles assessed for eligibility
Web of Science (n =**43**)
Scopus (n=**54**)

Records excluded (n=**46**)
Included if:
1) The proposed prototype was applied in the planning, design, and construction stages. Post-construction stages, such as facility management and maintenance were not considered.
2) The proposed prototype was tested or validated by case studies, experiments, or surveys.

Articles of total included studies (n=**51**)

Fig. 1. The PRISMA workflow in this review.

shown in Table 1.The seven identified construction tasks can be categorised into three work types: decision support, task assistance and situation prompt. Design review, progress management and planning simulation focus on utilising AR to help users make decisions, which can be categorised as decision support. Discrepancy check, assembly and positioning highlight the involvement of physical works with labour input, which can be categorised as task assistance. Hazard notification falls into the third category – situation prompt, as it prompts surrounding information to users. This review shows 58.8 % of AR applications were designed for decision support, and 33.3 % focused on task assistance. The number of AR applications for decision support is twice those for task assistance. A possible reason is that current AR devices are still limited to being implemented along with construction tasks on a

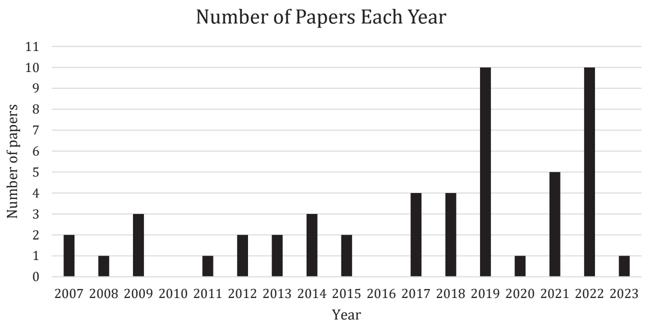


Fig. 2. Number of papers each year.

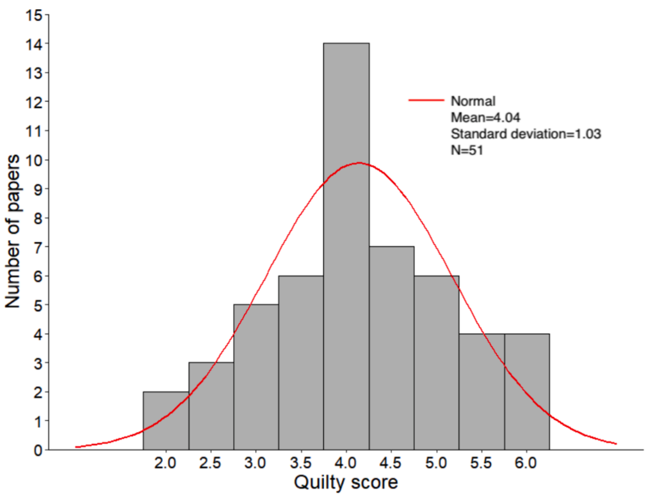


Fig. 3. Quality scores for 51 eligible papers.

Table 1
Number of articles for each construction task.

Construction tasks	Descriptions	Number of articles	Reference
Design Review	To visualise design models superimposed into the real world	13	[13,15,19,21,34,44,47,78,79,81,90,101,114]
Progress management	To overlay as-planed models onto the actual construction site for progress checking	10	[3,36,46,51,62,66,70,83,112,116]
Discrepancy check	To display the correct position and installation of a construction component for site inspection	8	[1,35,56,64,67,89,110,115]
Planning simulation	To simulate construction processes on real construction sites before starting construction	7	[9,16,32,39,50,99,101]
Assembly	To direct and instruct the assembly of building components	6	[11,24,43,54,57,106]
Hazard notification	To highlight potential hazard sources	4	[23,52,100,107]
Positioning	To display the positions for welding or drilling on manufacturing components	3	[27,86,97]

construction site, given a few constraints such as usability, portability, scalability, computing performance, internet connection, and battery life.

3.1.1. *Design review*

Most AR applications have been applied for design review (13 out of 51). These AR applications assist in design review in two ways: model demonstration and model interaction. Model demonstration means design models are visualised through AR in the real world. This application was mostly used for reviewing urban planning designs, with architectural models superimposed onto existing real-world buildings [13,15,79,114]. Traditionally, designers create rendered models by incorporating real-world photographs as a backdrop; however, it has a limited sense of reality. AR aligns designed models with real-world structures, providing a more intuitive urban layout plan before construction [79]. Another use case of design review is to compare the aesthetic impact of different exterior wall materials [81]. It allows designers to visualise different wall designs on a real construction site, facilitating their decision-making for selecting wall materials.

3.1.2. *Progress management*

AR can assist in monitoring construction progresses by superimposing a building model with as-planned progresses onto physical construction status. Most progress management AR applications integrate building information modelling (BIM) since BIM stores the geometry of design models and encompasses time dimension for construction progress scheduling [3,46,51,66]. Using traditional methods for progress monitoring typically requires a person to possess spatial awareness, as they need to translate information from 2D drawings into the physical construction status [66]. AR benefits this process by visualising design models with scheduled progresses, which allows comparing the as-planned progress with the actual construction progress directly. Reality capture is also employed with AR applications to assist in progress management. Photogrammetry and laser scanning can capture the actual construction status and produce point cloud data. It will then form a 3D mesh model of the as-built status and contain the geo-information. The AR system matches the as-planned model with the captured 3D mesh model to define the overlay position and display the as-planned model in the correct place [36,116].

3.1.3. *Planning simulation*

AR benefits the construction planning stage by simulating and visualising construction processes in the real world before commencing construction. AR has been deployed to simulate a wide range of construction processes. First, AR can visualise the transport operation of trucks on a construction site and support transport route planning [16]. The simulation of virtual truck movement on a real construction site background facilitates intuitive planning and coordination. Another similar use case is to simulate traffic conditions around a road construction site and evaluate road work's impact on traffic [9]. Traditionally, investigating the impact on traffic needs statistical data on traffic volume. AR allows users to see a virtual driving car in real-time traffic conditions without measuring the traffic volume. Second, AR can help plan heavy equipment operations on a real construction site to avoid risks during the construction phase [9,39]. Hammad et al. [39] proposed an AR prototype that a virtual full-scale crane model superimposed onto a real construction site. Users can interact with the crane model and simulate its operation to check its coverage areas and site constraints. This AR application helps a planner to identify crane operation issues before construction. Third, AR can visualise the utility layout plan in the real construction site to easily find the conflict before construction. Fenais et al. [32] proposed an AR-based underground utility mapping system integrated with a geographic information system. The application allows users to see the embedded pipes' layout and depth, which avoids striking pipes in excavation works. Similarly, Tsai et al. [99] adopted AR to plan mechanical, electrical and pumping (MEP) layouts. Before installing MEP systems, they visualised designed MEP models over onsite as-built pipes to inspect and resolve conflicts.

3.1.4. *Discrepancy check*

AR can assist site engineers in checking construction quality. Shin and Dunston [89] proposed an AR method to check column offsets and tilting degrees. They employed AR to display the designed position of a column over its actual position. The site engineer can manually adjust a virtual column to align with a built column, obtaining offset measures. Moreover, the site engineer can use AR to document the inspection result through plain text describing or annotating the captured real-world images. The construction workers can easily locate and understand the discrepancy through the images and rectify their work to eliminate it [67]. In addition to column inspection, AR can also help with tunnel segment displacement inspection [115]. When installing two adjacent segments during tunnel construction, it is common to observe misalignments (e.g., gaps). AR can facilitate site engineers to inspect installation errors by overlaying a 2D shape onto the connection between two segments. The width of the shape represents the designed safe range. The site engineers need to ensure that the width of the gap should be within the shape. Kumar et al. [56] adopted AR to inspect above-ground pipes outside the factory. The AR application placed the prebuilt designed pipeline model onto the designed position, and the engineer can check the offset of the built pipeline.

3.1.5. *Assembly*

In assembly tasks, AR typically displays assembly instructions step by step. According to the review, the most common use case for assembly tasks is for assembling pipelines. Virtual pipe components are displayed in assembly positions of the real world, eliminating the need to use 2D drawings for assembly workers [24,43]. Kwiatek et al. [57] extended this approach by adding a quality assurance feature to detect and check the correctness of assembly in real-time. This quality assurance feature is achieved by aligning designed models with as-built models generated from point clouds and calculating offsets. Wu et al. [106] proposed an AR application for rebar assembly. This application visualised the 3D model of concrete reinforcement. Additionally, the application provides instructional videos to guide assembling rebars. Another two AR use cases facilitate the assembly of some complex architectural building components, such as sun shading and tessellated structures [11,54]. AR can guide the user to assemble the structure step by step and show the spatial relationship between each assembly part.

3.1.6. Hazard notification

AR can boost workers' hazard awareness. Dai et al. [23] proposed an AR prototype to enhance communication and identify potential construction site hazards. The traditional communication methods include walkie-talkies, phone calls, video conferences, and paper-based reports, which are time-consuming and subject to misinterpretation. The proposed AR prototype allows site engineers to live stream their first-person perspective when walking on a construction site and annotate hazards. The site engineer wearing the HMD can make annotations on real-world objects to point out safety issues. Other workers watching the live streaming can also see the annotation through their screens to effectively understand and locate the identified hazards. Wallmyr et al. [100] adopted AR to notify heavy machine operators if obstacles or persons are approaching. The AR system shows the operator a stop sign or an attention sign superimposed onto real-world obstacles to enhance the operator's awareness. Sabeti et al. [80] proposed an AR system to warn the highway construction labour when there is a vehicle coming toward the safety zone. AR-based visualisation also can be integrated with site surveillance. A group of site surveillance will capture the real-time video around the construction site. The machine learning algorithm can recognise the trucks onsite and track their movement from the real-time video. The AR system can identify the location of the moving truck and the workers in the real world through coordination translation as the site surveillance position is known. Once the AR system detects the onsite worker approaching the moving truck, the worker can see a direction sign and a distance showing the truck's moving direction and distance to the worker on their AR device [52].

3.1.7. Positioning

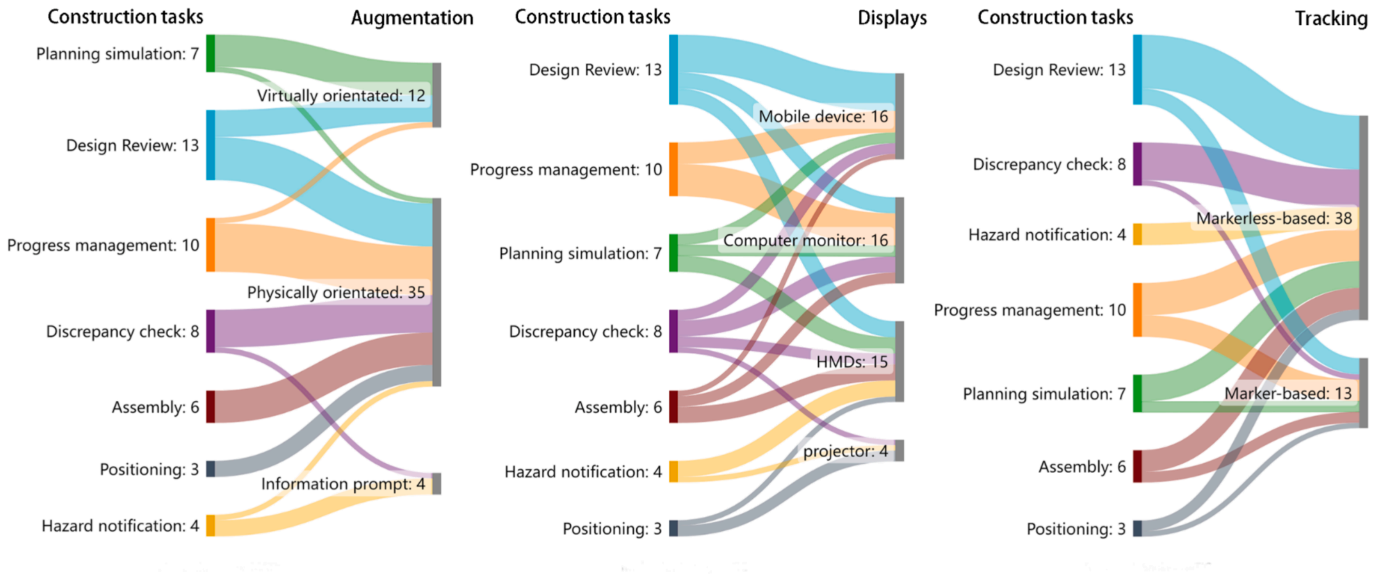
AR can assist in positioning during building components manufacturing. Tavares et al. [97] adopted AR in structural steel fabrication to facilitate operators locating welding joints. Settimi et al. [86] employed AR to position drilling points on timber. Traditionally, this task requires a worker to locate the points with measuring tapes and 2D drawings. That AR system displays the drilling points directly on a timber's surface. Moreover, the AR system can visualise the depth and angle of a drill bit with a sensor installed on a drill. Degani et al. [27] developed an AR application to project a floor plan drawing on an actual floor. This application helps workers mark building component positions on a floor surface without measuring and checking drawings.

3.2. AR features

The second research question of this paper seeks to understand how AR applications function to facilitate construction tasks. This section outlines three major features that make AR applications function for construction tasks: augmentation, display, and tracking. Fig. 4 summarises the three major features used in each construction task. The number of papers proposing their AR applications with different AR features is shown in each node. Based on the result, Most AR applications facilitated construction tasks using the physically orientated augmentation method (35 out of 51 papers) and markerless tracking (37 out of 51 papers). As for display tools, AR applications mostly use mobile devices, computer monitors and HMDs.

3.2.1. Augmentation

The identified seven construction tasks were facilitated using different augmentation methods that can be categorised into three categories: virtually orientated, physically orientated, and information prompt. The virtually orientated method involves using real-world images or videos as the background for virtual content. Virtual content does not interact with the real world directly. This method demonstrates virtual content without a specific location to overlay real-world objects. For instance, designers can use smartphones to visualise a 3D building model on the table while standing around it [34]. The 3D model can be displayed on the table or the ground, depending on where the user wants to see it. This augmentation method focuses on the virtual content itself rather than the real spatial relationship between it and the physical object, so it is called virtually orientated augmentation. An advantage of virtually orientated AR applications is that the system does not need a complex algorithm to register virtual contents accurately. This method augments virtual content's intuitiveness and allows users to perform physical measurements and interact with virtual content in the real



(i) Relationship between tasks and augmentation (ii) Relationship between tasks and displays (iii) Relationship between tasks and Tracking

Fig. 4. The Sankey diagrams showing the relationship between construction tasks and AR features.

world. For instance, users can evaluate the maintainability issue in the design stage by viewing a one-to-one scale virtual model and checking whether the maintenance service is accessible [47]. AR can mitigate the design errors relating to maintainability in the design stage and avoid rework in the construction stage. Almost a quarter of the reviewed articles (12 out of 51) proposed AR prototypes based on this augmentation method.

Regarding physically orientated AR, its virtual contents must be displayed at a specific position in the real world and overlaid with target objects. This method transfers the coordinates of virtual contents from the virtual environment to the real world, which requires a high level of tracking and registering accuracy. This augmentation method brings a few benefits. First, this method enhances spatial cognition for users. For instance, a worker can easily understand the spatial relationship among pipes and their positions in the real world [24]. Second, this method visualises construction statuses in the timeline. The visualisation is a simulation of the whole construction process and an intuitive comparison between as-built and as-planed statuses. For instance, as-planned construction progresses can be superimposed onto actual construction sites to analyse construction progress [3]. In this review, 35 of 51 articles proposed AR prototypes using the physically orientated method showing that most construction tasks require the spatial information. Interestingly, all AR applications assisting in assembly and positioning tasks adopted this method.

The third augmentation method is the information prompt, which focuses on communicating information with users through virtual content [3,24]. The virtual content visualised by this method can be a directional sign pointing to a potential hazard [52]. In another use case, the virtual content is the 2D drawings presented to site engineers to read and access building information conveniently [27,110]. This augmentation method delivers 2D information [52] or simple 3D symbols [23], so creating virtual content is easier than other augmentation methods. However, this method cannot provide more intuitiveness than the other two methods. Users can also interact less with the virtual content than using the other two methods [110]. Four out of 51 articles proposed AR prototypes based on this method.

3.2.2. Display

This paper identified four AR device types: head-mounted displays (HMDs), computer monitors, projectors, and mobile devices (e.g., smartphones or tablets). Table 2 summarises the four AR display tools. As shown in the table, each display mode has advantages and limitations. The four display tools might be suitable for conducting different construction tasks and improving productivity.

According to the review, fifteen studies utilised HMDs for their AR prototypes, with eleven of them using Microsoft HoloLens. Behzadan and Kamat [9] and Hammad et al. [39] proposed their prototype before the release of Microsoft HoloLens, so they used i-Glasses SVGA Pro and nVisor, respectively. Only one paper proposed the prototype using Google Glass [52]. While wearing HMDs, users could use their hands to assemble physical building components [54] or operate heavy equipment virtually via a controller [50]. Users can move freely due to the wireless solution provided by Microsoft HoloLens [24]. An advantage of using HMD devices in construction is that users do not need to hold the device by hand. Therefore they have both hands free to carry out other work, which is highly suitable for manual construction tasks [103]. However, HMD devices have the issue of a small field of view [17,64]. Evidence shows that the limited field of view will increase cognitive load during work [8].

Table 2
The classification of AR display tools.

Tools	Advantages	Limitations
HMDs	Hand free	Limited field of view
Mobile devices	Easy setup	Hand-occupied
Projectors	Hand-free	Lack of mobility and limited information display
Computer monitors	High compute performance	Limited real-time interaction

Sixteen studies used computer monitors to view virtual content. A computer computes, renders, and overlays virtual content onto real-world images or videos [12]. The primary reason for this solution is that computers offer better computing performance when handling large amounts of data, and consequently, computer monitors are used for display. For instance, Kumar et al. [56] introduced a registration method based on point cloud data, in which case a high-spec computer was necessary to serve as an AR platform. The monitor displayed the site video or image captured by the camera with a fixed position. [16]. Therefore, users cannot move the camera pose to view different real-world objects as freely as they use smartphones. It limits the AR's ability to interact in real time.

Sixteen articles introduced smartphones or tablets as the platform to deliver AR applications. Nowadays, the light sensors installed in smartphones and tablets have made handheld devices a powerful platform for AR applications [60]. A study comparing different devices used in construction progress inspection found that mobile AR suits the activity best due to its flexibility and minimal setup requirements [55]. Zollmann et al. [116] argued that mobile devices such as smartphones are more suitable for outdoor activities. One limitation of handheld AR is that at least one hand is required to hold a device, which restricts users from conducting manual work.

Lastly, four articles presented projection-based AR applications, where projectors were used to project 2D illustrations onto walls or floors. Degani et al. [27] projected the floor plan drawing of a room on the ground to show the layout. The projectors did not disturb the workers after the projector was set up. One limitation of projection-based AR is that projection requires a physical surface to display the projected content. Therefore, it is usually used to display text information and 2D drawings. Some large projectors are inconvenient to be moved with users, which limits users' mobility [12].

3.2.3. Tracking

This review discovered two types of tracking methods in construction AR applications: marker-based and markerless, following the classification method by Kolaei et al. [53]. Mere integration of virtual and real-world objects can be achieved by different technologies, such as visual effects. However, tools identified as AR must possess a tracking and registration system to fulfil the other two characteristics of AR: real-time interaction and 3D registration [7]. A tracking system measures the position and orientation of the AR implementation devices relative to real objects and estimates the relative pose of AR devices [82]. Marker-based AR requires a marker (e.g., an image or a QR code) to be placed in the real world as a target for registration or tracking. The marker can trigger a virtual content's registration or track a camera's pose. Marker-based AR provides robust and stable tracking without virtual object drifting [18]. Thirteen out of 51 studies used marker-based AR to deliver their applications, while the rest did not use markers.

Markerless AR does not need a marker to run the application. The tracking relies on the context awareness of an AR system. This review found three popular tracking methods in markless AR applications: depth sensing, image processing, and Global Navigation Satellite Systems (GNSS).

Eight AR applications used depth sensing. Depth sensing can detect a plane surface and place virtual building models on the plane surface [79]. As a depth camera can measure the distance between the camera and surrounding walls, an AR system can calculate and understand its current position in a room [27]. Another use case is to use the depth camera to generate the 3D point cloud of the surrounding environment and then overlay the prebuilt 3D building model onto the point cloud [56,116].

Eight articles used image processing. Image processing refers to employing the scale-invariant feature transform (SIFT) technique to detect and match key points in site photographs and subsequently utilise the structure from motion (SfM) technique to estimate a camera's pose [51,62,107]. The coordination relationship between the virtual content and the camera's pose will be calculated to register the virtual content.

This review identified five applications empowered by GNSS tracking. GNSS can acquire a user's position and real-time movement. This tracking method combines location data from GNSS and orientation data from a built-in gyroscope [13,32]. The AR system will know the users' position and where the user is looking and then translate the local coordination of the virtual content to global coordination. The virtual content is then registered in the global coordination.

In addition to the three popular tracking methods, Schweigkofler et al. [83] proposed an AR application for progress management using radio frequency identification (RFID) to track users' positions. The authors set up beacons at different positions on a floor that were used to detect and obtain distances from users to calculate users' positions. Markerless-based AR might be more flexible to implement at a construction site. However, it requires complex computing to achieve stable and accurate registration [12].

3.3. Impact on productivity

The seven construction tasks fall within the planning (planning simulation), design (design review) and construction phases (progress management, discrepancy check, assembly, hazard notification and positioning) of a project life cycle. The productivity issue during the project planning phases can be investigated from two aspects: the effort spent on planning and the outcome achieved by planning [30]. Effort spent on planning refers to the planning time, which is determined by the project size and construction firm's ability. The outcome achieved by planning can be evaluated through the cost performance and time performance during the construction stage [61]. Hence, improving planning productivity needs to reduce the time spent on planning and also achieve a more effective construction plan. AR is possible to reduce the planning time as the direct visualisation of the construction simulation on the real construction site may save time for the comprehensive site analysis. For complex construction sites, site analysis is more time-consuming and prone to errors. AR is also possible to achieve a more effective construction plan because the intuitive visualisation of construction processes may reduce misunderstandings between different stakeholders.

There is limited study discussing the productivity issue during the design phase. However, the general concept of productivity (ratio between output and input) can be applied. Similar to the planning tasks, reducing the time spent on design can improve the productivity of design tasks. AR can shorten the decision-making time when choosing cladding material because the 3D model of the designed wall can be visualised onsite [81]. Designers can directly compare the appearance of different materials in the real world. Based on the construction tasks identified in this paper, no other AR methods has been proposed to improve design productivity. However, the design error and buildability issues that occur in design phases can cause low productivity in construction phases [72]. Therefore, AR can facilitate the design process to improve productivity in construction phases. AR make it possible to mitigate design errors before construction by visualising the designed building in the real world [47]. A multi-user AR system can also provide a platform for different designers to collaborate with each other by reviewing the same design model, which might mitigate the design conflict [34]. Another factor that influences productivity in the construction phase is changing order [42]. The intuitive visualisation of the building model in the real world can make clear communication between clients and designers. AR is possible to reduce the occurrence of changing orders in the construction phases.

As for the construction phases, previous research identified various factors affecting productivity from the perspective of management, labour and work environment [5,42,72]. AR can impact the five productivity factors: management skill, task complexity, workers' skill, poor communication and site safety in construction phases.

Based on the construction tasks identified in this paper, AR can be applied to progress management and quality management. AR is possible to improve management skills through the intuitive comparison between the as-built and as-planned status. However, construction management in practice involves not only the construction data visualisation but also lots of data acquisition and analysis [38]. Therefore, AR improving construction productivity through management skills need further investigation or the integration of other methods to develop a comprehensive management tool.

As for task complexity, workers' skills and poor communication, AR can significantly impact these productivity factors, as shown in Section 3.1. AR's characteristic of intuitive visualisation might reduce the task complexity for the manual work. A direct overlay of positioning or assembling components may eliminate the repetitive activity such as checking drawings and manual measurement. Moreover, workers may experience low cognitive load as the complexity decreases [43]. Low cognition is also a key factor affecting labour productivity in the construction phase [72]. J. Zhang et al. [113] indicated that AR can improve workers' spatial cognition in indoor navigation by showing the direction in the real world. This can mitigate worker's cognitive load when finding their way at the construction site. As for communication, the capacity to convey information determines the effectiveness of communication [94]. AR connected to the internet can provide real-time communication channels by transmitting the user's first-person view, which is similar to a video call. However, AR can convey more information than video calls because users can directly mark the real-world object for the recipient to see [23]. As for site safety, AR offers real-time warnings to the user and improve users' awareness of the hazard. The improvement of site safety has a positive impact on construction productivity.

Different AR features determining different implementation methods can influence the performance of AR in construction tasks. Poor usability may constraint worker's performance and cause low productivity [72]. HMD is flexible because both hands can be free. However, a study indicated that the long-term weight on the head can increase the workload [45]. Therefore, a heavy HMD may cause low productivity. A mobile device is also flexible and easy to carry, however, it will constrain workers to use both hands, which also limits the worker's performance. Projectors and computers are inflexible because they need to be connected to an independent tracking system, such as the depth camera [27]. As for the tracking method, marker-based and RFID AR can provide a stable registration. However, it requires the initial setup of the marker or sensors, which increases the workload and may cause low productivity. Note that in five studies published from 2007 to 2009, the AR technology they used involved an independent optical tracking system [89], image processing [35,62], camera positioning module [70], separated GPS receiver and orientation tracker [9], which had more limitations than the current popular AR technologies. Currently, mainstream AR devices are integrated with sensors and cameras, making them convenient to use. Moreover, the improvement in processor computational capabilities will make the registration faster now.

3.4. Evaluation on productivity

Most AR applications are designed to assist in a single construction task. Given that, studying the effect of AR on construction productivity should also emphasise the task level. According to the productivity measurement framework proposed by Ayele and Fayek [6], productivity is determined by five factors: labour input, capital input, material input, energy input and other input. Productivity can be improved if the five input factors are reduced. In this paper, it is difficult to determine AR's impact on capital input, material input and energy input based on the reviewed papers. AR's impact on time was measured, so that task completion time can be used to evaluate AR's impact on productivity. The time factor can be used to measure the construction labour productivity: ratio of work hours to units of output [40]. The output can refer to the amount of work done, such as the number of panels installed [75]. In this paper, construction labour productivity is used to evaluate AR's impact on productivity.

Various factors affect construction labour productivity except for the time factor that is used in the metric of construction labour productivity [5,42,72,85]. El-Gohary and Aziz [29] categorised the labour productivity factors in terms of management, labour, and industry. Management involves factors such as site layout plans and competency of labour supervision. Ensuring effective management approaches throughout the design to construction phases is crucial for achieving high productivity [72]. The categories of labour involve factors such as labour experience, skills and motivation. The categories of industry focus on the labour productivity factors influenced by the industry such as new construction technologies. Although those factors are not considered for the metric of construction labour productivity, they can directly or indirectly affect the time factor and further affect productivity. Therefore, this paper considers these factors to evaluate AR's impact on productivity.

Additionally, implementing AR as an emerging digital technology should also consider the efficiency of operating the AR system [10]. The technology usage issue is considered a significant factor affecting productivity [37]. Improving productivity requires the technology to fit the project's and construction workforce's needs. For example, if the AR system is complex, the user might spend much time setting up and operating the system rather than producing actual work. Although the operation efficiency may not directly reflect the effectiveness of applying AR, an efficient operation of the AR application ensures ease of use and improves productivity [10].

This paper outlines the findings extracted from the experiments, case studies, or surveys of the reviewed studies. The time factors are extracted from the experiment result. Factors that influence construction labour productivity and technology usage factors are extracted from the results of the experiment and questionnaire. In total, this paper found seven factors that can impact productivity in construction tasks including registration accuracy and stableness, comfortability, entry barrier, task completion time, understanding, correct rate, and cognitive load. The first three factors are the technology usage factors of the AR system that influence productivity in construction tasks. Registration accuracy and stableness ensure the AR system can perform well during construction tasks. Comfortability issues can constrain workers' performance and further influence productivity. The entry barrier determines the skill required to operate the AR system, which can also influence productivity. The last four factors decide if the AR solution is effective. Task completion time can be used as the metric of productivity evaluation. Comprehending information can enhance stakeholders' understanding of the project, which can be considered a factor affecting labour productivity [72].

The correct rate can affect the quality of the construction and the frequency of rework, which can also affect productivity. Cognitive load affects the labour's mood and motivation, which can also affect productivity. This paper identified no additional productivity factors beyond the seven that were evaluated. The seven productivity factors were extracted from the findings and mapped into ease of use (Table 3) and effectiveness (Table 4). This paper found 35 papers that showed evidence of AR applications' impact on productivity. Twenty out of 35 papers evaluated the factors affecting ease of use, while 22 out of 35 papers showed evidence of AR's impact on effectiveness. The findings indicate that various AR features have both positive and negative impacts on productivity within different construction tasks. Table 5 summarises these impacts. The '+' and '-' symbols denote the positive and negative impacts on the productivity factor, respectively. The presence of multiple identical symbols indicates multiple viewpoints or perspectives on the matter from multiple eligible articles. Appendix 1 provides the comprehensive version of Table 5.

In terms of design review, progress management, and planning simulation, productivity can be defined as the efficiency of conducting these tasks. Moreover, an effective outcome achieved by these tasks can further improve productivity in other tasks during the construction phases. The factors of ease of use, task completion time, and cognitive load can be used to evaluate the efficiency of conducting these tasks. The factors of comprehending information and correct rates represent the effectiveness of the outcome, which further affects construction productivity. Regarding the other construction tasks, the seven factors are related to the tasks themselves.

Among the studies focusing on ease of use, nine papers concluded that their AR applications could register their virtual content accurately and stably, which satisfied the ease-of-use requirement, while four papers indicated that their AR application could barely achieve stable registration negatively affecting productivity in design reviews,

Table 3
Papers reported the ease-of-use impact on productivity and its factors.

	Ease of use								
Construction task (n)	Registration accuracy and stableness			Comfortability			Entry barrier		
	Reference	Evaluation method	Number of participants	Reference	Evaluation method	Number of participants	Reference	Evaluation method	Number of participants
Design review (12)	[14,15,34,114]	Qualitative Quantitative Quantitative Qualitative	30 Case study 11 Case study				[34]	Quantitative	11
Progress management (10)	[3,36,66]	Quantitative Quantitative Qualitative	22 Case study Case study				[3]	Quantitative	22
Planning simulation (7)							[32]	Quantitative	20
Discrepancy check (6)	[67]	Qualitative	Case study	[110]	Quantitative	34			
Assembly (6)	[11,24,57]	Quantitative Quantitative Quantitative	Case study 20 61	[24]	Quantitative	20	[24]	Quantitative	20
Hazard notification (3)	[107]	Quantitative	Case study	[23]	Quantitative	53	[23]	Quantitative	53
Positioning (3)	[27,86]	Quantitative Quantitative	Case study Case study						

1. n is the number of articles studying the construction task.
2. The blank space indicates that there are no articles mentioning this productivity factor in this construction tasks.

Table 4

Papers reported the effectiveness impact on productivity and its factors.

Construction task (n)	Effectiveness											
	Task completion time			Comprehending information			Correct rate			Cognitive load		
	Reference	Evaluation method	Number of participants	Reference	Evaluation method	Number of participants	Reference	Evaluation method	Number of participants	Reference	Evaluation method	Number of participants
Design review (12)	[81,101]	Quantitative Quantitative	Case study Case study	[21,47,81,90,19]	Quantitative Quantitative Quantitative Quantitative Quantitative	Case study 16 Case study 34 30	[47]	Quantitative	16			
Progress management (10)				[112]	Qualitative	Case Study						
Planning simulation (7)				[16]	Quantitative	32	[16]	Quantitative	32			
Discrepancy check (6)	[110,115,1]	Quantitative Quantitative Quantitative	34 Case study 15	[110]	Quantitative	34	[1,64]	Quantitative Quantitative	15 11	[89,1,64]	Quantitative Quantitative Quantitative	16 15 11
Assembly (6)	[24,43,54,57,106]	Quantitative Quantitative Quantitative Quantitative Quantitative	20 20 20 61 16	[43,54,106]	Quantitative Quantitative Quantitative	20 20 16	[43,106]	Quantitative Quantitative	20 16	[43]	Quantitative	20
Hazard notification (3)	[23,52]	Quantitative Quantitative	53 30	[52]	Quantitative	30	[23]	Quantitative	53	[100]	Quantitative	15
Positioning (3)	[97]	Quantitative	Case study									

1. n is the number of articles studying the construction task.
2. The blank space indicates that there are no articles mentioning this productivity factor in this construction tasks.

Table 5
Positive and negative impact on productivity by different AR features.

	AR features		
Productivity factors	*Augmentation*	*Display*	*Tracking*
Registration Accuracy and stableness		Design review (−)	Design review (+)(−) Progress management (+)(−) Discrepancy check (−) Assembly (+)(−)
Comfortability		Discrepancy check (−) Assembly (−) Hazard notification (−)	
Entry barrier	Planning simulation (+) Assembly (+)	Design review (+) Progress management (+) Planning simulation (+) Assembly (−)	
Task completion time	Design review (++) Discrepancy check (+) Assembly (+) Positioning (+)		Design review (−)
Comprehending information	Design review (++) Progress management (+) Hazard notification (+)	Discrepancy check (+)	
Correct rate	Design review (+) Planning stimulation (+) Assembly (+)		Positioning (+)
Cognitive load	Discrepancy check (+) Assembly (++-) Hazard notification (+)		

1. The '+' and '-' symbols denote the positive and negative impacts on the productivity factor, respectively.
2. The presence of multiple identical symbols indicates multiple viewpoints or perspectives on the matter (See Appendix 1).

discrepancy checks, assembly and progress management tasks [13,24,66,67]. One papers indicated that his application could satisfy the accurate and stable registration if the user holds the AR device (tablet) steady [114]. Four out of five papers concluded that their AR applications had a low entry barrier, improving users' intention to use AR. One out of five papers obtained a neutral result on the entry barrier for marking potential risk onsite through the AR system [23]. Three papers listed in Table 3 mentioned that the user felt uncomfortable with wearing HMD during work.

Concerning effectiveness, 22 out of 23 papers showed that AR positively affects productivity by reducing task completion time, improving comprehension, increasing correct rate and reducing cognitive load. However, one out of 23 papers concluded that AR did not affect completion time and the correct rate [106]. In that paper, the experiment participants installed the rebar of concrete columns by seeing the rebar model in the real world through AR. Participants using AR did not have much difference in completion time and correct rate with participants using drawing.

3.4.1. Ease of use

3.4.1.1. Registration accuracy and stableness. The accurate and stable registration ensures that the virtual content is superimposed onto the correct position and stays steady so that user can conduct their construction tasks smoothly. The user needs to recalibrate the registration when the virtual content is superimposed to the wrong place, wasting time and reducing productivity. The registration accuracy and stableness were investigated in design review, discrepancy check, assembly and positioning tasks (Table 3).

The AR application for design review tasks can place the 3D building model in an accurate position, and the 3D model does not have an unstable jitter [34]. In some circumstances, an AR system may lose track if its camera moves quickly, resulting in the incorrect placement of virtual models [114]. This issue frequently occurs when the designer views a full-scale building model in the real world with a mobile phone because the small display limits the user's field of view, and the user needs to move the phone around to view the building fully [13]. However, the tracking can be recovered if the user maintains the current posture for a certain second to recalibrate the building model's placement, which can satisfy the usability for design review [15].

Accurate registration and stable presentation are even more crucial for discrepancy check, assembly and positioning tasks. A stable and accurate registration ensures users can complete these tasks with less time and higher quality. A user may often move around while conducting these works, making registration more challenging. Virtual content cannot be registered accurately and in stable conditions if a camera has no fixed position and moves with a user. Mirshokraei et al. [67] concluded that the positioning accuracy of their AR system needs to be improved for geometric measurement during a discrepancy check task. DaValle and Azhar [24] indicated that 73 % of their participants who used Microsoft HoloLens to assist in assembling pipes reported the issue of models moving out of target positions.

Registration accuracy can be improved if a camera stays still or only moves in a small range. Bhatt et al. [11] kept the camera of their AR system in position, which yielded an error within 2 mm for registration. Kwiatek et al. [57] held a tablet and tried to steady the tablet on hand to conduct pipe assembly reaching a registration error limited to 5 mm. Settimi et al. [86] used Microsoft HoloLens to position drilling points on timber. The registration of the drilling point on the timber had an offset with a mean error of 6.37 ± 3.5 mm, which satisfied the design requirement. In the case of projection-based AR, a static projector used for positioning plan layout on a floor reached a maximum error of 10 mm [27].

For progress management tasks, the as-planned status can align with the as-built status on the correct position for the progress monitor. Marker-based AR is normally used to inspect the interior construction progress and can provide a satisfactory positioning of building components [3]. Another progress monitoring method was to inspect the progress of the whole building from the outside looking of a construction site. In this case, image processing accurately aligns with the as-built building status and the as-planed building model [36]. However, the image processing method cannot provide real-time tracking. GPS can provide real-time outdoor tracking; however, its accuracy cannot be assured at all times in all weather conditions [66]. Alternative outdoor tracking methods, such as simultaneous localisation and mapping (SLAM,) have been introduced for progress management [116]. However, according to this review, no evidence shows that the registration accuracy of SLAM is adequate for carrying out progress management tasks outdoors.

Although four papers mentioned the inaccurate and unstable registration, eight papers concluded that the registration is satisfied. In this case, this paper concluded that it is feasible for AR to provide accurate and stable registration for conducting design reviews, progress management, assembly, and positioning tasks, improving productivity. However, the registration for discrepancy check, planning simulation, and hazard notification tasks still needs to be proved.

3.4.1.2. Comfortability. Productivity may be reduced if a worker feels uncomfortable onsite conducting physical work. The uncomfortable feeling may constrain the workers' performance and increase the work hours [87]. In this paper, three articles mentioned the comfortability issue of HDMs. The three AR applications used wearable AR devices because workers need their hands to carry out physical tasks. DaValle and Azhar [24] illustrated that their participants felt uncomfortable wearing Microsoft HoloLens while assembling pipes. Similarly, Dai et al. [23] showed that 68 % of participants reported difficulty walking onsite while wearing Microsoft HoloLens. Yeh et al. [110] installed a projector on a safety helmet. This heavy helmet made workers uncomfortable to wear. Based on the result, the HDM used in discrepancy check, assembly, and hazard notice tasks constrains workers' performance and affects productivity. There is no evidence showing how much efficiency is affected by the uncomfortable device. It is suggested that future AR development should consider the comfortability issue.

3.4.1.3. Entry barrier. The entry barrier determines if a worker can get started with an AR application quickly. A complex AR application with a confusing user interface may reduce productivity as users have to spend more time configuring and operating the application. AR applications implemented with smartphones and tablets usually have a low entry barrier. In the experiment conducted by Garbett et al. [34], all participants highlighted that the user interface of the AR application was simple and intuitive. Alirezaei et al. [3] and Fenais et al. [32], using smartphone AR applications, drew the same conclusion. A possible explanation is that smartphones and tablets have become popular nowadays, so most people are familiar with basic smartphone interaction. Microsoft HoloLens, as a wearable AR device, has yet to be widespread in daily use. Therefore, the AR applications implemented with Microsoft HoloLens have a steep learning curve. Users need master operation gestures, user interface, and interaction before conducting construction tasks [24]. Failing to do so, users may waste more time manipulating the system, jeopardising productivity. In the experiment conducted by Dai et al. [23], 46 % of participants agreed that the user interface of HoloLens is easy, while 49 % of participants think it is neutral, which shows that the user interface design of HoloLens should be considered. Overall, AR applications implemented with mobile devices have a low entry barrier. The learning time can be reduced so that productivity can be improved. The articles implementing AR with projectors and computers have no discussion on the entry barrier issue.

3.4.2. Effectiveness

3.4.2.1. Task completion time. Productivity can be improved by reducing the time spent completing a construction task. This review found evidence of productivity improvement with five construction activities by reducing completion time facilitated by AR, including design review, discrepancy check, assembly, hazard notification and positioning.

AR improves productivity by spending less time mapping the construction information from drawings to the real world as the information can be visualised in the real world. For example, in a pipeline design review task, the speed of identifying design issues was increased by 41.7 % compared with a traditional method which used photographs to look for issues [101].

AR also benefits decision-making in design review tasks. A designer can compare the aesthetic performance of different wall materials by displaying them in the real world, significantly reducing the decision-making time from 65 min using Analytic Hierarchy Process (AHP) to 15 min using AR facilitating the AHP to rank the performance of six wall material [81].

For discrepancy checks, Zhou et al. [115] included AR system setup time in measuring productivity and found that using AR reduced the task completion time on inspecting tunnel segments. Five out of six studies about AR assisting in assembly tasks tested the impact of using AR on task completion time (Table 4). Hou et al. [43] concluded that AR reduced the completion time spent on assembling simple pipes by 50 % compared to 2D drawings.

When the assembly task was complex and closer to reality, AR reduced the completion time by 9 % compared to 2D drawings. Kwiatek et al. [57] argued that the impact on task completion time was due to the reduced time for absorbing and comprehending design information. Participants using 2D drawings spent a lot of time reading and interpreting the drawings. Qin et al. [77] also indicated that participants using AR spent less time on assembling timber frame than who uses paper-based drawing. However, in a rebar tying task, Wu et al. [106] found no significant differences between AR and 2D drawings in terms of affecting task completion time. Yet, the participants who used AR in the first test had better time performance in the second test than those who used 2D drawings in the first test, in which case the second task had the same work as the first task. Therefore, AR might outperform paper-based instructions in terms of helping participants develop rebar-tying skills.

Dai et al. [23] concluded that AR reduced communication time when identifying safety issues on a construction site. Kim et al. [52] argued that AR enhanced participants' awareness of potential hazards and reduced their response time by 26.74 % [52].

In terms of positioning tasks, Tavares et al. [97] demonstrated that their AR-based welding system decreased the welding time of a 12.72-meter total weld length from 100 min to 85 mins. AR can improve the productivity of design review, discrepancy check, assembly, hazard notification, and positioning tasks by reducing completion time.

3.4.2.2. Comprehending information. Construction tasks involve various data and information. Complicated information and inefficient communication may lead to confusion and misunderstanding, resulting in a negative impact on construction productivity. One advantage of using AR is visualising intuitive data and information in the real-world context. In design review tasks, 94 % of participants from Costa et al. [21] agreed that it was easier for them to comprehend urban designs using AR than 2D drawings since AR superimposed design models onto the real world. Moreover, participants can have more interaction, such as highlighting some building components and making annotations on them, which allows participants to have a comprehensive demonstration to the other collaborative participants [90]. Thanks to the intuitive presentation offered by AR, less experienced workers can complete the same construction tasks as experienced workers. In Khalek et al. [47], participants without maintenance experience performed well using AR in identifying maintainability issues from design models. Kontovourkis et al. [54] presented similar findings that AR enabled less experienced workers to assemble windows quickly and accurately. As for the construction site transportation planning, AR allows participants to observe virtual trucks' movement directly. The participant can plan the truck route by visualising the site condition [16]. Regarding hazard notification, hidden hazards onsite can be presented and communicated more intuitively using AR. The experiment conducted by Kim et al. [52] showed that participants equipped with AR achieved a 90 % awareness rate of potential hazards, while those participants without AR achieved 48 %. Overall, evidence was shown that AR could provide comprehending information in design review, progress management, discrepancy check, assembly, and hazard notice tasks and improve their productivity.

Misunderstanding of design drawings causes errors in construction tasks [77]. In an assembly task, the researcher finds that the instructions provided by AR are intuitive and help the user understand the task [69]. Marino et al. [63] believes that compared to traditional paper drawings, AR can reduce misunderstandings and errors caused by distractions between consulting the instructions and executing the task. Moreover, this understanding of the task can enhance users' assembly skills. Therefore, users who have previously used AR assistance can significantly improve their accuracy when assembling with traditional drawings later on [69]. In this way, AR's ability to facilitate information comprehension can also have a positive impact on accuracy.

3.4.2.3. Correct rate. The correct rate of tasks done highly affects productivity. Errors may cause rework or revision, which wastes time and resources. This review discovered that AR could improve the correct rate of several construction tasks. Hou et al. [43] showed that workers assisted by AR committed 50 % fewer errors than those who used 2D drawings in a pipe assembly task. This finding is also supported by Dai et al. [23], who reported that AR ensured correct and accurate information transfer during safety inspection. In Dai et al. [23] experiment, 80 % of participants acknowledged AR for providing better communication accuracy onsite than phone calls. In the experiment conducted by Khalek et al. [47], participants correctly identified 88.2 % of maintainability issues using AR, compared to a 75.3 % correct rate when using a traditional computer screen. May et al. [64] tested the correct rate of using AR in identifying the offset in building elements. The result showed that participants using AR can achieve 82 % of the correct rate, compared to 59 % when using paper-based drawings. However, another study presented an opposite finding. Wu et al. [106] found that both the AR and traditional groups committed the same number of errors in a rebar-tying task. One possible explanation is that participants could request extra assistance during the experiment, which interfered with the correct rates of both methods. Nonetheless, participants who used AR asked for less help than those who used design drawings. In a separate study by Abbas et al. [1] examining the use of AR for identifying rebar errors, participants utilizing AR spotted 9 % more spacing mistakes compared to those using 2D drawings. Overall, AR can improve the correct rate of construction tasks, thus, further increasing the productivity of a task.

3.4.2.4. Cognitive load. Heavy cognitive load causes construction workers to have low motivation and slow reactions, which impact their performance and productivity [68]. This review identified three studies that used the NASA-TLX index to evaluate the cognitive load of using AR [43,89,100]. NASA-TLX is a questionnaire-based method designed for participants to rate their cognitive load after completing a task [41]. Shin and Dunston [89] demonstrated that AR was perceived to impose approximately 1.9 times less cognitive load than a total station during steel column discrepancy checks. A total station setup process involved high physical and temporal demand, whereas AR was more straightforward to set up. Similarly, in assembly tasks, Hou et al. [43] indicated that AR reduced the cognitive load on perceptual tasks such as comprehending, exploring and remembering the steps to complete assembly tasks. Wallmyr et al. [100] evaluated the cognitive load for excavator operators in recognising potential hazards. The authors discovered that the physical demand for operators using AR was approximately half that of those who observed potential hazards by themselves.

Wu et al. [106] measured the cognitive load of experiment participants with AR assistance for rebar tying and drew contrast findings. The results showed that AR did not reduce cognitive load significantly compared to traditional paper-based methods. Cognitive load is divided into three types: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load [95]. Thees et al. [98] pointed out that while AR does not reduce the intrinsic complexity of tasks (intrinsic cognitive load), it can lessen the cognitive effort needed to manage irrelevant aspects of the learning environment (extraneous cognitive load). This includes the management of multiple information sources, both spatially and temporally. One possible reason is that the task of tying rebar is inherently complex. AR cannot reduce the complexity of the task and significantly impact the intrinsic cognitive load. Another possible reason is that the cognitive load measurement methods used by these studies do not give insights into different types of cognitive loads separately. For instance, using NASA-TXL to measure cognitive load can provide an overall task load estimation; however, analysing and interpreting the effects of each dimension and their interaction is challenging [76]. Last, several papers have also indicated that the complexity of interaction and limited FOV can influence cognitive load [8,14,49].

4. AR prototype development and evaluation framework

Based on the findings, this paper proposes a framework for developing and assessing AR applications assisting in construction task productivity (Fig. 5). The development and validation process for AR applications in the construction industry proposed in this paper is based on the currently known AR technology and experimental methods.

In the field of construction research, Wang et al. [104] proposed a framework that spans the entire process starting from the initial concept and idea of an AR solution through its development and adoption in industrial settings. Wang et al. [104] summarised the technologies and application scenarios of AR, as well as two aspects for evaluating AR applications: usability and effectiveness. In contrast, the framework proposed by this systematic literature review aims to analyse the usability and effectiveness factors based on productivity at a task level. One of the major contributions of our framework is that it outlines specific construction tasks and maps out AR features that could potentially impact productivity for construction tasks. Our framework also provides a systematic method for evaluating AR applications, specifically focusing on enhancing productivity, which guides future researchers in applying AR technologies to practical implementations in the construction industry.

Current evaluation methods are not enough to cover all productivity factors in the construction industry. However, this framework can still be used as a quick evaluation tool for the AR application in the construction industry. Other productivity factors or evaluation methods that are not mentioned in previous studies can be investigated based on the construction task's requirement. In the first stage, the developer needs to identify the target construction tasks. This review finds that AR is feasible to be applied to the seven construction tasks listed in Fig. 5. In the next stage, the three AR features of the proposed application need to be identified. First, the augmentation method needs to be decided based on the information required for the facilitated construction tasks. Virtually orientated and physically orientated augmentation can be used to demonstrate virtual information and obtain positional information in the real world, respectively. Information prompt enhances user's awareness. The feasible augmentation method for each construction task is shown in Fig. 4.

The developer needs to identify the display tools and tracking methods in the next step. The display tools are related to the application scenario, as discussed in Section 3.2.2. For example, a portal device is required if the working scenario needs the worker to carry the AR system onsite. If the AR system is for outdoor tasks, projectors and HDMs are

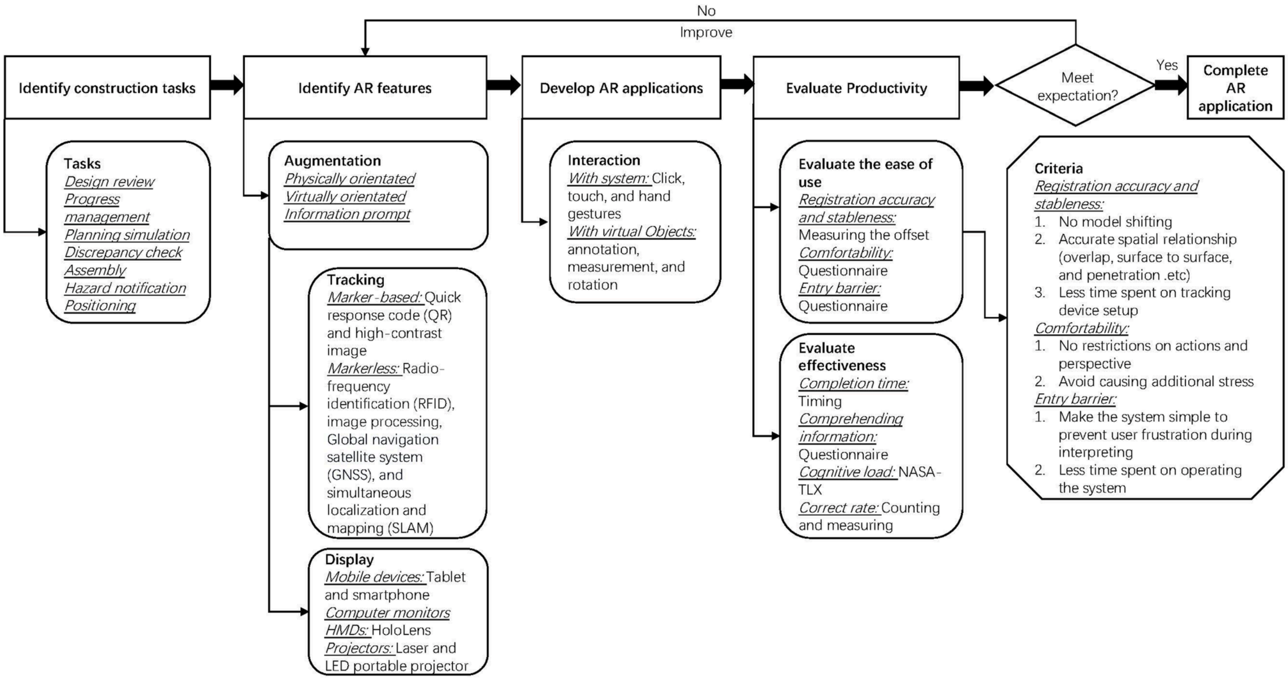


Fig. 5. A framework for AR application development and productivity evaluation.

unsuitable when there is strong light during the daytime. The tracking method should consider algorithm complexity as markless-based tracking is more complex than marker-based AR, as discussed in Section 3.2.3.

The AR application can then be developed. In this stage, the developer should be concerned with the users' interaction with the system and virtual objects. As for the interaction between users and the system, the camera is integrated into the smartphone and tablet, which allows users to rotate their view with the camera. The screen is also touchable for interacting with the system. HoloLens tracks hand gestures for users' interaction with the system. Computer monitors use mice and keyboards for clicking and typing. As for projectors, the user needs a controller or a smartphone to interact with the system. Multiple interactions between the user and virtual object were found in computer monitors, HoloLens, smartphones and tablets. Users can measure, annotate, rotate and move the virtual objects. However, projector-based AR only allows users to move the projecting content in two dimensions.

The developer should evaluate the ease-of-use and effectiveness factors for their prototypes, as listed in Fig. 5. The evaluation methods found from the eligible papers are also listed in Fig. 5. This stage evaluates the ease-of-use and effectiveness factors because those factors ensure the operational efficiency of the application and impact productivity collectively.

The ease-of-use factors can affect productivity as illustrated in Section 3.4. This framework lists the criteria that AR applications are expected to meet based on the ease-of-use factors. The criteria are proposed based on factors that have a negative impact on productivity, as mentioned in Section 3.4.1. Therefore, AR applications in construction tasks are expected to meet these criteria to improve productivity.

Current AR technology still has many technical issues, so it cannot simultaneously satisfy all the criteria. For example, if a user finds that the registration of virtual content is unstable and recalibration is time-consuming while conducting construction tasks, the AR application should be updated with a more stable tracking method (e.g., makerbased tracking). However, a marker is only suitable when there is an object surface to attach it. Attaching a marker also requires additional time and may reduce productivity. If marker-based tracking is not suitable, markerless tracking with an improve tracking algorithm becomes the only solution. When developing AR application, the critical factors that affect productivity based on the task characteristics should be considered. If the low productivity issue is mainly related to errors caused by design misunderstandings [77], the AR application should prioritise tracking accuracy rather than reducing setting-up time. Construction tasks, such as onsite inspections, require significant time to comprehend drawings and map them to the real world [115]. A slightly unstable tracking is still acceptable because the inspector only needs to obtain the design information at each position and spends most of the time walking onsite. In this case, the wearing comfort of an HMD or the use of a handheld device is more critical. In this sense, different construction tasks require different weights of the AR features.

Future research can investigate the weights assigned to each criterion based on task characteristics and productivity issues. A minimum acceptance level can also be established based on task requirements. The framework can be further validated through practical applications in the industry.

If the application meets the expectation of the ease-of-use and usefulness factors, the application is completed and proven to improve productivity. This framework can guide the development of AR applications and the evaluation of productivity. One limitation is that the review is conducted based on existing literature. Therefore, the proposed framework used the evidence from the existing literature, which may not be comprehensive and inclusive. Further research can expand the framework and validate it.

5. Discussion

5.1. Trend

Before 2015, most AR applications in the construction industry were based on computers equipped with cameras. The tracking method involves extracting feature points from images captured by the camera to estimate the camera's pose. This approach requires significant computational power; therefore, AR applications are typically run on computer platforms. During that period, most applications were designed to display construction progress, simulate the construction process, and plan the construction. These tasks could typically be completed in an office setting. Mobile devices can be used for applications in outdoor settings; however, due to technical limitations, most of these applications rely on GPS tracking, which is highly inaccurate [9,39,66].

Microsoft HoloLens, released in 2016, integrates multiple sensors to implement wearable AR technology. Researchers have used this technology to develop various applications, including assisting in assembly processes, reviewing design drawings, and providing hazard warnings. On mobile devices, the ARKit and ARCore, released in 2017, enable smartphones and tablets to easily implement AR technology. The widespread adoption of smartphones has also led most researchers to opt for mobile AR to review designs (see Fig. 4). Combining sensors and image processing technologies, researchers have developed an AR application to precisely locate nail positions [86]. Researchers have also explored collaborative AR platforms and remote collaboration AR systems to enhance productivity in the construction industry [34,102]. The integration of sensors with drilling machines enables users to receive real-time feedback on drilling direction in the AR environment, thus pioneering the convergence of AR and Internet of Things (IoT) [86]. The integration of Building Information Modeling (BIM) and AR facilitates the management and visualisation of construction processes more effectively, thereby leading to improved decision-making and productivity [3].

5.2. Challenges in improving productivity

There are several challenges associated with AR technology to improve productivity in the construction industry:

1. Computational power: While the hardware used in autonomous driving offers precise and stable positioning and tracking [96], AR devices, limited by their size and capacity, cannot provide similar computational power [93]. They rely on optimised algorithms to reduce computational demands, leading to unstable tracking. One potential solution is integrating AR with cloud computing, where computation is done in the cloud and a high-speed internet connection is essential.
2. Field of view: The field of view provided by current AR displays is significantly narrower than that from human eyes. This limitation necessitates frequent adjustments and movement of a viewer's perspective when inspecting augmented models on a 1:1 scale, thereby increasing the likelihood of tracking errors. Furthermore, with a limited field of view, health and safety are other concerns when people use AR devices on construction sites.
3. Comfortability: The weight of AR headsets, limited by battery capacity and computational power, makes them uncomfortable to wear for an extended period of time.

5.3. Future development

AR is primarily a display technology and still requires manual labour and input, unlike automation technologies that reduce physical workloads. A study shows that using AR for rebar tying tasks does not significantly reduce the time spent [106], indicating that AR's potential to boost productivity in labour-intensive construction tasks is inherently limited. In construction tasks that require physical labour, future research could integrate AR with collaborative robots [22]. The physical work could be performed by robots, while humans could use AR to supervise the robots' route planning or task schedules, allowing for better control of the robots.

AR significantly enhances our understanding of the real world, offering substantial benefits in that area. In construction management and design reviews, to further enhance productivity, AR should display models that are linked to the real world. For instance, by setting up a real-size room model in an actual space, designers can effectively evaluate whether the design of maintenance accesses is practical and reachable [47]. As a visualisation tool for BIM, in the future, AR could map information from BIM onto real-world construction sites, including building materials, transportation vehicles, and machinery. This can allow decision-makers to have a more intuitive and comprehensive understanding of construction progress, thereby facilitating better decision-making in construction program and methodology.

6. Conclusion

This literature review investigates the AR applications for construction tasks by reviewing 51 articles covering the planning, design, and construction phases. This literature review enumerates the currently known applications of AR in the planning, design, and construction phases, as well as the commonly used technologies to implement AR applications. Additionally, the review also analyses whether the current methods and technologies of AR can meet the productivity demands of these construction tasks according to the validated evidence. This review draws the following conclusion: (1) Main research on applying AR focuses on design review, progress management, and planning simulation. AR benefits these construction tasks by visualising the construction information intuitively. (2) AR offers flexibility in terms of augmentation methods, display tools and tracking methods. Developers can adapt the feature of AR to the usage scenarios and information needs of construction tasks. Physically orientated augmentation and markerless AR are widely used for most construction tasks; (3) Current AR technologies can fulfil the ease-of-use requirement for conducting most construction tasks as the virtual content registration is stable and accurate. It is found that AR can reduce the time spent, comprehend information, increase the correct rate and reduce the cognitive load in construction tasks, which directly impact productivity. Several studies showed improved productivity in different tasks facilitated by AR, including design review, discrepancy check, assembly, and hazard notification.

This article proposes a framework that combines the features of AR with mechanisms to enhance productivity in the construction industry. This framework provides concrete guidance for selecting AR technologies that have been proven effective in increasing productivity for various construction tasks. For the academic community, researchers can use it to analyse key factors (registration accuracy and stableness, comfortability, entry barrier, task completion time, comprehending information, correct rate, and cognitive load) affecting productivity in specific construction tasks and explore the role of different AR features in these factors. The validated data can be used to weigh the AR features in the framework.

The limitations of this systematic literature review are: (1) most experiments or case studies analysed in this literature review are conducted in a simulated situation, which may not reflect some productivity factors in a practical situation; (2) the research only focuses on evaluating construction productivity at the task level, which cannot explain the impact on productivity at the industry level; (3) the proposed framework used the evidence from the existing literature, which may not be comprehensive and inclusive.

A few knowledge gaps identified in this review. First, there is little evidence showing AR's impact on task completion time in progress management and planning simulation tasks. A possible reason is that the production of progress management and planning simulation tasks is difficult to measure. Second, evidence has shown that AR can meet the registration stableness and accuracy requirement for positioning tasks. However, the effectiveness factors impacting productivity for positioning tasks remain unclear. Although the AR system can provide an accurate registration, the worker still needs to physically mark the position in the real world. The error may occur when the worker marks the position in the real world because the virtual content may occlude their sight. Due to the lack of studies on using AR in positioning tasks, this systematic literature review suggests that future research can use the proposed framework to develop more AR applications in the positioning task and evaluate the impact on productivity systematically. The proposed framework can also be extended and validated by future research. Additionally, current validation is barely tested in a real construction project. Future research trends can focus on using AR in a real construction project. At last, the findings show that AR can enhance designers' understanding of the project and enhance communication between stakeholders. This advantage may benefit the design for manufacturing and assembly (DFMA) method in offsite construction. Future research can investigate the feasibility of applying AR to offsite construction tasks.

7. Declaration of Generative AI and AI assisted technologies in the writing process

Statement: During the preparation of this work the author(s) used ChatGPT in order to improve language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Zhidong Xu: Writing – original draft. **Zhenan Feng:** Writing – review & editing, Supervision. **Mostafa Babaeian Jelodar:** Writing – review & editing, Supervision. **Brian H.W. Guo:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix 1

AR features' impact on productivity factors in different construction tasks.

	Augmentation	Display	Tracking
Registration Accuracy and stableness		*Design review*: Negative: 1. Frequent camera movement due to limited field of view [13]	*Design review:* Positive: 1. Fast and stable marker-based tracking [34] Negative: 1. Loss of tracking with quick/frequent movement [114] *Progress management* Positive: 1. Accurate registration on the real construction progress [3,36] Negative: 1. Inaccurate GPS tracking [66] *Discrepancy check* Negative: 1. Insufficient accuracy for geometric measurement [67] *Assembly* Positive: 1. Accurate positioning of the assembly parts [11,57] Negative: 1. 3D model moving out of position due to marker-less tracking [24]
Comfortability		*Discrepancy check* Negative: 1. Uncomfortable headsets [110] *Assembly* Negative: 1. Physically uncomfortable headsets [24] *Hazard notification* Negative:	

(continued on next page)

(*continued*)

	Augmentation	Display	Tracking
		1. Difficulty wearing headset and walking [23]	
Entry barrier	*Planning simulation* Positive: 1. Low learning requirement for computer languages/modelling rules [16] *Assembly* Positive: 1. Increased productivity for unskilled labour [54,106]	*Design review* Positive: 1. Intuitive smartphone-based AR interface [34] *Progress management* Positive: 1. Easy interaction with smartphone-based AR [3] *Planning simulation* Positive: 1. Easy to use a smartphone-based augmented reality app [32] *Assembly* Negative: 1. Learning curve associate with interaction in HoloLens	
Task completion time	*Design review* Positive: 1. Reduced decision-making time [81]) 2. Reduced information retrieval time [101] *Discrepancy check* Positive: 1. Reduced time for reading 2D drawings and inspecting [89,111,115] *Assembly* Positive: 1. Reduced time for measuring and drawing interpretation [43,54,57] *Positioning* Positive 1. Reduced positioning time [97]		*Design review* Negative: 1. Time lost during tracking recovery [114]
Comprehending information	*Design review* Positive: 1. Easier design understanding [21,90] 2. Provides deeper visual information [81] *Progress management* Positive 1. Visualising information among all stakeholders [112] *Hazard notification* Positive: 1. Improving communication efficiency [23] 2. Enhancing awareness of the risk [52]	*Discrepancy check* Positive: 1. Comprehensive information visualised through real scale projection [110]	
Correct rate	*Design review* Positive: 1. Easier identification of design mistakes [47] Planning stimulation:Positive: 1. Fewer planning errors [16] *Assembly* Positive: 1. Reducing assembly error [43]		*Positioning* Positive: 1. Positioning errors within the tolerance [27,86]
Cognitive load	*Discrepancy check* Positive: 1. AR vs. total station: fewer physical steps, less cognitive load [89] *Assembly* Positive: 1. Reduced frustration [106] 2. Fewer perceptual activities (searching, comprehending) [43]		

(*continued on next page*)

(*continued*)

	Augmentation	Display	Tracking
	Negative: 1. No reduction in cognitive load for complex tasks *Hazard notification* Positive: 1. Lower mental load for hazard identification [100]		

References

[1] A. Abbas, J. Seo, M. Kim, Exploring the construction task performance and cognitive workload of augmented reality-assisted rebar inspection tasks, in: Construction Research Congress 2020, American Society of Civil Engineers, Reston, VA, 2020, pp. 448–456.

[2] Airbus. (2016). *Virtual Reality* https://www.airbus.com/en/newsroom/news/2016-12-virtual-reality.

[3] S. Alirezaei, H. Taghaddos, K. Ghorab, A.N. Tak, S. Alirezaei, BIM-augmented reality integrated approach to risk management, Autom. Constr. 141 (2022) 104458, https://doi.org/10.1016/j.autcon.2022.104458.

[4] J. Ara, F.B. Karim, M.S.A. Alsubaie, Y.A. Bhuiyan, M.I. Bhuiyan, S.B. Bhyan, H. Bhuiyan, Comprehensive Analysis of Augmented Reality Technology in Modern Healthcare System [Article], Int. J. Adv. Comput. Sci. Appl. 12 (6) (2021) 845–854, https://doi.org/10.14569/IJACSA.2021.0120698.

[5] R.H. Assaad, I.H. El-adaway, M. Hastak, K.L. Needy, Key Factors Affecting Labor Productivity in Offsite Construction Projects, J. Constr. Eng. Manag. 149 (1) (2023) 04022158, https://doi.org/10.1061/JCEMD4.COENG-12654.

[6] S. Ayele, A.R. Fayek, A framework for total productivity measurement of industrial construction projects [Article], Can. J. Civ. Eng. 46 (3) (2019) 195–206, https://doi.org/10.1139/cjce-2018-0020.

[7] R.T. Azuma, A Survey of Augmented Reality, Presence Teleop. Virt. 6 (4) (1997) 355–385, https://doi.org/10.1162/pres.1997.6.4.355.

[8] J. Baumeister, S.Y. Ssin, N.A.M. ElSayed, J. Dorrian, D.P. Webb, J.A. Walsh, T. M. Simon, A. Irlitti, R.T. Smith, M. Kohler, B.H. Thomas, Cognitive Cost of Using Augmented Reality Displays, IEEE Trans vis Comput Graph 23 (11) (2017) 2378–2388, https://doi.org/10.1109/tvcg.2017.2735098.

[9] A.H. Behzadan, V.R. Kamat, Simulation and visualization of traffic operations in Augmented Reality for improved planning and design of road construction projects, in: 2008 winter simulation conference, IEEE, 2008, pp. 2447–2454.

[10] J. Berlak, S. Hafner, V.G. Kuppelwieser, Digitalization's impacts on productivity: a model-based approach and evaluation in Germany's building construction industry, Prod. Plan. Control 32 (4) (2021) 335–345, https://doi.org/10.1080/09537287.2020.1740815.

[11] P. Bhatt, N. Bencini, S. Efthymiou, A. Stoitsova, Augmented assembly for tessellated structures, in: Proceedings of the Symposium on Simulation for Architecture and Urban Design, 2017, pp. 1–8.

[12] M. Billinghurst, A. Clark, G. Lee, A survey of augmented reality [Review], Foundations and Trends in Human-Computer Interaction 8 (2–3) (2014) 73–272, https://doi.org/10.1561/1100000049.

[13] U.C. Boos, T. Reichenbacher, P. Kiefer, C. Sailer, An augmented reality study for public participation in urban planning, Journal of Location Based Services 17 (1) (2023) 48–77, https://doi.org/10.1080/17489725.2022.2086309.

[14] J. Buchner, K. Buntins, M. Kerres, The impact of augmented reality on cognitive load and performance: A systematic review, J. Comput. Assist. Learn. 38 (1) (2022) 285–303, https://doi.org/10.1111/jcal.12617.

[15] L. Carozza, D. Tingdahl, F. Bosché, L. van Gool, Markerless vision-based augmented reality for urban planning, Comput. Aided Civ. Inf. Eng. 29 (1) (2014) 2–17, https://doi.org/10.1111/j.1467-8667.2012.00798.x.

[16] H.-M. Chen, P.-H. Huang, 3D AR-based modeling for discrete-event simulation of transport operations in construction, Automation in Construction 33 (2013) 123–136, https://doi.org/10.1016/j.autcon.2012.09.015.

[17] D. Cheng, Y. Wang, H. Hua, M.M. Talha, Design of an optical see-through head-mounted display with a low f-number and large field of view using a freeform prism, Appl. Opt. 48 (14) (2009) 2655–2668, https://doi.org/10.1364/AO.48.002655.

[18] J.C. Cheng, K. Chen, W. Chen, Comparison of marker-based AR and markerless AR: A case study on indoor decoration system, in: Lean and Computing in Construction Congress (LC3): Proceedings of the Joint Conference on Computing in Construction (JC3), 2017, pp. 483–490.

[19] H.Y. Chi, Y.K. Juan, S. Lu, Comparing BIM-Based XR and Traditional Design Process from Three Perspectives: Aesthetics, Gaze Tracking, and Perceived Usefulness, Buildings 12 (10) (2022) 1728, https://doi.org/10.3390/buildings12101728.

[20] T.M. Connolly, E.A. Boyle, E. MacArthur, T. Hainey, J.M. Boyle, A systematic literature review of empirical evidence on computer games and serious games, Comput. Educ. 59 (2) (2012) 661–686, https://doi.org/10.1016/j.compedu.2012.03.004.

[21] F. Costa, S. Eloy, M.S. Dias, M. Lopes, ARch4models: a tool to augment physical scale models, in: eCAADe 2017–ShoCK!, Vol. 1, 2017, pp. 711–718.

[22] G.D.M. Costa, M.R. Petry, A.P. Moreira, Augmented reality for human–robot collaboration and cooperation in industrial applications: A systematic literature review, Sensors 22 (7) (2022) 2725. https://www.mdpi.com/1424-8220/22/7/2725.

[23] F. Dai, A. Olorunfemi, W. Peng, D. Cao, X. Luo, Can mixed reality enhance safety communication on construction sites? An industry perspective, Safety Science 133 (2021) 105009, https://doi.org/10.1016/j.ssci.2020.105009.

[24] A. DaValle, S. Azhar, An investigation of mixed reality technology for onsite construction assembly, in: MATEC Web of Conferences, Vol. 312, EDP Sciences, 2020, p. 06001.

[25] J.M. Davila Delgado, L. Oyedele, T. Beach, P. Demian, Augmented and Virtual Reality in Construction: Drivers and Limitations for Industry Adoption, J. Constr. Eng. Manag. 146 (7) (2020), https://doi.org/10.1061/(ASCE)CO.1943-7862.0001844.

[26] L.F. de Souza Cardoso, F.C.M.Q. Mariano, E.R. Zorzal, A survey of industrial augmented reality, Comput. Ind. Eng. 139 (2020) 106159, https://doi.org/10.1016/j.cie.2019.106159.

[27] A. Degani, W.B. Li, R. Sacks, L. Ma, An Automated System for Projection of Interior Construction Layouts, IEEE Trans. Autom. Sci. Eng. 16 (4) (2019) 1825–1835, https://doi.org/10.1109/tase.2019.2897135.

[28] DHL. (2015). *DHL successfully tests augmented reality application in warehouse*. https://www.dhl.com/global-en/delivered/digitalization/dhl-successfully-tests-augmented-reality-application-in-warehouse.html.

[29] K.M. El-Gohary, R.F. Aziz, Factors influencing construction labor productivity in Egypt, J. Manag. Eng. 30 (1) (2014) 1–9.

[30] O.O. Faniran, J.O. Oluwoye, D. Lenard, Effective construction planning, Constr. Manag. Econ. 12 (6) (1994) 485–499, https://doi.org/10.1080/01446199400000060.

[31] S. Feiner, B. MacIntyre, T. Höllerer, A. Webster, A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment, Pers. Technol. 1 (4) (1997) 208–217, https://doi.org/10.1007/BF01682023.

[32] A. Fenais, S.T. Ariaratnam, S.K. Ayer, N. Smilovsky, Integrating geographic information systems and augmented reality for mapping underground utilities, Infrastructures 4 (4) (2019), https://doi.org/10.3390/infrastructures4040060.

[33] Z. Feng, V.A. González, R. Amor, R. Lovreglio, G. Cabrera-Guerrero, Immersive virtual reality serious games for evacuation training and research: A systematic literature review, Comput. Educ. 127 (2018) 252–266, https://doi.org/10.1016/j.compedu.2018.09.002.

[34] J. Garbett, T. Hartley, D. Heesom, A multi-user collaborative BIM-AR system to support design and construction, Autom. Constr. 122 (2021), https://doi.org/10.1016/j.autcon.2020.103487.

[35] P. Georgel, P. Schroeder, S. Benhimane, S. Hinterstoisser, M. Appel, N. Navab, An industrial augmented reality solution for discrepancy check, in: 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality, IEEE, 2007, pp. 111–115.

[36] M. Golparvar-Fard, F. Peña-Mora, S. Savarese, Integrated sequential as-built and as-planned representation with D 4AR tools in support of decision-making tasks in the AEC/FM industry, J. Constr. Eng. Manag. 137 (12) (2011) 1099–1116, https://doi.org/10.1061/(ASCE)CO.1943-7862.0000371.

[37] P.M. Goodrum, C.T. Haas, C. Caldas, D. Zhai, J. Yeiser, D. Homm, Model to predict the impact of a technology on construction productivity, Journal of construction engineering and management 137 (9) (2011) 678–688, https://doi.org/10.1061/(ASCE)CO.1943-7862.0000328.

[38] Halpin, D. W., Lucko, G., & Senior, B. A. (2018). *Construction management* (5th edition ed.) [Online Non-fiction Electronic document]. Wiley. https://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=cat09011a&AN=mul.oai.edge.massey.folio.ebsco.com.fs00001086.82dde02c.7e6a.5144.ba68.b929c0bbaf0a&site=eds-live&scope=site&authtype=sso&custid=s3027306. http://ezproxy.massey.ac.nz/login?url=https://ebookcentral.proquest.com/lib/massey/detail.action?docID=5716990.

[39] A. Hammad, H. Wang, S.P. Mudur, Distributed augmented reality for visualizing collaborative construction tasks, J. Comput. Civ. Eng. 23 (6) (2009) 418–427, https://doi.org/10.1061/(ASCE)0887-3801(2009)23:6(418).

[40] M. Hamza, S. Shahid, M.R. Bin Hainin, M.S. Nashwan, Construction labour productivity: review of factors identified, Int. J. Constr. Manag. 22 (3) (2022) 413–425, https://doi.org/10.1080/15623599.2019.1627503.

[41] S.G. Hart, L.E. Staveland, Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research, in: P.A. Hancock, N. Meshkati (Eds.), Advances in Psychology, Vol. 52, Elsevier Science, 1988, pp. 139–183, https://doi.org/10.1016/S0166-4115(08)62386-9.

[42] A. Hasan, B. Baroudi, A. Elmualim, R. Rameezdeen, Factors affecting construction productivity: a 30 year systematic review, Engineering, Construction and Architectural Management 25 (7) (2018) 916–937, https://doi.org/10.1108/ECAM-02-2017-0035.

[43] L. Hou, X. Wang, M. Truijens, Using augmented reality to facilitate piping assembly: an experiment-based evaluation, Journal of Computing in Civil Engineering 29 (1) (2015) 05014007, https://doi.org/10.1061/(asce)cp.1943-5487.0000344.

[44] J. Hui, Approach to the interior design using augmented reality technology, in: 2015 Sixth International Conference on Intelligent Systems Design and Engineering Applications (ISDEA), IEEE, 2015, pp. 163–166.

[45] K. Ito, M. Tada, H. Ujike, K. Hyodo, Effects of the Weight and Balance of Head-Mounted Displays on Physical Load, Appl. Sci. 11 (15) (2021) 6802. https://www.mdpi.com/2076-3417/11/15/6802.

[46] Y. Jiao, S. Zhang, Y. Li, Y. Wang, B. Yang, Towards cloud Augmented Reality for construction application by BIM and SNS integration, Autom. Constr. 33 (2013) 37–47, https://doi.org/10.1016/j.autcon.2012.09.018.

[47] I.A. Khalek, J.M. Chalhoub, S.K. Ayer, Augmented reality for identifying maintainability concerns during design, Advances in Civil Engineering 2019 (1) (2019) 8547928, https://doi.org/10.1155/2019/8547928.

[48] K.S. Khan, R. Kunz, J. Kleijnen, G. Antes, Five steps to conducting a systematic review, J. R. Soc. Med. 96 (3) (2003) 118–121.

[49] K. Kia, J. Hwang, I.-S. Kim, H. Ishak, J.H. Kim, The effects of target size and error rate on the cognitive demand and stress during augmented reality interactions, Appl. Ergon. 97 (2021) 103502, https://doi.org/10.1016/j.apergo.2021.103502.

[50] B. Kim, C. Kim, H. Kim, Interactive modeler for construction equipment operation using augmented reality, J. Comput. Civ. Eng. 26 (3) (2012) 331–341, https://doi.org/10.1061/(ASCE)CP.1943-5487.0000137.

[51] H.S. Kim, S.K. Kim, A. Borrmann, L.S. Kang, Improvement of Realism of 4D Objects Using Augmented Reality Objects and Actual Images of a Construction Site, KSCE J. Civ. Eng. 22 (8) (2018) 2735–2746, https://doi.org/10.1007/s12205-017-0734-3.

[52] K. Kim, H. Kim, H. Kim, Image-based construction hazard avoidance system using augmented reality in wearable device, Autom. Constr. 83 (2017) 390–403, https://doi.org/10.1016/j.autcon.2017.06.014.

[53] A.Z. Kolaei, E. Hedayati, M. Khanzadi, G.G. Amiri, Challenges and opportunities of augmented reality during the construction phase, Autom. Constr. 143 (2022) 104586, https://doi.org/10.1016/j.autcon.2022.104586.

[54] O. Kontovourkis, C. Georgiou, A. Stroumpoulis, C. Kounnis, C. Dionyses, S. Bagdati, Implementing augmented reality for the holographic assembly of a modular shading device, in: Proceedings of the international conference on education and research in computer aided architectural design in Europe, 2019, pp. 149–158.

[55] M. Kopsida, I. Brilakis, P.A. Vela, A review of automated construction progress monitoring and inspection methods, in: Proc. of the 32nd CIB W78 Conference 2015, 2015, pp. 421–431.

[56] G.A. Kumar, A.K. Patil, T.W. Kang, Y.H. Chai, Sensor fusion based pipeline inspection for the augmented reality system, Symmetry 11 (10) (2019) 1325, https://doi.org/10.3390/sym11101325.

[57] C. Kwiatek, M. Sharif, S. Li, C. Haas, S. Walbridge, Impact of augmented reality and spatial cognition on assembly in construction, Autom. Constr. 108 (2019) 102935, https://doi.org/10.1016/j.autcon.2019.102935.

[58] H. Lasi, P. Fettke, H.G. Kemper, T. Feld, M. Hoffmann, Industry 4.0, Business and information systems engineering 6 (2014) 239–242, https://doi.org/10.1007/s12599-014-0334-4.

[59] X. Li, W. Yi, H.L. Chi, X. Wang, A.P.C. Chan, A critical review of virtual and augmented reality (VR/AR) applications in construction safety [Article], Autom. Constr. 86 (2018) 150–162, https://doi.org/10.1016/j.autcon.2017.11.003.

[60] G. Luetzenburg, A. Kroon, A.A. Bjørk, Evaluation of the Apple iPhone 12 Pro LiDAR for an Application in Geosciences, Sci. Rep. 11 (1) (2021) 22221, https://doi.org/10.1038/s41598-021-01763-9.

[61] M.D. Mainul Islam, O.O. Faniran, Structural equation model of project planning effectiveness, Constr. Manag. Econ. 23 (2) (2005) 215–223, https://doi.org/10.1080/0144619042000301384.

[62] M. Golparvar-Fard, F. Peña-Mora, S. Savarese, D4AR–a 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication, J. Inf. Technol. Constr 14 (13) (2009) 129–153.

[63] E. Marino, L. Barbieri, F. Bruno, M. Muzzupappa, Assessing user performance in augmented reality assembly guidance for industry 4.0 operators, Comput. Ind. 157–158 (2024) 104085, https://doi.org/10.1016/j.compind.2024.104085.

[64] K.W. May, C. Kc, B.H. Thomas, J.J. Ochoa, N. Gu, R.T. Smith, J. Walsh, The Identification, Development, and Evaluation of BIM-ARDM: A BIM-Based AR Defect Management System for Construction Inspections [Article], Buildings 12 (2) (2022), https://doi.org/10.3390/buildings12020140.

[65] McKinsey Global Institute. (2017). *Reinventing construction: A route of higher productivity*. https://www.mckinsey.com/capabilities/operations/our-insights/reinventing-construction-through-a-productivity-revolution.

[66] S. Meza, Z. Turk, M. Dolenc, Component based engineering of a mobile BIM-based augmented reality system, Autom. Constr. 42 (2014) 1–12, https://doi.org/10.1016/j.autcon.2014.02.011.

[67] M. Mirshokraei, C.I. De Gaetani, F. Migliaccio, A web-based BIM-AR quality management system for structural elements, Applied Sciences (switzerland) 9 (19) (2019), https://doi.org/10.3390/app9193984.

[68] P. Mitropoulos, B. Memarian, Team Processes and Safety of Workers: Cognitive, Affective, and Behavioral Processes of Construction Crews, J. Constr. Eng. Manag. 138 (10) (2012) 1181–1191, https://doi.org/10.1061/(ASCE)CO.1943-7862.0000527.

[69] M. Moghaddam, N.C. Wilson, A.S. Modestino, K. Jona, S.C. Marsella, Exploring augmented reality for worker assistance versus training, Adv. Eng. Inf. 50 (2021) 101410, https://doi.org/10.1016/j.aei.2021.101410.

[70] J. Moon, Y. Son, S. Park, J. Kim, Development of immersive Augmented Reality Interface for Construction Robotic System, in: 2007 International Conference on Control, Automation and Systems, IEEE, 2007, pp. 1192–1197.

[71] M.Z.A. Muthalif, D. Shojaei, K. Khoshelham, A review of augmented reality visualization methods for subsurface utilities, Adv. Eng. Inf. 51 (2022) 101498, https://doi.org/10.1016/j.aei.2021.101498.

[72] S.G. Naoum, Factors influencing labor productivity on construction sites, Int. J. Product. Perform. Manag. 65 (3) (2016) 401–421, https://doi.org/10.1108/IJPPM-03-2015-0045.

[73] M. Noghabaei, A. Heydarian, V. Balali, K. Han, Trend Analysis on Adoption of Virtual and Augmented Reality in the Architecture, Engineering, and Construction Industry, Data 5 (1) (2020) 26. https://www.mdpi.com/2306-5729/5/1/26.

[74] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ 372 (2021) n71, https://doi.org/10.1136/bmj.n71.

[75] H.-S. Park, S.R. Thomas, R.L. Tucker, Benchmarking of Construction Productivity, J. Constr. Eng. Manag. 131 (7) (2005) 772–778.

[76] M. Pušica, A. Kartali, L. Bojović, I. Gligorijević, J. Jovanović, M.C. Leva, B. Mijović, Mental Workload Classification and Tasks Detection in Multitasking: Deep Learning Insights from EEG Study, Brain Sci. 14 (2) (2024) 149. https://www.mdpi.com/2076-3425/14/2/149.

[77] Y. Qin, E. Bloomquist, T. Bulbul, J. Gabbard, K. Tanous, Impact of information display on worker performance for wood frame wall assembly using AR HMD under different task conditions, Adv. Eng. Inf. 50 (2021) 101423, https://doi.org/10.1016/j.aei.2021.101423.

[78] F.P. Rahimian, V. Chavdarova, S. Oliver, F. Chamo, OpenBIM-Tango integrated virtual showroom for offsite manufactured production of self-build housing, Autom. Constr. 102 (2019) 1–16, https://doi.org/10.1016/j.autcon.2019.02.009.

[79] M.K. Rohil, Y. Ashok, Visualization of urban development 3D layout plans with augmented reality, Results in Engineering 14 (2022) 100447, https://doi.org/10.1016/j.rineng.2022.100447.

[80] S. Sabeti, O. Shoghli, M. Baharani, H. Tabkhi, Toward AI-enabled augmented reality to enhance the safety of highway work zones: Feasibility, requirements, and challenges, Advanced Engineering Informatics 50 (2021) 101429, https://doi.org/10.1016/j.aei.2021.101429.

[81] V. Sangiorgio, S. Martiradonna, F. Fatiguso, I. Lombillo, Augmented reality based-decision making (AR-DM) to support multi-criteria analysis in constructions, Autom. Constr. 124 (2021) 103567, https://doi.org/10.1016/j.autcon.2021.103567.

[82] Schmalstieg, D., & Hollerer, T. (2016). Augmented reality: principles and practice. Addison-Wesley Professional.

[83] A. Schweigkofler, G.P. Monizza, E. Domi, A. Popescu, J. Ratajczak, C. Marcher, M. Riedl, D. Matt, Development of a digital platform based on the integration of augmented reality and BIM for the management of information in construction processes, in: Product Lifecycle Management to Support Industry 4.0: 15th IFIP WG 5.1 International Conference, PLM 2018, Turin, Italy, July 2–4, 2018, Proceedings 15, Springer International Publishing, 2018, pp. 46–55.

[84] S.M.E. Sepasgozar, M. Ghobadi, S. Shirowzhan, D.J. Edwards, E. Delzendeh, Metrics development and modelling the mixed reality and digital twin adoption in the context of Industry 4.0, Eng. Constr. Archit. Manag. 28 (5) (2021) 1355–1376, https://doi.org/10.1108/ECAM-10-2020-0880.

[85] N.G. Seresht, A.R. Fayek, Dynamic Modeling of Multifactor Construction Productivity for Equipment-Intensive Activities, J. Constr. Eng. Manag. 144 (9) (2018) 04018091, https://doi.org/10.1061/(ASCE)CO.1943-7862.0001549.

[86] A. Settimi, J. Gamerro, Y. Weinand, Augmented-reality-assisted timber drilling with smart retrofitted tools, Autom. Constr. 139 (2022) 104272, https://doi.org/10.1016/j.autcon.2022.104272.

[87] N. Shamil George, Factors influencing labor productivity on construction sites : A state-of-the-art literature review and a survey [JOURNAL], Int. J. Product. Perform. Manag. 65 (3) (2016) 401–421, https://doi.org/10.1108/IJPPM-03-2015-0045.

[88] D.H. Shin, P.S. Dunston, Identification of application areas for Augmented Reality in industrial construction based on technology suitability, Autom. Constr. 17 (7) (2008) 882–894, https://doi.org/10.1016/j.autcon.2008.02.012.

[89] D.H. Shin, P.S. Dunston, Evaluation of Augmented Reality in steel column inspection, Autom. Constr. 18 (2) (2009) 118–129, https://doi.org/10.1016/j.autcon.2008.05.007.

[90] B. Shouman, A.A.E. Othman, M. Marzouk, Enhancing users involvement in architectural design using mobile augmented reality, Eng. Constr. Archit. Manag. (2021), https://doi.org/10.1108/ECAM-02-2021-0124.

[91] A. Sidani, F. Matoseiro Dinis, J. Duarte, L. Sanhudo, D. Calvetti, J. Santos Baptista, J. Poças Martins, A. Soeiro, Recent tools and techniques of BIM-Based

Augmented Reality: A systematic review, Journal of Building Engineering 42 (2021) 102500, https://doi.org/10.1016/j.jobe.2021.102500.

[92] D. Sims, New realities in aircraft design and manufacture, IEEE Comput. Graph. Appl. 14 (2) (1994) 91, https://doi.org/10.1109/38.267487.

[93] J. Song, J. Kook, Mapping Server Collaboration Architecture Design with OpenVSLAM for Mobile Devices, Appl. Sci. 12 (7) (2022) 3653. https://www.mdpi.com/2076-3417/12/7/3653.

[94] Svalestuen, F., Knotten, V., Lædre, O., Drevland, F., & Lohne, J. (2017). Using building information model (BIM) devices to improve information flow and collaboration on construction sites.

[95] J. Sweller, J.J.G. van Merrienboer, F.G.W.C. Paas, Cognitive Architecture and Instructional Design, Educ. Psychol. Rev. 10 (3) (1998) 251–296, https://doi.org/10.1023/A:1022193728205.

[96] R. Taranco, J.M. Arnau, A. González, A low-power hardware accelerator for ORB feature extraction in self-driving cars, in: 2021 IEEE 33rd International Symposium on Computer Architecture and High Performance Computing (SBAC-PAD), IEEE, 2021, pp. 11–21.

[97] P. Tavares, C.M. Costa, L. Rocha, P. Malaca, P. Costa, A.P. Moreira, A. Sousa, G. Veiga, Collaborative Welding System using BIM for Robotic Reprogramming and Spatial Augmented Reality, Autom. Constr. 106 (2019), https://doi.org/10.1016/j.autcon.2019.04.020.

[98] M. Thees, S. Kapp, M.P. Strzys, F. Beil, P. Lukowicz, J. Kuhn, Effects of augmented reality on learning and cognitive load in university physics laboratory courses, Comput. Hum. Behav. 108 (2020) 106316, https://doi.org/10.1016/j.chb.2020.106316.

[99] L.-T. Tsai, H.-L. Chi, T.-H. Wu, S.-C. Kang, AR-based automatic pipeline planning coordination for on-site mechanical, electrical and plumbing system conflict resolution, Autom. Constr. 141 (2022) 104400, https://doi.org/10.1016/j.autcon.2022.104400.

[100] M. Wallmyr, T.A. Sitompul, T. Holstein, R. Lindell, Evaluating mixed reality notifications to support excavator operator awareness, in: Human-Computer Interaction–INTERACT 2019: 17th IFIP TC 13 International Conference, Paphos, Cyprus, September 2–6, 2019, Proceedings, Part I 17, Springer International Publishing, 2019, pp. 743–762.

[101] D. Wang, X. Wang, B. Ren, J. Wang, T. Zeng, D. Kang, G. Wang, Vision-Based Productivity Analysis of Cable Crane Transportation Using Augmented Reality-Based Synthetic Image, J. Comput. Civ. Eng. 36 (1) (2022), https://doi.org/10.1061/(ASCE)CP.1943-5487.0000994.

[102] J. Wang, X. Fan, Y. Zhu, X. Yang, X. Yin, Cross-platform AR annotation for assembly-design communication in pipe outfitting, Int. J. Adv. Manuf. Technol. 121 (7) (2022) 4981–4998, https://doi.org/10.1007/s00170-022-09637-8.

[103] X. Wang, P.S. Dunston, Compatibility issues in Augmented Reality systems for AEC: An experimental prototype study, Autom. Constr. 15 (3) (2006) 314–326, https://doi.org/10.1016/j.autcon.2005.06.002.

[104] X. Wang, M.J. Kim, P.E.D. Love, S.-C. Kang, Augmented Reality in built environment: Classification and implications for future research, Autom. Constr. 32 (2013) 1–13, https://doi.org/10.1016/j.autcon.2012.11.021.

[105] Woetzel, J., Mischke, J., Barbosa, F., Ribeirinho, M. J., Sridhar, M., Parsons, M., Bertram, N., & Brown, S. (2017). *Reinventing Construction: A Route to Higher Productivity*. M. Company. https://www.mckinsey.com/business-functions/operations/our-insights/reinventing-construction-through-a-productivity-revolution.

[106] S. Wu, L. Hou, H. Chen, G. Zhang, Y. Zou, Q. Tushar, Cognitive ergonomics-based Augmented Reality application for construction performance, Autom. Constr. 149 (2023) 104802, https://doi.org/10.1016/j.autcon.2023.104802.

[107] S. Wu, L. Hou, G. Zhang, H. Chen, Real-time mixed reality-based visual warning for construction workforce safety, Automation in Construction 139 (2022) 104252, https://doi.org/10.1016/j.autcon.2022.104252.

[108] Y. Xiao, M. Watson, Guidance on conducting a systematic literature review, J. Plan. Educ. Res. 39 (1) (2019) 93–112.

[109] J. Xu, F. Moreu, A Review of Augmented Reality Applications in Civil Infrastructure During the 4th Industrial Revolution, Frontiers in Built Environment 7 (2021) 640732, https://doi.org/10.3389/fbuil.2021.640732.

[110] K.-C. Yeh, M.-H. Tsai, S.-C. Kang, On-Site Building Information Retrieval by Using Projection-Based Augmented Reality, J. Comput. Civ. Eng. 26 (3) (2012) 342–355, https://doi.org/10.1061/(asce)cp.1943-5487.0000156.

[111] Z. You, L. Feng, Integration of industry 4.0 related technologies in construction industry: a framework of cyber-physical system, Ieee Access 8 (2020) 122908–122922, https://doi.org/10.1109/ACCESS.2020.3007206.

[112] M. Zaher, D. Greenwood, M. Marzouk, Mobile augmented reality applications for construction projects, Construction Innovation-England 18 (2) (2018) 152–166, https://doi.org/10.1108/ci-02-2017-0013.

[113] J. Zhang, X. Xia, R. Liu, N. Li, Enhancing human indoor cognitive map development and wayfinding performance with immersive augmented reality-based navigation systems, Adv. Eng. Inf. 50 (2021) 101432, https://doi.org/10.1016/j.aei.2021.101432.

[114] X. Zhang, J. Yao, L. Dong, N. Ye, Research on 3D architectural scenes construction technology based on augmented reality, J. Comput. Methods Sci. Eng. 21 (2) (2021) 311–327, https://doi.org/10.3233/jcm-204390.

[115] Y. Zhou, H. Luo, Y. Yang, Implementation of augmented reality for segment displacement inspection during tunneling construction, Autom. Constr. 82 (2017) 112–121, https://doi.org/10.1016/j.autcon.2017.02.007.

[116] S. Zollmann, C. Hoppe, S. Kluckner, C. Poglitsch, H. Bischof, G. Reitmayr, Augmented reality for construction site monitoring and documentation, Proceedings of the IEEE 102 (2) (2014) 137–154, https://doi.org/10.1109/JPROC.2013.2294314.