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A Review of AR Applications in Construction Management: 2018-2022

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In the dynamic realm of Architecture, Engineering, and Construction (AEC) projects, technological advancements have played a pivotal role in enhancing efficiency, accuracy, and safety on construction sites. Augmented Reality (AR) has emerged as a transformative tool, revolutionizing how construction projects are planned, executed, and monitored. This paper presents a comprehensive review of AR applications in construction management from 2018 to 2022, offering insights into the evolution, impact, and potential of this innovative technology. This study encompasses various AR applications, including design, fabrication, safety, education and training, and construction and facility management. The development of AR hardware and software solutions was explored. Notable developments and their implications have also been highlighted for the construction industry. Furthermore, the challenges and barriers hindering the widespread adoption of AR in construction management were analyzed, such as cost considerations, technological limitations, and workforce readiness. This comprehensive review serves as a valuable resource for researchers, practitioners, and decision-makers seeking to navigate the transformative landscape of AR in construction management.

Key Words: Literature Review, Augmented Reality, Construction Management, AEC industry

Introduction

The construction industry, characterized by its complexity and dynamic nature, has historically been lacking at adopting innovative technologies to improve efficiency, safety, and productivity. However, the construction industry has witnessed a profound transformation with the introduction of Building Information Modeling (BIM). BIM stands out as a revolutionary approach to digitally managing design data throughout a project’s entire life cycle. This signifies a paradigm shift in information management within the industry (Volk et al., 2014). The construction industry has transitioned from conceptualization to actualization by embracing BIM for construction project management and creating data-rich models (Scheffer et al., 2019).

Over the past few years, the construction industry has witnessed a surge in interest and investment in Augmented Reality (AR) applications. This surge can be attributed to several factors, including the rapid development of AR hardware and software, increasing affordability, and a growing recognition of the value AR can bring to construction projects. As a result, the use of AR in construction management has transitioned from experimental pilot projects to mainstream adoption, with companies seeking to gain a competitive edge by leveraging this technology. AR has emerged as a transformative force within construction management, promising to redefine how projects are planned, executed, and monitored. With the aid of cutting-edge modeling software, engineers can craft AR models that are both parametric and object-oriented, and these models are also enriched with comprehensive data for both ongoing and future construction projects. AR is a central data repository accessible to designers, architects, service engineers, mechanical, electrical, and plumbing (MEP) contractors, operators, and facility management (FM) companies. This data hub can be utilized for constructing new buildings of various sizes and types, as well as for managing existing projects (Bianchini et al., 2017).

This review aims to comprehensively explore the evolution, impact, and potential of AR applications in construction management, spanning from 2018 to 2022. This review serves as a timely and comprehensive resource for researchers, practitioners, and decision-makers seeking to understand the transformative impact of AR in construction management. By examining the trends, opportunities, and challenges within this evolving field, a deeper understanding of the role of AR technology in shaping the future of construction management practices should be contributed.

Background

The construction industry is a cornerstone of economic development, urbanization, and infrastructure growth. Its pivotal role in shaping the modern world comes with inherent challenges, including tight project schedules, complex designs, evolving safety regulations, and the need for precise coordination among various stakeholders. In response to these challenges, the construction sector has continuously sought innovative solutions, and in recent years, AR has emerged as a promising technological frontier.

AR is a technology that superimposes digital information, such as 3D models, data, and visual cues, onto the physical environment, enhancing our perception of reality. AR facilitates the real-time exchange of information, enabling users to put digital information management into practical use and realize its value (Rahimian et al., 2020). The objective is to oversee the design, construction, and maintenance of a project throughout its entire life cycle. This endeavor encompasses a wide range of projects, including both new and existing ones, such as residential, commercial, industrial, heavy, infrastructure, and heritage construction (Saieg et al., 2018).

AR overlaps computer-generated content with the real world, enabling seamless real-time interaction with the environment (Li et al., 2018). Unlike traditional methods, AR eliminates the occlusion between computer-generated and real-world content. The AEC industry stands to benefit significantly from AR, particularly in applications where virtual and physical contexts overlap or interact within construction sites. Prominent Mixed Reality (MR) headsets, such as Microsoft HoloLens, Magic Leap One, and DAQRI Smart Glasses, dominate the current market. Alizadehsalehi et al. (2018) noted a rising trend in software vendors integrating with AR technology. For instance, Bentley Synchro provides a plugin for Revit, showcasing BIM elements in a 4D simulation with lean construction schedule inputs like P6. This plugin empowers users to review construction sequences using Microsoft HoloLens in specific task areas on the job site. Trimble XR10, combined with HoloLens 2, further integrates AR functionalities into safety helmets, enabling workers to inspect construction scenes on-site intuitively.

Researchers have proposed multiple strategies for leveraging AR in Architecture, Engineering, Construction, and Facility Management (AEC/FM) projects, offering numerous benefits for enhancing and advancing representation techniques on construction sites (Alizadeh et al., 2019). Rankohi and Waugh (2013) conducted a statistical analysis of recent AR research within the AEC field, pinpointing the keen interest of field workers and project managers (PM) in employing non-immersive and desktop standalone AR technologies during the construction phase. These technologies are primarily used for progress monitoring and defect detection. In a separate study, Pratima et al. (2020) created a comprehensive map delineating potential AR application areas in industrial construction. They identified eight work tasks, namely layout, excavation, positioning, inspection, coordination, supervision, commenting, and strategizing-as likely candidates for AR support. Sutcliffe et al. (2019) conducted a comprehensive overview of AR technology’s application in construction management.

However, forecasting the future of AR utilization in the AEC industry is challenging due to the rapidly evolving nature of technology, software, and devices. Cheng et al. (2020) have summarized the key challenges in AR, including spatial registration accuracy, user interface (UI), data storage and transfer, and multiuser collaboration. Nonetheless, the ongoing advancements in AR tools and software continually enhance performance, making AR more effective with each passing year.

In parallel with these developments, researchers and industry experts have been investigating the impact of AR on the AEC field, conducting case studies, and identifying best practices. This review will draw upon these studies and experiences to provide a comprehensive assessment of the state of AR in the AEC field, its current applications, as well as the challenges and opportunities that lie ahead. By examining the background and evolution of AR, this review is to provide valuable insights that will inform future developments and the continued integration of AR into AEC field practices.

Methodology

The methodology employed in this study adhered to the systematic literature review (SLR) procedures recommended and utilized by MacDonald (2014). Pertinent publications were identified from various sources and scientific databases, employing specific keywords, inclusion criteria, and exclusion criteria.

Collecting and synthesizing relevant data is crucial in conducting a comprehensive review of AR applications in construction management from 2018 to 2022. A systematic and linear approach to data collection is applied to ensure the accuracy and depth of the evaluation:

- Identifying Sources: Begin by identifying a range of sources that provide information on AR applications in construction management during the specified timeframe. Citations may include academic journals, conference proceedings, industry reports, white papers, and case studies.
- Keyword Search: Use relevant keywords and phrases to conduct searches on academic databases (e.g., ScienceDirect, ASCE Library), industry-specific platforms (e.g., Construction Dive, Engineering News-Record), and search engines (e.g., Google Scholar). Keywords may include “Augmented Reality in Construction,” “AR in Construction Management,” “Construction Industry AR Trends,” and similar terms.
- Database Searches: Conduct searches on academic databases using combinations of keywords and filters to identify peer-reviewed research articles, conference papers, and dissertations related to AR applications in construction management within the specified timeframe. Review existing literature on AR in construction management to identify seminal works, theoretical frameworks, and critical trends.

- Data Extraction: Organize the collected data systematically. Create a database or spreadsheet to record relevant information, including publication details, key findings, methodologies, and any quantitative or qualitative data related to AR applications in construction management.
- Data Validation: Ensure the credibility and reliability of the collected data by cross-referencing information from multiple sources. Verify statistics and facts through reputable sources and peer-reviewed research.
- Thematic Analysis: Collected data into thematic categories, such as AR use cases (e.g., design visualization, safety management), technological advancements, challenges, and future trends.
- Synthesis: Synthesize the collected data to provide a coherent narrative highlighting the evolution, impact, challenges, and potential of AR applications in construction management from 2018 to 2022.

Analysis of AR Applications in Construction Management

Overview

The literature examined in this review was sourced from a curated list of academic journals and conferences specializing in construction management from 2018 to 2022, as outlined in Table 1. In total, 37 pieces of literature underwent evaluation, comprising 18 journal papers and 20 conference papers. Remarkably, articles from Automation in Construction constituted approximately 28.9% of the literature reviewed.

Table 1
Journals and conferences selected for data collection of the literature

Journal Name	No. of Papers
Automation in Construction	11
Journal of Computing in Civil Engineering	4
Journal of Information Technology in Construction	3
Total Journal Papers	18
Conference Name	**No. of Papers**
ASCE Construction Research Congress	2
ASCE International Conference on Computing in Civil Engineering	4
Associated Schools of Construction Annual International Conference	3
International Conference on Construction Applications of Virtual Reality	10
Total Conference Papers	19

After identifying the different construction project activities and training involving AR integration, the benefits of using AR in construction projects are numerous. It can improve collaboration, planning, data, and 3D model visualization for more transparent communication among stakeholders and better coordination among all trades leading to better quality project outcomes. AR technology can also be a useful collaborative 3D tool and promises a different way to represent and interact with BIM data in the physical world. Figure 1 illustrates the number of publications studying AR in construction projects during the construction phase. Its multifaceted applications span design, fabrication, safety, education and training, and construction and facility management, bringing many benefits and innovations to the construction sector.

Design

AR technology, as exemplified by Microsoft HoloLens, has rapidly transformed the construction industry by enhancing the way construction site designs are conceptualized, planned, and executed. This innovative tool offers a range of applications in construction site design, revolutionizing traditional practices and streamlining processes. The integration of AR into construction site design not only optimizes efficiency but also enhances safety, collaboration, and decision-making.

Dan et al. (2021) initiated an on-site design application at a community park that demonstrated its main workflow and functionalities. The results proved that HoloDesigner could successfully render on-site 3D visualization and real-time interactions to control 3D models in the natural surrounding environment. Carrasco and Chen (2021) initiated an experiment in which participants were divided into two groups and analyzed an original architectural renovation design. The conclusion indicated mixed reality (MR) can enhance the client's comprehension of the aesthetic characteristics of materials, giving the possibility to replace physical samples during the finishing stage of construction. Mutis and Desai (2019) presented technical features for rapid customization for design. The approach builds an MR environment to create holographic visualizations from representations of designs generated from BIM and construction document data.

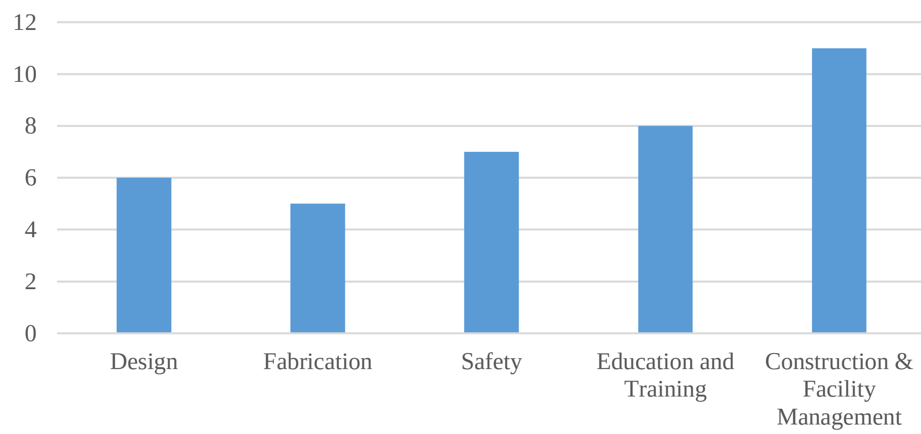

Figure 1. Number of publications in AR technology by construction phase

Fabrication

AR technology has emerged as a game-changing tool in construction site fabrication. It offers various applications that transform how materials are fabricated, assembled, and integrated into construction projects. AR enhances precision, efficiency, and collaboration, making it an indispensable asset in the fabrication phase of construction projects.

Chai et al. (2021) developed a mold-free approach for double-curved glulam production. The system will be further developed to be transferred to industrial practice. This approach could eliminate complex molds in curved glulam production, significantly reducing waste in the post-processing process. Settimi et al. (2022) outlined improvements in the proposed tool fabrication process and clarified the potential role of augmented carpentry in the digital fabrication landscape. Computer vision tools and sensors are used to implement an inside-out tracking technique for retrofitted drills based on a reverse engineering approach.

Safety

The construction industry is fraught with risks and challenges, and ensuring site safety is paramount.AR technology has emerged as a groundbreaking tool for enhancing safety in the construction field. It offers many applications that revolutionize how safety measures are implemented, monitored, and improved, making construction sites safer for workers and more efficient for project managers.

Wu et al. (2022) provided a new perspective for construction safety managers to analyze construction safety status. System tests were conducted under three quasi-on-site scenarios, and the feasibility was proven in terms of synchronizing construction activities over a large area and visually representing hazard information to its users. These evidenced merits of the development testing scenarios can improve workers' risk assessment accuracy and reinforce workers' safety behavior. Olorunfemi et al. (2018) evaluated the feasibility of applying emerging MR technology in ameliorating safety risk communication at construction job sites. A holographic application on Microsoft HoloLens to enable visual interaction and remote collaboration was developed.

Education and Training

The construction industry is dynamic and complex, requiring a highly skilled workforce. Education and training are vital to ensuring construction professionals are well-prepared for their roles. AR technology is making a significant impact on construction site education and training. It offers innovative applications that revolutionize how knowledge and skills are imparted to construction students and workers, creating a safer, more efficient, highly skilled workforce.

Song et al. (2021) reviewed and analyzed the development of AR technologies and highlighted new emerging fields in AR research and the future trends of AR function in architectural digital fabrication. AR is aimed to help unskilled laborers with holographic on-site previewing and instruction training experimental and practice-based studies in AR for an architectural digital copy. McCord et al. (2022) tasked student participants with virtually constructing a wood-framed wall through AR with Microsoft HoloLens. The findings contributed to the understanding of how AR may be leveraged in classrooms to provide learning experiences that yield similar outcomes to those offered in more resource-intensive physical construction site environments. Shore et al. (2022). Analyzed and compared the effectiveness of AR as a new tool to enhance current teaching methods. The results demonstrated that AR enables students to visualize buildings with greater speed, accuracy, and confidence than paper drawings during a mock.

Chalhoub et al. (2021) studied whether AR can enable untrained individuals to complete construction tasks by analyzing the whole investigation and comparing the different data to analyze the conclusion. The conclusion indicated that construction companies can leverage unable individuals to perform specific construction tasks with AR, enabling trained and experienced professionals to focus on more challenging tasks. Tayeh et al. (2021) evaluated how MR applications of integrated BIM-GIS can improve the online learning experience of construction management students. An experimental study was conducted to assess the effect of using AR on handheld devices and MR on head-mounted devices on their spatial-temporal reasoning and understanding skills. Ogunseiju et al. (2021) utilized the survey investigation and did the survey analysis. The study revealed a technical skill gap for deploying sensing technologies in the construction industry and a need to equip the future workforce with the required skills.

Construction and Facility Management

The construction and facility management industry is experiencing a significant transformation with the adoption of AR technology. AR is revolutionizing how construction projects are executed and how buildings and facilities are managed post-construction. This technology offers many applications that enhance efficiency, streamline processes, and improve management.

Baek et al. (2019) presented an AR system for facility management using an image-based indoor localization method that estimates the user's indoor position and orientation by comparing the user's perspective to BIM based on a deep learning computation. Tsai et al. (2022) developed an on-site pipeline inspection and automatic coordination approach using AR and a grid-based path-planning algorithm. The site practitioners can compare the newly added pipe layout plan with the existing pipelines and re-plan the pipe layout to obtain a solution without clashes.

Xu et al. (2022) discussed the necessity and workflow of utilizing two distinct scanning sensors, including a depth camera and light detection and ranging sensor (LiDAR), paired with a quadrupedal ground robot to obtain spatial data from an ample complex indoor space. A digital twin model was built in real-time with two SLAM methods and then consolidated with the geometric feature extraction methods of fast point feature histograms (FPFH) and fast global registration.

Kopsida and Brilakis (2020) implemented a system based on mobile devices that could potentially enhance the inspection process and reduce the required time by allowing the inspector to acquire progress data by simply walking around the site. The method was tested, and 95.2% accuracy, 96.5% precision, and 97.3% recall were achieved by using the optimum set of parameters. Abbas et al. (2020) compared the cognitive load (CL), task performance (TP), and situational awareness (SA) of users of two types of AR systems, i.e., head-mounted and handheld-against those of inspectors using traditional paper-based methods. The impact of the MAR system on rebar inspection tasks from cognitive and safety perspectives was also discussed. Chalhoub and Ayer (2019) evaluated the effect of AR devices by utilizing the investigation and comparing the different methods. The results suggested that the AR device can display content with a locational accuracy of five centimeters from intended design, equally distributed along the X-axis and Y-axis on the design plane.

Conclusion

AR technologies are emerging tools that have greatly impacted AEC projects. This study shows that AR technologies are being used in different project stages, such as the design phase of the project, the construction phase, and the FM phase. This study also revealed that research trends over the last few years have been driven by the release of increasingly sophisticated AR devices and frameworks. AR is often used with tablets and mobile devices for maintenance, quality control, and construction management activities. The applications of AR in construction design, learning, preventive, and safety activities have received a considerable amount of academic attention. Furthermore, BIM can be integrated with AR tools to visualize 3D models and their metadata for 3D, and 4D uses.

This research indicates that recent AR technologies and framework developments have significantly influenced research trends over the past five years. The application of AR in maintenance, quality control, and construction management activities, particularly on mobile devices, has become increasingly sophisticated. Academic focus on learning, preventive measures, and safety activities in AR has positively contributed to integrating national safety regulations. Integrating BIM with AR tools to visualize 3D models and their metadata for 3D BIM applications poses challenges. Once parametric data is incorporated into a virtual environment or augmented through its digital model, modifications become difficult due to the transformed file format. While commercial solutions offer streamlined workflows, they still present limitations as generic 3D applications that lack adaptability for scripting or training purposes in virtual and augmented environments. Current built-in tools in AR platforms continue to improve and new tools and functionalities are being added. Future research will aim at exploring the HoloLens's remote assistance/interactive collaboration functionality to test the advantages of user collaboration from different remote locations to manage as-built turnover quality.

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