37 Implementation of Augmented Reality Throughout the Lifecycle of Construction Projects

Fopefoluwa Bademosi and Raja R. A. Issa

Abstract

Over the years, information and communication technologies (ICT) have advanced significantly to where their applications in the construction industry have improved the efficiency of projects to a large extent. To continuously thrive in the information and technology-driven industry, it is imperative for construction companies to modify their mode of operations to embrace new technology, methods, and processes to influence the performance and efficiency of construction projects positively. Augmented Reality (AR) as a new and emerging technology generates several opportunities for enhancing traditional methods through the integration of AR technologies in the architecture, engineering, construction, and operations (AECO) industry. However, AR technologies are yet to become prevalent in the AECO industry. While AR has a great potential of impacting the construction process, there has been insufficient research on the identification of specific areas for the integration of AR in all phases of construction projects. The purpose of this paper is to offer construction professionals and researchers an account of the possible implementation of AR technologies in each stage of construction projects. The study provides construction professionals the latest research trends and developments in the application of AR, thus helping in the advancement towards significant implementation in the industry for the improvement of construction processes. The paper describes work performed in different construction stages and presents the potential benefits of AR implementation. Finally, recommendations for future research are discussed.

Keywords

Augmented reality (AR) • Construction • Project lifecycle • Productivity

37.1 Introduction

Over the years, information and communication technologies (ICT) have advanced significantly to where their applications in the construction industry have improved the efficiency of projects to a large extent. The advancement of technology has sparked a revolution in the construction industry regarding the way construction and engineering related tasks are being carried out [1]. To continuously thrive in the information and technology-driven industry, it is imperative for construction companies to modify their mode of operations to embrace new technology, methods, and processes to influence the performance and efficiency of construction projects positively. Augmented Reality (AR) is an evolving technology, and over time it has attained substantial significance in research and development in the AECO industry.

The paper begins by introducing AR as a concept, its definition, as well as its different systems and enabling technologies. In totality, this study aims to discuss the reality of AR, and its objective is to offer a review of the present applications of AR technologies in all the phases of construction projects and the associated potential benefits to implementing this technology.

F. Bademosi · R. R. A. Issa (✉)
Rinker School of Construction Management, University of Florida, Gainesville, FL, USA
e-mail: raymond-issa@ufl.edu

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The paper contributes to the level of understanding of AR, by highlighting its potentials and provides future recommendations regarding AR applications and the adoption of the technology.

37.2 Augmented Reality

37.2.1 Defining Augmented Reality

Over the years AR has been defined in different terms by several researchers. One of the most universally accepted definitions by Azuma [2] states that AR is technology that has three fundamental features:

(1) It combines both the real and the virtual contents in the real world
(2) It runs interactively in real time
(3) It is registered in three dimensions.

Primarily, AR is perceived as a medium between virtual reality and telepresence as it amplifies reality instead of substituting it [3, 4]. However, perhaps the most uncomplicated definition is that AR is the augmentation of the real world (reality) with information from the virtual world (virtuality) [1].

37.2.2 AR Systems and Enabling Technologies

AR systems combine the virtual and the real world, they are interactive in real time and synchronize three-dimensional items in the mixed reality. To combine virtual objects and real images, three central systems can be implemented to overlay virtual components on the real world environment [5–7].

1. GPS and Compass Based AR systems which use the built-in GPS and compass to determine the current position of the user and aligns the virtual objects accordingly. This system is mostly applicable for use on mobile phones and hand-held devices.
2. Marker Based AR systems utilize tracking methods for detecting fiducial markers that act as a fixed point of reference for the position or scale of the virtual object to be recognized in augmented view.
3. Marker-Less AR systems depend on the physical features of the real world to accomplish object tracking, which eliminates the need for fiducial markers.

The main hardware components required for performing AR applications and their functions include processing devices, displays, tracking and calibration systems [7, 8].

1. The processing device which is primarily a computer is used for creating virtual objects and accurately aligning them and the position of the user with the real environment. It is also used to run all other devices in the AR system.
2. Displays for observing the merged virtual and real environments can be classified into three categories; (a) head-mounted displays (HMD), which are mounted on the head of users, (b) hand-held displays (HHD), which acts as a window that shows the real objects with an AR overlay, such as a tablet or cell phone, and (c) spatial displays (SD), which project the desired virtual information directly on the physical objects to be augmented.
3. Tracking systems are required to log and verify the position and orientation of the user in the real environment, to ensure accurate alignment and registration of the virtual image to the physical object.

37.3 Review Methodology

To effectively present the applications of AR technologies in all the phases of construction projects and the associated potential benefits, as well as the challenges to implementing this technology, a content analysis-based review method was completed. Through this method, several publications were reviewed, from which outcomes were rationalized and integrated into this paper.

The content analysis-based review method was conducted in two phases to accomplish a focused and organized review in literature from the period 2008 to 2018. Phase 1 involved a comprehensive search of literature using the Google Scholar search engine. Numerous keywords such as AR, mixed reality, construction, lifecycle, and so on were included in the search with the aim of including a wide range of related disciplines. After completing phase 1, 215 related articles were identified from the journals listed below:

- Advances in Computer Science
- Advances in Engineering Software
- Automation in Construction
- IEEE Computer Graphics and Applications
- International Journal of Advanced Research in Computer Science
- International Journal of Architectural Computing
- International Journal of Virtual Reality
- Journal of Computing in Civil Engineering
- Journal of Construction Engineering and Management
- Journal of Information Technology in Construction
- Presence: Teleoperators and Virtual Environments
- Visualization in Engineering.

Phase 2 involved the process of screening out publications that were not relevant to this research through a brief review of the content of the articles. After the screening process, a total of 79 publications were selected for additional examination. Although this two-phase search does not provide a full representation of the publications deserving evaluation, it sufficiently provides a substantial amount of significant research, from which this study could infer conclusions and recommend areas for future research.

37.4 Augmented Reality Applications in the Project Lifecycle

Research on the applications for AR ranges across several fields of study, including the construction industry. Applications of this technology in the (AECO) industry spans over the entire lifecycle of construction projects, and they include as-planned to as-built progress monitoring, training, dynamic site visualization, construction defect detection and integrating with various building information modeling (BIM) workflows [9]. For the purposes of this paper, the lifecycle of a construction project is comprised of the conceptual planning, design and preconstruction, construction, operation and maintenance, and demolition phases [10–12].

37.4.1 AR and Conceptual Planning

A construction project usually begins with a conceptual idea visualized by the owner and its possibility of fruition is determined by the success of the conceptual planning phase. During this phase, a feasibility study is conducted to determine the projects needs and objectives. To conduct such a study as accurately as possible within an all-encompassing scope, all project stakeholders need to thoroughly understand the inherent limitations that affect the scope of the project. By overlaying a three-dimensional space with the conceptual model developed using Building Information Modeling (BIM) technology at full-scale, the project team can easily understand the parameters of the space so that they can speedily decide how to proceed with the project [13].

The application of AR technology in the conceptual planning phase can be applied to all sizes and complexities of projects, but most especially large-scale complex projects which require that the project need and objectives be communicated to a large number of people [14, 15]. Also, by integrating AR with other technologies like laser scanning and GIS technology, the project team can obtain more accurate and detailed information about the project, such as volume and location [13]. The accuracy of information in conceptual planning is essential as the detailed design drawings, cost estimating, scheduling, and cost control will emanate from the scope defined in this phase.

37.4.2 AR and Design and Preconstruction

During the design and preconstruction phase, project owners, important stakeholders and project team members need to be continually apprised on the status of the project, per the rate of recurrence and means of communication agreed on in the contract. One of the key factors to be considered when communicating ideas at the design stage is the ability of the project team to visualize the different components of the project as shown in the architects and engineers design. AR allows users to have the ability to view a proposed three-dimensional model in the actual environment [13]. Using data from BIM, the system can combine the three-dimensional architectural layout of a building with the GPS data of a specified location on the site. With the aid of enabling technologies, such as head-mounted displays (HMD) and mobile devices, an individual can visualize a three-dimensional concept of where components need to go relative to their current location on the site [15].

One of the emergent trends of AR technologies are platforms that enable a walkthrough of virtual buildings, as early on as the design phase through to construction completion [14]. With mobile augmented reality (MAR), the actual scale of the three-dimensional model can be conveyed in its proposed final location, which gives all project stakeholders an adequate interpretation of the scale of objects. This information can help support decision-making processes that enable costs savings on fabrication and materials of the building components in reality. Also, MAR applications that scale components to size are useful in clash detection and coordination, to discover any conflicts between the proposed design models and real-world elements [14].

37.4.3 AR and Construction

The construction phase is the implementation phase, where the plan for the construction project is set into motion, and the project tasks are performed practically on site. With construction sites being very dynamic, it requires mobility of the users, and technologies that provide access to information at any time and any place needed to be implemented, thereby warranting the use of mobile devices [5]. AR is a wide-ranging technology that provides mobile computing solutions that provide constant access to information and situate it in time, place and context to accommodate the constant change that occurs on construction sites [16].

One of the notable applications of AR during the construction phase is that it provides a visual aid to supervise the construction process and also to inspect the finished product [17, 18]. Also, coordination is one of the keys to a successful project. AR can be used for facilitating construction discussion through multiscreen environment [3] and for producing construction simulations that provide a visual representation of the current conditions of the project [17, 19]. AR offers visual aids for interpreting drawings and specifications and for communication on construction projects [17]. AR can be used for visualizing BIM on site, conceiving conflict detection during coordination and visualizing the construction sequence on site to improve the efficiency of site logistics [20, 21].

Other applications of AR during the construction phase include geo-locating BIM data on the construction site, task support for construction processes [20, 21], real-time field reporting [14], way-finding and site navigation [14], on-site building information retrieval by using projection-based augmented reality [22], construction safety [23], and construction site monitoring and documentation [24].

37.4.4 AR and Operation and Maintenance

During the operation and maintenance phase, the maintenance professionals need to grasp a significant amount of relevant information to promptly locate a maintenance point in a building. AR systems can enable maintenance workers to evade concealed features such as hidden infrastructure, electrical wiring, and structural elements as they complete maintenance tasks on buildings and outdoor environments [25].

AR can be used for locating and replacing building elements for maintenance purposes [20]. A combination of BIM and MAR devices can be used to provide virtual data and information about actual building components and systems to facility managers on their mobile devices [26]. AR can also be used to train professionals to complete complex repair and maintenance tasks on building systems [14].

37.5 Benefits of AR Implementation

The use of AR with a combination of other supporting technology, computer software, and hardware offers several intangible, qualitative and quantitative benefits that improve construction, engineering, and other related tasks. One of the factors that result in a successful construction project is completion on-time and within or even under budget. To effectively measure the benefits of AR implementation throughout the lifecycle of construction projects, it is important to categorize the potential benefits of AR under quantitative units such as schedule and cost savings [27]. Table 37.1 shows the potential benefits of AR and their quantitative units.

37.6 Challenges to AR Implementation

Regardless of the appeal of AR to researchers and industry professionals, AR technology is advancing, and it is not flawless. Some drawbacks need to be overcome before AR can be fully integrated into daily construction activities, as it gains widespread acceptance in the industry. A few of the challenges that need to be addressed include portability and suitability for outdoor use [32, 33], tracking and auto-calibration in an unprepared environment [1, 32, 33], accurate depth perception [33], overload of information [33], lack of support staff and available resources that aid ease of use [32], absence of integration standards that support integration [34], and social acceptance [32, 33].

37.7 Conclusions

Owing to the significant advancement of information and communication technologies, the application of AR technologies in construction to improve the efficiency of projects to a large extent is feasible. AR technologies have shown the potential to enhance productivity, improve coordination and collaboration, as well as the quality of work and safety of workers in every phase of the construction lifecycle. The paper reviews the present applications of AR in the all the phases of construction projects. However, despite the relevance of the technology described by researchers, it has not attained its maximum abilities in the construction industry.

This study aims to contribute to the level of understanding of AR by highlighting the application of areas of the technology throughout the construction lifecycle and illustrating that AR is a valuable investment for industry professionals. Nevertheless, the potential of every AR technology needs to be carefully considered before they can be efficiently integrated into the construction industry. The issue is not a question of whether AR is useful in enhancing construction-related tasks. Instead, the challenge is understanding how to implement this technology to exploit its full potentials competently.

Table 37.1 Benefits of AR implementation

Reduced complexity [5]	Time savings
Improved efficiency [5, 19, 28, 29]	
Improved decision-making [5, 28, 29]	
Reduction in the quantity of paper [21, 28, 29]	Cost savings
Improved quality by reducing rework and defects [30]	
Delivery of project on-time and on-budget [31]	
Reduced physical and mental workload for employees [19]	
Enhanced safety [5, 29]	

37.8 Recommendations for Future Study

This study reviews literature to document present applications of AR in the all the phases of construction projects. However, there were insufficient studies showing applications of AR during the deconstruction phase of the project lifecycle. Further study in this area could explore possible applications of AR in building deconstruction and material disposal. Possible future directions in this study could involve the development of an AR technology integration plan tailored to the construction industry.

Finally, there is a need to verify the quantitative and qualitative benefits and value of implementing AR technology in the construction industry, throughout the lifecycle of construction projects, through a controlled and structured evaluation process. With the data collected from closely monitoring the use of AR through-out the lifecycle of these projects, an accurate monetary value of the investment and operation costs of AR, as well as the dollar value of time and money savings amassed from implementing AR can be projected. The cost of capital and savings can then be used to establish the return of investment on AR.

References

1. Cleveland Jr., A.B.: Emerging tools to enable construction engineering. J. Constr. Eng. Manage. **137**(10), 836–842 (2010)
2. Azuma, R.T.: A survey of augmented reality. Presence: Teleoperators Virtual Environ. **6**(4), 355–385 (1997)
3. Lin, T.H., Liu, C.H., Tsai, M.H., Kang, S.C.: Using augmented reality in a multiscreen environment for construction discussion. J. Comput. Civil Eng. **29**(6), 04014088 (2014)
4. Milgram, P., Takemura, H., Utsumi, A., Kishino, F.: Augmented reality: a class of displays on the reality-virtuality continuum. In: Photonics for Industrial Applications. International Society for Optics and Photonics, pp. 282–292 (1995)
5. Izkara, J.L., Pérez, J., Basogain, X., Borro, D.: Mobile augmented reality, an advanced tool for the construction sector. In Proceedings of the 24th W78 Conference, Maribor, Slovenia, pp. 190–202 (2007)
6. Vyas, D.A., Bhatt, D.N.: Augmented reality (AR) applications: a survey on current trends, challenges, & future scope. Int. J. Adv. Res. Comput. Sci. **8**(5), 2724–2730 (2017)
7. Dini, G., Dalle Mura, M.: Application of augmented reality techniques in through-life engineering services. Procedia CIRP **38**, 14–23 (2015)
8. Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., MacIntyre, B.: Recent advances in augmented reality. Comput. Graph. Appl. IEEE **21**(6), 34–47 (2001)
9. Rankohi, S., Waugh, L.: Review and analysis of augmented reality literature for construction industry. Vis. Eng. **1**(1), 9 (2013)
10. Azhar, S.: Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry. Leadersh. Manage. Eng. **11**(3), 241–252 (2011)
11. Azhar, S., Khalfan, M., Maqsood, T.: Building information modelling (BIM): now and beyond. Constr. Econ. Build. **12**(4), 15–28 (2015)
12. Eadie, R., Browne, M., Odeyinka, H., McKeown, C., McNiff, S.: BIM implementation throughout the UK construction project lifecycle: an analysis. Autom. Constr. **36**, 145–151 (2013)
13. Ren, J., Liu, Y., Ruan, Z.: Architecture in an Age of Augmented Reality: Applications and Practices for Mobile Intelligence BIM-based AR in the Entire Lifecycle. DEStech Transactions on Computer Science and Engineering, (ICEITI) (2016)
14. Abboud, R.: Architecture in an Age of Augmented Reality: Opportunities and Obstacles for Mobile AR in Design, Construction, and Post-Completion (2014)
15. Broschart, D., Zeile, P., Streich, B.: Augmented reality as a communication tool in urban design processes. Proceedings REAL CORP, pp. 119–126 (2013)
16. Meža, S., Turk, Ž., Dolenc, M.: Measuring the potential of augmented reality in civil engineering. Adv. Eng. Softw. **90**, 1–10 (2015)
17. Dunston, P.S.: Evaluation of augmented reality in steel column inspection. Autom. Constr. **18**(2), 118–129 (2009)
18. Feiner, S.K., Webster, A.C., Krueger III, T.E., MacIntyre, B., Keller, E.J.: Architectural anatomy. Presence: Teleoperators Virtual Environ. **4** (3), 318–325 (1995)
19. Wang, X., Dunston, P.S.: User perspectives on mixed reality tabletop visualization for face-to-face collaborative design review. Autom. Constr. **17**(4), 399–412 (2008)
20. Danker, F., Jones, O.: Combining augmented reality and building information modelling—an industry perspective on applications and future directions. Educ. Res. Comput. Aided Architectural Des. Eur. **32**, 525–536 (2014)
21. Golparvar-Fard, M., Savarese, S., Peña-Mora, F.: Interactive Visual Construction Progress Monitoring with D4 AR—4D Augmented Reality —Models. In: Construction Research Congress 2009: Building a Sustainable Future, pp. 41–50 (2009)
22. Yeh, K.C., Tsai, M.H., Kang, S.C.: On-site building information retrieval by using projection-based augmented reality. J. Comput. Civil Eng. **26**(3), 342–355 (2012)
23. Li, X., Yi, W., Chi, H.L., Wang, X., Chan, A.P.: A critical review of virtual and augmented reality (VR/AR) applications in construction safety. Autom. Constr. **86**, 150–162 (2018)
24. Zollmann, S., Hoppe, C., Kluckner, S., Poglitsch, C., Bischof, H., Reitmayr, G.: Augmented reality for construction site monitoring and documentation. Proc. IEEE **102**(2), 137–154 (2014)
25. Gheisari M., Irizarry J.: Investigating human and technological requirements for successful implementation of a BIM-based mobile augmented reality environment in facility management practices. Facilities **34**(1/2) (2016)

26. Gheisari, M., Goodman, S., Schmidt, J., Williams, G., Irizarry, J.: Exploring BIM and mobile augmented reality use in facilities management. In: Proceedings of the Construction Research Congress, pp. 1941–1950 (2014)
27. Oesterreich, T., Teuteberg, F.: Evaluating augmented reality applications in construction–a cost-benefit assessment framework based on VoFI. In: Proceedings of the Twenty-Fifth European Conference on Information Systems (ECIS), Guimarães, Portugal, pp. 342–358 (2017)
28. Kamat, V.R., Martinez, J.C., Fischer, M., Golparvar-Fard, M., Peña-Mora, F., Savarese, S.: Research in visualization techniques for field construction. J. Constr. Eng. Manage. **137**(10), 853–862 (2010)
29. Wang, X., Love, P.E., Kim, M.J., Park, C.S., Sing, C.P., Hou, L.: A conceptual framework for integrating building information modeling with augmented reality. Autom. Constr. **34**, 37–44 (2013)
30. Forcada, N., Gangolells, M., Casals, M., Macarulla, M.: Factors affecting rework costs in construction. J. Constr. Eng. Manage. **143**(8), 04017032 (2017)
31. Wang, X.: Augmented reality in architecture and design: potentials and challenges for application. Int. J. Architectural Comput. **7**(2), 309–326 (2009)
32. Mekni, M., Lemieux, A.: Augmented reality: applications, challenges and future trends. In: Applied Computational Science—Proceedings of the 13th International Conference on Applied Computer and Applied Computational Science (ACACOS '14) Kuala Lumpur, Malaysia, pp. 23–25 (2014)
33. Van Krevelen, D.W.F., Poelman, R.: A survey of augmented reality technologies, applications and limitations. Int. J. Virtual Reality **9**(2), 1 (2010)
34. Sanna, A., Manuri, F.: A survey on applications of augmented reality. Adv. Comput. Sci.: Int. J. **5**(1), 18–27 (2016)