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Exploring the Current and Future States of Augmented Reality in the Construction Industry

Hala Nassereddine[1], Awad Hanna[1] and Dharmaraj Veeramani[1]

[1] University of Wisconsin-Madison, Wisconsin, USA
hala.nassereddine@hotmail.com

Abstract. In construction, adoption of advanced technologies has the potential to significantly improve the performance of projects. The construction industry has experienced a radical evolution as it entered the era of digital documentation and information exchange. Construction design began with drafting boards, then moved to Computer-Aided-Design, and finally to Building Information Modeling. At each stop along that journey, gains were made in information density and exchange. However, for all the progress made thus far, the paradox of designing the 3D in 2D space remains. As Industry 4.0 continues to evolve, it is imperative that construction firms seek, find, and adopt new technologies – both to remain competitive and to grow in the industry. Augmented reality (AR), a pillar of Industry 4.0, has the potential to transform the construction industry. This paper explores the current and potential future states of AR in construction. Might this technology gain momentum and take hold in construction, as it has done in other industries? To investigate this question, industry practitioners were surveyed. 128 responses were collected and analyzed to provide insight into the current and potential future states of AR in construction.

Keywords: Augmented Reality, Construction Industry, Current State, Future State.

1 Introduction

Industrial interest in Augmented Reality (AR) has increased in the past decade, across sectors including automotive, aerospace, marketing, gaming, and others [1]. Construction has begun to follow suit in this area, and there has been a significant increase in research published on the subject. Researchers, however, have tended to issue their own definitions of AR. Therefore, in the interest of streamlining this paper, the authors describe AR both as an information aggregator and a data publishing platform that allows the user to (1) passively view displayed information, (2) actively engage and interact with published content, and (3) collaborate with others in real time from remote locations. Numerous research efforts have been undertaken to explore AR use-cases and develop applications to integrate the technology in the construction industry. The majority of this research explored AR from the academic perspective and developed prototypes and proof-of-concepts to study and prove the potential impact of AR on construction. While these research endeavors are the cornerstone for investigating the potential of the technology, it is equally important to investigate the state of practice of AR from the perspective of the construction industry itself. For instance, [2] interviewed two general contractors and one software company and investigated the application of available construction AR technologies during the construction phase of a building project with a specific focus on as-built, quality assurance, and safety. Extant research such as the work of [2] does not, however, provide a comprehensive investigation of the current state of AR in construction from the perspective of different construction stakeholders. Therefore, using industry-driven data collected from 128 practitioners, this research will assess the current state of the practice of AR in the construction industry. This study will also provide insights into the potential future of AR in construction.

2 Literature Review

Ever since humanity started building structures, there have been accompanying methods for drawing, sketching, and planning these buildings. The two-dimensional (2D) drawings for architectural purposes have been traced back to Ancient Egypt and have evolved over the course of history to keep pace with the advancing complexity and ambition of the built environment [3]. However, the use of 2D drawings and instructions in a 3D world requires multiple translations – from the initial concept in the designer's head, onto paper, and then into reality. As such, numerous efforts have been made to improve the quality of design drawings. These efforts are motivated by the need to reconcile planned solutions with practical implementations, poor communication between project parties, and inefficient scheduling of construction activities [4]. Ref. [5] postulated that the need for teamwork, flexibility, coordination, and communication in construction gave the industry a great potential to integrate Information Technology (IT). Froese has divided the innovations in IT into three eras [6,7]. The first era is comprised of stand-alone tools that improve specific work tasks – Computer Aided Design (CAD), Structural Analysis, Estimating, Scheduling – which are all individual programs that each work on a single facet of the construction process. During the early 1980s, CAD became commonplace in architectural work and soon supplanted the drafting board as the most common method of producing drawings. Eventually CAD also supported 3D design, making it a more attractive and efficient option than hand-drafting [8,9]. The second era includes computer-supported communications (i.e. email, web-based messaging), and document management systems. The third era is where construction currently sits – reconciling the first two eras into a unified platform wherein project teams can collaborate to produce a virtual model of all aspects of the construction project. One of the limitations with the early iterations of CAD was that while it could represent geometric objects and show the relationship between them in space, it was lacking a precise understanding of how the relationship functioned. For example, it could be communicated that a beam is connected to a column, but the number, size and placement of the bolts to connect it would not be communicated [10]. More modern iterations of CAD have included this process, commonly known as Building Information Modeling (BIM). BIM has been widely hailed as a successful innovation in the construction industry [11], with numerous competing products available on the market today. However, even these types of advanced software still do not solve the problem that the project stakeholders faced – designing that which is 3D in a 2D environment. Thus, the industry must move beyond Froese's third era into a fourth era – the era of enhanced, or augmented, reality. Introducing Augmented Reality (AR) into existing BIM applications has immense transformative potential. It allows users to work on their 3D design in a 3D space that they can interact with as they would interact with the final product.

Augmented Reality (AR) originated in 1962 when Morton Heilig, a cinematographer, created a Sensorama, motorcycle simulator with visuals, sound, vibration, and smell. In 1966 Harvard Professor Ivan Sutherland invented the first Head-Mounted-Display (HMD), a device that allows the user to experience computer-fed graphics [12]. The term "Augmented Reality" was first coined by Caudell in 1990 and was defined as the technology that is used to "augment" the visual field of the user with information necessary to perform a task [13,14]. Unlike Virtual Reality (VR), AR amplified the real world with virtual (computer-generated) information instead of substituting it [15]. There are two definitions of AR commonly referred to in the body of literature. One definition was proposed by [16] who described AR from the perspective of the mixture between real and virtual environments. Ref. [17] created the "Reality-Virtuality (RV) Continuum" in which the "real" and "virtual" environments are two ends of the continuum. The second well-known definition of AR was put forward by Azuma who defined AR as any system that has the following three characteristics: 1) combines real and virtual objects, 2) is interactive in real-time, and 3) is registered in 3D [18]. Azuma later modified the third characteristic to only require the real and virtual objects to be registered with each other.
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3 Methodology

To better understand the current and potential future states of AR in the construction industry, a survey was developed and distributed to industry practitioners. The survey included qualitative and open-ended questions to allow respondents to elaborate on their AR experience and current practcies in the construction industry. The perspectives of the entire construction industry was needed for a holistic and comprehensive investigatin of AR in construtcion, and therefore, different stakeholderswere targeted. As the final stage of development, the survey was pilot tested by industry experts to allow for a comprehensive industry-driven assessment of AR in the construction industry. A total of 128 responses were collected from industry practitioners. Since the population dataset, i.e., the dataset that contains all stakeholders working within the construction industry, is not available, true values are not known and the variability in the sample dataset needs to be accounted for. Therefore, standard errors were used to represent variability in estimates of a parameter and to compute a 95% Confidence Interval (CI) that defines a range of values that contains the population parameter.

4 Analysis

4.1 Data Characteristics

A total of 128 responses were collected from industry practitioners, with the bulk of responses obtained from the United States. The survey included a question concerning the role performed by their firm: 36% of respondents reported that they work for General Contractors/Construtcion Managers (GC/CM), 27% work in the Mechanical/Electrical/Plumbing Trades (MEP Trades), 16% work for Owners, 12% work for Architect/Engineer firms (A/E), and the remaining 9% work for Owner's Representatives (OR).

To assess their level of expertise with AR on a professional level, respondents were asked to select their level of familiarity with the technology and their level of usage of the technology in the construction industry. The breakdown of the responses shows that the majority of respondents (84%) have some level of familiarity with AR in construction with 17% being extremly familiar with the concept of the technology, 27% moderately familiar, 16% somehow familiar, and 24% slightly familiar. The remaining 15% indicated that they are not familiar with AR. On the other hand, only 47% of respondents (i.e. 60 respondents) have had some level of experience interacting with the technology in construction – 15% have used AR on at least one construction project, 13% have tested or are testing AR applications for future use, and 19% have explored or are exploring potential AR applications.

In order to understand and investigate the current state of AR in construction, the 60 respondents who indicated that they have experience with the technology were asked to eleborate on their experience through a series of questions that we will be discussed in the following sections.

4.2 Current State of Augmented Reality in Construction

4.2.1 Augmented Reality Platforms

Out of the 47% of respondents (i.e. 60 respondents) who specified that they have had experience using AR in the construction industry (Explored/Exploring applications, Tested/Testing applications, and Used on at least one project), 65% indicated that they have used wearable technology to interact with AR and 62% specified that they have used mobile phones and tablets to interact with AR.

4.2.2 Augmented Reality Wearables

The 60 respondents who indicated that they have experience with AR in the construction industry were asked to select the AR wearable(s) that they have tried or used. The results showed that the HoloLens headset by Microsoft is the device that is most commonly used in construction with 68% of the "experienced" respondents reporting that they have used it for their AR application. Meta and Magic Leap were found to be the headsets that respondents are the least used in the construction industry.

4.2.3 Augmented Reality Wearables Concerns

Respondents who indicated that they have used AR warbles in construction were asked to identify any negative feedback they experienced from the use of the Head-Mounted-Display. Respondents reported that Safety Concerns (39%) was their most frequent deterrent from using AR wearable, followed by Discomfort (29%), Inaccuracy (29%), and Motion Sickness (27%). Headache was reported to be the least frequent concern (8%). In additions to these five concerns provided in the survey, some respondents specified other concerns including: narrow field of view and unclear vision when the device is used outside in the daylight.

4.2.4 Augmented Reality Phases

The potential of AR in the AEC industry has been explored by various researchers whose work has identified potential applications of AR throughout the life-cycle of a construction project. The life-cycle of a construction project consists of a series of phases and the literature review showed that there is no single definition for what the phases are [19,20]. The stages of the lifecycle adopted in this research are as follows: conceptual planning, design, pre-construction planning, construction, commissioning, operation and maintenance, and decommissioning. Respondents who had experience with AR in construction were asked to indicate the phase in which AR has been used.

The 60 respondents reported that they have employed AR in 5 phases of the lifecycle of a construction project. The majority specified that they have used AR during the construction phase (70%), design phase (67%), and pre-construction phase (60%). Few respondents have also used AR in the Operation and Maintenance (O&M) phase (12%), and commissioning phase (5%). None of the respondents reported any use of AR in either the planning or decommissioning phases. The breakdown of the respondents' experience with AR in each phase of the lifecycle of a construction project.

4.2.5 Augmented Reality Hands-on Experience

Respondents who indicated that they had hands-on experience using Augmented Reality were asked to elaborate on their experience and use of the technology. This section summarizes the input of the respondents by company type.

4.2.5.1 Architects/Engineers

Respondents who work for A/E reported that they have used AR to leverage 3D visualization and enhance the client experience when exploring the design of the facility. Using the HoloLens, the 3D BIM model of the project was project in a conference room and clients were able to walk around, visualize the project in real time and discuss the design with the A/E. In addition, clients were able to interact with the project content and turn on and off layers such as structural steel, MEP, facade, and design options. Another use-cases of AR is the creation of coordination models in the HoloLens for complex mechanical spaces so that the end users and facility managers can better understand the spaces that they will be expected to operate and raise their opinions about clearances and access requirements. Others reported the use of AR for planning purposes and engaging the client in the design process.

4.2.5.2 General Contractors/Construction Managers

The experience of GC/CM respondents were divided into in-house experience, and experience with other stakeholders such as designers, owners, and suppliers. Some respondents reported using Trimble Connect for HoloLens to improve Quality Control (QC) processes by allowing the user to compare the planned versus the installed systems. One particular case was the use of AR for quality control and inspection of pre- and post-concrete pours. Others used the HoloLens for filed layout and verification of the installation of the MEP systems on site and coordination with concrete penetrations. Another respondent reported that their company has used AR to visualize virtual mockup of a project. The use of AR to look at mockups provides a safe environment to review construction models, verify the design, and suggest and implement changes immediately. Another AR use-cases was the full-scale visualization of projects and overlays of planner systems onto the real structures. Respondents commented that AR fills in the gap between office (design work) and field (placing work) as it helps communicate the design and supports real time decisions that field personnel can make without having to go back to the office and look at a model. Another respondent described their use of the HoloLens to install in-wall blocking in the field while. A number of respondents indicated the use of AR for project proposal and presentations and pre-construction planning without expanding on the applications. Additionally, one respondent indicated that they have developed proof-of-concept applications for the HoloLens and have evaluated off the shelf applications for the last 3 years. However, the respondent did not provide further detail regarding their use of the technology. Moreover, GC/CM respondents reported using AR to review designs with A/E and walk the owner and users through their new space prior to building it. One respondent shared a story where AR allowed the client and A/E to notice that the doors were placed in the wrong spots. Finally, GC/CM have also worked with their suppliers and vendors to strategize how AR could be integrated into construction by listening to their needs. No details were provided regarding specific use-cases of AR.

4.2.5.3 MEP Trades

MEP respondents did not elaborate much on their use of the technology as the majority of their hand-on experience was at conference and during showcases, where they had the opportunity to demo the HoloLens and DAQRI for a few minutes. Although MEP respondents did not have any formal use of AR, they did indicate that the technology has a promising future in the construction industry.

4.2.5.4 Owners

Owners reported that they have mainly used AR to review designs and physically walk through their future projects, such as touring the planned expansion of a property.

4.2.5.5 Owner's Representatives

Owner's representatives indicated that they have used AR to gain owner buy in by allowing them to physically walk through the facility and to provide contractors with a better understanding of the projects.

4.3 Potential Future State of Augmented Reality

4.3.1 Use of Augmented Reality on Construction Projects

All 128 respondents were asked to select the types of projects on which they believe AR will be used in the future. The majority of respondents believe that AR will be used on Healthcare (92%), Industrial (88%), Institutions (72%), Commercial (72%), Renovation (67%), and Infrastructure (63%) projects and only 25% think that AR will be used in Residential.

4.3.2 Augmented Reality Adoption in Construction Companies vs Industry

Respondents were asked to identify the timeline of the common use of AR within their company and the construction industry as well. The timeline was evaluated on an ordinal five-point scale from: [0-5 years] coded as 1, [5-10 years] coded as 2, [10-15 years] coded as 3, [More than 15 years] coded as 4, and [Never] coded as 5. The results show that employees believe that the industry is slower to adopt AR while their organization is ahead of the curve than the construction industry as a whole.

The Mann-Whitney-Wilcoxon (MWW) test was conducted to statistically verify the difference in the AR adoption timeline at the company and industry levels. The low p-value resulted from of MWW test (0.037) provides a statistical evidence at the 95% confidence level indicating that, on average, construction companies are ahead of the curve than the construction industry as a whole.

5 Conclusions

This study explored the current state of AR in the construction industry, with a dual aim of cataloguing current trends in the industry and forecasting potential future applications. A total of 128 reponses were collected, 60 of which have indicated that they had interacted with the technology in the context of construtcion. Respondents who have had some experience exploring, testing, and using AR in the construction industry reported that they have predominantly used the HoloLens head-mounted display as their AR platform. The majority of those respondents have indicated that they have employed AR in the Construction, Design, Pre-Construction Planning, Operation and Maintenance, and Commissioning phases. Respodnents also elaborated on their experience with the tehcnology, showing that GC/CM had the most experience employing AR in most of the phases of a construtcion project lifecycle. The majority of respondents reported that they see AR being used on Healthcare and Industrial projects. Finally, respondents were asked to specify the timeline of their companies as well as the construction industry as a whole for using AR. The findings of this study contribute further knowledge to understanding the current and future potential of using AR in the construction industry. This research serves a shared-knowledge platform to exchange AR practcies and experiences among construction staekholders. Further research could be conducted to expand the sample size, include other types of companies, such as Facility Managers, and perform a more detailed analysis for each stakeholder.

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