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Augmented Reality Applications for Synchronized Communication in Construction: A Review of Challenges and Opportunities

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Abstract: Many researchers in the construction field have explored the utilization of augmented reality (AR) and its impact on the industry. Previous studies have shown potential uses for AR in the construction industry. However, a comprehensive critical review exploring the ways in which AR supports synchronized communication is still missing. This paper aims to fill this gap by examining trends identified in the literature and by analyzing both beneficial and challenging attributes. This work was performed by collecting numerous journal and conference papers, using keywords including "augmented reality", "construction", and "synchronous communication". The papers were then categorized based on the reported attributes that were indicated to be challenges or benefits. Throughout the analysis, several benefits were consistently reported, including training, visualization, instantly sharing information, decision making, and intuitive interaction. Similarly, several challenges were consistently reported, such as difficulty in manipulation, unfriendly interface, device discomfort, and sun brightness. Regarding other attributes, such as field of view, cost, safety hazards, and hands-free mode, researchers provided divergent reports regarding whether they were beneficial or detrimental to AR communication. These findings provide valuable guidance for future researchers and practitioners, enabling them to leverage AR for synchronized communication in ways that consistently offer value.

Keywords: augmented reality; communication; construction industry

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1. Introduction

The construction industry generates considerable economic activity and contributes to the growth of nations. The construction industry involves the coordination and the collaboration of a number of firms and organizations engaged in the process of building a facility. Despite the importance of this industry to the economy, it has historically been criticized for low productivity compared to other industries [1]. Some of these productivity issues relate to the large number of stakeholders involved in a construction project and the communication process among them [2]. A lack of innovation in the construction industry has been listed as one of the multiple reasons resulting in low productivity [3]. This shows the importance of implementing new technologies that ease collaboration of all parties involved through effective communication mechanisms.

Augmented reality (AR) is one of the emerging technologies that can be used in the construction industry, which involves overlaying virtual objects on the existing real environment so that it appears as if they are both present at the same time [4]. In the construction industry, AR has been explored in many fields including communication [5], visualization [6], inspection [7], and education [8]. Communication is a method of exchanging information in real time or with a time lag between two or more parties [9]. Asynchronous communication is a method of interaction that does not happen in real time [10].

To facilitate synchronized communication between an on-site user and an off-site user with AR, an online platform can be utilized (e.g., Microsoft Dynamics 365 Remote Assist). This approach enables individuals in remote locations to communicate with each other using AR. Off-site users can elect to use traditional computers to create and view AR annotations, while field users can elect to use head-mounted displays (e.g., Trimble XR 10 and Lynx R-1) or handheld devices for AR interaction [11]. Figure 1 represents a strategy for facilitating synchronous AR communication in order to illustrate the fundamental aspects of AR that support synchronous communication in the construction industry. This figure highlights how different types of users (top) may interact with different hardware (middle) through a common software (bottom) in order to support synchronous AR communication between on- and off-site individuals.

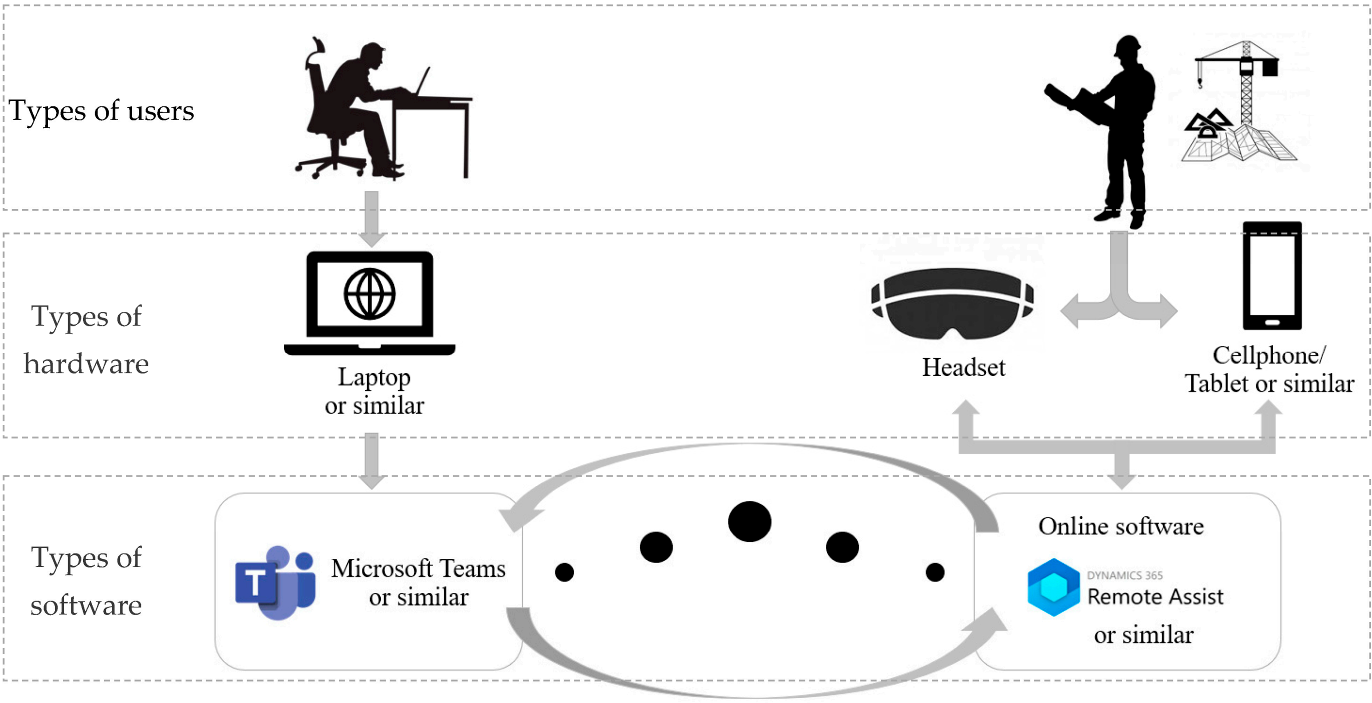

Figure 1. Off-site and on-site users' hardware and software.

While there have been numerous studies that have explored the trends of using AR for asynchronized communication [12–14], there is a noticeable gap in the literature regarding comprehensive reviews of trends specifically focusing on real-time communication (i.e., synchronized communication) across various contexts. Conducting such studies would greatly benefit practitioners by providing a deeper understanding of the advantages offered by AR for synchronized communication, the challenges encountered in its implementation, and the specific contexts where AR is most effective or needs to be approached with caution.

This study explores the literature on the topic of using AR for synchronized communication in order to answer the following two main questions:

(1) What attributes related to AR for synchronized communication are consistently reported by researchers to be either challenging or beneficial?
(2) For the attributes where researchers diverge in characterizing the benefits or drawbacks, what contextual elements within the papers differ in a manner that may contribute to the differing reports?

This paper aims to identify the contexts in which AR has been implemented for synchronized communication, while also examining the benefits and challenges reported by AR researchers in the industry. An understanding of this information is important and critical, especially since the application of AR in the construction industry is being constantly developed and different studies may show divergent trends. For example, some studies have mentioned challenges related to limited vision provided by the tools supporting AR, while others have disagreed and consider this challenge to be an opportunity to share a clear vision for the site. The results of this analysis of the literature will inform researchers to include or exclude contextual factors to gain or mitigate benefits or challenges when using AR for synchronized communication in the construction industry and will inform practitioners to mitigate the challenges that are consistently faced during the use of AR for synchronized communication.

2. Literature Review

Many researchers have reviewed the use of AR in the construction industry. These studies have explored the implementation of AR for specific uses, such as design review [6], exchange of information methods [15], construction inspections and monitoring applications [16,17], construction layout tasks [18], and construction activity visualization [19].

In order to understand the trends reported in previous studies among the different uses of AR, several studies have explored the state of knowledge around AR. For example, a critical review of academic publications that investigated how learning is different between AR and non-AR experience was conducted to provide a comprehensive understanding of how the medium of AR differs from other educational media [20]. Chi et al. (2013) discussed trends in AR applications for architecture, engineering, construction, and facility management (AEC/FM) by summarizing the results of 101 research efforts, and they outlined the research trends and opportunities for applying AR focusing on four technologies, i.e., localization, natural user interface (NUI), cloud computing, and mobile devices [21]. An AR literature study has also been conducted to provide a statistical review of the use of AR in the AEC industry offering construction practitioners and researchers an assessment of AR application including the purposes for which these technologies have been applied in different project phases from 1999 to 2012 [22]. In addition, El Asmar et al. (2021) investigated the most common limitations and benefits reported by construction-related research publications using current generation AR technology [12]. Moreover, a meta-analysis of AR challenges in the underground utility construction industry was conducted by Fenais et al. (2018) that aimed to make the construction industry aware of the benefits of leveraging AR to prevent utility strikes, while enhancing productivity [23]. In 2020, Fenais et al. conducted a systematic review of AR applications in the industry to better understand the state-of-the-art of this technology in the underground construction field, and to identify challenges and barriers [24].

While these studies delved into the implementation of AR in the industry and the reported patterns, their focus may not have necessarily been on real-time, synchronous usage of AR in the field. This emphasizes the importance of gaining a deeper understanding of the influential factors that specifically impact AR applications in the construction industry, particularly in the context of synchronized communication.

Given the novelty of AR and the practical implications from testing unproven technologies on site, it seems logical that the majority of studies would focus on lab-based environments to test various aspects of AR prior to practical implementation. However, after testing AR in a controlled environment, several studies expressed the importance of AR testing on uncontrolled live construction sites where user performance was affected by site conditions such as noise, labor congestion, and safety concerns [18]. Testing the application in a real environment helps to evaluate the flexibility of AR leading to real improvements in performance and productivity. Chalhoub and Ayer (2018) mentioned that the performance of the user was affected by site conditions [18]. Cote et al. (2014) stated that investigating the development factors of 3D perception using AR in a construction context would be more valuable [25]. Similarly, some studies have encouraged the need for future studies to be conducted on construction sites [21]. The high percentage of AR studies conducted in controlled environments highlights the need to build on the findings of these studies and to explore AR research in uncontrolled environments in the construction industry. This highlights the necessity of comprehending the various types of environments and contextual factors that can impact the implementation of AR for communication in the construction industry.

3. Methodology

This research presents a comprehensive review of numerous journals sand conference papers obtained from various sources. We applied a systematic review methodology for collecting and analyzing data from a number of research publications in the industry, following the processes described by Briner and Denyer (2012), and Denyer and Tranfield (2009) [26,27]. To conduct this systematic review, we structured the method into the following three distinct phases: criteria selection, search and filtering, data collection and classification [24]. The method employed is illustrated in Figure 2 and elaborated in the subsequent sections. The figure provides an overview of the process and highlights the criteria considered during the review.

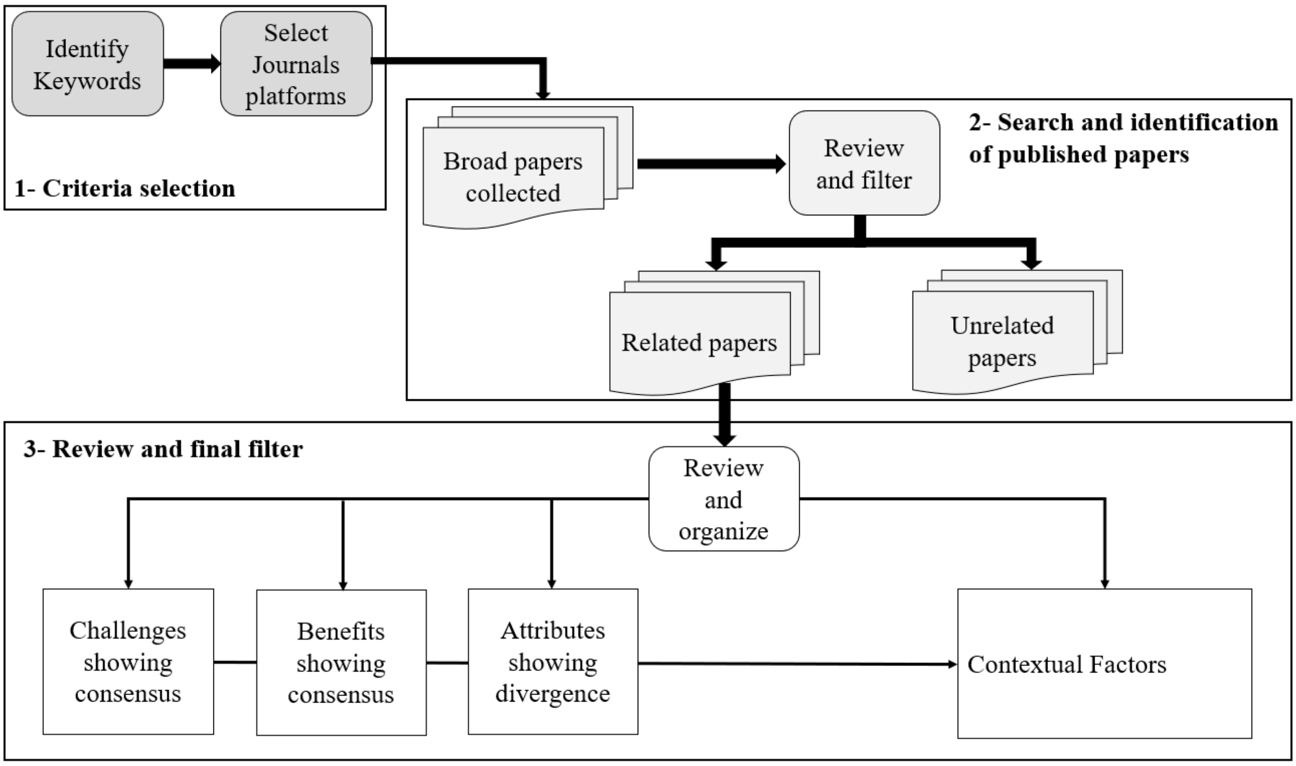

Figure 2. Research method.

3.1. Criteria Selection

As an initial step, we identified the following three keywords highly related to the topic: "augmented reality" representing the technology in use, "construction" representing the field where this technology is applied, and "communication". Limiting the research to these key words helped elicit the papers that were of interest to this study.

Next, we selected a number of journals and peer-reviewed conference proceedings related to the construction industry and augmented reality to ensure a large and comprehensive review. We targeted the following journals and conferences: Multidisciplinary Digital Publishing Institute (MDPI) Journal of Applied Science, Journal of Information Technology in Construction (ITcon), Journal Automation in Construction, Journal of Computing in Civil Engineering, Journal of Construction Engineering and Management, Journal of Management in Engineering, Journal of Computing and Information Science in Engineering, Visualization in Engineering, Advances in Civil Engineering, Advanced in Engineering Informatics, International Journal of Human–Computer Interaction, Organization Technology and Management in Construction, Journal of Infrastructures Systems, as well as proceeding from the Institute of Electrical and Electronics Engineers (IEEE) and the American Society of Civil Engineering (ASCE) Construction Research Congress (CRC). These journals and peer-reviewed conference proceedings are related to the construction industry and regularly include publications relevant to innovative construction strategies such AR.

3.2. Search and Identification of Published Papers

As a second step, we collected all the papers and conducted a more thorough review of each article to identify the studies directly relevant to synchronized communication. We carefully read the abstract, the objective, the methodology, and the conclusion sections of each paper to identify which studies were related to the main subject and which studies were not reporting on the use of AR for synchronous communication.

While reading these parts of the papers, we went through the cited references that had the same key words mentioned in the first phase. These cited references were reviewed using the same criteria as the papers initially identified using a keyword search. If papers pertained to the topic studied, they were included in the review. If they did not pertain to AR for synchronous communication, they were excluded. This process helped ensure that we identified relevant studies in the literature that may not have been identified in initial searches.

3.3. Review and Final Filter

As a third step, we categorized the papers based on the information that each paper offered. First, the papers were classified based on the type of environment in which the research was conducted, i.e., either in controlled environments (i.e., lab-based) or uncontrolled environments (i.e., construction site), based on the setting described in the paper. A controlled environment was defined as an enclosed space with precisely regulated environmental variables to meet operational needs; these variables could be temperature, light, pressure, and humidity [28]. Conversely, an uncontrolled environment was a representation of the "real word" where unpredictable outdoor conditions and variational environments were left as they affected any ongoing situation [29]. Then, the papers were classified by type of project, i.e., either horizontal, vertical, or academic research. Vertical projects include all construction structures that stretch vertically, for example, skyscrapers, towers, apartment buildings, office buildings, and other types of commercial buildings. Frequently referred to as heavy civil construction projects, horizontal projects are structures that stretch in length more than height, such as bridges, roads, highways, railroads, airfields, pipelines, and transit. Some academic studies did not relate to a specific construction project but included academic exploration through a survey, a questionnaire, university experiment, or AR implementation in lab-based environments.

The next classification of the papers focused on the documented challenges identified in relation to AR usage. We carefully recorded all the challenges mentioned throughout the papers and examined how frequently each challenge was cited by different sources. Similarly, the next classification examined the documented benefits of utilizing AR. Using a similar approach to the previous approach, we documented all the benefits identified in the 59 papers and analyzed the number of times each benefit was mentioned.

Once the deep review of each paper was completed, each paper was classified by type of environment and type of project. In addition, challenges and benefits reported in each paper were grouped in one table with the number of times each attribute (challenge or benefit) was mentioned. In some cases, when a challenge or a benefit was reported only once but never repeated a second time by any other paper, the attribute was removed from the table considering that there was no consensus from more than one paper. In other cases, divergence was noted when the same attribute was reported as a challenge in a paper and a benefit in another paper. In these cases, we went back to the paper referencing the attribute and tried to understand the context and the type of project in which AR was used, to try to understand the reason behind the divergence. Once all attributes were identified and those that were reported more than once were noted, the results showed patterns for which there was consensus or divergence in attributes reported in the research.

4. Results and Discussion

We initially identified 171 papers through the keyword search. After reviewing the papers to determine relevance to AR for synchronized communication, 59 papers were identified for analysis. Table 1 shows the organization of the final list of collected papers by journal and conference venue.

Table 1. Journals selected before and after the filter.

Journals	After Filtering
Automation in Construction	22
Journal of Applied Science	5
Journal of Computing in Civil Engineering	5
Journal of Information Technology in Construction (ITcon)	4
Visualization in Engineering	2
Advances in Civil Engineering	2
Advanced Engineering Informatics	2
International Journal of Human–Computer Interaction	2
Journal of Construction Engineering and Management	2
Journal of Management in Engineering	1
Journal of Computing and Information Science in Engineering	1
Organization, Technology and Management in Construction	1
Journal of Infrastructures System	1
Conferences	
Institute of Electrical and Electronics Engineers (IEEE)	7
Construction Research Congress (CRC)	2
TOTAL	59

After conducting a thorough review of the collected papers, the challenges and benefits associated with AR application in synchronized communication were extracted and classified, as summarized in Figure 3. While some attributes exhibited consensus across the papers, others displayed divergence. These discrepancies could be the results of contextual differences between projects or types of research projects. A number of challenges reported related directly to the type of device in use, AR application, and the environment surrounding the practitioner using AR. A total of twenty-four attributes were reported, with seven benefits and eleven challenges showing unanimous agreement among all the papers. However, six attributes demonstrated divergent findings within the existing literature.

4.1. Consensus on Challenges

4.1.1. Interface Manipulation

Interface manipulation is a challenge that was highly reported in the review of these papers and showed consensus among 13 papers. Not all devices supporting AR are manipulated virtually and require gesture control; only head-mounted displays (i.e., headsets) require virtual manipulation. Research has reported that this manipulation is not easy [30–32]. While implementing AR in a lab-based environment for multiscreen construction discussion, users reported that AR models (i.e., annotations and similar features) were hard to control [30]. In addition, when implementing AR in uncontrolled environments (i.e., live construction sites), the virtual interface manipulation of a head-mounted device was reported to be complicated and not easy, especially when physically moving [11].

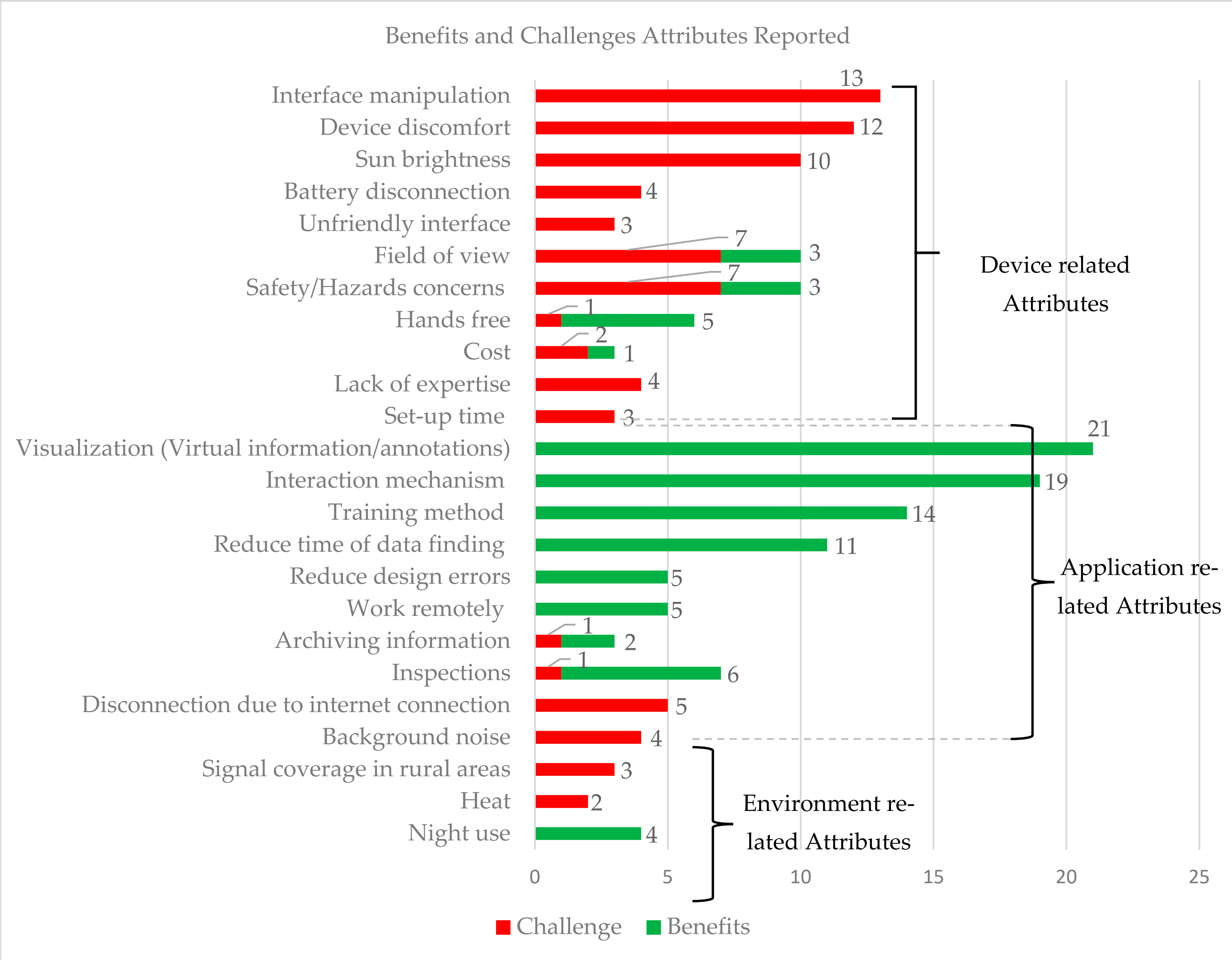

Figure 3. Number of attributes (i.e., benefits and challenges) showing consensus/divergence.

Although some papers mentioned that previous training provided to the users might ease the manipulation of the virtual interface and would provide a solution to overcome this challenge [33–35], studies still identified this attribute as a challenge, since most researchers were implementing AR with new practitioners who had no previous experience using virtual manipulation or had no extensive training. Therefore, this challenge is directly related to the type of device and software in use.

4.1.2. Device Discomfort

Most of the collected papers reported the use of AR through the implementation of software in a headset device such as "Trimble XR10" and also reported a challenge related to the weight of the device on the head of the user [19,33,34,36,37]. The weight is considered to be a considerable constraint of the device supporting the application, especially when using the device over a long period of time. Twelve papers reported the same attribute related to the device being uncomfortable which showed a consensus among them. Even though AR hardware and software are being consistently improved, the size of the hardware installed on the head is a challenge considering the incorporated hardhat needed to address safety and PPE requirements. Therefore, this challenge is related to the type of device in use.

4.1.3. Sun Brightness

Sun brightness was another challenge identified by ten papers. Implemented in a construction environment, users expressed concerns about the clarity of vision due to sun glare. In addition, even in controlled environments, researchers mentioned that the display platform of the AR virtual interface provided by head-mounted devices needed ambient to low lighting for the display to be more effective and that the use of an interactive hologram in outdoor environments could be challenging [29]. However, some studies introduced low-cost solutions using crafted tinted films mask, to be installed on the front visor of the device to mitigate the limitations during daylight [38]. Therefore, it seems that trials to overcome this challenge have been introduced and future research has the potential to address it. This challenge is related to the type of device in use since it is related only to head-mounted hardware supporting AR applications and may not be applicable to cellphones, tablets, and or similar hardware supporting AR applications.

4.1.4. Battery Disconnection

Disconnection of hardware physical components such as the battery was identified as a challenge by four papers. This challenge was mentioned considering the use of the application independent of site context and project type. Researchers mentioned that adapting to some requirements before the use of the devices (e.g., by making sure that the device is fully charged) could help overcome this challenge [11]. Others suggested the use of power banks during AR application to ensure battery charging [36]. This challenge is related to the type of hardware's battery, which may have implications for all types of AR devices (i.e., head-mounted displays, cell phones, and tablets).

4.1.5. Unfriendly Interface

The use of head-mounted displays was reported to be unfriendly, and practitioners were unfamiliar with these types of interfaces. Three papers mentioned that the interface could be more user friendly or customizable according to the user's needs [19,30,36]. In a lab setting, students suggested that the user interface for the data-finding tasks offered by the virtual manipulation of a head-mounted device was not user friendly. Similar to a construction environment, users reported that the same interface could be more friendly, or custom-made for specific users. This interface is offered only when using a head-mounted device; AR applications supported by mobile hardware are different. The interface on mobile or pad devices is offered through the screen and manipulation through finger touch movements. Therefore, some studies reported that, with training and practice, users could become more familiar with the gesture interface offered by the head-mounted device which helped in overcoming this challenge [34,35]. This attribute is related to the type of device in use supporting the application.

4.1.6. Lack of Experience

Lack of experience was a challenge related to AR application that was identified by four papers. As mentioned earlier, AR highly depends on virtual manipulation. Researchers have reported that this manipulation in addition to the interface constitutes challenges, thus practice and experience is needed. Independent of any contextual factor, this challenge is related to the practitioners using AR, their use cases, and how much they are exposed to the technology. Recommendations were provided in some studies suggesting training sessions and practice to overcome this challenge.

4.1.7. Set-Up Time

Set-up time was reported to be a challenge related to the application as well as how much time is needed to set up the hardware, power it on, run the software, and use the application the way it is intended to be used. AR applications require previous preparation. For example, 3D models need to be previously drawn using other software in order to be incorporated during a visualization application. Therefore, this challenge is related to the development of the application. Users need guidelines and instructions to guide them on what to prepare and how to set up and use this application, so they become more familiar with the software and the hardware (head-mounted displays, cellphones, and tablets) and ease its implementation.

4.1.8. Environment Related Challenges

AR implementation highly depends on an internet connection. Signal coverage in rural areas is a challenge that is crucial for the AR application, and without it, no synchronized communication between stakeholders can occur [35,39]. Other weather and environmental issues have been reported to affect the use of AR, for example, noise and heat. Although these challenges seem to have been encountered in real time during one uncontrolled environment study, they were, in fact, also mentioned in other papers.

4.2. Consensus on Benefits

There were a number of challenges for AR implementation that were consistently reported among the identified papers, but there were also several beneficial attributes that demonstrated the effectiveness of AR in construction research for communication. These reports showed the potential of AR and the opportunities that AR supports in the industry. The following sections review the seven main benefits for which there is consensus in the literature about AR.

4.2.1. Visualization

Seventeen papers agreed that the use of AR application for communication enabled the visualization of information and site activities. This visualization can be achieved through various devices such as head-mounted displays, cellphones, or tablets that support AR applications. Within an uncontrolled environment, Lin et al. (2019) mentioned that AR provided better visualization results which allowed the users to interact with reality more intuitively [40]. In addition, visualization of the site helps in understanding and preventing design issues and monitoring construction activities [41]. This shows the advantage of AR for exchanging information in real time to provide the experience of site visits and in-person meetings in addition to the verbal conversion and discussion needed on site. Therefore, this benefit is related to the AR application, independent of the type of environment and type of project.

4.2.2. Interaction Mechanism

Nineteen papers mentioned that AR application is an interaction mechanism between different parties. Within a construction environment, on-site users can communicate with off-site users allowing for a natural flow of information [11,30]. It has also been mentioned that this interaction mechanism can be conducted with multiple people at the same time allowing for better collaboration [42]. In addition, mobile AR and head-mounted AR create a context-immersive space that facilitates social interactions among users, construction places, and objects, and provide multi-user-based contents in the linked structure [42]. Therefore, the papers suggest that there is consensus about the beneficial aspect of AR being an interaction tool that allows for a visual experience between users to communicate verbal and contextual information of the site, allowing for collaborative decision making.

4.2.3. Training Method

Fourteen papers agreed that AR application helped in training personnel and referred to AR as a learning and educational tool. Hou et al. (2013) mentioned that using AR for communication helped to improve the learning curve of trainees significantly, and fewer errors were made on site [42]. In addition, AR eased the transferability of knowledge between the participants in the learning activities [43]. Regardless of the type of device in use (i.e., head-mounted displays, cellphones, or tablets), the type of environment, or the type of project an application is being implemented in, this benefit does not depend on other contextual factors, based on the literature. This highlights the importance of AR in sharing information and expanding knowledge through communication in the industry, especially, since all the identified papers agreed on this topic.

4.2.4. Reduce Time of Data Finding

Reducing time of data finding was a benefit reported with consensus by 11 papers. This data finding ability that AR offers reduces wasted time and enhances the flow of information [30,44]. Finding building elements without looking at maps or complex 3D models is considered to be time saving [45]. In addition, Kim et al. (2013) stated that AR had a positive impact on site monitoring, task management, and real-time information sharing [44]. AR improves the performance of existing on-site management processes and gives direct access to project information databases resulting in finding the location of construction resources on site without any time-consuming effort. Therefore, AR application offers the benefits of quick access to soft data and reduces the time for data searching regardless of the type of device in use. Having a consensus between a number of papers on this benefit highlights the potential of AR during communication use cases for inspections and sharing of information.

4.2.5. Reduce Design Errors

Five papers reported that AR application for communication helped to reduce design errors. Within the construction context, AR applications have been developed to combine virtual object information with real elements. This visualization of construction information results in better coordination and an easier understanding among project stakeholders. Kim et al. (2013) stated that using AR visualization was expected to help reduce design and construction errors in advance and to reduce the time taken to select an optimized construction method and structure element [44]. Reducing design errors prior to the start of construction helps save cost and change orders to resolve those errors. In addition, the time needed to answer requests for information (RFIs) during the construction process is expected to be reduced when using AR to find design errors. AR for communication using visualization is a benefit that demonstrated a consensus among many papers.

4.2.6. Work Remotely

Working remotely without spending time traveling to the site is another advantage of AR application. Five research papers reported that AR allowed site quality managers and trade managers to inspect construction works from the office without visiting the site [35,36,46–48]. This highlights the importance of communication supported by AR in the construction industry. Whatever the contexts of the users or the type of project in which the study has been conducted, researchers showed consensus about these benefits reported during the use of AR for communication.

4.2.7. Night Use

AR application for communication purposes is not only used during daylight; four reports mentioned that AR could be used during dark hours [11,30]. This attribute is related to the surroundings of the practitioner. Therefore, this benefit is related to the environment of the user. The consensus shown among the papers and the low number of papers (four) reflecting this consensus is arguably a product of the small number of studies conducted in uncontrolled environments during dark hours using both head-mounted displays and handheld mobile devices.

4.3. Divergence of Attributes

While the previous findings show consensus among the papers, we also collected attributes for which there were differences in findings among papers. In this section, we describe attributes that were viewed as beneficial attributes in some papers, while in other papers they were identified as a challenge.

4.3.1. Field of View

The field of view provided by the frame of the visor of a head-mounted device and the resolution of the shared picture were challenges reported in the literature by six studies [18,31,32,34,36,49]. These six studies were conducted in lab-based environments. Conversely, two other studies that reported positive results were conducted in different contexts. El Kassis et al. (2022) and El Ammari and Hammad (2019) both reported positive results related to the field of view. El Kassis et al. (2022) stated that based on the perception of on-site and off-site users, the shared vision of the site through the use of Trimble XR10 (version of HoloLens-2 incorporated in a hard hat) was clear and that the device had the ability to share exactly what the on-site user is viewing and looking at [35].

It is noteworthy to mention that reviewing 59 papers as part of this analysis of the literature, the authors found that 72% of the studies were conducted in controlled environments, whereas only 28% were conducted in uncontrolled environments. El Kassis et al. (2022) implemented AR in live construction sites and Ammari and Hammad (2019) developed AR applications in controlled environments but then applied them in a real environment [35,45]. While the field of view seems to be related intuitively to the type of device in use (i.e., mobile vs. head-mount device), in the case of communication, this attribute was also related to the type of environment in which a study was conducted. Within the construction context, the purpose of using AR and the field of view that needs to be shared is wider than when using AR in controlled environments where the vision can focus on a defined object or area. This divergence indicates that the vision transferred by the device during an AR application is highly affected by the surrounding of the users performing the call and the goals of using AR for the project at hand.

4.3.2. Safety/Hazards Concerns

Seven papers reported safety concerns when implementing AR on construction sites [30,36,45,46,49,50]. Although some of these papers recommended training to overcome this challenge [48], other papers showed variance and considered that no safety/hazardous issues were faced during AR application for synchronized communication on site [10,51]. Reviewing the context and the type of project during which each paper recorded these findings, only one paper among the seven papers that reported that safety was a challenge, was conducted in a real environment [45]. This study implemented AR in a real environment to facilitate the communication of site issues related to thermostats, showing no movement for the user during the application. Moreover, regarding the two studies that considered that no safety issues were faced during AR application, one study was conducted in an uncontrolled environment [10], while the second study was conducted in a controlled environment [51]. The only difference between these papers was the type of project studied; one paper studied AR in a vertical project (i.e., a 10-story building) [51] whereas the second paper studied AR in horizontal road infrastructure work [10]. This indicates that safety issues affecting the use of AR devices could be related to the type of projects and the movement of the practitioner while using AR.

4.3.3. Hands-Free Mode

Hands-free mode is another attribute that showed divergence among papers. Having one's hands free during an AR call is a benefit mentioned by five papers [13,31,32,35,38]; these papers implemented AR for communication in different environments (both controlled and uncontrolled) and for different types of projects or applications (i.e., infrastructure and academic research). Conversely, Ammari and Hammad (2019) stated that AR modules could not be used in hands-free mode [45]. The literature provides a variation in the results. The five papers that reported a benefit used head-mounted devices supporting AR, whereas Ammari and Hammad (2019) used a tablet [45]. Therefore, and to no surprise here, there is a consensus among the papers that the type of the device in use (head-mounted versus tablet) is related to considering this item a benefit or a challenge, supporting the premise of this literature analysis paper in which we are analyzing the findings of various studies around this same topic and identifying the contexts in which these findings are made.

4.3.4. Cost

Two studies agreed that the cost of the equipment and overall implementation cost of AR in the construction industry pose a challenge [36,37]; however, Kim et al. (2013) reported an opposite finding [44]. Upon comparing these three papers, we found that the type of devices used by Kim et al. (2013) was a head-mounted AR device (example, HoloLens-2), whereas the other papers used an AR module embedded in a smartphone. It is not surprising that the cost of using an existing smartphone is relatively not as much of a challenge compared to other types of devices, also considering that a smartphone would already be available with most personnel working on site. This indicates that "cost" is another attribute that is directly related to the type of device in use.

4.3.5. Archiving Information

Two papers identified the ability to archive information after AR calls and that archiving the information exchanged was a benefit related to the application [38,52]. However, Delgadoa et al. (2020) mentioned that archiving the outcomes of an AR call was difficult [36]. The reports were different and showed a variation in the outcomes. When examining the differences among these papers, we noticed that these three papers were conducted in different contexts. First, the study by El Kassis et al. (2022) was conducted in an uncontrolled environment, while the other two studies were conducted in controlled environments [38]. Second, the information reported in the study by Patil et al. (2020) were based on a finding reported by a different research study and not explored by the study itself [52]. Third, the findings by Delgadoa et al. (2020) were reported based on a series of exploratory workshops and questionnaires [36]. This might be the result of simply not being able to explore the application to its maximum since users were novice and not familiar with the application. Therefore, the ability to archive information without facing difficulties needs experienced practitioners and could be the subject of future research.

4.3.6. Inspections

Conducting inspections is a critical activity in the construction of any project. It typically involves significant time spent on traveling to the site, accessing relevant information, and sometimes consulting with other experts [53]. The ability to conduct inspections using AR for communication might ease the challenges related to the inspector or engineer's physical presence. Several papers mentioned that AR application could facilitate inspections [10,17,35,45,47,54]. However, Harikrishnan et al. (2021) mentioned that not all types of inspections could be conducted using AR, specifying that complex and in-depth inspections still needed a physical presence on site [46]. By reviewing the context of each paper, we noticed that in-depth inspections were mentioned as a challenge only when interviewing experts through a questionnaire [46], whereas the remaining papers that mentioned using AR to conduct inspections was a benefit were conducted in uncontrolled environments [10,17,35,45,47,54–56] where practitioners used AR on site [57]. Although exploring the perceptions of future users is important, this does not mean that their insights are 100% true and might not change while implementing the application [58,59]. This indicates that conducting inspections using AR is independent of the contexts in which the user exists in.

5. Limitations

This study provides valuable insights into the observed trends in reports about AR in the construction industry. However, it is important to acknowledge the inherent limitations of this work. One limitation arises from the focus on the technological development of AR over a 10-year period, specifically examining papers published during this time that address AR for communication in construction tasks. Such limitations are expected when exploring emerging technologies that are still in their early stages of adoption. Additionally, it is important to consider that other domains may have reported diverse benefits and challenges associated with AR performance, extending beyond a simple examination of advantages and limitations. It is also worth noting that attributes mentioned 10 years ago may have since been resolved, which would make them no longer relevant to the use of modern AR technology. While reports from other fields could potentially validate or raise questions about the findings of this construction-centered study, they were intentionally excluded due to the defined scope of the paper. Therefore, while the observed trends in this study may not encompass all possible viewpoints, they effectively illustrate the general trends found within the published research on the construction industry. These trends can serve as a valuable foundation for guiding future studies and providing them with evidence derived from recent AR works in the construction domain.

6. Conclusions

This paper provides a systematic analysis of the literature on the use of augmented reality (AR) for synchronized communication in the construction industry. It identified and analyzed trends related to the type of environment as well as the type of project that the studies were conducted in, and also identified challenges and benefits reported while implementing this technology. We identified eleven challenges, seven benefits, and six additional attributes that could be either a benefit or a challenge depending on the context. Several contextual attributes related to how AR was implemented were identified, related to the type of environment in which each study was conducted, the type of project, the activity of the practitioner, the type of the device in use, the year in which the study was completed which reflected the development of the application, and the experience of the user. Future AR developers and researchers should build on the identified benefits, challenges, and contextual factors to strategically incorporate or avoid certain settings during AR implementation and to maximize the beneficial aspects of AR that have been reported in the literature.

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