IMPACT OF AUGMENTED REALITY ON THE METHODS, PROFESSIONALS, AND OVERALL FIELD OF CONSTRUCTION

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

For the past decade, Augmented Reality (AR) has become increasingly popular, especially in the gaming, entertainment, and marketing industries (Javornik, 2016). Other industries such as healthcare, military, tourism, sports, and real estate/interior design have been quick to adopt AR technologies to improve the way they do work and interact with their customers (Poetker, 2023). One industry that has been slow to adopt these technologies is the construction industry. However, in recent years, AR technologies are becoming more prevalent in the construction industry as their potential to improve safety, efficiency, and communication is being discovered by the construction professionals who are using the technologies. Additionally, AR creators are beginning to understand how big the market for AR in construction is, so they are taking advantage of the market to develop new technologies specifically for construction.

Augmented Reality is "an interactive experience that enhances the real world with computer-generated perceptual information," meaning AR "overlays digital content onto real-life environments and objects" (SAP, n.d.). Considering this technology combines the real world and virtual world, it will impact how humans interact with and think about the physical world and subsequently shape the methods and professionals of the construction industry. AR is in the future of the construction industry, whether we like it or not. Therefore, the goal of my sociotechnical research is to understand how this technology will change the methods, professionals, and overall field of construction. Considering safety, efficiency, and communication as three main areas of improvement for the construction industry, AR technologies will be an important tool for helping these areas reach their potential.

Background and Significance

The first AR technology was a head mounted display system developed in 1968, but AR didn't start to gain traction until the late 90's with its use in NASA flight training and the yellow first down line on NFL broadcasts (Poetker, 2023). Even with these great strides and more in the early 2000's, AR didn't become commercially available to anyone to use until around 2010 when magazines used it to make the pages more interactive with their readers (Poetker, 2023). While the marketing industry was one of the first industries to recognize the value and possibilities of AR, the entertainment industry put it on the map and made everyday people interested in it and aware of what it can do. From Pokemon Go, Snapchat filters, and now the Apple Vision Pro, AR technologies have made significant strides in their complexity and popularity. But one industry that is just now recognizing the power of AR technologies is the construction industry, with its level of digitization index being the lowest of 22 industries (Davila, 2020). The construction industry needs to catch up and it is a good time for the industry to be investing in AR technologies because "the Global Augmented Reality (AR) Market size was valued at USD 31.97 billion in 2022 and is projected to reach USD 88.4 billion by 2026" (Markets and Markets, 2021). That is, the market for AR technologies is already lucrative and projected to keep growing.

In recent years, some AR technologies are beginning to be adopted into the industry, and they are yielding good results in terms of improving safety, efficiency, and communication. These positive results are allowing AR to gain even more traction in the construction industry, as shown by Noghabaei et al.'s (2020) series of surveys that show industry experts foreseeing "strong growth in the use of AR/VR technologies over the next 5 to 10 years" in addition to the results showing a "significant increase in AR/VR utilization in the AEC industry

over the past year and potential opportunities." Improvement in safety, communication, and efficiency are three important areas of construction where AR could make a big impact on the industry, especially considering the interconnectedness of these aspects of construction: "One key factor that significantly impacts both productivity and safety is effective communication. By facilitating clear and efficient information exchange among all stakeholders, communication plays a vital role in enhancing productivity and ensuring safety in construction projects" (First Compliance, 2023). Due to AR's infancy in the construction industry, many of its impacts are still unknown, so I want to understand how AR can improve these crucial areas of construction and, in turn, how it can change the methods, professionals, and overall field of construction.

Methodology

I will use the Actor Network Theory (ANT) to help me understand my sociotechnical topic of how AR will impact the methods and professionals of the construction industry. ANT says that "an actor is a patterned network of heterogeneous relations, or an effect produced by such a network" (Law, 1992). This means that these human and nonhuman actors, such as machines and organizations, form networks of which technology becomes a product. Additionally, ANT argues that "we wouldn't have a society at all if it weren't for the heterogeneity of the networks", so these relationships and networks between the human and nonhuman actors actively shape and are shaped by technology (Law, 1992). Therefore, ANT will help me to understand how construction professionals adapt to new AR technologies and how those technologies are being created to best serve the professionals' needs. Understanding the relationships between technology and humans, both users and creators, is key to analyzing the impact AR will have on the construction industry.

I will first approach my research by conducting a literature review to analyze different AR technologies and understand the ways they are impacting some aspect of the construction industry. This literature review will serve as a summary of what technologies are in development, being researched, or already in the field and will identify any common themes among the research on how the industry is already being shaped by AR. In addition, I will conduct an interview with Tim Gaylord, who is the Corporate Director of Innovations at DPR Construction, to get his perspective on how AR has already impacted and is likely to continue to impact the construction industry. This interview will be a great addition to the method of reviewing and analyzing literature because I will receive information about this topic through someone whose job is to explore new technologies for DPR to implement in the field, understand how these technologies will be used in the field, and understand the benefits and disadvantages of implementing these technologies. Gathering information through secondary sources, such as literature, is important, but being able to gather information through a primary source, such as an interview, is crucial to understanding what is happening in the real world and supporting the information gathered through the secondary sources. Lastly, I will use the method of participant observation to draw examples from my experience seeing AR used in the field; my experience comes from my time working as a Project Engineer on a construction site this past summer. Having first hand experience at seeing how a new AR technology could impact construction is invaluable to my research on this topic and supporting the information gathered from both the literature review and the interview.

Using these research methods to analyze information within the ANT Framework will help me understand and explore the relationship between AR technologies, the construction professionals using them, and the means and methods that will be impacted by this technology.

Literature Review

To begin my research, I conducted a literature review to discover what kind of research has already been done on AR in the construction industry and to make connections between the different research on how AR will affect the industry. Wu et al. (2023) proposed that the Cognitive Ergonomics Theory is reasonable and can be utilized when designing and developing wearable AR devices for improving the kinaesthetic performance of construction workers performing assembly tasks. The results of their experiment showed that "the developed AR application had significant advantages in improving kinaesthetic performance and understanding assembly workmanship" and "the application allowed the participants to complete the task more independently" (Wu et al., 2023). Zollmann et al. (2014) "introduced an approach for using AR for on-site construction site monitoring and documentation" and by combining different components in this approach, they were able to show that "AR can support the documentation and monitoring of construction sites." Kim et al. (2012) proposed an AR visualization system that can simulate equipment operation during different phases of a construction project, with an emphasis on spatial constraints, and it was determined that the "use of the interactive modeler in the planning or design phase would ensure cost and time efficiency of design and project specifications." Hajirasouli et al. (2022) conducted a systematic literature review and identified the stages in the project lifecycle that were found to benefit the most from AR. The study found that the application of AR in these stages resulted in "increased safety and precision, reduced overall cost and time spent on a project as well as reduced number of errors" (Hajirasouli et al., 2022). The findings from a literature review conducted by Behzadi (2016) provide evidence of how AR will improve scheduling, communication and information retrieval, man-labor hours, and safety in the construction industry.

A common theme among these works is that AR technologies are capable of improving safety, communication, and efficiency on job sites. This literature review led me to focus on those three aspects of the construction industry as areas where AR will have the greatest impact and therefore change the professionals, methods, and overall field of construction.

However, through this literature review, I did discover some gaps in the research around AR in the construction industry. Many of the AR technologies discussed in the research are not currently being used in the construction industry, and the articles did not offer any clues as to whether they are beginning to be used in the industry. Therefore, while there is plenty of research surrounding how AR technologies can impact the industry, research surrounding how these technologies will be adopted into the industry is lacking. It is important to understand the effects new technologies will have on the people using them and the methods for which they will use them, but none of that will matter if there is no research or plan on how these technologies will be adopted into the industry.

Discussion/Results

Augmented Reality will impact the methods and professionals of the construction industry in more ways than one. The current methods will be challenged to change with the use of new AR technology improving communication, efficiency, and safety. Considering safety, there will be better ways to monitor field workers' health, alert field workers of safety hazards, and ensure safety is the number one priority on a job site. Therefore, new ways or methods of thinking about safety and how to keep the job site safe will emerge as new AR technologies geared towards safety emerge. With regards to communication and efficiency, AR technologies will improve the information gap between the field and the office by providing digital platforms that are capable of aiding in things such as clash detection, mock-ups, and quality control.

Having digital files that can be shared among workers will change how professionals communicate with each other and will lead to less information getting lost in the building process. Additionally, AR technology can be used in the field to help find potential issues earlier and visualize what comes next in the building process, leading to less rework and ultimately saving time and money on the project. Traditionally, a professional must compare paper drawings to what is already built, so AR technologies addressing this issue will significantly change the methods of clash detection and quality control. According to the Actor-Network Theory, as new methods emerge with new AR technologies,, the professionals must also adapt to how the new technologies will benefit them and the project the most.

AR has substantial potential to improve communication on job sites. According to Tim Gaylord, the Corporate Director of Innovation at DPR Construction, the biggest problem in the construction industry that AR is fixing is the information gap between the field and the office. With so much information being shared daily between the office and the field, incorrect information could be communicated, information could be missing, and information could be old. This is due to it being hard for field workers to track and show the extent of incorrect information they find when building. With AR, a 3D model can be shared with all parties who are able to display the model onto the physical building, and then they can annotate and document anything needed in real time. Field workers would be able to immediately document a question, problem, or solution directly onto the relevant part of the model. Office workers will automatically have the updated version, eliminating information loss in the process of getting it from the field to the office. The reverse is also true. If the office receives a revision of the drawings, they can update the model, which will directly update the field workers' models. This is one example of many that shows how AR can improve communication on the job site by

getting updated model information out in the field in order to avoid rework. Communication is the key to a successful project, and by having good communication among all parties, safety and efficiency tend to improve as well because everyone is on the same page.

Secondly, AR has considerable potential to improve efficiency on job sites through performing mock-ups, clash detection, and quality assurance/control. Mock-ups are an important part of most construction projects because they allow the contractor to verify the quality of the product prior to actual construction and to ensure they meet the desired design intent and specifications (Great Rivers Greenway, 2024). They are also a good visualization tool for owners to make sure they like how it looks and to identify any changes they want in the final product. Mock-ups come at a cost and take time, so AR is valuable in that it would allow contractors to virtually build an in-place mock-up. With normal mock-ups, whoever hears the owners' changes must take note of them, report the changes to the rest of the team, and make note on all the drawings. It is highly likely that some of the information will get lost in that process, so an important advantage of the AR mock-up is that all the changes can be made in real time to avoid rework in the future. Being able to make changes in real time as well as save a significant amount of time by not physically constructing the mock-up will increase efficiency on the project by avoiding rework and making coordination among parties easier.

Clash detection is an important step early in the construction process to identify any "clashes" or conflicts between at least two different elements in the design. Even with all of the software being used to identify clashes in models, it is never perfect. During construction, contractors will still run into clash issues in the field, even if the clash detection program run on the model said there was not one there. However, according to Gaylord, AR enables a subcontractor to overlay the plans onto what is currently in the building to identify if there will

be any clashes before they begin to install their work. Gaylord also explained that if something needs to be changed, the subcontractor can mark-up the changes in his model in real time while looking at the issue. Similarly to its use in mock-ups, AR used for clash detection will increase the efficiency of the project by avoiding rework and closing the information gap between the field and the office.

Quality assurance/control (QA/QC) is crucial in construction projects because it ensures "that the end product meets the specified quality standards, conforms to the design specifications, and complies with regulatory requirements" (Coury & Hanes, 2023). According to Gaylord, the goal for QA/QC using AR is to "ensure that either what was installed is in the right place or that something is set to be installed in the right place, with the ultimate goal being to avoid rework". Avoiding rework saves time and money, therefore making the project more efficient. For example, it would be beneficial to know if concrete embeds are placed correctly before pouring the concrete because once the concrete is poured, it takes a lot of rework to drill away the concrete to move the embeds. With AR, according to Gaylord, the model would be overlaid on top of the area where the embeds are to ensure that they match the model before the concrete is poured, therefore avoiding rework. This is one of many examples of how AR improves QA/QC, and currently there are programs and softwares being created and piloted that can be used for this purpose.

One example of a software being created to use for QA/QC is called Sitelink. This software was being piloted on my jobsite for my summer internship, so I got a first hand look at how AR technologies are beginning to change the industry. QR codes were posted around the building in order for the tablet to orient the model with the building. Since the model is directly overlaid onto whichever part of the building the tablet is pointed at, we were able to easily check

to make sure systems and pieces installed in the field matched the model. There were several instances where they did not match, so in real time using Sitelink, we were able to make a note to go check those areas and get the issues solved. Alternatively, without Sitelink, those discrepancies between the field and the model would not have been discovered until further down the line when a lot more rework would be needed, therefore losing time and money. According to Gaylord, QA/QC is a big market for construction AR technologies right now because the positive impacts are being recognized and there is no new hardware needed since it can work on a smartphone or tablet.

Lastly, AR has great potential to improve safety on jobsites by reducing the risk of accidents and improving hazard awareness. AR "can be used to create immersive training simulations" for workers to practice procedures in a controlled, safe environment in order to be more prepared for what they might experience in the field (Hazwoper-OSHA, 2023). According to OSHA, the top four causes of construction fatalities are falls, struck-by, caught-in/between and electrocutions (Occupational Safety and Health Administration, 2007). Using simulations and trainings of how to properly build scaffolding, where a crane will be lifting materials, how to safely navigate around trenches located on the site, and where overhead power lines are for operating equipment are a few of the many examples of how AR simulations can help reduce the risk of accidents in the field. However, according to Gaylord, these types of technologies are the "future state". The potential of what AR can do for industry safety is identified, but it is yet to be practically built upon.

AR can also be used to provide workers with real time hazard alerts. For example, "AR glasses could be used to overlay warning signs onto the real world" so that a worker will immediately recognize the potential danger, whereas without the glasses, the worker may not

know the hazard is there or may be too rushed to double check first (Hazwoper-OSHA, 2023). AR glasses are also the future state, but according to Gaylord, something similar that is currently achievable is using a smartphone or tablet to scan QR codes posted around the project to pull up safety visuals and information associated with the piece of equipment or room. Gaylord claims that the current state of AR in the construction industry is not focused on the safety aspect of construction very much, even though there is incredible opportunity there for the future.

Conclusion

In conclusion, there is ample opportunity for AR technologies in the construction industry to help bridge the information gap between the field and the office and improve safety. As AR becomes more popular on construction sites, it will force changes in the traditional construction methods and for the professionals who are using the technology. The technologies are being created to aid the needs of the professionals and the industry, but the professionals and the industry must adapt to the new technology as well. While there is strong evidence of many ways AR will benefit the industry, there is a gap between the research and the scalability of the actual hardware needed on project sites. Therefore, the next steps in understanding the full impact of AR on the construction industry are to research how to meet the scalability and cost issues and then research the most effective way to implement the technologies in the industry on a wide scale. In order for AR to reach its potential impact, it must be used across the industry at a large scale, which will be its greatest challenge. AR in the construction industry is still in its infancy, but once the industry realizes how significant of an impact it can make, there will be an even greater push towards utilizing Augmented Reality in the construction industry.

References

Coury, B. H., & Hanes, B. (2023, December 11). *QC in construction: How builders manage quality control.* Procore. https://www.procore.com/library/construction-quality-control

Davila Delgado, J. M., Oyedele, L., Beach, T., & Demian, P. (2020). Augmented and virtual reality in construction: Drivers and limitations for industry adoption. *Journal of Construction Engineering and Management*, *146*(7). https://doi.org/10.1061/(asce)co.1943-7862.0001844

First Compliance. (2023, September 15). *Boosting productivity and safety: The importance of communication for contractors.* https://firstcompliancesafety.com/boosting-productivity-and-safety-the-importance-of-communication-for-contractors/#:~:text=Effective%20and%20transparent%20communication%20plays,necessary%20precautions%2C%20thus%20averting%20accidents.

Great Rivers Greenway. (2024). *During construction - mock-ups.* https://greatriversgreenway.org/design-guidelines/construction/construction-mock-ups/#:~:text=Construction%20mock%2Dups%20are%20to,desired%20design%20criteria%20and%20intent

Hazwoper-OSHA. (2023, November 1). *AR/VR: The future of industrial safety*. https://hazwoper-osha.com/blog-post/arvr-the-future-of-industrial-safety#:~:text=Reduced%20risk%20of%20accidents%3A%20AR,with%20real%2Dtime%20hazard%20alerts

Javornik, A. (2016, October 4). *The mainstreaming of augmented reality: A brief history.* Harvard Business Review. https://hbr.org/2016/10/the-mainstreaming-of-augmented-reality-a-brief-history#:~:text=The%20first%20AR%20technology%20was,for%20wearables%20and%20digital%20displays.

Law, J. (1992, August). Notes on the theory of the Actor Network: Ordering, strategy and heterogeneity. *Systems Practice 5,* 379–393. https://doi.org/10.1007/BF01059830

Markets and Markets. (2021, August). *Augmented Reality (AR) market.* https://www.marketsandmarkets.com/Market-Reports/augmented-reality-market-82758548.html#:~:text=The%20Global%20Augmented%20Reality%20(AR,witness%20highest%20CAGR%20of%2060.4%25.

Noghabaei, M., Heydarian, A., Balali, V., & Han, K. (2020). Trend analysis on adoption of virtual and augmented reality in the architecture, engineering, and construction industry. *Data,* 5(1), 26. https://doi.org/10.3390/data5010026

Occupational Safety and Health Administration. (2007). *Top four construction hazards.* U.S. Department of Labor. https://www.osha.gov/sites/default/files/publications/construction_hazards_qc.pdf

Poetker, B. (2023, August 9). *A brief history of Augmented Reality (+ future trends & impact).* G2. https://www.g2.com/articles/history-of-augmented-reality

SAP. (n.d.). *What is augmented reality (AR)?.* https://www.sap.com/products/scm/industry-4-0/what-is-augmented-reality.html