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Exploring the Use of Augmented Reality Paired with GPS for Construction Installation Activities

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In the construction industry, ensuring timely and precise material installations is paramount. However, reliance on two-dimensional representations of three-dimensional structures in paper documents often leads to errors and inefficiencies, particularly among inexperienced installers. With seasoned professionals leaving the workforce, there is a growing expertise gap, undermining the industry's ability to deliver high-quality products. Augmented Reality (AR) emerges as a promising solution to these challenges, offering quick comprehension of the construction process. The main hurdle with AR is its precision. This study is a continuation of a prior study in which the authors discovered that although AR was extremely easy to use and its comprehension almost immediate its accuracy and precision prevented it from being utilized as a measurement aid where tolerances were minimal. This study evaluates some newer technology which pair the AR devices with a GPS receiver which should enhance the accuracy and precision of the system. The research replicates a typical construction scenario involving the positioning of underground utilities before concrete placement, emphasizing the importance of accuracy in layout and placement. Results indicate significant improvements in accuracy and precision when utilizing the AR devices that were paired with GPS, but the technology still has a way to go before it can be relied upon for construction installation activities.

Keywords: Augmented Reality, Global Positioning Systems, Building Layout

Introduction

The construction industry faces challenges in maintaining quality standards while also managing the side effects of a declining skilled labor workforce. Accurate and timely material installations and inspections are crucial (Clough et al., 2015), yet these processes heavily rely on interpreting two-dimensional paper documents to represent three-dimensional structures. Inexperienced workers often struggle with this task, leading to errors and inefficiencies. As experienced professionals retire, the gap in expertise grows, contributing to the industry's reputation for declining quality and customer satisfaction (Arditi and Gunaydin, 1997). This situation is further aggravated by the limited focus on quality management investments and slow adoption of modern technologies within the industry (Prashar, 2023). To address these challenges, innovative solutions are essential. Augmented Reality (AR), a Construction 4.0 technology, offers promising benefits for training and enhancing comprehension. AR integrates digital information with real-world environments, which can improve construction workflows and help bridge the skills gap (Sawhney et al., 2020). Studies demonstrate AR's effectiveness in training applications, both in classrooms and on-site, making it a valuable tool as AR adoption increases with the use of headsets, phones, and tablets (Kim and Irizarry, 2021; Olbina and Glick, 2023). However, questions remain about AR’s effectiveness for training and its reliability for use during inspections and installations.

As has been suggested by past research, AR can help inexperienced workers build foundational skills which should support their transition to effective practitioners. By providing insights into the precision and reliability of AR tools, this research also aims to support industry professionals interested in modernizing inspection and installation practices through Construction 4.0 technologies. The study lays the groundwork for using AR in construction activities, offering a modernized approach that could help mitigate the expertise gap left by retiring professionals, enhancing productivity and reputation within the construction sector.

Background

Construction involves coordinating various activities, some interdependent and others not, all vulnerable to delays and disruptions if not well-managed (Clough et al., 2015). Effective project management relies on thorough and timely inspections, which are typically performed before significant steps, such as sealing wall cavities or placing concrete (Shafiei et al., 2023). Concrete placement is especially critical; correcting mistakes in placement is costly, time-consuming, and can disrupt the project timeline and affect multiple trades. However, current inspection processes often rely on outdated methods, such as paper plan reviews and manual inspections (Prashar, 2023). This approach is prone to errors, with inspectors sometimes overlooking issues, less experienced inspectors missing key details, or delays in communicating findings. In an industry facing a shortage of qualified inspectors and installers, tools that enhance effectiveness are critical, but finding enough skilled workers remains a persistent challenge.

One of the industry’s major challenges is replacing skilled workers as they retire. Reports, including those from the National Center for Construction Education and Research, estimates that about 41% of the current construction industry workforce will retire by 2031 (retrieved from: https://www.byf.org/what-will-happen-when-the-baby-boomers-retire/). Efforts to counter this shortage include finding alternative labor sources and funding programs that support workforce training at trade schools, colleges, and universities. Nevertheless, experienced workers, who are often adept at spotting issues that could escalate into larger problems, are exiting the workforce faster than they are being replaced. This type of insight, developed through experience, is difficult to teach, yet critical for many construction activities. While there is no immediate solution to this skills gap, educational institutions can address it by integrating hands-on active learning that simulates the field experience needed for effective inspection (Motta and Galina, 2023). If we look at newer technologies, visualization tools that use AR seem to be the most promising for inspection processes (Kim and Irizarry, 2021; Olbina and Glick, 2023).

Research on using AR for construction activities shows potential, though it remains limited. Each process—such as concrete placement, window glazing, or steel erection—requires a unique approach, so AR applications need to be tailored for specific tasks. The existing research struggles to fully address the diverse needs of AR applied to various construction activities. For instance, Chi et al. (2022) used laser scanning with AR to evaluate concrete reinforcement placement, although the AR was applied only for post-installation review, not real-time inspection. Dunston (2009) took a more practical approach by testing AR for steel column placement in a controlled study, showing AR’s potential for real-time issue detection, which is ideal for inspections. Girgin et al. (2023) explored

AR's potential in coordinating mechanical, electrical, and plumbing (MEP) installations, proposing an AR-based methodology from interview data to improve overhead work coordination. While these studies highlight AR's benefits, they lack the practical, extensive testing needed to make AR tools viable for broad industry use, revealing a gap in the research.

Research Rationale

How can the construction industry modernize its outdated quality control processes while addressing both its quality control reputation and workforce challenges? The industry often clings to practices that have *worked* in the past, but a shift in mindset is necessary, especially in training a new generation of workers. Addressing the skilled labor shortage and enhancing quality control will require equipping the workforce with effective training and advanced tools. Therefore, this study aims to evaluate the accuracy of a new AR tool for construction activities. By involving students in a construction management course, the research will assess AR's potential to improve installation quality and provide practical training to the next generation of construction professionals. Prior research had been undertaken by the investigators looking at more traditional AR devices and the accuracy and precision of those for construction activities. The results of that study revealed the potential that AR devices possess for construction installation and inspections, but the accuracy and precision of the tools would limit their applications. To realize some of that potential shown by AR devices the investigators procured an advanced AR tool that is coupled with GPS unit in the hopes that it would show significant gains in its accuracy and precision.

Methodology

This study utilizes an action research approach to determine the usefulness and effectiveness of an advanced augmented reality tools paired with GPS. This study is a continuation of prior research which explored the accuracy and precision of augmented reality without GPS and the data from that study will serve as a control or baseline for this study. The study’s test subjects were students enrolled in a four-year construction management degree program. A common construction activity, under slab utility placement, was chosen as the contextual activity to evaluate the precision of the GPS enabled AR tool. An actual construction activity was chosen because laboratory tests and theoretical performance specifications do not necessarily manifest when applied to the environmental conditions and realities of an actual construction site.

Participants

Approximately 36 students participated in these experiments. All 36 students were in their senior year of a construction management degree program and most have some practical knowledge of the trades along with some construction management experience gained through either an internship or cooperative program. Participation was voluntary and conducted during regular class times. Students were paired in teams so for the 36 participants we had 18 teams. One team member utilizing the augmented reality hardware provided positioning guidance to the other team member for their installation activity. Each team was given a brief introduction and training session then were tasked with completing the installation activity. Instructions were minimal as the hardware and software were found to be intuitive by the students.

AR Devices

The chosen AR device was the Apple iPhone 13 Pro Max (iPhone). The phone was paired with Trimble’s Site Vision GPS receiver and its HPS2 integrated handle. The GPS unit attached to the phone provided a constant reference for the anchoring of the hologram during the experiment. The iPhone was selected for its portability, and its integration with the Trimble software and hardware, in addition students are remarkably familiar with this hardware platform. Our previous control study was also performed with the Apple iPhone 13 and Trimble's Connect AR app without GPS.

Simulated Construction Site

The study was conducted in a simulated foundation slab form. (see Figure 1). The slab form measured 20 feet by 20 feet and was designed to mimic an actual construction project site's environment. Students used the AR devices to position plumbing penetrations within the slab form. This type of rough plumbing must occur before concrete placement and positioning is critical as plumbing penetrations margin of error is minimal. Mistakes can be costly as they involve a significant amount of demolition and rework.

Figure 1. Simulated Construction Site

Simulated Construction Activity

Students were given the Trimble Site Vision system and tasked with using the AR device to assist in positioning the plumbing penetration (survey prism) at the observed center location of virtual pipes. The accuracy of their placements was measured using a total station, which recorded both northing and easting coordinates. The difference between the design coordinates as established in the BIM model and the observed coordinates determined the placement accuracy. Students also provided qualitative feedback through open-ended questions, offering insights into the AR tool's utility, usability, and areas for improvement. The site was outdoors and exposed to full sun to mimic typical construction site lighting conditions, adding practical relevance to the study.

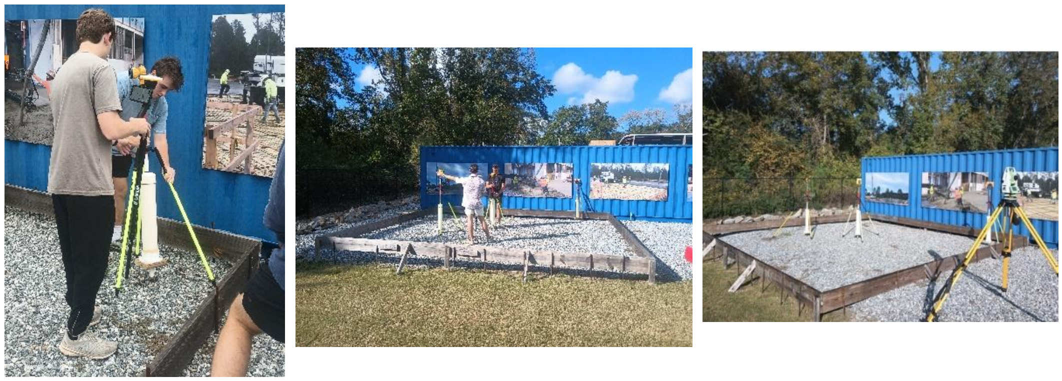

Figure 2. Simulated Construction Activity

Results

Figure 3 identifies the positional observations of three pipes recorded by students using the GPS enabled AR devices. Each of the 18 student groups individually located the pipes using their GPS enabled AR devices, resulting in three observations per group. Below is a graphical representation of the results (See Figure 3).

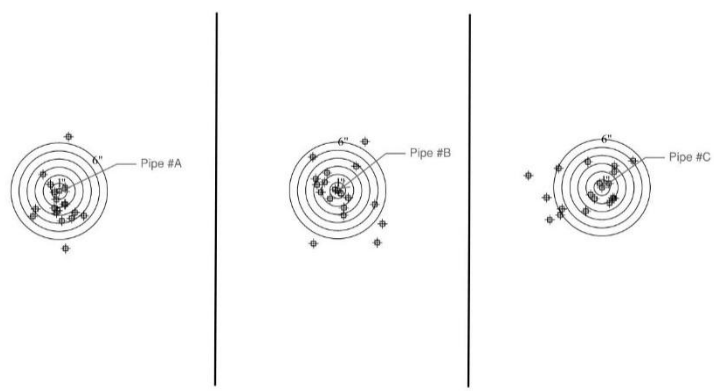

Figure 3. Positional Observations of the Virtual Pipes

The northing and easting coordinates for each point were measured using a total station and compared to control points to determine placement errors. Table 1 presents the average error distance (in inches), standard deviation, and the quantity of points recorded for each pipe.

Table 1. Error in GPS enabled AR		
Pipe A (n=18 for each pipe)	Average SD	3.048 in. 1.85
Pipe B (n=18 for each pipe)	Average SD	3.597 in. 2.40
Pipe C (n=18 for each pipe)	Average SD	3.906 in. 2.53
Overall Average		**3.51 in.**

This accuracy was a substantial gain over prior research which utilize the same iPhone without GPS. Figure 4 identifies the positional observations of three pipes recorded by students in a prior study using the non-GPS enabled AR devices. Each of the 8 student groups individually located the pipes using their non-GPS enabled AR devices, resulting in three observations per group. The methodology was essentially the same for the non-GPS enabled devices except for the hardware and software used. Below is a graphical representation of the results (See Figure 3).

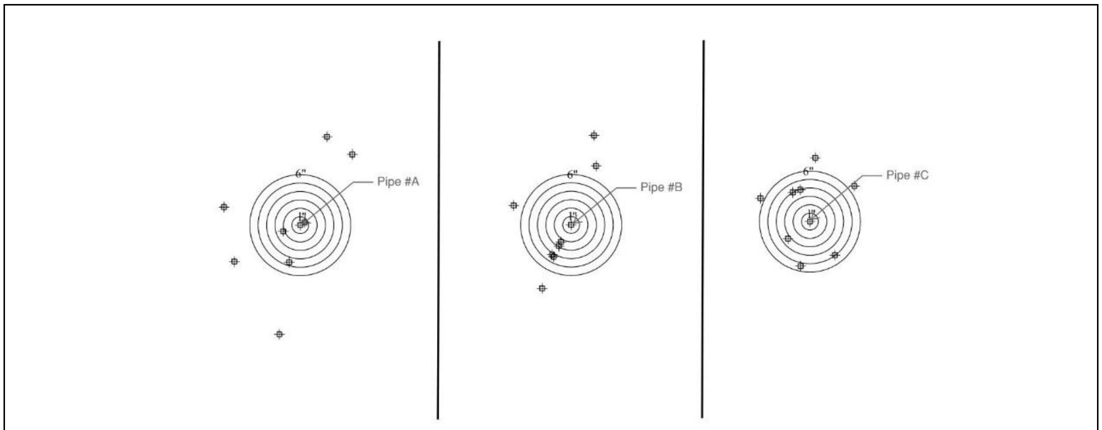

Figure 4. Positional Observations of the Virtual Pipes

As before, the northing and easting coordinates for each point were measured using a robotic total station and compared to control points to determine placement errors. Table 2 presents the average error distance (in inches), standard deviation, and the quantity of points recorded for each pipe.

Table 2. Error in non-GPS enabled AR		
Pipe A (n=8 for each pipe)	Average SD	7.509 in. 4.51
Pipe B (n=8 for each pipe)	Average SD	5.966 in. 2.99
Pipe C (n=8 for each pipe)	Average SD	5.300 in. 1.53
Overall Average		**6.25 in.**

Discussion

The study reveals significant advantages to utilizing the AR devices which are connected to a GPS unit. Traditional AR devices use sensors to identify vertical and horizontal surfaces to anchor the holograms in the real world. The GPS enabled devices work similarly but have the added advantage of using GPS to provide a constant correction. The investigators personally observed all the experiments and can attest to the fact that most groups started their mock installation with pipe C. For the non-GPS enabled devices it appears that as the groups got further away from their starting point the accuracy and precision of the hologram degraded. The AR devices with the GPS units appear more consistent than the non-GPS devices. Said plainly, the non-GPS units lost accuracy the longer they were used. This result seems logical since the GPS units received constant corrections. Also, the investigators observed more anomalies and had to perform more troubleshooting with the non-GPS enabled devices. The GPS-enabled AR device was more user friendly.

The results of this study reveal an average precision of 3.5” off-center for the installation of plumbing penetrations in a slab on grade. This is a significant improvement over the original study that had a 6.25’ average variance. Although this improvement is dramatic it would still likely not provide sufficient precision to professionally rely on the device as a measurement aid for plumbing installation. All who participated in this experiment were excited about the technology and found it extremely easy to use and intuitive.

Future Research

Although the process and workflow were essentially the same for both the GPS enabled and non-GPS enabled AR devices, the investigators believe they can make some improvements in both the setup and measurements to further improve on the 3.5” precision. As the precision improves the applications for this type of technology expands.

Conclusion

Augmented Reality technology has broad potential to help our industry solve some of its fundamental problems related to a lack of available skilled labor and difficulties in training and development. Other technologies are available to assist with positioning and locating construction components, but AR devices have the distinct advantage of ease of use and almost instantaneous comprehension. Currently the technology including the GPS-enabled devices do not appear to be able to achieve a level of precision which would allow for their broad adoption for tight-tolerance construction installation activities. While the current GPS-enabled devices are an improvement over the traditional AR devices they do carry the additional limitation of working only outdoors where you can receive satellite signals.

Despite the limitations related to precision and accuracy, the tools could be very useful and effective for field verification and inspection. In addition, certain planning and coordination activities would benefit from the technology as it can project a design solution in the real world to give you a full-scale representation of different alternatives. Although tight-tolerance installation activities (such as plumbing rough-in, framing and anchor bolt installation) cannot be reliably located with AR devices, other installation activities like site utilities, site furnishings and specialties (toilet accessories, fire extinguishers, display boards) may achieve some immediate benefits from incorporating AR into their installation workflow as they do not require the same level of precision. To our knowledge, use of AR devices has been sparse and limited to corporate VDC departments and other one-off type applications. It seems like the potential productivity benefits and advantages of AR technologies is not yet fully exploited by construction professionals. It appears that the technology is headed in the right direction and as improvements in precision and accuracy are made new applications will become possible and expanded use will become likely.

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