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Expanding the Analysis of Using Augmented Reality for Construction Embedment Inspections

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Embedments (embeds) are commonly used when dissimilar construction materials such as steel and concrete or wood and masonry need to be anchored together. The embed serves as a structural connecting point for different materials. Construction managers are aware of the significance in terms of lost time and cost overruns when these embeds are not properly installed. Missing embeds require extensive structural re-work that is costly and involves a significant amount of time to remedy. The inspection process directly impacts the success of a project when missing embeds can be identified early. This research analysis expands on a past research study involving the use of an augmented reality headset to assist inspectors in the process of examining a simulated embed installation. This paper will identify shortcomings from the original study that were used to further develop and refine the augmented reality inspection process. While the use of improved equipment helped to stabilize the virtual image when viewed through a head-mounted augmented reality headset, newly discovered visibility issues turned out to be problematic for its use. The researchers found that virtual image opacity and image drift were problematic in the follow-up study, resulting in inaccurate inspections. As a result of these findings, the researchers recommend adjustments to the virtual overlay presented by the head-mounted augmented reality headset in a future iteration of this study.

Key Words: Augmented Reality, Productivity, Construction Inspections, Embeds

Introduction

One of the primary roles of the construction manager is to supervise the means and methods of the construction process (Clough, Sears, Sears, Segner, & Rounds, 2015) and part of this supervision includes the responsibility for coordinating the installation of numerous dissimilar components of the project. Often the installation of these components relies on predicting, well in advance, the installation of an element that another future item needs in order for it to be installed. Embedments (embeds) fit this type of coordination situation. An embed creates a connecting point in a structural surface for the attachment of another structural component or some other element of the project that needs anchorage to the structure. It is ideal if they can be installed during the completion of the

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structure (Saleem, Al-Kutti, Al-Akhras, & Haider, 2016) and most structural engineers design these embeds for in-situ placement. Based on conventional structural design methodologies, if the embeds are not installed along with the construction of the structure several problems will arise (Kwon, Park, & Lim, 2014; Mohr & Harris, 2011), some of which include:

- Drilling holes for a post-installation anchor that often hit or compromise the internal steel reinforcing
- Lost time related to re-design and retrofit of the structure for post-installation anchors
- The added cost of re-design and specialized post-installation anchors

This research study is motivated by the need to minimize these types of events on a project. This type of re-work is wasteful and may compromise the integrity of the structure. Therefore, it is reasoned that if the inspection process can be improved the re-work can be minimized. Construction managers should welcome a process that minimizes cost and schedule risks for their projects (Thomsen & Sanders, 2011).

Lastly, as identified in 2012, the industry is seeing a reduction in its skilled workforce (McGraw Hill Construction, 2012). It is reasonable to assume that some of these seasoned practitioners are adept at identifying missing embeds – many of them have probably lived through the onerous experience of missing embeds many times during their careers. Unfortunately, their replacements (recent academic graduates), lack the experience necessary to accurately identify these types of problems in advance. They too will need to make some of the same mistakes as their predecessors to gain this experience. Along with this issue, the construction industry at large faces waning productivity forecasts when compared to other non-farming industries in the United States (Sveikauskas, Rowe, Mildenberger, Price, & Young, 2016). While the industry is focusing on research and development to combat this problem, those efforts have been paltry at best – yet may be slowly improving (JBKnowledge, 2020). Therefore, an underlying motivation for this research study is to create a tool that improves accuracy, productivity and bridges the ever-widening skills gap for at least a small yet significant part of the construction process.

Background and Previous Research

This research study is an expansion of a previous similar research study conducted by the authors of this paper. In this section, the authors provide context for the use of augmented reality (AR) for a construction inspection process along with some of the results and findings that are pertinent for continuing this research study.

Augmented Reality

Augmented reality is a technology that is used to add supplemental information to a real-world view (Azuma, 1997). Adding this meta-information to a person's perception of the real-world view adds insights that are not available without the added virtual information (Kim & Irizarry, 2020). These insights help to inform the viewer and can assist them with tasks that they are not familiar with (Kwon et al., 2014). When a novice inspector performs an inspection for the first few times, they gain insight each time they inspect. Inspectors using AR gain insights through the added virtual information that is presented to them (Kim & Irizarry, 2020). When inspectors can gain these additional insights early, they can enhance their inspection work and help resolve issues before they become too costly and time-consuming, especially later in the construction process when the changes become more inflationary due to a limitation of options (Thomsen & Sanders, 2011). The use of AR for this study as well as the originating study was motivated by its potential to improve the inspection process by providing additional information to the inspector at the time of their review.

Findings from the Originating Research Study

The previous study on this topic was conducted to establish a framework for testing accuracy while identifying areas of improvement when using AR technology and provides the basis for this section of this paper (Kim & Olsen, 2020). In the prior study, the demographics consisted of postsecondary students in a construction management program in the Southeastern United States. These students were selected for convenience and because at this point and time in their academic career, had taken plan reading courses, understood building information modeling practices, and several of the students had some construction-related internships. The study was conducted in a vacant space within the academic building where the students took their classes. The space was 54’-0” long and 12’-6” wide. The height of the room was 17’-0” with no finished ceilings and an exposed structure and exposed building systems. One side of the room had a 30’-8” x 12’-6” window wall without window treatments – the room included parabolic fluorescent lighting and was supplemented with natural light from the large window-wall (see figure 1a and 1b).

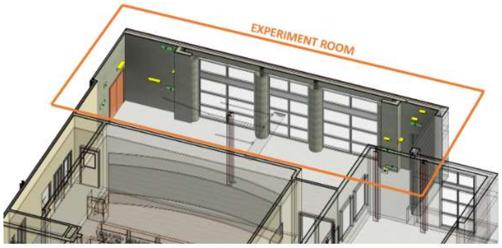

Figure 1a. Rendering of the experiment room.

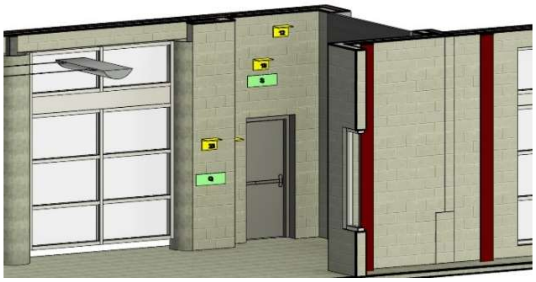

Figure 1b. Closeup of the right side of the room.

The experiment consisted of simulated embeds that were fabricated from colored cardboard (yellow and green) and installed within the experiment room identified above. The placement of the embeds within the experiment room was matched to the placement of embeds that were included as a part of a building information model (BIM) of the experiment room. Exact placement within the experiment room was established by using total station layout equipment. Attention was given to making sure that the embeds in the room were accurately placed as they appeared in the BIM, however, some embeds were deliberately omitted to test the participant’s accuracy. This study was conducted using a between-group design. One group would use a Microsoft HoloLens (generation 1) to perform the inspection and a separate group would interpret 2-dimensional (2D) embed placement drawings for their inspection. The researchers gathered data for comparison between the two methods of inspection. The table below summarizes the key finding from the originating study and were used to develop the continued study.

Table 1

Key findings from the originating study conducted by Kim & Olsen (2020)

No.	Finding description
1	A statistically significant difference, in terms of accuracy, was observed, favoring the use of the HoloLens (generation 1) when compared to using 2D plans for inspection. T-Test results with a Confidence Interval percentage of 95% (*CI*=95%) and $t_{(38)}=-2.281802$, $p=-0.0342029$ ($p \leq 0.05$).
2	Image drift in AR is identified as an unlocking of the virtual image from its connectedness with the real-world view (Azuma, 1997). When this happens, the equipment must be recalibrated to connect the virtual and real-world views together in order to continue the inspection. This image drift happened frequently in the originating study.

Methodology

This section will describe the methodology used in the continued study. Furthermore, the authors explain key parameters of the continued study that were modified based specifically on the finding from the originating study.

Demographics and Setting

Like the originating study, the participants for this study were postsecondary students in a construction management program in the Southeastern United States. The total population for this study included 27 students (*n*=27). Most were classified as *Seniors* (96.3%) and only one was classified as a *Graduate* student (3.7%). When asked about their construction-related experience, 3.7% reported having less than one year of experience, 77.8% reported between one and three years of experience, and 18.5% had more than three years of experience. There were two different methods used for inspections in this study, AR assisted or 2D paper plan inspection. As such, the students were asked about their experience with using each of the methods. 11.1% had used AR before, while the remaining 88.9% had not. Most of the students (85.2%) had used paper plans to build things while the remaining students (14.8%) had learned to read them from classroom instruction but had not used them specifically for building things. The room identified in the originating study was used for the continued study, however, only the right side of the room was used.

The Embeds

The embeds were fabricated from white foam boards and adhered to the walls of the experiment room. It was reasoned that the white-colored embeds, although not consistent with the colors observed on a construction project site, contrasted enough with the walls of the experiment room to be visible to the inspectors in this study. In this way, a color contrast is present that is also observed on a construction project site (see figure 2a). A few embeds were painted the same color as the surrounding walls, much like what is observed on a construction project site, where the embed is difficult to locate because the surface face color of the embed is similar to its surrounding concrete color (see figure 2b).

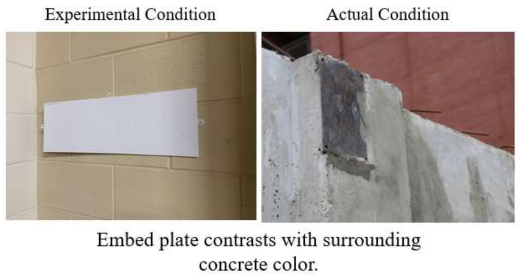

Figure 2a. Embed contrasts with surrounding.

Figure 2b. Embed blends in with surrounding.

The researchers arranged the embeds in the experiment room using a total station and surveying equipment so that their locations matched locations in a BIM of the experiment room. Some of the embeds were preselected to have identifiable issues in order to measure the accuracy of the inspectors. The embed conditions have been summarized in table 2.

Table 2.

Embed placement condition.

Embed ID	Embed color	Illuminance (Lux)	Installation condition	HoloLens Error Freq. (*n*=17)	2D Plan Error Freq. (*n*=10)	△ Error (HOLO – 2D)
Plate 1	Missing	162	Missing	35.3%	10.0%	25.3%
Plate 2	Wall color	218	Installed	29.4%	0.0%	29.4%
Plate 3	White	295	Installed	5.9%	10.0%	-4.1%
Plate 4	White	188	Installed	5.9%	0.0%	5.9%
Plate 5	White	98	Installed	5.9%	10.0%	-4.1%
Plate 6	Missing	72	Missing	58.8%	10.0%	48.8%
Angle A	White	295	Installed	5.9%	0.0%	5.9%
Angle B	White	299	Installed	0.0%	0.0%	0.0%
Angle C	Wall color	159	Installed	5.9%	0.0%	5.9%
Angle D	Missing	191	Missing	47.1%	10.0%	37.1%
Angle E	White	239	Installed	5.9%	0.0%	5.9%
Angle F	White	283	Installed	5.9%	0.0%	5.9%
Angle G	White	72	Installed	11.8%	0.0%	11.8%
Angle H	White	160	Installed	5.9%	0.0%	5.9%
			Overall Average	*16.4%*	*3.6%*	*12.8%*

Inspection Methods

The between-group experiment consisted of allowing the inspectors to use either the HoloLens (generation 2) or 2D paper plans to inspect embeds in the experiment room. Inspectors that used the HoloLens were asked to visually observe where they perceived a difference between the image rendered in the HoloLens's overlay of the room to installed condition within the experiment room (see figure 3 for observation procedure). The use of the HoloLens in this way allowed for the inspector to view the correct placement through a model that was superimposed on the visual of the *real-world* experiment room. Inspectors using the 2D paper plans were to visually compare what they interpreted on the 2D plans, matching to what was installed within the experiment room.

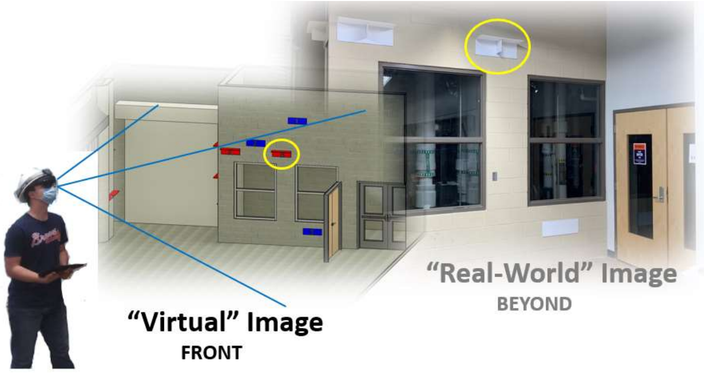

Figure 3. HoloLens inspection method.

All the inspectors regardless of inspection method were asked to record their findings on an iPad that was used to record and collate the data for this study.

Data and Results

A total of 27 student inspectors participated in this study (*n*=27). Seventeen student inspectors used the HoloLens (generation 2) and ten student inspectors used the 2D paper plans for inspection. Table 2 tabulates the error frequency for each of the embeds by the method used.

Unlike the originating study, the researchers also collected time to complete the inspection for all inspectors. The time to complete between the different methods was nearly identical. The HoloLens inspectors completed their inspection in an average of 3 minutes 20 seconds (MAX 5:28, MIN 1:58, SD 00:59) compared to those using the 2D paper plans that completed their inspections in 3 minutes 15 seconds (MAX 5:29, MIN 1:37, SD 01:00).

Discussion

The results are insightful in that they expose some significant shortcomings when using the AR assisted inspection method. The key findings in the originating study (see table 1) will be readdressed here and compared to the findings in the continued study.

Finding 1: Accuracy of the HoloLens Inspection

Indications from the originating study favored the accuracy of the HoloLens inspection method, the findings in the continued study did not agree. The HoloLens inspection was found to be less accurate, especially when observing *Missing* or *Wall Colored* embeds (see table 2). Apart from Angle C, all the *Missing* or *Wall Colored* embeds (Plate 1, Plate 2, Plate 6 and, Angle D) resulted in an average error frequency of 42.7% when using the HoloLens method compared to an average of 7.5% for the 2D plan inspection method. This higher error frequency, specifically for these types of embeds, indicates that the observation for the HoloLens inspectors was in some way obscured using the AR technology. The researchers surmise that the positioning of the virtual embed, when viewed through the HoloLens, covered up the real-world condition in the experiment room – not allowing the inspector to make an accurate assessment of the embed. Figures 4a and 4b illustrate this finding.

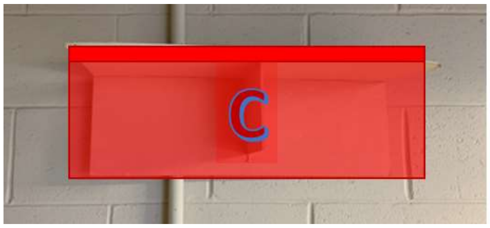

Figure 4a. Obscured view of real-world embed by the virtual embed in the HoloLens.

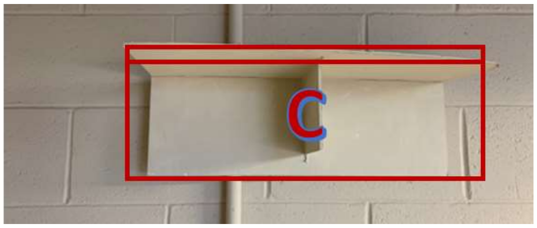

Figure 4b. Recommended wireframe virtual embed overlay.

Opacity needs to be considered when displaying the virtual embeds in the HoloLens. Figure 4a shows the HoloLens virtual embed superimposed over the real-world embed and it is difficult to see the real-world embed. Inspectors may assume an incorrect condition for this embed based on this condition. The problem is made worse when the real-world embed is missing or is also the same color as the surrounding wall surface, as indicated by the data. Embeds that contrast in color to their surrounding surface had a lower frequency of error and were easier to notice by the HoloLens inspectors. Therefore, for future iterations of this inspection methodology, it is recommended to consider the opacity of the virtual image when making comparisons in this manner, it may be better to wireframe the virtual embed to increase assessment accuracy (see figure 4b).

Finding 2: HoloLens Image Drift

In the originating study, the researchers often had to contend with issues of image drift, where the virtual and real-world view would disconnect. This condition required the HoloLens inspector to stop and, through the assistance of the researchers, recalibrate the HoloLens so the inspection could continue. Although data was not gathered for its frequency in the originating study, it was noticeably distracting and caused the researchers to disqualify some of the data. In the continued study, the second-generation variety of the HoloLens was used, and the hardware is much improved – no incident of image drift as previously described was observed.

Despite this improvement, drift was still present. However, the researchers surmise that this finding resulted from a parallax effect with the new equipment. When observing embeds straight on at 90° perpendicular to the embed, the virtual embed was fully superimposed over the real-world embed. As the inspector moved right or left of 90° perpendicular, the real-world embed moved slower than the virtual embed, causing the appearance of an incorrectly positioned embed or the effect of an image drift (see figures 5a and 5b). This is a considerable shortcoming when planning to use AR for this type of inspection. The researchers hypothesize that when locking the virtual model to the real-world surroundings if the virtual model's scale or positioning in X, Y and, Z planes is not perfected, the image drift issues will complicate more accurate assessments by the inspectors.

This finding was shared by many of the participants during their inspections. The researchers anecdotally recorded this finding but did not gather enough data to assess its direct impact on the results.

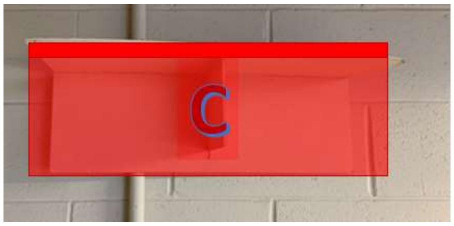

Figure 5a. Observed embed 90° perpendicular.

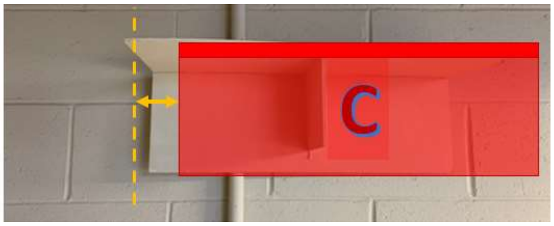

Figure 5b. Same embed observed +5° right of perpendicular.

Other Research Consideration

The researchers gathered illuminance data for the experiment room and for each of the embeds used in this continued study. The use of AR technology outdoors has been examined since the 1990s (Azuma, 1999) and is a necessary consideration when using this methodology as an assistive technology for construction inspections – since construction mostly occurs in fully sunlit spaces. Although illuminance data appears inconclusive in this study it is assumed that a more reliable future study should consider lighting variances that are commonly observed on construction project sites.

Conclusion and Future Work

Unlike the predecessor study, this study yielded opposite results in terms of accuracy – not favoring the HoloLens assisted inspection. When designing the virtual elements that are viewed in the HoloLens, it is important to consider the opacity of the images. This inspection methodology relies on the inspectors observing both the virtual image and comparing it to the real-world view, yet if the technology obscures this process, the results of this study show that the accuracy of the HoloLens method is compromised. A condition was similar in both the originating study and the continued study concerns image drift. While the originating study was technically hampered by this condition, the continued study exposed some shortcomings that may be attributed to scaling and fiducial (Azuma, 1997) accuracy, complicated by a parallax effect. A future iteration of this study should consider a redesign of the virtual overlay that is used. The authors further recommend, that with the improved hardware of the 2nd generation HoloLens, the blending of machine learning and/or artificial intelligence (AI) into the process of this inspection method could create a more assistive tool that identifies errors requiring a *human* judgment. The inspector's attention could be drawn to questionable errors that the AI finds meets a certain threshold, saving the inspector time from having to pass judgment on conditions that are more obviously noticeable.

The motivation for the continued study, like the originating study is a need to improve construction quality inspections to minimize cost overruns and schedule delays. The authors of this continued study contend that the continuation of the study will strengthen the AR method and eventually positively support the construction quality inspection process.

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