A Framework for Augmented Reality Assisted Structural Embedment Inspection

Jeffrey Kim[a] and Darren Olsen[a]

[a]McWhorter School of Building Science, Auburn University, United States
E-mail: jeff.kim@auburn.edu, dao0002@auburn.edu

Abstract –

Embedments (embeds) placed in concrete or masonry structures are used extensively in construction to connect the final product of one trade-contractor's work to another and are therefore, a critical coordination facet for most construction projects. A failure in this coordination usually leads to lost productivity. Therefore, the need to productively improve the installation quality is paramount. A between-groups experimental study was designed to measure embed placement accuracy within an experimental space. One group inspected the work with a 2-dimensional set of construction plans while another group carried out the work with the assistance of an augmented reality (AR) inspection tool. An AR headset was used that presented a parametric model as a visual overlay on the walls of the experimental space. In this way, the embed placement accuracy could be inspected. The results indicated that accuracy was weakly significant between the two methods of embed inspection. However, a shortcoming discovered during the research required the precision of the AR tool to be tuned because of an image drift within the AR visualization. This paper analyzes the AR shortcoming, differences in accuracy, proposes reasons for the differences, and addresses the accuracy trade-off in a broader context of the framework.

Keywords –

Augmented Reality; Productivity; Construction Inspections; Embeds

1 Introduction

Construction coordination is a risk that is customarily assigned to the construction manager of a project. While the construction manager is often rewarded commensurate with accepting this risk, there is often a desire for them to develop better ways to manage this risk. Pre and post construction inspections are one way that construction managers have mitigated their risk, but sometimes this process fails. Sometimes, a lack of time becomes the root cause [1] and defects end up costing the project time and money.

In this research, we explore a framework that addresses inspection defects with the understanding of the pivotal role that this process plays in a project's productivity and for its success.

2 Background and Rationale

Concrete and masonry anchors are commonly used for the attachment of other structural members to concrete and masonry. In construction and civil engineering disciplines they are commonly called embedments (embeds). It is best if they can be installed prior to the completion of the concrete or masonry structure [2]. Failure to place embeds prior to the concrete or masonry construction can be problematic for several reasons [3], [4], some of which include:

1. Drilling holes for a post-installation anchor will often hit or compromise the internal steel reinforcing
2. Lost time to re-design and retrofit the structure for a post-installation anchor
3. Added cost of re-design and specialized post-installation anchors

Augmented reality (AR) is a technology that is used to add supplemental information to a real-world view [5]. By adding this meta-information to a person's perception of the real-world view, more insight may be gained by the viewer of what is being observed [6]. AR is quickly finding practicality in the construction industry and some researchers are beginning to refine the ways by which AR can be used for inspection of defects [4]. When inspectors can gain additional insights about what they are observing, they can enhance their work and help to resolve issues prior to construction, when cost and time are less vulnerable to inflationary change [7].

The process of embed placement prior to the construction of concrete and masonry structures is one such situation on a construction project that is vulnerable to cost and time inflation if they are missed or improperly installed. Therefore, the need for this research was determined based on this observed dilemma and the aim for this research is to use AR technology to assist an inspector in the process of defect detection of embed placement.

3 Methodology

This study was conducted using a between-groups design. One group of randomly selected students were chosen to perform an inspection of installed embeds using 2-dimensional (2D) embed placement drawings. The other group was randomly selected to conduct the same inspection using an AR inspection tool. The following section describes the setting, tools, and procedures that each group was to follow.

3.1 Demographics

A convenience sample was used consisting of postsecondary students in a construction management program in the Southeastern United States. These students were requested to participate in this study at a normally scheduled class time. Students in this CM program, at this point and time in their academic career, have taken plan reading courses, understand building information modeling practices, and several of the students have had some construction-related internships.

3.2 Setting

The study was conducted in a vacant space within the academic building where the students take their classes. This indoor space is approximately 54'-0" long (16.5 m) and 12'-6" wide (3.8 m). The height of the room is 17'-0" (5.2 m) with no finished ceiling – all MEP equipment, conduit, and piping are exposed. On the long side of the room is a 30'-8" x 12'-6" (9.4 m x 3.8 M) window wall, which does not have any window treatments and allows an abundance of outdoor natural light within the space. Refer to Figure 1 for a composite layout of the experiment room.

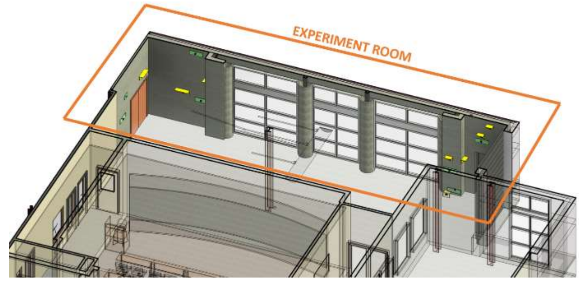

Figure 1. Rendering of the experiment room

The room in Figure 1 has exposed masonry walls and provided a setting to place mockup embeds on the walls of the space. A parametric model of the room was created in *Autodesk's Revit* and embeds were positioned throughout the room as shown in the closeup rendering of one side of the room (see Figure 2).

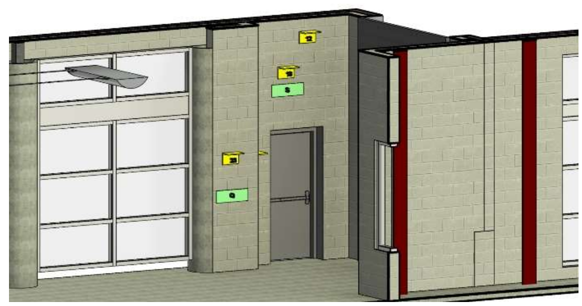

Figure 2. Closeup within the parametric model of experiment room showing embed placement

Some embeds were designed to simulate steel angles (colored yellow) and others were designed to simulate flat plates (colored green). Upon completing the parametric model, the embed coordinates were loaded into a total station and the researchers positioned the mockup embeds within the room to match their locations in the parametric model.

3.3 The Embeds

The mockup embeds were fabricated from colored cardboard and matched the color of the embeds in the rendering shown in Figure 2. A *Microsoft* first generation *HoloLens* was used for the AR inspection. The researchers used *HoloLive* and *Visual Live* to upload the model into the HoloLens and for the inspection of the mockup embeds. Figure 3 illustrates the workflow involved in transitioning the parametric model coordinates to the total station that was used to layout the mockup embeds in the experiment room.

Figure 3. Workflow for migrating parametric model information to a total station for embed layout

The researchers preselected that some of the embeds would be placed with identifiable issues. The student-inspectors would have to identify these preselected issues. These issues are summarized below along with the frequency of their use identified in Table 1. The embed issues (listed below) were categorized into three *Issue Categories*.

1. Embed was installed with no issues
2. Embed was installed but has a placement issue
3. Embed was NOT installed

Table 1. Embed configuration

Embed ID	Status	Color	Issue Category
10	Installed	Yellow	1
12 Left	Missing	Yellow	3
12 Right	Installed	Yellow	1
14	Installed	Yellow	1
15	Missing	Yellow	3
16	Missing	Yellow	3
21	Installed	Yellow	1
23	Installed	Yellow	1
A	Installed	Green	1
B	Installed	Green	1
D	Installed	Greed	1
G	Installed	Green	1
P	Missing	Green	3
Q	Installed	Green	1
S	Installed	Green	1
TOTAL 15 Embeds			

Lastly, once the coordinates for each embed was determined, the researchers affixed the mockup embeds to the wall as shown in Figure 4.

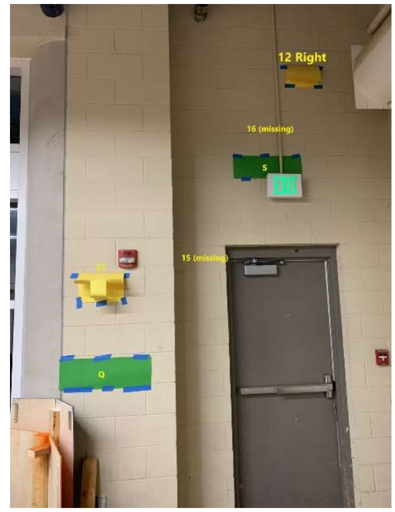

Figure 4. Mockup embeds placed in the experiment room (descriptions are shown for clarity but were not included in the experiment room)

3.4 2D Embed Placement Drawings

The parametric model was used to create 2D embed placement drawings. These drawings were printed on 8 ½" x 11" paper without color. The 2D drawings used interior elevations and annotated dimensions to locate the embed within the experiment room. An example of the 2D embed placement drawing is shown in Figure 5.

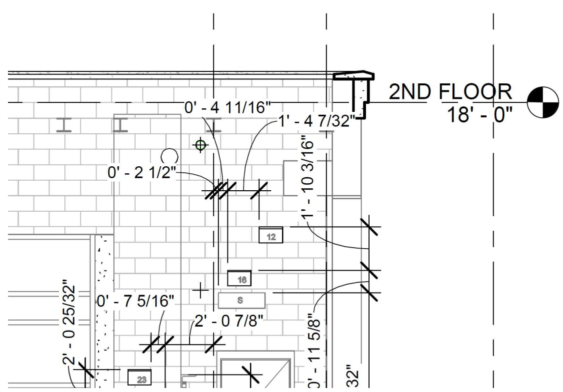

Figure 5. Partial image of 2D embed placement drawings

Students using the 2D placement drawings were to visually compare what they observed on the 2D drawings, matching to what was installed within the experiment room.

3.5 AR Inspection

Students using the HoloLens were to visually observe where they perceived a difference between the image rendered in the HoloLens' overlay of the room to the installed condition within the experiment room. Figure 6 shows what an inspector using the HoloLens would see when inspecting embeds in the experiment room.

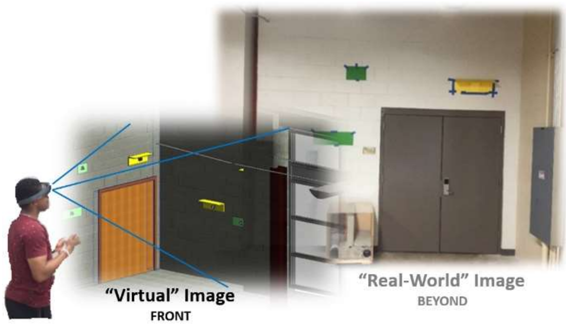

Figure 6. Framework of inspecting embeds using AR

The use of the HoloLens in this way allowed for the student inspector to view the correct placement through a model of the room that was superimposed on the visual of the *real-world* experiment room.

3.6 Experiment Procedures

As mentioned, this experiment was designed as a between-groups procedure. The students were randomly selected to conduct an inspection of the experiment room's embed layout using either 2D embed placement drawings or using the HoloLens for inspection.

All students were asked to record their findings on a paper inspection sheet. Because AR does not completely replace the view of the user, the student inspectors were able to report their findings on the paper inspection sheet. Both groups of students used the same type of inspection sheet to record their findings. The inspection sheet contained numbers ranging from 1 to 31 and letters A through Z. With both methods, if the student identified an error, they were asked to record the problem on the inspection sheet with the associated embed identification (number or letter). There were more numbers and letters on the inspection sheet than were embeds placed within the experiment room. This open-endedness was purposefully designed to control for a situation where students may assume that all embeds on the inspection sheet needed to be identified to properly complete the inspection. All inspection sheets were collected and tabulated at the end of the experiment.

4 Data and Results

A total of 46 students participated in the experiment. 25 students used the 2D embed placement drawings to conduct the inspection while 21 students used the AR inspection method.

Table 2 tabulates the error frequency for each of the 15 embeds used in this experiment grouped by inspection method. An error was determined if the student inspector did not accurately identify the installation state of the mockup embeds. While conducting the experiment, some students using the AR inspection reported seeing illusions that obscured the reality of what was installed within the experiment room. The researchers identified these visual anomalies as *mirages* in Table 2. The frequencies identified for the *AR Inspection Errors* is independent of the *AR Mirage Errors*.

Table 2. Embed error frequency for each inspection method

Embed ID	2D Embed Placement Drawings Errors (*n*=25)	AR Inspection Errors (*n*=21)	AR Mirage Errors
10	1	1	-
12 Left	-	-	-
12 Right	-	-	-
14	3	4	1
15	24	11	1
16	-	4	1
21	22	1	-
23	-	1	-
26	-	-	1†
A	-	-	-
B	-	-	-
D	-	-	-
G	-	1	1
P	1	5	1
Q	-	1	-
S	-	2	2

† denotes an embed that was identified as a mirage and not a part of the experiment.

The researchers tabulated the errors per embed ID and calculated an accuracy score for each inspection method. The average accuracy for the 2D embed placement drawings was 86.4 out of a possible perfect score of 100. The average accuracy for the AR inspection method (not including the observed mirages) was 90.2 out of a possible perfect score of 100. A Two-Sample T-Test was calculated for the difference between the two averages. Eight outlier results were excluded to correct for skewness of the data. Assuming a Confidence Interval percentage of 95% (*CI*=95%) then $t_{(38)}$=-2.281802, *p*=0.0342029 ($p \leq 0.05$), resulting in a weak significance in the difference between the two averages.

5 Discussion

The weak significance resulting from the difference between the average accuracy scores for both methods leads to a conclusion that is somewhat indeterminant. In this section, the impact of the results are discussed along with suggestions for the outcome.

5.1 Visibility

The experiments were conducted during day-light hours. With the room lighting and the allowable natural light in the room, there were no significant shadows or dark areas of the room that could notably affect either method of visual inspection. Despite this fact, the data indicate that identification of embeds “15” and “21” were more successful when the AR method of inspection was used. Embed “15” was accurately reported 4% of the time using the 2D placement drawings and 48% using the AR inspection. Embed “21” was accurately reported 12% of the time using the 2D placement drawings and 95% using the AR inspection. Both embeds were simulated steel angles (yellow) and place in a *side* view when observed from the elevation view of the wall (example embed “15” shown in Figure 7). One embed was missing (embed “15”) and the other was installed (embed “21” see Figure 8).

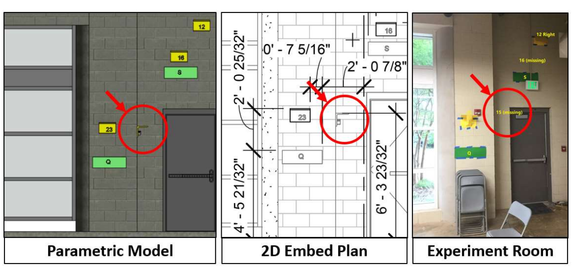

Figure 7. Placement of embed “15” (side view)

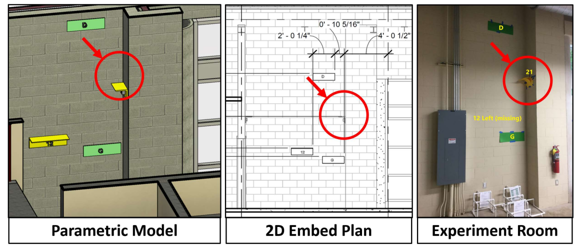

Figure 8. Placement of embed “21” (side view)

The low profile of these embeds on the 2D placement plans made it difficult to verify, especially when the embed was missing, as is the case for embed “15”. This condition is a reality for most construction projects. If an inspector takes 2D plans to the field for inspection and only observes what is available to them in an *elevation* view without querying for alternate *detail* views – omissions can occur. With the AR inspection, the original model is available, and an infinite amount of *views* are available to them by simply adjusting their physical position on the construction site – much like an inspector naturally does to inspect installed work at a construction project. Lastly, although the condition was not tested in this study, the embeds tend to be distinguished during the inspection process because a *colored* view was available during the inspection process using the HoloLens. Conversely, the monochromatic view when looking at 2D construction plans does not have this advantage which is why most inspectors tend to highlight their inspection drawings with colored annotations.

5.2 Accuracy

The findings are not strongly significant for the AR inspection method and the data indicate that the 2D embed placement plans were in most cases equally accurate. Aside from the visibility issue discussed for embeds “15” and “21” in the previous subsection, most of the time, the 2D plan inspection method had slightly fewer errors. For instance, embed “16” was a missing embed and was erroneously reported five times with the AR method. It was not erroneously reported using the 2D plan method. Additionally, embed “P” was also a missing embed and erroneously reported once with the 2D plan method and five times with the AR method. Nothing was controlled in the experiment to gather data for these occurrences; however, it is speculated that something within the AR inspection distracts the viewer while performing their inspection. As will be discussed in the next subsection, illusions were noted that caused some misreporting during the inspection process for the AR inspectors.

5.3 Mirages

During the AR inspection, it was anecdotally noted to the researchers that in some cases, the student inspectors could not see the embed or that there appeared to be an embed present, when in fact it was not. The researchers allowed for this condition by having the student inspectors note the aberrations in their inspection reports. As seen in Table 2, this occurred eight times. In two cases, a missing embed was not accurately identified as missing and in the remaining six cases, the embed was present but was missed in the inspection report.

During the experiment, the researcher needed to continually adjust the HoloLens for a condition called "drift" [8]. Drift was identified by the student inspectors as they conducted their inspection and would notice that the image of the model in the HoloLens was not superimposed accurately within the experiment room. In some cases, the difference was slight – enough so that the inspection could continue without stopping the experiment. At other times, the drift was noticeably distracting to the point that a satisfactory reporting could not be made. It is surmised that this condition was responsible for the mirages present during the inspection. This condition is not localized to the HoloLens, it is in fact a common issue within the AR discipline [9].

5.4 Limitations

While the researchers sought to minimize the conditions of the study that could adversely affect the results, upon completion of the experiment some elements became known that should be considered if the study were to be repeated.

5.4.1 Color and Shape

The researchers did not collect data explicitly regarding the shape and color of the embeds used in this experiment. In fact, the color of the embed was not typical to the actual color of an embed installed on a construction project (see Figure 9).

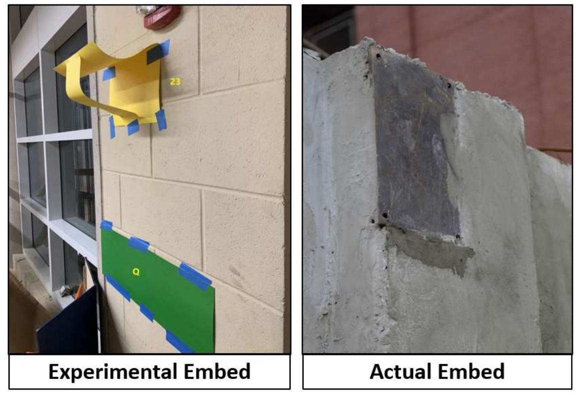

Figure 9. Visual comparison of experimental embed and an actual embed.

The difference between the two images in Figure 9 is obvious. Because this study was designed to establish a framework for future experimentation, it was not necessary to obtain data from actual conditions just yet. In future studies, the color of the surrounding material (concrete, stone, masonry, etc.) may not have enough contrast to make a successful inspection. Therefore, a consideration of the color of the embed and the color of the surrounding materials would be prudent.

5.4.2 Student Work Experience

This study was conducted with a convenience sampling that is not representative of practitioners in the construction industry. While the students that volunteered for this study do have some construction knowledge and skills, they lack experience and advanced visualization skills that more seasoned practitioners may have [6]. Consequently, the results when practitioners are involved in the study may yield different results. Again, future iterations of this study should be conducted with practitioners to obtain more practical results in the accuracy of inspection using the two methods.

5.4.3 Image Drift

Image drift is an issue when working with AR [8], [9]. This study did not collect data for this condition, including its effect on accuracy. However, a more detailed study should be attempted that ascertains the accuracy of the HoloLens when used for inspection, controlling for variables such as lighting (natural and artificial), temperature, reflectivity, and other items that may affect the visual acuity of the inspector.

6 Conclusions and Future Work

This experiment yielded a significance that was weak in terms of accuracy when student inspectors were trying to identify errors in embed placement. The data however, eluded to some interesting points about using AR as an inspection tool for embed inspections, and quite possibly for other types of inspections as well. In this study, the researchers aimed to create a framework that could be used in ongoing and future studies where AR is used to assist a construction inspector. One key finding that was advantageous when inspectors used the AR method was the visibility of certain elements that were difficult to find on a 2D plan. The drawback with using plans has always been the experience of the person reading and interpreting them [10]. In a time within the construction industry when many seasoned professionals are departing from the workforce [11], either through retirement or disability, their replacements (recent academic graduates) lack the experience to accurately perform these inspections at the same level as their predecessors. This experience gap creates a challenge and an opportunity that the construction industry has always seemed to face. When compared to other non-farming industries, the construction industry's productivity has not made significant improvements [12]. Similarly, the industry's focus on research and development has been paltry – yet may be improving slowly [13]. Therefore, the overarching goal for this research study was to set forth a framework that can improve accuracy, productivity, and fill the ever-widening skills gap in a small part of the construction process.

The researchers acknowledge that the practicality of this tool is *experimental* at the moment, however, through continued field experimentation and with the continual improvement in the hardware and software, there is promise for more advantageous results for the AR method.

Lastly, the researchers would like to express that future developments in this research will include an approach toward having the AR make use of artificial intelligence (AI) for the automatic recognition of embed placement errors. The inspector's attention could be drawn to errors that the AI finds, allowing the inspector to focus more on the serious problems and waste less time on the embeds that meet a certain threshold for accuracy. This process, if perfected, could save a tremendous amount of time for inspectors to perform more worthwhile tasks.

References

[1] D. D. de Saram and S. M. Ahmed, "Construction Coordiantion Activities: What is Important and What Consumes Time," *J. Manag. Eng.*, vol. 17, no. October, pp. 202–213, 2001.

[2] M. Saleem, W. A. Al-Kutti, N. M. Al-Akhras, and H. Haider, "Nondestructive Testing Procedure to Evaluate the Load-Carrying Capacity of Concrete Anchors," *J. Constr. Eng. Manag.*, vol. 142, no. 5, pp. 1–8, 2016.

[3] B. A. Mohr and S. K. Harris, "Marrying Steel to Concrete: A Case Study in Detailing," *Struct. Mag.*, no. November, pp. 34–36, 2011.

[4] O. S. Kwon, C. S. Park, and C. R. Lim, "A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality," *Autom. Constr.*, vol. 46, pp. 74–81, 2014.

[5] R. Azuma, "A survey of augmented reality," *Presence Teleoperators Virtual Environ.*, vol. 6, no. 4, pp. 355–385, Aug. 1997.

[6] J. Kim and J. Irizarry, "Evaluating the Use of Augmented Reality Technology to Improve Construction Management Student's Spatial Skills," *Int. J. Constr. Educ. Res.*, 2020.

[7] C. Thomsen and S. Sanders, *Program Management 2.0: Concepts and strategies for managing building programs (revised)*. The Construction Management Association of America Foundation, 2011.

[8] Y. Liu, H. Dong, L. Zhang, and A. El Saddik, "Technical evaluation of HoloLens for multimedia: A first look," *IEEE Multimed.*, vol. 25, no. 4, pp. 8–18, 2018.

[9] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent Advances in Augmented Reality.," *IEEE Comput. Graph. Appl.*, vol. 21, no. 6, p. 34, Nov. 2001.

[10] M. Alias, T. R. Black, and D. E. Gray, "Effect of instruction on spatial visualization ability in civil engineering students," *Int. Educ. J.*, vol. 3, no. 1, p. 12, 2002.

[11] McGraw Hill Construction, *Construction Industry Workforce Shortages: Role of Certification, Training and Green Jobs in Filling the Gap*. 2012.

[12] L. Sveikauskas, S. Rowe, J. Mildenberger, J. Price, and A. Young, "Productivity Growth in Construction," *J. Constr. Eng. Manag.*, vol. 142, no. 10, p. 04016045, Oct. 2016.

[13] JBKnowledge, "The 6th Annual Construction Technology Report," 2017.