From BIM to Inspection: A Comparative Analysis of Assistive Embedment Inspection

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Abstract –

Embedments (embeds) are used extensively in construction for the attachment of dissimilar construction materials, such as, concrete to steel and wood to concrete. Coordinating the layout, delivery, and placement of these embeds is a sensitive construction chore, one that if not done properly, can lead to considerable lost productivity, delayed schedules, and cost overruns. This coordination is further complicated by the fact that most embeds are installed in the project by one trade contractor to be used by an entirely different trade contractor later in the project. As a result, the construction manager undertakes routine inspections to minimize future complications if those embeds are missed or incorrectly placed. Therefore, it is crucial that the inspection process is as complete as possible to ensure a project's success. The construction industry is also shifting to a digital twin approach in the management of the construction process whereby parametric models are finding more use in the inspection process. Coupling this technology with augmented reality (AR) allows inspectors to use BIMs in unique and more informative ways. In this paper the researchers examine three different inspection processes, a traditional 2-dimensional paper inspection, an AR + BIM inspection, and an AR + BIM inspection with interactive queues. Quantitative data were collected with each method along with qualitative feedback from the participants to gauge perceived effectiveness of their inspection. Among the three methods, it was evident that the use of AR improved through its development. However, from the qualitative feedback, it was discovered that some visuals in the AR assisted inspection were distracting, leading the researcher to conclude that visual elements in AR can affect the inspection outcomes. Furthermore, the researchers discuss recommendations for using AR + BIM for embed inspections in the context of using assistive technology for that process.

Keywords –

Augmented Reality; Productivity; Inspections; Construction Quality

1 Introduction and Background

Coordination during the construction process involves risk and, in many cases, the practice of routine inspections enables a construction manager to manage this risk better than its competitors. The rewards for effectively managing construction risk are evident with increased profits for the construction manager [1]. The inspection process, regardless of what is being inspected, is a welcome process that minimizes cost and schedule impacts to a construction project [2]. The lack of good inspection practices, especially when multiple trade contractors are involved, compounds the problem. One such situation concerns the construction embedment (embed). Embeds serve to connect dissimilar parts of the project together, such as steel to concrete and wood to masonry. Their installation often relies on predicting, well in advance, what other materials will be affected if the embeds are not properly installed. Furthermore, it is ideal if they can be installed when the structure is being assembled and not afterwards [3]. Based on conventional structural design methodologies, if the embeds are not installed along with the construction of the structure several problems will arise [4][5], some of which include:

1. Drilling holes for a post-installation anchors that often compromises the internal structural reinforcing
2. Lost time related to re-design and retrofit of the structure for post-installation anchors
3. The added cost of re-design and specialized post-installation anchors

It is crucial that the inspection process happens, and that it is properly conducted. The research literature demonstrates that technology devices can be used as an assistive device for inspectors [6]. Technology devices using augmented reality (AR) as an assistive inspection tool is demonstrated in the research [7][8] and also has potential as an inspection tool where embeds are concerned. AR expands a wearer's view by adding a virtual overlay to their *real-world* view. In doing so, the wearer is provided additional details that are otherwise not readily available. 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 [9]. Therefore, the use of AR within the inspection process is arguably a viable enhancement.

2 Rationale and Research Aim

Understanding that missing embeds directly impacts the cost, schedule, and quality of a project supports the need for better tools to improve the inspection process. This necessity alone is a strong reason for continuing research that improves the inspection process.

The research described in this paper is a continuation in the development of a prototype AR inspection tool [10]. The tool has been designed to assist an inspection of embeds with comparisons to the more conventional methods of visual examination using two-dimensional (2D) paper plans. This paper documents the iterations of design with recommendations for future design improvements.

3 Methodology

This paper describes three independent procedures for inspecting embeds and analyzes the differences between them. The methodology for all procedures was the same so that analytical comparisons could be made that would directly inform future iterations of an assistive device that could be used to improve embed inspections. Two variables were analyzed in this study: the AR visualizations and the participants. While the researchers realize that participant variance may reduce the validity of the results, the researchers did attempt to solicit participation from the same population (undergraduate construction management students). The differences within the population will be described later.

The study was conducted using a between-groups design. All groups were chosen to perform an inspection of demonstration embeds within a controlled experimental space. The inspection consisted of identifying if an embed was installed or missing – installation accuracy was not measure in this study. There are known accuracy errors caused by image drift and parallax with the *Microsoft HoloLens* that were defined in Kim & Olsen's research [10]. Therefore, for the purposes of this study and comparison, only the accuracy in identifying if an embed was installed or missing was measured. The method of inspection differed between the groups and became the independent measured variable of the study. The participants of GROUP 1 were selected to visually observe the demonstration embeds using 2D paper plans. GROUP 2 was selected to use a *Microsoft HoloLens* (second generation) with AR visualizations developed using *Trimble Connect's* integration with HoloLens (https://connect.trimble.com/integrations-overview) as described in Kim & Olsen's research [10]. Lastly, GROUP 3 was selected to use the same *Microsoft HoloLens* as group 2 to conduct their inspection, but the AR visualizations were developed using *Enklu* software (https://www.enklu.com/). The differences between the AR visualization software will be described later.

3.1 Demographics

As previously mentioned, the researchers controlled the convenience sampling by selecting students from the same population where they had similar attributes. All students in all groups were postsecondary students in a construction management program in the Southeastern United States. The students were asked to participate as a part of their regularly scheduled class time. The students, at this point in their academic careers have taken plan reading courses, have an understanding of building information modeling practices, and several of these students have had a construction-related internship. Table 1 describes the academic classification of the students that participated.

Table 1. Participant's academic classification

Classification	GROUP 1	GROUP 2	GROUP 3
Freshman (first-year)	0	0	0
Sophomore (second-year)	0	0	0
Junior (third-year)	0	0	16
Senior (fourth-year)	10	16	9
Graduate (fifth-year +)	0	1	1
Population *n*	*n*=10	*n*=17	*n*=26

3.2 Setting

The experimentation was conducted in the same space as mentioned in Kim & Olsen's research [10] and is described again here. The 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.

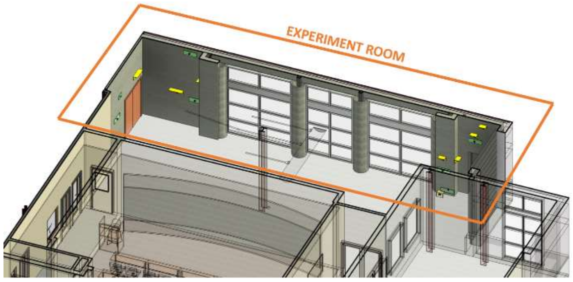

Figure 1. Rendering of the experiment room

The room in Figure 1 has exposed masonry walls and provided a setting to place demonstration 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).

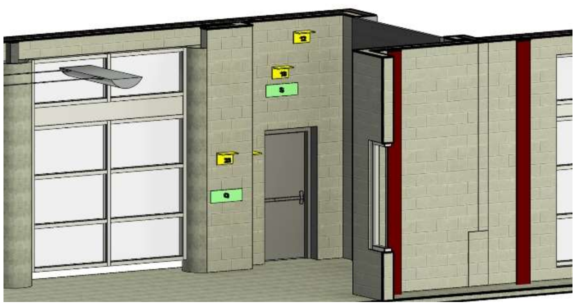

Figure 2. Closeup within the parametric model of experiment room showing embed placement

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

3.3 The Demonstration Embeds

The demonstration embeds were fabricated from rigid ¼ inch (6.35 mm) foam board and affixed to the walls of the experimentation space. Attention was given to having some of the embeds minimally contrast with the surrounding wall color of the experimentation space. It is reasoned that embeds on an actual construction project site are often difficult to find because they look similar in color to the surrounding structure that they are affixed to. Figure 3 shows an embed in the experiment space that contrasts with its surrounding color and Figure 4 shows an embed that minimally contrasts with its surrounding color.

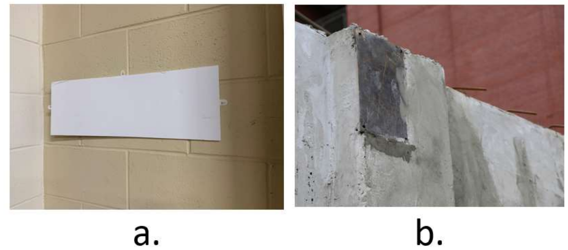

Figure 3. (a.) Demonstration plate embed and (b.) actual plate embed with contrasting colors

Figure 4. (a.) Demonstration angle embed and (b.) actual angle embed with minimally contrasting colors

3.4 2D Embed Placement Drawings

The parametric model used to layout the demonstration embeds in the experimentation space was created through a laser scan of the space that was later converted into a parametric model using *Autodesk Revit*. This model was used to create a 2D paper plan set that GROUP 1 used for their inspection. A partial illustration of the 2D paper plan is shown in Figure 5.

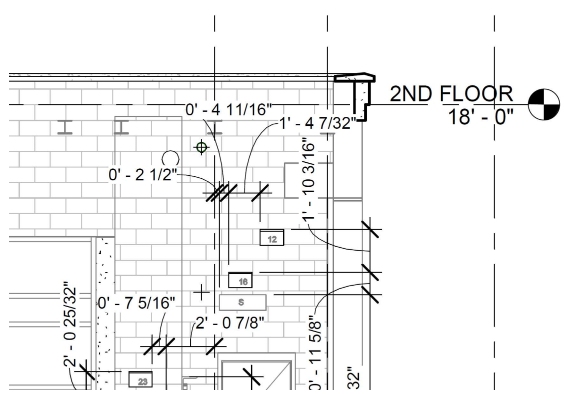

Figure 5. Partial image of 2D embed placement drawings

GROUP 1 used these 2D plans for their inspection of the demonstration embeds in the experimentation space.

3.5 AR Visualizations

GROUP 2 and GROUP 3 used the AR headset to conduct their inspections. The difference between GROUP 2 and GROUP 3 was the AR visualization. Two different authoring tools were used to create the AR visualizations and are described in the next subsections.

3.5.1 GROUP 2 – *Trimble Connect* AR

GROUP 2's AR environment was authored using *Trimble Connect*. With this authoring tool, the parametric model is uploaded to a cloud site and processed using *Trimble Connect's* proprietary software. The model can then be viewed in the Microsoft HoloLens once it is registered to the room's surroundings [12, p. 18]. In this experiment, the parametric model only included embed outlines and positional information so that the embeds, when viewed with the HoloLens would be superimposed over the real-world location of the demonstration embeds in the experimentation space. The student inspector would then be able to compare the AR view with the real-world view to assess an embed's installation state. A representation of the *Trimble Connect's* AR visualization is shown in Figure 6.

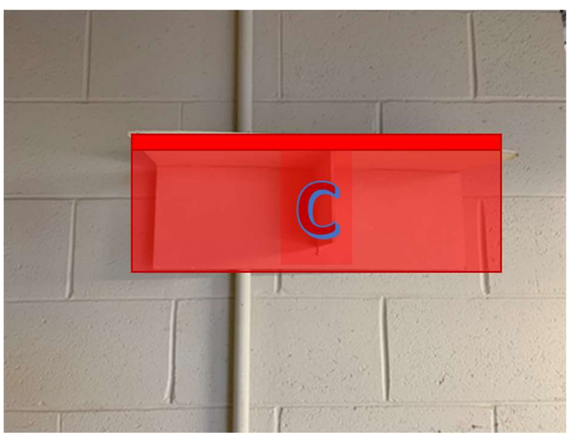

Figure 6. Representation of the *Trimble Connect* parametric model AR view

3.5.2 GROUP 3 – *Enklu* AR

The AR environment for GROUP 3 was authored using *Enklu*. This authoring tool makes use of the *Microsoft HoloLens*' ability to "spatial map" (https://docs.microsoft.com/en-us/archive/msdn-magazine/2017/january/hololens-introduction-to-the-hololens-part-2-spatial-mapping) the surrounding experiment space. In short, it is scanning the walls, ceilings, and floors of the space to anchor or register [12, p. 18] visual elements to the real-world space. *Enklu* uses this data and presents it as a canvas upon which interactive AR elements can be added that the wearer of an AR device can use. In this study, demonstration embeds were added as the AR elements – they were positioned in the "spatial map" so that the student inspectors could observe and compare the planned demonstration embed placement with its actual placement in the real-world. An illustration of the Enklu AR visualization is shown in Figure 7.

Figure 7. The *Enklu* AR view

Some technical limitations prohibit an actual *HoloLens* snapshot in this paper of the *Enklu* AR view. In Figure 7, when wearing the *HoloLens*, the yellow and green walls shown in this figure are not visible – the real-world walls are directly observed by the wearer.

The difference between the authored *Trimble Connect* AR experience and the *Enklu* AR experience is in the interactivity of each environment. It is intended that the differences between the two AR experiences is the independent variable that is measured. The differences are enumerated as follows (these differences were not measured independently for this study):

- The *Trimble Connect* AR visualization is static (no elements move).
- The *Enklu* AR visualization contains a pop-up menu that appears over a demonstration embed allowing the wearer to record the observed embed's installation state.
- The *Enklu* AR environment includes a prompting queue – there is a visual glowing dot that prompts the wearer where to find the next embed during the inspection process.

4 Data and Results

A total of 53 students (*N*=53) participated as representative inspectors for this study. GROUP 1 included 10 students (*n*=10), GROUP 2 included 17 students (*n*=17), and GROUP 3 included 26 students (*n*=26). The experiment was designed so that 14 demonstration embeds needed to be assessed by the students during their inspection. Each embed was predetermined to have a specific installation state as follows:

- INSTALLED – the embed was observed to be installed in the experiment space
- NOT INSTALLED – the embed was observed to be missing from the experiment space

The results of the student's assessment were recorded and tabulated for errors in observing the accurate predetermined installation state of the embed. The error frequency is tabulated in Table 2 for each embed.

Table 2. Embed error frequency for each group

Embed ID	State	GR 1 (*n*=10)	GR 2 (*n*=17)	GR 3 (*n*=26)
Plate 1	Missing	10%	35.3%	11.5%
Plate 2	No Contrast	0%	29.4%	26.9%
Plate 3	Contrasts	10%	5.9%	3.8%
Plate 4	Contrasts	0%	5.9%	7.7%
Plate 5	Contrasts	10%	5.9%	15.4%
Plate 6	Missing	10%	58.8%	15.4%
Angle A	Contrasts	0%	5.9%	3.8%
Angle B	Contrasts	0%	0%	0%
Angle C	No Contrast	0%	5.9%	3.8%
Angle D	Missing	10%	47.1%	3.8%
Angle E	Contrasts	0%	5.9%	3.8%
Angle F	Contrasts	0%	5.9%	3.8%
Angle G	Contrasts	0%	11.8%	7.7%
Angle H	Contrasts	0%	5.9%	3.8%
Mean	--	3.6%	16.4%	8.0%

5 Discussion and Analysis

For the purposes of reviewing the results, the researchers assign GROUP 1 as the control group since their method of inspection closely resembles the traditional method of construction quality inspections [13]. Therefore, GROUP 2 and GROUP 3 represent the independent variables of the study and the topic of discussion in this section of the paper.

Reviewing the error frequencies in Table 2, it is apparent that the control group has a lower mean error frequency (3.6%) – the tests groups have higher error frequencies (16.4% and 8.0%). This is an indication that if the process of inspection is to be improved by introducing AR, there are some improvements that need to be made. This experimental study describes one incremental step toward resolving this issue.

The researchers conducted inspection testing with GROUP 2 about three months before engaging GROUP 3 with the same experiment. The intent was to learn from the results found in the experiment with GROUP 2.

5.1 Analysis of GROUP 2

It was discovered through experimentation with GROUP 2 that the AR visualization often interfered with the inspection process – causing a larger error frequency. This is evident in the embeds that were missing from the experiment space (Plate 6 and Angle D) along with the embeds that had no color contrast with their surrounding structure (Plate 2 and Angle C). Each of these embeds had much higher error frequencies when the AR tool was used. The researchers concluded through this data and through anecdotal feedback during the experiment that the *HoloLens* impaired the wearers vision enough to make the assessment problematic for these embeds. It was further commented by one student that the AR visualization "got in the way of seeing if the embed was there or not". From this feedback and through analysis of the data, the researchers modified the AR visualization of the experiment before GROUP 3's turn to inspect.

5.2 Analysis of GROUP 3

The AR visualizations were re-designed using the *Enklu* platform. The researchers were attentive to the opacity of the embed visualizations – reducing the opacity enough to enable better inspection of the demonstration embeds. Cross comparing the error frequencies of GROUP 3 to the control group (GROUP 1) it is apparent that the error frequencies are more similar than those between GROUP 2 and the control group. While the control group's error frequency is still lower, the gap has tightened and GROUP 3's error frequency in most cases has dropped by half. The only exception to this is Plate 2 where the error frequency to that of GROUP 2 is nearly identical. In short, it appears that it is difficult to make an accurate assessment when the color of the embed matches its surrounding structure's color.

5.3 Limitations and Future Work

While the researchers sought to minimize the conditions that could affect the result of this study, it became apparent that some elements of the experiment should be considered if the study were to be repeated.

5.3.1 Lighting

The researchers acknowledge that lighting is a significant issue with AR [14]. In this study this element was not controlled. Although lighting (luminance) data was collected, it was inconclusive about how this may have affected the research results.

5.3.2 The Subject of Inspection

This study was intentionally limited in its scope; choosing only to analyze installation state of the embeds.

It is recognized by the researchers that installation accuracy is also a significant quality issue when embeds are concerned. However, as explained earlier there is an inherent limitation with the Microsoft HoloLens concerning image drift that makes a comparison of using AR for this type of inspection problematic. In the future, analysis of accuracy should be considered and added to the comparison once hardware improvements are made.

5.3.3 The Inspectors (Students)

This study used a convenience sample of students that were marginally experienced in the inspection of embeds. For the purposes of the methodology, students were consistently used throughout the three different studies to control for "experience" bias. Future iterations of this research should be conducted with willing and "seasoned" inspection practitioners.

5.3.4 Headset Design

The findings in this research lead to the conclusion that the AR visualizations interfere with the inspection process. This was discovered for both GROUP 2 and GROUP 3. The *Microsoft HoloLens* (second generation) has a flip visor that allows the wearer to remove the AR visualization by flipping the lens up allowing the viewer to see the real-world view unobstructed, see Figure 8.

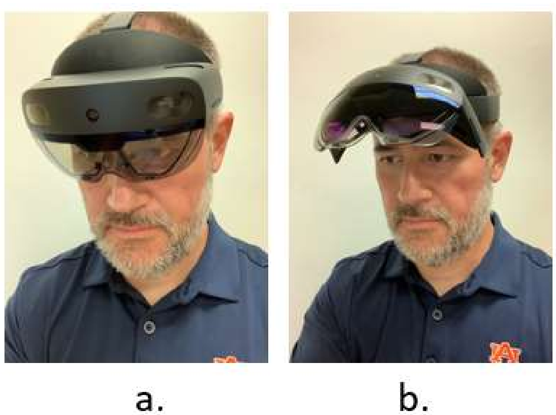

Figure 8. (a.) HoloLens with visor down and (b.) HoloLens with visor up

Conditions in a future study should include this as an option for the student inspectors where a simple removal of the AR visualization could resolve the interference present in this study.

6 Conclusions

This is a continuing study that has evolved as newer iterations of AR technology, both hardware and software, have allowed for improved results when using AR as and assistive technology. Aside from the limitations discussed in the previous section of the paper, the authors contend that a broader experimentation including revised hardware, the inspection and measurement of embed placement accuracy, and the timing of the accuracy (i.e. inspection before the embed is cast in-situ or afterwards) are all variables to be measured. The motivation to undertake this study emerged from the necessity to improved quality and productivity in an industry that is often viewed as failing in both [15]. It has been reasoned that one of the root causes for poor construction quality is the lack of proper inspections [1][3][4] and the authors contend that early inspections can help minimize or eliminate retrofit work that disrupts productivity.

During the experimentation the researchers observed that some of the student inspectors were overly distracted by the "new" technology. The authors contend that that distraction was a good thing and once the normalcy of AR technology takes root in the construction industry, we may see more innovative ways in which the technology can improve the industry's reputation.

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