

Applications of Augmented/Mixed Reality Head Mounted Displays in the Construction Industry

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In the last two decades, the construction industry has begun to adopt new technologies to help improve safety and quality and minimize time and costs associated with construction projects. Industries combining the use of virtual and physical data discovered that most mistakes arise due to disconnect between a user's view of the real-world and what they are comparing it to in 2D sketches or a 3D model. This disconnect is one of the major contributing factors to costly change orders during project execution. The use of optical Head Mounted Displays (HMDs), capable of superimposing holographic images into a real-world space, is being considered by several researchers and practitioners as a possible remedy. HMDs use augmented/mixed reality concept as a platform for their execution. These advancements are leading us to entirely new ways of thinking and visualizing construction processes. The future of technology in the construction industry points to wearable technologies, though more research is required before HMDs or similar technologies can be readily used. Many of these technologies are currently in beta testing stage and require further examination before being implemented on a larger scale. This pilot study identifies applications of HMDs in the construction industry. Microsoft HoloLens is tested as a potential visualization tool to determine its usefulness and limitations in comparison to traditional 2D sketches or 3D models.

Keywords: Augmented Reality, Mixed Reality, Head Mounted Displays, Microsoft HoloLens, Construction Technology

Introduction

The world of technology is ever changing and evolving. Currently, Augmented Reality (AR) or Mixed Reality (MR) headsets are on the forefront of new technologies being tested and tweaked. The AR/MR technologies superimposes a computer-generated image on a user's view of the real world, thus providing a composite view. There are various display forms of AR/MR, including monitor-based, see-through, and spatial. Many industries have already started researching how AR/MR Head Mounted Displays (HMDs) can apply to everyday tasks or as a tool for enhancing user experience. The construction industry is one such industry where the applications of AR/MR are potentially endless. Researchers are hoping to produce tools that can help with cost and time savings, while also enhancing safety and quality. It is important to note that at this point the distinction between AR and MR is not clearly enough drawn and both terms are currently being used interchangeably (Wang *et al.*, 2013a).

According to an Engineering News Record (ENR) article written in 2015 (Rubenstone, 2015), wearable technologies that mimic what workers already wear on a daily basis is where the era of new technologies is leading us. For example, the smart hard hats with a built-in 3D visual display that superimposes information onto the wearer's field of vision, can guide workers how to operate machinery or where to place interior wall partitions on a slab. Safety vests with vital sign recognition capabilities can determine levels of heat exposure and heart rate. Vests with GPS tracking can monitor a worker's position in relation to an equipment or a danger zone (*ibid*, 2015). Whether the goal is ease of use, an increase in quality, a decrease in costs and time to completion, or increasing safety on the jobsite, this is just a small sample of the many ways wearable technologies can impact the construction industry. AR/MR technology is still a rare thing on a construction jobsite, but designers are already utilizing this type of technology for owner/client visualization and walkthroughs. It won't be long before AR/MR wearables will migrate us out of the design phase and into construction. There is still much research to be done before this becomes a real possibility. The technology exists, but funding and testing will need to continue before it can shape more than a great idea. As John Carpenter of Caterpillar stated in an ENR excerpt, “The capability is here now. The question is getting it to work with all of the foreign material and dust” (Rubenstone, 2015).

Review of Literature

The Architecture, Engineering, and Construction (AEC) industries rely heavily on visualization, integration, and collaboration in order to turnover high quality cost effective projects to their end-users. In the last two decades, design and construction industries have begun to implement new technologies, such as Building Information Modeling (BIM) and/or Laser Scanning, as tools to improve the quality, time and costs associated with construction projects. Although BIM has now become essential part of the design and construction industry, there is still a need for integration of real-time, on-site applications (Heydarian *et al.*, 2015; Wang *et al.*, 2013b). Industries that combine the use of virtual data and physical data are discovering that most mistakes arise due to disconnect between a user’s view of the actual site and their perception of the 3D model. Construction often requires the viewing of detailed sections of information from construction documents while on site, so this disconnect is a contributing factor to change orders and punch list items. For example, a construction worker cannot walk around a construction site and view the BIM model overlaid on the wall to see if the structure is built as intended. They are instead carrying around a laptop or tablet with the 3D model and information loaded on to it. If the model could be overlaid onto the physical building, this would eliminate the disconnect (White *et al.*, 2014). Bae *et al.* (2013) stated that "Automated, on-demand, and inexpensive access to project information on-site" could decrease the time it takes to make decisions and perform operations and management activities. This information also helps with jobsite progress monitoring and would reduce overall time and costs (*ibid*, 2013). To address this, new technologies have emerged such as Virtual Reality (VR), which has translated into Augmented Reality (AR) and Mixed Reality (MR) technologies. These advancements are leading us to entirely new ways of performing design and construction processes. The future of technology in the construction industry points us to wearable technologies. Companies are currently looking to bring wearable technologies onto their jobsites by starting with items already being worn by construction workers such as boots, vests, hardhats, and safety glasses. The idea behind this is that adoption of new wearable technologies will be easier if the workers are not having to add additional items to their everyday work attire. VR and AR/MR technologies are still a new concept for the construction industry, but many design firms are already using these technologies for virtual client walkthroughs. It is exciting to see how these new technologies will be adapted into the construction industry (Rubenstone, 2015).

Construction Applications

There are many applications of AR/MR technology in the construction industry, including safety and context awareness, and projectable information using holograms. According to an ENR article written in 2016, AR/MR is currently being used in the construction industry for building-to-specifications by visually seeing dimensions, section details, etc., while in the act of physically building (e.g. a bathroom pod). In a controlled environment, a worker built the entire pod with no tape measure, level, or written instructions - they simply put on a HMD (such as Microsoft HoloLens) and began work. There is still more research to be done outside a controlled environment, but this is a very promising area of application in the construction industry (Rubenstone, 2016).

The construction industry is one of the most hazardous industries with construction jobsites being considered one of the most dangerous places to work. Construction workers play a vital role in their own safety by how they behave on-site; a worker can follow every protocol set but can still make a bad decision which puts him/her in harm's way. Safety management relies on the ability of construction workers to analyze their surroundings; this is known as hazard recognition. Safety training is usually delivered through on-site workshops or training sessions, but these traditional methods do not always generate the intended results due to poor design or execution of the curriculum. A survey of 105 workers who participated in the OSHA 10-hour course cited dissatisfaction with the way the course was taught (Sacks *et al.*, 2013). In an attempt to improve the education and training of construction workers, technologies such as AR and VR are being integrated. The use of VR for safety training began years ago, with the introduction of flight simulators, which were proven to be very effective for safety training. VR was also used to simulate surgical procedures for training doctors without having to train on humans or animals which would greatly increase the risk (Sacks *et al.*, 2013). The interaction within a virtual environment allows for the use of perception, memory, and decision-making, which can lead to better understanding of safety hazards on-site (Bhoir and Esmaeili, 2015). AR/MR creates immersive learning environments which may be able to reduce safety risks prior to the project start. AR/MR allows users to view potential hazards and also react to them in a virtual environment (Pedro *et al.*, 2016). Research done by Albert *et al.* (2014), developed an AR interface called SAVES. SAVES is a "user-controlled system" which provides clues in the 3D environment for locating hazards. Once the hazards are identified, a real-time feedback is provided to the users (Albert *et al.*, 2014).

The importance of accessing on-site information was discussed earlier; despite this, most current progress monitoring systems are time-consuming and visually complex. Bae *et al.* (2013), proposed an AR system that identifies the location of field personnel. This would allow the user to understand where he/she was on the jobsite and could then access stored information and see it overlaid on top of real-world 3D imagery of the site. This allows the user to be more aware of what context they are in for safety purposes, but also for purposes such as simulation of a new structure onto an empty lot or visualizing a renovation plan while standing inside an old structure. AR/MR technology can also provide visualization of as-built structures versus as-planned, and also visualize construction progress if data is available (Zollmann et. al., 2014).

Applications of AR/MR based Head Mounted Displays (HMDs) in Construction

The section will present three scenarios, applicable to the construction industry, where AR/MR HMDs (specifically the Microsoft HoloLens) can be effectively used. Scenario 1 is based on hazard identification (safety), scenario 2 explores design visualization in a real space (renovations), and scenario 3 depicts the use of HMD's in building a modular bathroom component (new construction).

Scenario 1 - Safety in Construction (Hazard Identification)

Safety is a huge area of concern in the construction industry, and it has already become an obstacle in the adoption of wearable technologies. An ENR article written in 2016 discussed this concern by stating that augmented or mixed reality headsets are not safety-certified and even if the technology is approved, it is likely that resistance from safety managers who do not want a constant distraction in their field of view, will occur (Rubenstone, 2016). Due to this reason, the construction industry is currently utilizing more VR technology because VR scenarios are not a part of the real-world. That being said, the Microsoft HoloLens and other AR wearable headsets may still have a use on the construction jobsite. If the MS HoloLens could be preloaded with safety information that can be worn by a safety manager on site, he/she may be able to view potential areas of safety hazards and have a warning symbol that indicates where this potential hazards are and help him to "check off" the safety list. For example, any building over 2 stories would need a fall hazard remedy implemented by way of railings, any low hanging structure would need to be marked for equipment managers to determine access issues, and any workers on a roof would need to be tied off (Sacks *et al.*, 2013). The safety manager could wear the HoloLens, which would show him a number of predetermined hazards with colored markers that could be located, via GPS, and overlaid on the model (Figure 1). He could go down a virtual checklist to make sure those major hazards have been mitigated. In addition, a safety manager could use the HoloLens to review all the marked safety hazards overlaid directly onto the site. This would be one of the most effective ways to utilize the HoloLens without added safety risk to workers.

Figure 1: Use of MS HoloLens for Hazards Identification and Safety Planning. (*images courtesy HITT Contracting*)

HMDs may not be the sole answer for jobsite safety issues, but combined with other wearable technologies may be useful in assessing jobsite safety. For example, a smart hard hat with a 3D display visor could monitor construction workers' vital signs as well as their proximity to danger zones. Safety precautions could be projected via augmented reality in known hazardous areas or in hazardous situations. The smart helmet would need to be able to collect data from movement and behaviors of workers, as well as the jobsite itself. This would be done by equipping the helmet and 3D display with sensors that can send alerts to the users when they are about to, or have, entered a dangerous situation. Monitoring proximity to machinery and vital signs of workers can help to minimize health and safety risks on the jobsite (Friedman, 2015).

Scenario 2 – Enhanced Visualizations

Another application of the HMDs (such as Microsoft HoloLens) is enhanced visualization. Imagine seeing exactly where an element will be placed on the site, ahead of time, or seeing how furniture fits in every room before it is even ordered. Designers are already taking clients on 3D virtual tours of their facilities and using the MS HoloLens for owners to view design options. Retailers such as Lowe's have even partnered with Microsoft to work on an in-store headset where you can pick out kitchen equipment layout, paint colors, cabinet types and more (see Figure 2). Lowe's utilizes two blank walls that mimic an unfinished kitchen, they then overlay a room hologram that, connected with a tablet app, can be manipulated to whatever finish the owner desires (Erikson, 2016).

Figure 2: Use of HoloLens for Kitchen Remodeling. (*image courtesy Lowe's Inc. and Microsoft Corp.*)

Visualization tools are used by design and marketing professionals on a daily basis. The question that lingers is how to adopt this tool as an asset to the construction phase. A good example might be seeing machinery, in a space designed to house it, before dropping it in to make sure it fits. This can be done by simply viewing a hologram of the machinery on a 1:1 scale via the HoloLens. Specialized equipment rooms, such as MRI rooms in hospitals, need to be built to exact standards. In most cases, this specialized equipment is not even ordered until construction is sufficient and the machinery is ready immediate installation. Once the specs are determined and the room size is calculated, the machine can be exported as a hologram to the HoloLens and put inside the room before delivery. If any size restrictions arise, the room can be changed before it is too late. Another example might be viewing the airflow of an air diffuser in a room. Being able to visualize how a diffuser will distribute air in a room would make it easy to determine if the equipment is sized correctly. An air conditioning company called Galanz and Casper is already prototyping a model to do just that (view https://www.youtube.com/watch?v=HWZ10NjmjwE).

Scenario 3 – Building-to-Specifications

A third scenario where the construction industry may begin to see the adoption of the HMDs (or HoloLens) is in controlled modular construction environments. In an article ENR mentioned a contractor out of California, Martin Bros., who utilized the HoloLens to frame a bathroom pod (Rubenstone, 2016). The contractor relied solely on visual cues to build the bathroom from the floor up. Studs were put in place without a level or a tape measure since the dimensions were preprogrammed into the hologram. As long as the hologram is spatially mapped to the area, errors would be minimized and corrected in comparison to traditional stud layout.

Figure 3: Use of HoloLens for building a bathroom pod using a hologram. (*images courtesy Martin Bros., CA*)

The layout of interior partitions and exterior studs, on top of a slab on grade, would be a great area to start exploring. A modeled hologram could have all interior and exterior wall lines preprogrammed into the model so the studs could be put in without measurements or calculations in the field. The same idea would go for framing and placement of door and window openings. All the information would be preprogrammed by designers, or virtual design and construction coordinators, without ever stepping foot on site. Technology such as the Microsoft HoloLens has a potential to minimize human errors by allowing workers to have the exact measurements and layout points at their fingertips. Hologram technology even has the potential to highlight areas that do not line up after installation, with a simple scan of the area based on programmed spatial cues and light reflection off objects - much like a total station does with the laser light (Rubenstone, 2016).

Research Aim and Methodology

The aim of this research study is to investigate the usefulness of AR/MR based Head Mounted Displays (HMDs) in a classroom setting and to determine their effectiveness in improving students' understanding of construction drawings. Microsoft HoloLens is used as a preferred HMD due to its easy setup and non-dependence on any external computer hardware (e.g. high-end graphics computers). Ten students in the advanced Construction Information Technology class were selected for this study. They were first asked to view a 3D model of framing for a bathroom pod built in SketchUp (See Figure 4, Left).

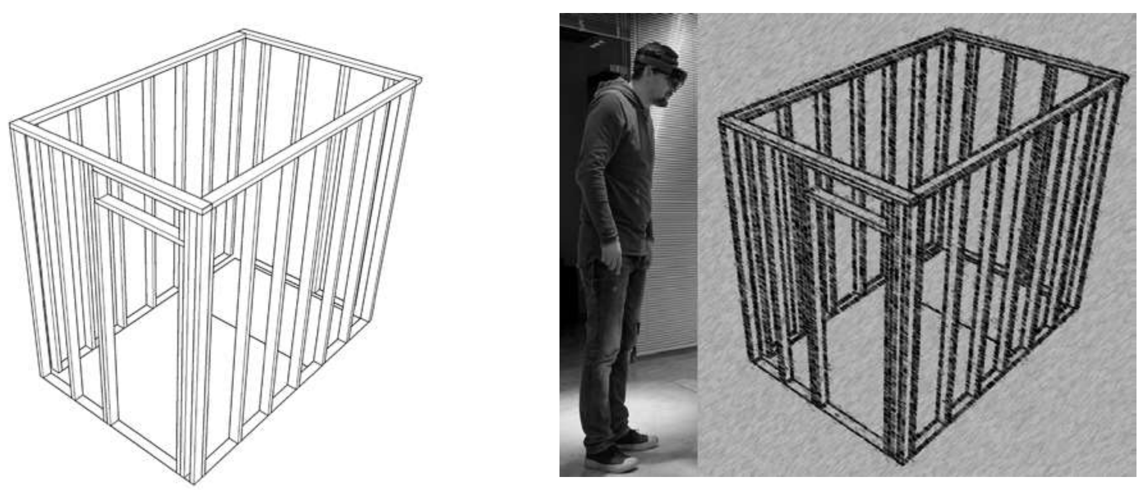

Figure 4: (Left) 3D Framing Model in SketchUp; (Right) 3D Framing Model Hologram in MS HoloLens.

After that, the same group was asked to view a 3D holographic model of the stud walls via the HoloLens (see Figure 4, Right). Before viewing any models, the participants were asked to answer the first question of a questionnaire (see Appendix A) about their perceived usefulness of a hologram in building a modular bathroom. After viewing both models, participants were asked to answer 4 more questions. The purpose of this questionnaire was to answer these key question:

1. What is the perceived usefulness of a 3D Hologram in Building-to-Spec prior to seeing it in action?
2. What is the perceived usefulness of a 3D Hologram in Building-to-Spec after actively viewing both models?
3. Do participants prefer the traditional 3D SketchUp model or the 3D Hologram model?
4. If participants were asked to frame this bathroom, would they be comfortable using the HoloLens? Why?

The questionnaire analysis and main findings are shown in the next section.

Main Findings and Discussion

Tables 1 shows survey results about perceived usefulness of the HoloLens in Building-to-Specifications and students' preference of technology. Please refer to questionnaire in Appendix A while looking at the results.

Table 1

Perceived usefulness of the HoloLens in building-to-specifications and students' preference of technology.

Level of Interaction	Average Score	Model Type	Preference
Perceived usefulness prior to interaction with the HoloLens	6.0	3D Model	10%
Perceived usefulness after interaction with the HoloLens	7.5	Hologram	90%

The results show that the students' perceptions about the usefulness of the HoloLens increased after viewing the capabilities of a holographic model in a real-world setting. The results further indicate that only 10% of participants preferred the typical 3D Model over a holographic model if given the choice to build with either option.

Figure 5 shows results about students' confidence and comfort levels of using the HoloLens, which indicate that on average the students' confidence and comfort level is pretty good. Seventy percent (70%) of the respondents stated they were both confident and comfortable using the HoloLens vs. a traditional 2D drawing or a 3D model. An additional 10% indicated they would be extremely confident and comfortable.

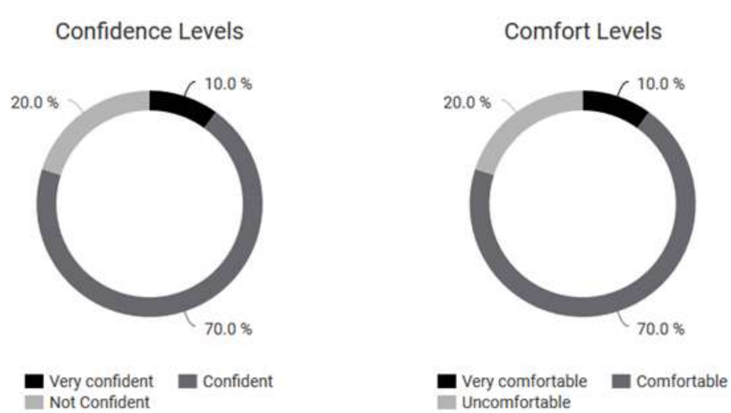

Figure 5: Students' confidence and comfort levels of using the MS HoloLens.

Survey participants were then asked to point out positive and negative attributes of using HoloLens (or a holographic model). The results (see Figure 6) indicate that there was an overwhelmingly positive outlook on the use of the HoloLens as a tool for framing a modular bathroom pod. Seventy-six percent (76%) of the responses were in favor of the HoloLens use. Thirty-two percent (32%) stated that because the model includes accurate and detailed information, they would be confident using the HoloLens in future projects. Twenty-nine percent (29%) mentioned that the HoloLens is a good visualization tool that would significantly aid in better understanding construction drawings and specifications. Fifteen percent (15%) stated that it would make the overall building and layout of the bathroom much easier. Only 24% of participants indicated a negative outlook, 9% indicated that it would be difficult to trust the accuracy of the model, 6% mentioned that the current conditions, such as an un-level floor slab, might hinder the accuracy of the hologram and that the nature of the HoloLens might lead to a hindered field of vision making the physical use of the HoloLens difficult. Three percent (3%) also indicated concerns that a high level of expertise may be needed in order to properly frame a bathroom with just a holographic model.

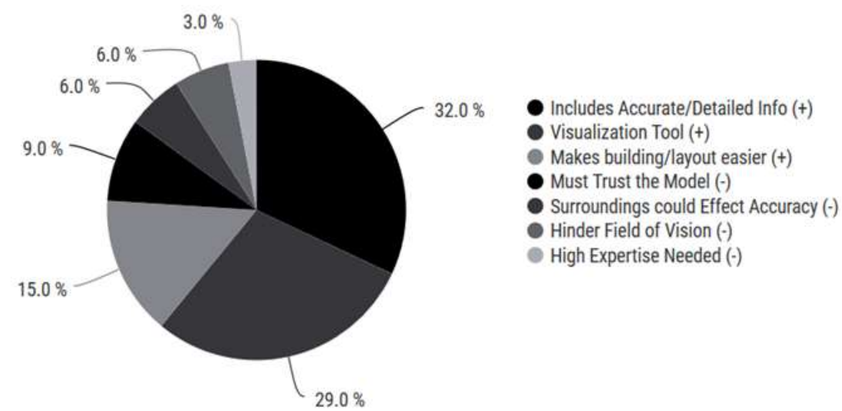

Figure 6: Reasons for, or against, the use of a Holographic model vs. traditional drawings and 3D models.

Concluding Thoughts

The goal of this pilot study was to determine the level of perceived usefulness by participants, prior to, and after viewing a holographic model. Questions were also asked to determine the reasons behind each individual participant's perceptions. From the findings discussed above, it has been determined that perceived usefulness of the HoloLens to aid in framing a bathroom increased after the use of the device. This indicates that there is a need to provide proper training and education before implementation should be considered. The results also indicated that over 70% of users would rely on the use of a holographic model to aid in the ease and speed of construction if asked to do so. It was also determined that 80% of users were confident in the holographic model's accuracy and comfortable with the use of the holographic model as a tool (for framing). However, it is important to note that the holographic technology is still in its infancy stage and there are many limitations that for the time being prevent use of this technology at a larger scale. Holograms are very light sensitive, thus sunlight is not conducive to hologram projection. Since sunlight is a common occurrence in construction, a way to overcome this barrier will be needed before holograms make their way on to construction sites. Secondly, there is the need for reliable applications to be developed specifically for the construction industry. Prior to having full usability by construction professionals, and not just by computer programmers, apps that can connect data to models with ease will be needed. These downfalls will need to be overcome before full integration of the HoloLens and other HMD's in the construction industry. And lastly, as discussed previously, there are safety concerns due to the visual hindrances an HMD introduces to a user's field of vision. The HoloLens and other 3D AR/MR technologies show promise in mitigating jobsite risk, but the nature of this wearable technology still has some growing to do before it is considered a safe practice. AR/MR technology still have a long way to go before being fully integrated, at a higher functional level, in any industry. Manufacturing and industrial sectors, where environments can be more controlled, will be the first to fully integrate this technology. The need for mobile and on-site applications is present and many platforms for running this technology is still in the beta testing stages. Only time will tell which of the current wearable technologies will make their way into the construction industry.

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Appendix A - Questionnaire

1. On a scale of 1-10, how useful do you see a HoloLens holographic model to be, in building a modular bathroom?
2. Now that you have viewed the model, how useful do you see a HoloLens holographic model to be, in building a modular bathroom?
3. (A) If you had to choose, which model would you like to use for building this bathroom? (Circle your answer); (Option 1) 3D Model (Revit/Sketchup); (Option 2) HoloLens Holographic Model; (B) Why? Please explain.
4. If you were told to build a bathroom based solely on a holographic model (circle your answers):

4a. How confident would you be that the data is accurate?	Very Confident	Confident	Not Confident	Extremely not confident
4b. How comfortable would you be using the holographic model & HoloLens, vs. other methods?	Very Comfortable	Comfortable	Uncomfortable	Extremely uncomfortable

5. What are the two main reasons for your answers to Question 4 above?