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Uses of Augmented Reality Technology During Construction Phase

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Abstract
Widespread implementation of Building Information Modeling (BIM) in the Architecture, Engineering, and Construction (AEC) industry has revolutionized the way professionals design and visualize their projects. BIM can provide design professionals with a 3D model that can encapsulate a structure, and also contains accurate building information within the model. In the last decade, major advances in augmented reality (AR) technologies have made it possible to bring the 3D models created by a project's designer into the field. The aim of this research is to investigate the benefits and challenges of currently available augmented reality technology for construction uses during a building project, to examine the current technologies used during construction phase as opposed to design phase, and to determine the long range potential for AR technology uses by the building trades. The methodology of this research used interviews with general contractors and technology companies working in the field of augmented reality. The data collected through the interviews was compiled, analyzed, and reported in this paper. The outcome of this research provided insight into a technology that has lots of potential but is still not sufficiently developed and available for widespread implementation on construction jobsites. The interview findings discussed present uses of AR, opportunities and challenges of using augmented reality, and hopes for how the technology could be applied. The main risks of augmented reality are the costs associated with implementation, and the extent that the technology is ready to be used in the field.

Keywords
Augmented Reality, Building Information Modeling, Construction

1. Introduction

Widespread implementation of Building Information Modeling (BIM) in the Architecture, Engineering, and Construction (AEC) industry has revolutionized the way professionals design and visualize their projects. BIM can digitally represent the physical and functional characteristics of a building, and adds realistic information to elements that could once only be represented in a 2D version. BIM can provide design professionals with a 3D model that can encapsulate a structure, and contains accurate building information within the model. But what happens after a project is designed? Being able to look at a 3D rendering of a building system is great for dealing with customers and investors, but what application does it have to actual constructability, and collaboration between the architects and engineers and the building trades?

In the last decade, major advances in virtual reality technologies have made it possible to bring the 3D models created by a project's designer into the field. A special class of virtual reality technology, Mixed Reality (MR), is used for creating environments wherein the real world and the virtual world are

presented together in a single display (Wang et. al 2004). A subset of MR with particularly great potential for construction applications is Augmented Reality (AR), which can insert models stored and interacted with in virtual space digitally into a physical space where actual work is taking place. As the technologies develop, MR and AR have the potential to build on the success that BIM has already found within the AEC industry and eliminate the need for traditional 2D drawings and plans altogether. The technology will allow the AEC industry to better envisage designs, detect issues during construction, improve safety, and potentially reduce cost and waste by better understanding the project at hand.

Applications for the use of augmented reality technology in construction are still being developed, and mainstream adoption isn't universal except some building projects that have used augmented reality technologies. AR technology can provide major benefits on construction projects such as real time visualization of projects, improved collaboration and communication, increased safety, better-quality scheduling and budget-management, and greater implementation of BIM (Jones 2014). In an application of AR technology for earthquake reconstruction answered many questions about how the technology can be applied on an ordinary building project, and what the potential and challenges of Augmented and Mixed Reality could be (Williams 2011).

2. Research Aim, Objectives and Scope

The aim of this research is to investigate the application of currently available augmented reality technologies during the construction phase of a building project, specifically relating to as-built, quality assurance, and safety. To achieve this aim, the following objectives have been set.

1. To investigate the benefits and challenges of currently available augmented reality technology for construction applications.
2. To compare the AR technologies used during construction phase with design phase.
3. To determine the long-term potential for AR technology applications for building trades.

The research scope is limited to general contractors who have previously used or are currently using augmented reality technology, as well as software developers who developing augmented reality technology for construction applications.

3. Literature Review

3.1 Mixed and Augmented Reality Defined

Virtual Reality is in one form or another nearly 50 years old. The use of virtual reality and its associated technologies, such as augmented reality, to support construction is nearly 25 years old (Cleveland 2010). Augmented Reality is an environment where virtual elements are embedded in a live picture of real surroundings. It combines the real world and computer generated data (Wang et al. 2013). AR is an environment where additional data generated by a computer is fed into the user's view of a real scene. Augmented reality systems are generally composed of three elements: data, computing, and presentation (Meza et al. 2014). The general explanation of Mixed Reality technology is that it encompasses the continuum of combinations of elements from both the virtual (computer generated) and real environments (Dunston & Wang, 2005). Figure 1 illustrates the continuum.

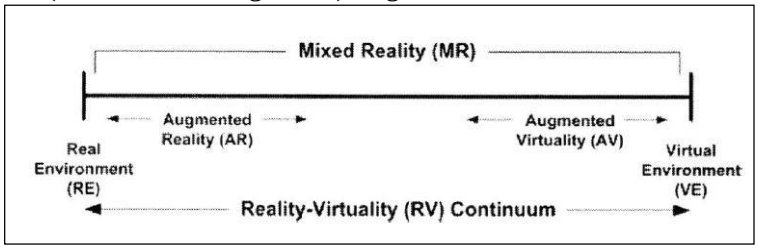

Figure 1: Reality-Virtuality Continuum

3.2 Augmented Reality Technology in Architecture, Engineering, and Construction

The AEC industry constitutes a market for using AR technologies and not having to return to an office to access a conventional desktop PC or laptop (Dunston & Wang, 2005). AR can supplement the user's normal experience using context-related objects, such as looking through walls to see columns, or beneath the ground to inspect subsurface utilities that have been installed. From the perspective of evaluation, authentic virtual models can be deployed to measure the physical condition of real objects, such as evaluation of earthquake-induced building damage, or construction progress monitoring (Kamat, et al, 2010).

Other uses for the AR technology related to construction is to train heavy equipment operators to use the machinery in an inexpensive way. Simulations of earthwork situations can be created. Further uses of AR may include using virtual tags surrounding the real instrument panel to learn the function of each item, step by step instructions for starting procedures, watching pre-recorded training video or automatically popping up of safety instructions (Wang et al., 2004). Research has also shown that the understandability and usability of project documentation in different formats including 2D plans, BIM on a PC, the viewing of schematics on tablets, and augmented reality, the comparisons showed that AR was at least one grade better than any other presentation technique (Meža et al., 2015).

3.3 Integration of Building Information Modeling and Augmented Reality Technologies

Studies have analyzed the potential for how augmented reality technology can be used to efficiently implement a BIM-based augmented reality system for construction (Meza et al. 2014). Augmented reality can be used for the real-time visualization and monitoring of activities and tasks. The integration of BIM with AR can provide a platform for a site management team and sub-contractors to effectively interact and utilize data contained within a BIM model (Wang et al. 2013). BIM could be used to model and store digitally much of the documentation associated with a project, yet it would eventually all be printed out and used on a construction site in physical 2D form. Researchers are now trying to facilitate the process of mapping 2D design documentation to 3D real world construction reality by mixing virtual information with the real environment, using augmented reality (Meza et al. 2014). Figure 2 shows how a worker on a construction site could use a mobile device to view a 3D model overlaid onto the real world.

Augmented Reality is regarded to be an 'information aggregator' that can collect and consolidate information from individual tools such as BIM, and also from context-award sensors. AR can visualize as-planned BIM facility information in the context of the real workplace to enable project managers, subcontractors, and other shareholders to review the as-built progress against as-planned. Using augmented reality, a construction manager on site can detect the potential conflicts by retrieving and visualizing all the properties and details concerning building elements from BIM (Wang et al. 2013).

Figure 2: Using AR on a Mobile Device

3.4 Augmented Reality Uses for Construction Quality Assurance

Advanced technologies such as BIM and AR can enable the storage and retrieval of defect data visually. These technologies provide great opportunities to enhance construction quality assurance work. Using these technologies, workers and managers can automatically confirm results of tasks by augmenting virtually created information onto real objects or even photos taken of the work performed on site. These innovations have the potential to allow site quality and trade managers to identify and address quality issues that would in effect save time and reduce rework related costs at construction sites (Kwon et al. 2014). Augmented reality showed promise for performing construction inspection tasks. Augmented reality based inspection devices may be simpler and may facilitate more rapid task performance (Dunston, 2009).

3.5 Augmented Reality Uses for Safety in Construction Projects

To improve safety conditions, construction projects require more visual-based, straight-forward training methods and solutions for safety applications to produce better understanding and recognition of safety risks. With the introduction and increasing use and integration of Building Information Modeling and Augmented Reality, there are opportunities to improve the current safety management practices, and take advantage of the proven benefits of these technologies to improve working memory ability, increase workforce cognitive ability of spatial information, and have better reliance on past experience and memory (Park & Kim 2013). Figure 3 shows what the interface could be on a mobile device, where one could mark a hazard on a jobsite, and then anyone using AR to look at that area would get a warning of exactly where the hazard is. Once the hazard is being addressed, the hazard warning could be removed and it would stop showing up on augmented reality displays.

3.6 Challenges of using Augmented Reality

There are numerous barriers that hinder greater acceptance of AR in everyday practice. Two of the most common are the determination of the user's position, and what is called visual occlusion (Meza et al. 2014).
In research done on AR technology, the main technical challenge is how to accurately determine the user's position in space. The AR system needs the data on the current position and orientation in space. During field tests it has been established that the accuracy of GPS antennas embedded in mobile devices lacks the required precision (Meza et al. 2014). The authors of that research believed that in the near future commercial AR software will take the advantage of alternative positioning methods and the AR display component can be easily replaced with one that will provide more accurate method of positioning (Meza et al. 2014).

Figure 3: Augmented Reality for Safety Purposes

The other main technical difficulty is the issue of how to accurately align the user's field of view with the position of a model that is being viewed. There are two practical problems that arise when comparing

the actual state on the construction site with the state in the model. The first problem develops when physical objects are positioned between the user and the site where the building is located (such as site fences, tower-cranes, etc.). Another problem is the overlapping of elements which have already been built (Meza et al. 2014). These issues are not new issues, and have challenged all researchers engaged in studying AR technology.

There are also challenges relating to using AR technology when working on indoor construction projects. It has been shown that in low light areas, it is often difficult for cameras to detect the real world elements that need to be compared to models. On construction projects where no lighting systems are installed indoors, it will be necessary to improve the ability of device recognition (Kwon et al. 2014).

4. Methodology

The initial data that comprises the literature review section of this paper was compiled through online academic research databases of academic journals and text articles. The literature review process served as a foundation of knowledge from which was developed a concept of holding interviews with various industry corporations, namely general contractors and software developers, who have experience designing and using augmented reality technologies for construction applications.

Interviews were held to gain qualitative information on the AR technologies currently available, if/how they are being utilized in the field, and the types of projects they are currently be used on. The interviews also attempted to determine the benefits and challenges that contractors and developers have by using and implementing the technologies, and also to study the impact the technologies are having on the building trades.

Interviewee's were selected based on internet research of construction companies that have experience using augmented reality technology. Interviews were conducted with three companies, with both General Contractors and software developers being represented. Interviews were conducted by first sending a list of questions to the company, and then following up with a telephonic interview to discuss the questions. Interview questions were created with the intention of attempting to gain understanding of the issues stated above. The interviews were held between October 12th and 26th 2016.

The data collected from the interviews was analyzed to ascertain if companies were currently using augmented reality in the field on construction job sites, and if so how it's being used. The data collected from interviews with software companies was also be analyzed to determine the biggest problems that companies were trying to solve with the further development of augmented reality technology, as well as the value they were hoping to provide by having construction companies adopt and implement their technology.

5. Data Analysis and Discussion

Interviews were held with three companies BNBuilders, Augment, and Gilbane Building Company. The data collected through interviews conducted was reviewed, analyzed, and is presented.

BNBuilders stated that they believed that most construction companies have probably looked into augmented reality technology as it has become available, but as an industry, the set-up currently required to deploy it widely is the biggest challenge. They have found that while there is potential for AR technology in construction, at its current limitations, and because it is still a new technology and hasn't become commoditized yet, implementation hasn't been widespread in the construction industry. BNBuilders does more with Virtual Reality than Augmented Reality. It's felt within their organization that VR is more advantageous in terms of visualization of projects, which where augmented reality is being used most commonly at this time in the AEC industry. The engineers interviewed have had experience with AR applications for the Microsoft HoloLens, but they find that since its uses are mostly

still for visualization, there are more cost effective ways to present the same information. The biggest take away from this part of the interview was that their company didn't see a lot of value to using this new technology when it isn't fully capable, at the present, of doing something differently than what other methods can provide, and there isn't much reason to invest if the value provided in the return on investment isn't there.

BNBuilders also believed that there would be resistance to implementation of AR technologies until you can demonstrate that is will add value, and provide a method of completing a project in a way that is better than what they are doing now, i.e. from paper to mind to building. Based on the interviewees experience with augmented reality, they felt that AR offers a profound ability to have access to large quantities of data derived from BIM, and rapidly communicate it. At this point in time, it appears that the place of most value for augmented reality is for people who aren't as involved with the physical building process, such as the owners, due to its uses as a visualization tool. The general feeling, based on BNBuilders experience with augmented reality technology is that it could really help with complicated methods of construction, where crews could be at a location and be watching a video on a headset with step by step instructions of how to do put some piece of work in place, while they do it in real time.

Gilbane Building Company has been using augmented reality technology in the field for the past two to three years, with more attention being paid to the technology in the last year. Gilbane recognized that blending the model-based world and the real world is the natural culmination of the construction industry, and therefore the decision was made to start using AR technology. Gilbane has been using AR for a lot of sensitive projects, like curtainwalls and building envelopes. Essentially projects where the details absolutely have to be correct. It has also been used for logistic planning. They've also been currently working on using augmented reality for safety purposes, but it's a work in progress. The issue Gilbane has had with implementing it currently is the scale. On their jobs, large enough to warrant using augmented reality, they are often having to orient ten workers a day, which limits the use of AR. Gilbane also commented that every mistake not made is a day saved, and by that logic, the more information available in an easy to understand format is better than less information in a not-to-scale drawing. Gilbane reports that the biggest impact to collaboration and communication that AR can have on a project is the ability to educate those with an inability to read the drawings or models that a designer has been commissioned to create.

AugmenteDEV SAS stated that they find that a lot of people in the architecture, engineering, and construction industries are looking for better ways to visualize their products, from residential homebuilding to commercial applications. Their staffs are mostly made up of 3D design experts. However, quite a few of the 3D designers are aware of things such as how a construction site functions, or principles of architecture, and are using that knowledge to inform their decisions as they develop this technology. They try to improve communications and the ability to communicate a design to people in and out of the AEC community. Augment wants to help bring designs to life without having to send it over email or having people gather around a computer. Their applications are used on mobile devices, and they want them to be used to get people excited about their projects, by being able to visualize it in a new and exciting way. Currently they are seeing the most widespread implementation by A/E firms. Augment hasn't created anything yet that is for field application.

When asked where they see augmented reality in five or ten years, the answer was that it was hard to say. An analogy was made to smart phones, which just a few years ago did not have the capability to do what they do today. Augment feels that augmented reality is the same way. Because it's still new as a practical technology, it's hard to envision just where it can go from here. But the feeling was that it will continue to be implemented and used in AEC communities in the future, and will probably have incredible uses on construction sites. There is also potential for use for onsite safety measures, especially as it becomes totally and completely integrated into projects.

Upon analyzing the information collected, the main finding is that augmented reality does not seem to be widely used by contractors, especially not for field applications. While AR is being used in limited capacities by some General Contractors, it appears that the technology is not sufficiently advanced

enough to make widespread acceptance for field applications plausible. At this time it does not appear that General Contractors believe that the costs associated with implementing AR technology in the field would be a value adding endeavor.

It also does not appear that augmented reality technology and applications are sufficiently developed enough to provide widespread value to builders for use for safety or quality management applications. Currently, the research seems to show that the primary use for augmented reality is as a tool for visualizing projects, and is being used to good effect as an asset to help communicate project visions between designers and non-technical stakeholders.

It also appears that AR technology companies have identified AR as an intuitive next step to bring BIM modeling out of the office and into the field, however, the technology is just not advanced enough and has not been commoditized to the extent where any one AR firm has been able to offer a product that has become the "standard" AR application. At this point, it would appear that general contractors who are interested in testing or implementing AR on their projects are developing the products themselves in-house, based on their exact needs.

6. Conclusions

The purpose of this research was to attempt to ascertain how augmented reality technology was currently being used, who was using it, who was developing it, and what the practical applications looked like.
After having conducted a literature review of augmented reality technology use for construction phase, it became apparent that most of the available literature focused on augmented reality from a very theoretical and prototypical point of view. The studies available provided next to no practical experience using augmented reality on construction projects, and instead focused on how the technology could be used, instead of how it is actually used. Based on the analysis of the information gathered during interviews with building companies and technology developers, it seems that at the current time, the main practical benefits of augmented reality technology are uses for visualization of projects from a marketing and communication standpoint, and that the technology has not been widely implemented, or even seemingly developed for use for practical applications on a construction site, such as for quality assurance or safety applications. That's not to say that no companies have in the past, or are currently using augmented reality on site. On the contrary, augmented reality is being used on active sites, but it appears that use is so limited as to be practically negligible compared to the amount of construction taking place and the amount of augmented reality being used on those sites.

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