Augmented Reality Use in Construction – A Case Study of the Industry

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The construction industry has been lagging in adopting technology applications but has begun to integrate them in the past few years. Augmented reality (AR) is an innovative technology that allowed for the visualization of virtual objects in the real world. Presently, it can be used for various activities and tasks in construction but does not yet have the accuracy to be relied on. This case study interviewed industry personnel to determine if AR should be implemented into practice based on their experiences in the field. Based on the responses, the majority believed that it was a potential technological tool that had a high ceiling but was not at the level yet where it must be widely incorporated. However, they reported that there were many beneficial uses to AR, such as quality control/assurance, clash detection, visualization of the building, and double-checking work being performed. Many interviewees stated that technology is a revolutionary tool that has simplified and increased efficiency in construction. Ignoring technological advances will only hinder the growth of the company. Competition is constantly happening in the industry, so being ahead of competitors by adopting innovative technology is an advantage that must not be overlooked.

Key Words: Augmented Reality, Construction Technology, Visualization, Innovation

Introduction

Compared to the other industries, the construction sector is lacking in adopting change. According to a global report by McKinsey & Company, they ranked the Construction Industry as the second lowest, only ahead of agriculture and hunting, to integrate technology into their systems (Agarwal et al., 2020). While other sectors were incorporating technology to increase overall efficiency, the construction sector continued to use traditional and outdated practices. However, over the past decades, more companies have begun to perform R&D on innovative technologies. They were beginning to realize that the industry was quickly changing and falling behind would hinder their growth as a company against their competitors (Morozova, 2018).

Efficiency is imperative in construction as most of the projects are on a tight schedule with a limited budget. Technology is a huge contributing factor for productivity in construction as it has made both the management and construction process more efficient (Morozova, 2018). Over the past few decades, the internet has engrained itself in the industry, becoming an essential resource for everyday use. The key benefit of the internet was that it allowed for the quick transfer of information so that all members of the project team could access the database from any location at the same time (Bello et al. 2020). This sparked the digital transformation age of the industry, as people began to develop software programs that were not only efficient but could also combine multiple aspects of traditional construction practices into a digitized resource. These programs improved collaboration capabilities, increased productivity, and reduced construction errors (Bello et al. 2020). Communication software platforms have helped aid in real-time collaboration among employees in the field and office, allowing for issues to be resolved immediately. Construction software programs have also reduced the number of errors through clash detection and allowed for visualization of the building systems and structure (Machado and Vilela, 2020).

Visualization technology was a major technological development, as it played a key factor in client satisfaction and other purposes. Ensuring the client's satisfaction with the result is a major goal for each project, so the interior and exterior design must meet the client's expectations. Visualization technology like augmented reality (AR) can create a virtual rendering of the final project overlayed on the site during the preconstruction phase. AR mixes the virtual and real world, allowing the user to visualize the product without it physically existing (Kipper and Rampolla, 2012). The owner could make any changes to the building design before breaking ground, decreasing the costs and time added to the schedule with any change orders. AR has many other uses as well.

Literature Review

AR is an interactive technology that overlays virtual objects on the real world, responding to real time changes in the user's environment. It is a newly introduced technology that has potential to greatly increase efficiency, saving both time and money (Morozova, 2018). AR is a variation of Virtual Reality, where the user is completely immersed inside a computer-generated environment. In contrast, AR combines the real world with virtual objects, allowing the user to see the final product in the real world (Kipper and Rampolla, 2012). It specializes in stimulating our sense of sight, allowing us to see things we do not normally discern. AR is very effective as it enables the user to see the prospective product in the real world when completed (Ranhoki and Waugh, 2013). Visualization is important for construction as the goal is to create a product that meets the client's specifications. By creating a virtual rendering of the final building, it can be used to cross check the current real-time progress of the building (Machado and Vilela, 2020).

There are two basic categories of AR systems, mobile and fixed. Mobile systems allow the user to use AR while moving in an environment, whereas fixed systems are stationary and can only be used where they are set up. This study focused on mobile systems as many of the AR technology programs are used on mobile devices. AR systems are designed with three aspects in consideration: 1) Combination of real and virtual information; 2) Interactivity in real time; and 3) Registration in 3D (Kipper and Rampolla, 2012). All three of these aspects must be accounted for to maintain a stable image seen through the AR equipment. These three aspects are fulfilled by the hardware and software of the AR systems. For hardware, there must be a computer, display screen, camera, tracking and sensing system, network infrastructure, and marker. As for software, it requires an application to run locally, web services, and a content server to store the renderings (Kipper and Rampolla, 2012).

There are numerous AR devices utilized in the industry, but this study specifically focused on the HoloLens made by Microsoft, as many of the people interviewed utilized this AR device. The HoloLens used was an untethered AR device that included a self-contained computer with Wi-Fi capability. It created an immersive experience with a wide field of view, that allowed for easy-to-read text and intricate details on 3D images. The computer was programmed to display the holograms in a way that felt natural, responding a lot like real objects. It had hand and eye tracking capabilities, along with voice recognition that allowed for real-time interactions, constantly updating the model to match the user's point of view (Microsoft, 2021).

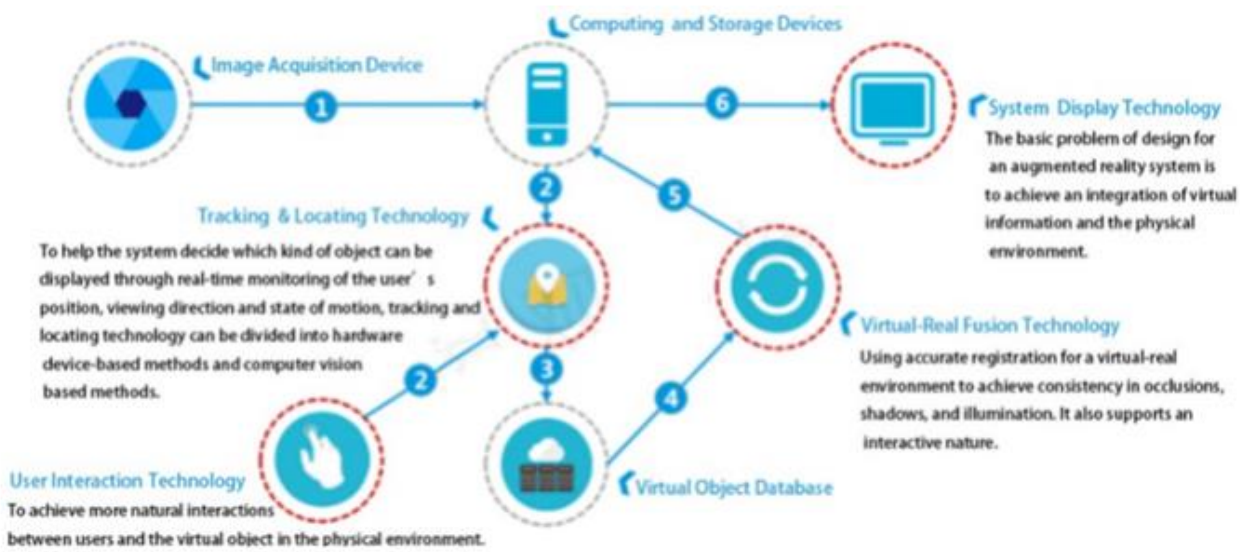

Figure 1: Flowchart for an Augmented Reality System (Cheng et al. 2018)

The entire process of AR visualization can be broken down into six steps. As seen through Figure 1, Step 1 begins with the camera, taking pictures of the environment as seen from the user's point of view and uploading it to the computer. Step 2 is where the computer creates markers on the image to establish the boundaries where the virtual objects will be overlayed via infrared, laser, GPS, or sensors. The computer also takes into consideration the user's position, viewing direction, and state of motion to produce a clear image. User interaction technology also complements the tracking & locating technology to allow for more natural interactions between users and the virtual object in the physical environment. The 3rd step is where the computer accesses a virtual object database to search for the object or model to be projected. It then moves onto Step 4 where virtual-real fusion technology combines the identified virtual objects and the real world to create an accurate model. It is then sent back to the computer in Step 5 where it is stored and sent to the system display in Step 6 to display the model to the user. A constant loop is formed from Steps 2 to 5, constantly updating the model to match real-time changes in the real world (Cheng et al., 2018)

There are numerous uses of AR technology in the industry. For example, it can be used for safety training as safety is paramount in construction. Any injuries on the jobsite can cause delays in the schedule, as construction must be stopped to follow required procedures. Safety training is key to ensuring the safety of the workers and others around them. The issues with safety training are the cost, time used for training, and the fact that it is potentially hazardous to new workers. AR can cover these concerns as it can simulate the tools and equipment, preventing injuries and reducing costs. Additionally, AR can provide certain scenarios which will train workers to act when accidents do occur on the jobsite. It can be repeated multiple times, allowing workers to learn from their previous mistakes (Li et al., 2018).

Another use for AR is real-time project information to help increase collaboration and communication. Workers can walk the jobsite at any time to compare its current progress to the final design. Collaboration is also increased as remote experts can tune into video feeds shared by field workers, providing feedback and input to solve the problem. This results in less downtime and faster decision making (Morozova, 2018). On large tenant improvement projects with intricate HVAC and piping systems, clash detection is important to prevent any issues from occurring. Some construction projects build on an existing site, which has underground utilities that cannot be seen by the naked eye. AR helps with this as it gives the workers a general location of the pipes and wires, so they can be cautious when making cuts or installing equipment. They will be able to see the location of pipes, anchor bolts in slabs, door and window locations, HVAC systems, and so much more given the empty shell of a building (Morozova, 2018).

Research Questions

For this study, the overall research question was the following: Should companies implement AR into practice?

To address the overall research question, three sub questions were created.

1. How developed is AR technology?
2. Is adopting AR worth the cost?
3. What is the future of AR?

Methodology

This study used structured interviews to collect personalized information from four general contractors that were known to utilize AR technology and a consulting company that specialized in construction technology. The companies that responded to the interview were from faculty connections and interview requests. Several companies were interviewed in hopes of gathering varying opinions about their stance on AR, as they utilized this technology in the field. A specialized construction technology consulting company was interviewed to gain perspective from the research and development side of AR. Interviewees were told the overall research question and the three sub questions that would help answer the overall research question. The first two sub questions had four follow up questions and the last sub question had two follow up questions. The interviews each took around 30-45 minutes. All the interviews were conducted over a video call due to the COVID-19 pandemic.

To answer sub question 1, interviews were conducted with each selected company to ask more in-depth questions related to the current development of AR technology. The in-depth questions were personalized to gather the opinion of each interviewed company and their opinion regarding AR technology. Additional research was conducted to understand the information gathered by scholars and researchers for the development of AR.

For sub question 2, interviews were conducted to determine the amount that each company spent on AR technology and what benefits or downsides they discovered while using it. Secondary sources and peer-reviewed sources were analyzed to provide a basis for the general costs.

For sub question 3, interviews were conducted to ask what the interviewed companies thought about the future of AR and the effects that would occur from adopting it.

Company Information

Company A is a small-sized general contractor founded in 2000 with an annual revenue of $36 million and about 150 employees. They are based in Washington state and provide services for education, biotechnology, healthcare, and retail sectors.

Company B is a mid-sized general contractor that has been in the industry for over 100 years. They have an annual revenue of $1.3 billion with about 500 employees and is based in California.

Company C is a mid-sized contractor that was founded in 2011 with an annual revenue of $1.2 billion. They have about 400 employees and is based in California.

Company D is a large-sized commercial contractor that is ranked among the top 25 contractors in the country. They have a yearly revenue of $4.6 billion with about 4300 employees and have multiple offices throughout the United States.

Company E is a construction technology consulting company that was founded in 2010. They have several locations in the United States and has expanded out into other countries. Their headquarters are based in San Francisco with about 30 employees.

Interview Questions

Overall Research Question: Should companies implement augmented reality into practice?

Preliminary Question: Can you list the augmented reality programs that you are using?

Sub Question 1: How developed is AR technology?
- 1.1 How reliable is it?
- 1.2 Can it replace current/traditional practices?
- 1.3 What needs to be fixed/addressed for AR technology to be viable?
- 1.4 What is the biggest hindrance with AR technology?

Sub Question 2: Is adopting AR worth the cost?
- 2.1 What upfront costs must be made before AR technology can be used? (Training, software, hardware)
    - 2.1.1 How much would that cost be?
- 2.2 What productivity values does it bring?
- 2.3 Does it decrease the time/increase efficiency for typical tasks?
- 2.4 Would you recommend/continue using this technology/software?

Sub Question 3: What is the future for AR?
- 3.1 What are the upsides if AR technology were polished to be utilized in the field?
- 3.2 What traditional practices will it replace?
- 3.3 What programs/technologies can AR be combined with?

Results

All the interviewed companies were first asked to list the AR programs they used. These programs included VisualLive, Spectar, and Trimble Connect. All these programs used HoloLens as the preferred device to display the projected visuals.

<u>Question 1.1</u> (How reliable is it?): Majority of the interviewees stated that AR technology was not very reliable, due to the inaccuracy of the models. If a user walked too far from the anchor points, it would result in shifting in the model. Additionally, the AR models were not very accurate, citing a margin of error that was too large for workers to depend and rely on. Company D believed AR to be reliable if the models were accurately set up to match the building. It could be used for real life coordination and reducing human error. The main issue was finding anchor points to match the 3D model to the 2D model.

Question 1.2 (Can it replace current/traditional practices?): There was a split agreement for this question, as Company B and E stated that the current development with AR could not completely replace current practices. It could only help make the task more efficient or provide a preliminary reference that must be cross checked with other technologies. They did however agree with the other companies that it could help with the visualization of the project in the early stages of preconstruction and surveying with total stations. The other interviewees' responses were checking plans, clash detection, review of quality assurance (QA) and quality control (QC), virtual mockups to show interior finishes, facilities management for visualization of MEP systems, and drilling into concrete for embeds.

Question 1.3 (What needs to be fixed/addressed for AR technology to be viable?): The consensus by all the companies were the reliability and accuracy of the AR models, better connectivity with Wi-Fi, and higher frames per second display. Company A stated that the stability of the models when moving needed to be fixed with faster loading times for large sized buildings. Company E specified that the user interface and experience needed to be further developed. AR equipment was not comfortable to wear and not user friendly; it was also difficult to see the displays in dark environments and in direct exposure to the sun.

Question 1.4 (What is the biggest hindrance with AR technology?): All the companies agreed that the biggest hindrance with AR was getting familiar with the technology as many people do not have the technical skills. It was also slow to load big models and frequently crashed. It was also hard to see the display in dark rooms and outdoors in the sunlight. Company B, D, and E agreed that the poor connectivity on certain jobsites was a big issue with the addition of user interface not having a wide field of view. Company E provided a report that listed the biggest flaws with AR: constantly having to adjust the model, not durable to withstand use during installation on construction sites, and not convenient or comfortable to wear.

Question 2.1 (What upfront costs must be made before AR technology can be used?): A few recurring costs that were brought up were the initial costs for the software programs, hardware equipment, and training for users. The general costs for the software programs varied as they were charged based on the square footage of the project and hardware costs being around $4,000 for each HoloLens. Company E specified that additional programming was required to implement personalized applications for any real use case, where personalized apps must have an initial investment of $10,000 that would not guarantee results. Company A stated that the training costs were not as high, since there were plenty of free videos that taught users how to use AR equipment.

Question 2.2 (What productivity values does it bring?): Almost all the interviewees except Company E agreed that there was productivity value for using AR. The models could be viewed in real-time to compare the differences with the real building. AR also helped with coordination to double check subcontractor work before going into the field, visualization for the owner during preconstruction, building layout for finishes and equipment, QA/QC, clash detection of existing systems, and allowing for project members to see the building without going to the site. Company E stated that AR was not worth adopting as it does not provide real value to make construction easier. It was not convenient, fast, flexible, user-friendly, comfortable to wear, and simple to use. It was simply a technological tool in the early stages of development that provided few to no benefits.

Question 2.3 (Does it decrease the time/increase efficiency for typical tasks?): Companies A – D stated that AR helped save many man hours that were spent on traveling between the office and field, looking through 3D models and referencing the 2D plans, and time spent on QA/QC. It was especially helpful for identifying the location of underground utilities and systems. Engineers and managers were also able to tune into the displays shown by the superintendent in the field, allowing for real-time collaboration from different locations. Company E reported that AR was not useful for many scenarios but could reduce time for QA/QC by displaying a checklist of items that still needed to be installed or if there were any existing issues with the system.

Question 2.4 (Would you recommend/continue using this technology/software?): There were many split answers for this question. Company A would recommend AR as it was better to use the technology than be ignorant and fall behind the competitors. It would be helpful for double checking the work performed but should not be relied on. Company B had a similar statement to Company A, stating how more R&D must be done to be more dependable, but it would still be helpful for common tasks. Company C said that it depended on the needs of the company. If more than 50% of the projects were designed in BIM, it would be very beneficial, especially for medical buildings as their systems were more complex. Company D would recommend AR for large contractors that could afford the initial costs and have multiple large projects. The larger and more complex the project, the better for AR to be used. Company E disagrees with the other opinions, stating how it only adds value for specific situations, but there are many limitations in the field. It was not ready for industry use.

Question 3.1 (What are the upsides if AR technology were polished to be utilized in the field?): Some of the benefits for AR if it were further developed would be for inspections, recording as-built conditions, QA/QC, clash detection, accurate representation for existing and hidden systems, increasing collaboration between architects and engineers, safety mitigation and precautions, and dependable real-time collaboration. It could also combine multiple aspects of construction into one centralized resource to boost performance.

Question 3.2 (What traditional practices will it replace?): AR could replace the traditional layout practices with total stations for formwork, sleeves, embeds, studs, etc. It could also replace training for equipment and services, trade installation conflicts, subcontractor work with specialized interfaces, and the initial design phase with 3D augmented design. However, many of the interviewees stated that AR would not necessarily replace traditional practices but act as a complementary tool to help increase efficiency.

Question 3.3 (What programs/technologies can AR be combined with?): Company B believed that AR could be combined with AI. Future jobsites will not have people on them, as they will be in field offices operating robots from their command stations. The cameras would overlay with the field to perform the work. The other companies stated that AR could be combined with visualization software like BIM and VDC, LIDAR sensors to measure dimensions of a space, 360 photo documentation, and 3D laser scanners.

Analysis

How developed is AR?: It seemed like both the general contractors and the technology consulting company had a similar stance of AR technology not being very developed, as they identified many flaws and problems. There were inaccuracies in the AR models that had a margin of error far too large. There were also many instances where the model would shift and had to be constantly adjusted. If the user left a certain range from the existing structure, the model would be out of sync and had to be recalibrated. Another key development that needed to be addressed was the AR display equipment. Connectivity was a big liability on jobsites that did not have stable connection, as they were unable to utilize AR programs. The loading time of large, scaled models was also very substantial and the program frequently crashed. User interface needed to be further developed to include a wider field of view for the user as well as tuning the equipment to display the visuals in various environments, such as in the direct sunlight and dark enclosed areas. The state of AR technology needs more development to make it a reliable tool. However, there are still many beneficial uses that can help increase productivity and efficiency.

Is it worth it?: All the contractors believed that AR had many beneficial uses and provided productivity value. It acted as a supporting tool that helped cross reference the primary programs. The models could be viewed in real-time to compare the differences with the existing building and help with the coordination of subcontractors in the field. AR could also identify the general locations of existing systems to prevent any accidental damages that may occur when cutting through concrete slabs or walls. While the initial costs were relatively high, the productivity value and benefits outweighed them. Only the consulting company believed that AR was not yet worth adopting as it did not fulfill the requirements of making construction easier. This difference in opinion can be overlooked as the contractors working in the field have found practical uses, while the consulting company only tests the technology with theoretical situations. AR also helped save a lot of man-hours by reducing time spent on commuting and looking through 3D models and 2D plans. AR is worth investing in to get ahead of competitors that do not decide to adopt it. Depending on the size and number of projects a company has, it would be more beneficial for projects that are more complicated and encompass multi story buildings. The initial cost is a small expense to be made that can provide increased productivity and reduce costs in the long term.

What is the future of AR in construction?: AR has a high ceiling, where it can be further developed to complete multiple construction tasks and replace many traditional practices. If the issues identified by the contractors are addressed, AR would be a revolutionary technology that would simplify the preconstruction and the construction phase. It will allow for shorter construction schedules and save on project costs. Additionally, it could also be combined with multiple construction software programs to create one centralized resource to boost overall productivity. There are many resources in the industry that specialize in certain aspects of construction, but AR can help reduce the number of resources that a company needs to buy.

Conclusion

The construction industry is going through a technology adoption phase where more resources and tools are being introduced and developed to increase productivity. The industry has been lagging in adopting technology but has begun to address this issue. AR is one of the innovative programs that have been introduced to increase productivity. The overall research question for this case study was to determine whether companies should implement AR into practice. Based on the interviews and research conducted, the key takeaway was that it had many benefits that could help with a company's productivity. The interviewees listed the benefits of AR, stating how it has helped with QA/QC, clash detection, visualization, and many more. While AR is a tool that cannot be depended on, it can be utilized with other resources to act as a safety net to double check the work being done. Companies should be adopting and implementing AR into practice to not only boost productivity, but to be familiar with the technology and not fall behind other competitors. It is a beneficial tool that has a high ceiling, so while AR is being developed to the point where it can be relied on, it will still be a useful tool that will benefit a company in the long run.

Future Research

In the interviews, a few of the companies talked about the various realities, such as cross reality (XR), mixed reality (MR), and virtual reality (VR). They are all very similar to AR but have different visualization and forms. One possible case study or research project might be to analyze the differences between the various realities and determine which one is more practical for construction. There are many forms of visualization in construction and AR only covers a small sliver of it. There is still room for additional research and data collection on the overall technological development of visualization

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