PROJECT SCOPE, OBJECTIVES AND, LITERATURE REVIEW REPORT

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Project 140:

Improve the effectiveness of design meetings in projects with smartphone AR

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1.0 Project Scope and Research Need

The construction industry plays a significant role in New Zealand's economy, due to its ability to support large amount of employment opportunities for the workforce, along with the benefits in which it delivers in many aspects of our society. Hence why during both construction and design phases, it is vital for stakeholders to visualize and collaborate effectively to minimize inefficiencies and delays in projects.

From the previous research project "Augmented Reality Applications to Design Meetings in Architecture, Engineering and Construction", it has concluded that Augmented Reality (AR) is more suitable than Virtual Reality (VR), as AR shows promising indications in resolving issues regarding visualization and collaboration by allowing virtual objects to be perceived without impeding normal collaboration. Therefore, there is an opportunity to explore the feasibility of smartphone-based AR with Hololens. The intention is to compare smartphone-based AR with Hololens in order to measure its feasibility in terms of time and cost.

2.0 Aim and Objectives

Although there has been studies on exploring the usage of AR and VR technologies in the AEC industries. To the author's knowledge, there has not been any research in the implementation of smartphone-based AR in comparison with HoloLens in their effectiveness and feasibility in facilitating design meetings for the AEC industries.

The aim of this study is to improve the effectiveness of an existing AR system prototype from a previous research project by implementing it with smartphone AR, conduct similar trials as the previous research project. This allows us to quantitatively and qualitatively determine whether the model is more feasible on smartphone AR. The first objective is to further develop the AR system prototype from the last year's research project to allow its implementation on a smartphone. Subsequently, the second objective is to conduct 2 sets of test, one set for participants who has completed/currently completing a degree associated with the AEC industry, and another set for those who doesn't. This would allow a comprehensive evaluation in determining the feasibility of smartphone-based AR.

3.0 Introduction

The Architecture, Engineering and Construction industries are influenced by the sophisticated blend of different parties across different disciplines. The construction process can be divided into two main phases: design and construction. Regardless of which phases, collaboration often occurs between many different parties. For example, discussing specifications and client requirements with professionals across different specialization during design meetings. Visualization is also another important process to be considered as difficulties are often arise from constructing a clear 3D mental image (Tory & Staub-French, 2008).

Collaboration and visualization are closely related in the AEC industries, as both play significant roles in the design meetings. If the visualization process was taken place effectively, collaboration will therefore be undertaken smoothly. Visualization becomes more difficult as information becomes more complex and science oriented (Tory & Staub-French, 2008). It is evident that conventional ways of collaboration and visualization in design meetings can be improved to allow the design process to be more streamlined (Tory & Staub-French, 2008).

Smartphone-based AR and Hololens have shown its potential in their ability to facilitate the visualization and collaboration processes for design meetings. Numerous studies have showcased the feasibility of implementing smartphone-based AR in the AEC industries. However, to the author’s knowledge. There haven’t been any studies being done which showcases a comprehensive comparison in different AR-based devices, especially between smartphone-based AR and Hololens.

This report is divided into 5 main sections. The section 1 and 2 explains the motivation for this study, as well as the aim and objectives respectively. Section 3 provides an introduction to common issues in design meetings. Section 4 elaborates the background of the study and relevant technologies. Section 5 showcase the potential for the smartphone-based AR and comparison to Hololens. Lastly, Section 6 discusses the relevant research in the implementation of smartphone-based AR in the AEC industries.

4.0 Background

4.1 Architecture, Engineering & Construction Industries

The Architecture, Engineering and Construction industries contributes significantly to the country’s GDP and employment, as it is the nation’s 5th largest sector in terms of employment and provides 8% of the total GDP (Valuing the role of construction in the New Zealand economy, 2016). It comprises a sophisticated mix of stakeholders from a variety of disciplines, who require excellent visualization and collaboration skills to successfully deliver high-quality construction projects (Wang & Dunston, 2007). In general, the construction process can be divided into two main phases: design and construction. During the design phase, stakeholders such as architects and engineers often uses CAD software to demonstrate models from 2D to 3D throughout the projects (Bouchlaghen, Shang, Whyte, & Ganah, 2005). Their main objective is to identify and fulfill client requirements by creating models, process and the technical specifications (Alarcón & Mardones, 1998). On the other hand, the construction phase is mainly in charged by contractors who are responsible for carrying out the physical design while ensuring that all design criteria are fulfilled.

As a result of complex combination of relationships amongst stakeholders, it requires numerous lines of communication, it often leads to reduction in efficiency throughout construction process. Especially for interactions between different parties from design and construction phases, which subsequently give rise to miscommunication, and consequently lead to additional cost and time delay (Alarcn & Mardones, 1998). Therefore, adversely affecting the profitability of construction firms, which already tends to be relatively low (Chiang, Albert, & Eddie., 2002). As a result of the AEC industries' significant role in the nation's economy and other industries, inefficiencies would consequently impact the overall productivity of the country and commercial operations (Valuing the role of construction in the New Zealand economy, 2016).

The process of refinement and discussion of the design is taken place in design meetings, which involves various parties such as architects, engineers, clients and contractors (Tory & Staub-French, 2008). Therefore, design meetings can be undertaken in many different combinations of these stakeholders. It is crucial in retaining a high degree of efficiency in design meetings to prevent delays and add-on costs, as key decisions related to the project are made during this process (Tory & Staub-French, 2008).

4.2 Mixed Reality Overview

There are two main variations of mixed reality in the reality-virtuality continuum as show in figure 1: Augmented reality (AR) and virtual reality (VR) (Milgram & Kishino, 1994). The continuum diagram allows a better understanding of the difference between the two types of mixed reality, as one side, the environment is comprising of entirely physical objects. Whereas the other side is surrounded by virtual objects that are only visible through a VR device (Wong, Yu, & Giacaman, 2019). The usage of AR/VR technologies has recently experience significant growth, as the sale of AR/VR headsets were predicted to be 13 million units in 2020 (Panetta, 2018). Furthermore, technologies were also listed in the Top 10 Strategic Technology Trends for 2018 (Panetta, 2018).

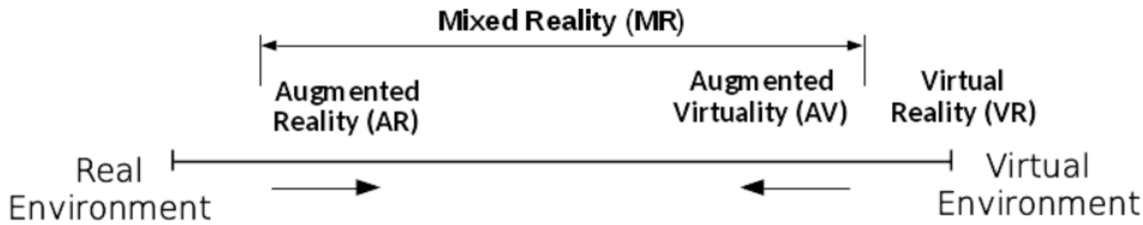

Figure 1: Reality-Virtuality Continuum (Milgram & Kishino, 1994)

Virtual reality is a medium that delivers an experience in which the user is immersed into a computer generated 'virtually real' world. While immersed, users are not exposed to any elements of the real-world environment around him (Schwienhorst, 2002). This is most commonly achieved by the implementation of a head-mounted audio-visual display which fully encloses the human eyes from the real environment (Bowman & McMahan, 2007). The main benefit of virtual reality is its flexibility in various different applications such as indicating potential risks of flood for urban water management (Winkler, Jonathan, & Wolfgang, 2017) and providing trainings for workers in the mining industry without safety concerns (Van Wyk & dr Villiers, 2009). It can also be used in the AEC industries, where it's able to assist in recognizing errors in the design (Whyte, 2003), along with assisting architects' in developing their conceptual designs

Augmented reality is the other variation of mixed reality which involves the combination of virtual elements to supplement the real-world environment (C, Azuma, & M, IEEE). Therefore, allowing both virtual and real objects to 'co-exist' (Azuma & Ronald, 1997). One of the exclusive advantages of augmented reality is that the interaction with virtual objects does not interfere with the user's perception to the real-world surrounding. For example, incorporating AR in a sewing workshop to facilitate students' learning experience (Yip, Wong, Yick, Chan, & Wong, 209). Additionally, it can also be implemented in the AEC industries, such as projecting 3D models in site visits (Woodward, et al., 2010). One study indicated there's a difference viewing a model in 3D rather than through a 2 desktop (Perdomo, Shiratuddin, Thabet, & Ananth, 2005).

4.3 Overview of Hololens and smartphone AR

4.3.1 Hololens

Hololens is a mixed-reality wearable device in which blends the real and virtual world through overlaying holographic-like images onto the real-world surroundings (also known as an Optical See-Through Head-Mounted Display) (N & Fitzgerald, 2018) (Tuliper, 2016). It's the world's first "untethered Mixed reality Head Mounted Display system, released to developers in March 2016 as a Development Kit" by Microsoft Corp (Hololens, 2016). Unlike any other AR device, the most unique advantages of Hololens are its high degree of mobility and convenience, which is achieved by its self-contained computer with Wi-fi and Bluetooth connectivity, along with the "dial-in fit system" that allows a seamless transition between AR and real environment (Hololens, 2016).

The logic board at the top of the hololens consists of 64GB of flash memory, Custom-built 2GB of RAM and Windows 10. Advanced sensors are used to consistently to collect data from the activities and surrounding of the user, this allows to develop an in-depth understanding of the real-world environment, which consequently allows for a more seamless integration between the virtual and real world. On top of that, it can also perceive gestures from the ability of tracking eyes and hands (Hololens, 2016). Additionally, the Hololens also consists of a widescreen stereoscopic head-mounted display with a resolution of 1268 x 720 pixel per eye. The combination of this and an advanced optical projection system allows the hololens to generate three-dimensional full colour images with very low latency (Hanna, Ahmed, Nine, Prajapati, & Pantanowitz, 2018).

Figure 2: Hololens architectures: Left: Logic Board, Middle: Sensors, Right: Display (Hololens, 2016)

4.3.2 Smartphone

Due to the significant growth in the development of smartphone hardware recently. Not only are smartphones used as a way of communication, but also commonly used for entertainment purposes such as watching videos and playing games (e.g. Pokemon Go shown in figure 3). Simultaneously, it also introduced other technologies such as AR (Permana, Tolle, Utaminingrum, & Rizdania, 2018). The camera system within a smartphone can be utilized to interact with the real-world environment in real time (Mobile Augmented Reality, 2013). Location-based services such as GPS along with accelerometers can detect the location of device and user, which ultimately enhance the AR technology by expanding the user knowledge about their surroundings (Permana, Tolle, Utaminingrum, & Rizdania, 2018).


Figure 3: Implementation of smartphone AR for Pokemon go (Niantic, 2020)

Currently, Smartphone-based AR can be divided into two main categories of marker-less and marker-based. Marker-less is the concept in which position data or image recognition is used to determine the user's location and overlay virtual objects, this is done by utilizing tracking services such as Global Positioning System (GPS) and sensor technology (Cheng, Chen, & Chen, 2017). Whereas marker-less is solely based on proprietary labels such as a bar code, to identify the device's location (Cheng, Chen, & Chen, 2017)

5.0 Key Issues

5.1 Visualisation

Visualisation is an integral unit of the AEC industries, especially during the design phase. Drawings are often presenting either in 2D or 3D in design meetings, depending on the complexity and recency of the project (Ku, Pollalis, Fischer, & Shelden, 2008). It is common for designers from different disciplines to review drawings collectively, which often leads to difficulties when interpreting 2D or 3D drawings into accurate 3D representations for constructability review (Wang & Dunston, 2007). Hence why in recent years, the implementation of 3D interpreting technologies such as Building Information Management and computer-aided design (CAD) software are commonly found in the AEC industries.

Despite the fact that people tend to have a higher level of engagement with 3D models than 2D (Wu & Chiang, 2013), 3D models tend to take much more time and cost to be processed than a mixed of 2D and 3D models (Tory, Kirkpatrick, Atkins, & Moller, 2006). Furthermore, since the nature of the interaction is heavily based in 2D, this means it still requires cognition cost for visualization (Taylor & Tversky, 1996). This ability is known as spatial cognition. Furthermore, 3D models are often not effective for precise navigation (Tory, Kirkpatrick, Atkins, & Moller, 2006).

Interactivity is an important element that facilitate the process of visualization, which is why 2D drawings are often used in the design meetings as the ability for parties to annotate freely to allow higher level of simulation (Melanie & Staub-French, 2014). The importance of interactivity is apparent especially within 3D objects, a study on construction education indicated higher performance in performing certain tasks with the implementation of 3D models (Ku K. , Pollalis, Fischer, & Sheldon, 2008).

5.2 Collaboration

Due to the fact that the AEC industries comprise many different disciplines partaking in different phases of the construction process, substantial collaboration skills are mandatory to keep up with the constant changing and complex work force, in order for the construction process to be highly efficient (Ozbek & Clevenger, 2017). The productivity and quality of the project are often affected adversely due to the lack of effective communication and coordination. A study on optimizing the cost performance of design phase found that the having at least one design meetings per month can lower the cost by at least 35%, where producing status report once or more per month can only reduce this cost by more than 14% (Kuprenas, 2003). This is not limited to the AEC industries, as it applies to other industries where collaboration from different expertise is need as part of the iterative process (Regenbrecht, Wagner, & Baratoff, 2002).

Collaboration in the design phase had always been taken place with the assistance of traditional technologies such as paper drawings and excel spreadsheets developed from different parties in the design team, which are compiled for final review after numerous of comprehensive comparison in meetings (Wang & Dunston, 2008). Despite the recent rapid increase in the usage of 3D modelling for some projects, where the models can be inspected prior to final review. 2D drawings are still being used in most projects (Bressler & Bodzin, 2013). The 3D models for the design cannot be showcased easily in design meeting to supplement collaboration (Melanie & Staub-French, 2014). As a result, one of the biggest drawbacks is the different levels of perceptions during the mental image development. This is a major concern since retaining a common ground in visualization is a vital to achieve effective collaboration (Yusoff & Salim, 2015). Furthermore, it is inevitable that 2D drawings lead to lower degree of engagement as mentioned above, mainly due to the it’s bland characteristic from the lack of small details.

6.0 Potential of Hololens and Smartphone-Based AR solution

Both Hololens and smartphone-based AR platforms are suitable for building a more intuitive and interactive environment for content-heavy activities, especial for resolving visualization issue as mentioned previously. Design meetings are not limited to a particular view on screen due to its nature of displaying virtual objects on top of the real world. As a result, it has been proven in studies that it reduces the cognition cost (Dong, Behzadan, Chen, & Kamat, 2013). It is crucial to allow designers to be able to interact freely in order to minimize the cognitive cost required for a comprehensible 3D mental image (Taylor & Tversky, 1996).

Smartphone-based AR provides a more compelling solution than Hololens, as the monetary cost for hololens is $3500 USD per device, there are also two other packages of Dynamic 365 Remote and Development edition that are $125 USD and $99 USD per month respectively (Microsoft, 2016), these packages are considerably higher than the monetary cost of any high-end smartphones. Hence, the barrier of entry is substantial lower for smartphone-based AR (Azuma, et al., 2001). This is further supplemented by its lightweight and compact size (Mobile Augmented Reality, 2013). On top of that, other advantages of smartphones include their cellular connectivity, social interactivity and portability (Klopfer, Squire, & Jenkins, 2002).

In terms of convenience, using Hololens would require users to have an additional device solely for design meetings, which becomes an additional liability to the designers. On the other hand, this issue is nonexistent for smartphone-based AR due to our reliance on mobile devices in many aspects of our lives. Subsequently, not all user will be familiar with the user interface of Hololens, especially those who do not use Windows 10 regularly (Ogdon & Carol, 2019). Meanwhile, smartphone interfaces are often developed with the aspect of being user-friendly to cater for users in the older demographic. This is shown through conducting various interviews and questionnaire studies (Leung, et al., 2012) (Renaud & Biljon, 2010).

7.0 Related work

There are a number of studies that showcase the development of smartphone-based AR solutions that are used to tackle visualization and collaboration issues in the AEC industries. A mobile application has been developed from Mendez et al. (2006), where it allows architects to visualize architectural models of the pipes and underground services with their smartphones. The virtual 3D models are superimposed over the real-world models (Wang & Schnabel, Mixed reality in Architecture, Design and Construction, 2006). Another study shows an increase in effectiveness of information delivery using a collaborative context-aware mobile augmented reality tool (CAM-ART) as it provides an interactive workspace which promotes collaboration between parties (Shirzai & Behzadan, 2014).

Hybrid 4-Dimenstional Augmented Reality (HD^{4}AR) is a system developed to support site engineers by autonomously identifying the location and orientation of the site engineer from a photography of the site (Bae, Golparvar-Fard, & White, 2013). It also allows site engineers to have immediate access details as it superimposes over the photographs from different perspectives as shown in figure 3 below (Bae, Golparvar-Fard, & White, 2013). HD^{4}Ar can be used effectively on any mobile device as it determines the user's position by using a site photograph as input for the computer vision algorithms, making it an inexpensive investment. The motivation of this prototype is lack of efficiency in the current approaches for in-site analysis and obtaining information, as site engineers have to spent large quantity of time to compute and compare with related online information. This can cause time delay or extra work which will ultimately result in schedule delays and increase in expenses (Bae, Golparvar-Fard, & White, 2013).

Figure 3: BIM information being displayed on top of the photos (Bae et al. 2012)

BIM2MAR is another smartphone-based AR application that allows the integration of BIM into smartphone-based AR to be more effective. Data and 3D spatial information from BIM can be displayed live view and provides the details needed to perform their tasks in a single domain (Williams, Gheisari, Chen, & Irizarry, 2015). The apparent contribution of this application is the ability to transfer BIM into an AR environment cost-effectively and an important milestone in ultimately developing an entirely autonomous process of integrating BIM into AR (Williams, Gheisari, Chen, & Irizarry, 2015).

8.0 Conclusions

This literature review report explored the possibility of using smartphone-based AR in comparison to Hololens in facilitating design meetings and reduce cognition cost in the AEC industries, and ultimately improving the efficiency and cost of projects which is beneficial for the country's economy. Collaboration and visualization were shown to be the most crucial issues that need improvement. Interactions between stakeholders across different disciplines were proved to be difficult along with the cognition cost for humans to mentally develop 3D models. Smartphone-based AR was suggested to be a more compelling solution in terms of cost-effectiveness and convenience. This suggestion was consolidated during the exploration of related work in which has shown benefits. Thus, the report should investigate further in regard to the feasibility of smartphone-based AR compare to Hololens.

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