PROJECT 140: IMPROVE THE EFFICIENCY OF DESIGN MEETINGS IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION INDUSTRIES USING SMARTPHONE AUGMENTED REALITY

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October 2020

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Disclaimer *– All these conference papers have been submitted as partial fulfilment for the project requirement for the BE (Hons) degree. Although they have been assessed, no errors or factual information have been corrected or checked*

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Glossary of Terms

Augmented Reality – A type of visual software that overlays virtual objects with the real environment.
HoloLens – A piece of augmented reality hardware created by Microsoft that is worn on the head and eyes of the user and projects virtual aspects onto their field of vision through a transparent screen.
Spatial ability – A person's ability to imagine and manipulate a 3D object in their head.
Virtual Reality – A type of visual software that enables the user to experience a completely virtual environment.
Visualisation – The act of imagining a 3D object from only 2D drawings or screens.

Abbreviations

2D – two dimensional
3D – three dimensional
AEC – Architecture, Engineering and Construction
AR – Augmented Reality
BIM – Building Information Modelling
CAD – Computer Aided Design
GDP – Gross Domestic Product
VR – Virtual Reality

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Abstract

Collaboration is a necessary process of involved in the Architectural, Engineering and Construction (AEC) Industries, as the various parties have different specialisations. There are multiple different interfaces through which information must be conveyed, which is where there are most likely to be misunderstandings leading to costly errors. The standard method of communicating design information between parties is through design meetings where 2D drawings are shared, annotated and discussed. How these drawings are interpreted can vary depending on the individual's spatial ability and how they visualise the design, especially with complicated 3D models. Therefore, the use of mixed reality, specifically augmented reality (AR), may aid with the visualisation of construction designs as they would be visible to the user in 3 dimensions. A prototype of a building model viewable using smartphone AR was developed and tested on 32 participants and compared with a paper model in a design meeting environment. The purpose of the testing was to evaluate the user's ability to visualise more effectively while maintaining natural communication. The results show that Augmented Reality improves visualisation in terms of both accuracy and speed, and therefore has the potential to aid with the issues currently faced in the AEC industries.

1 INTRODUCTION

The construction industry makes a significant contribution to New Zealand's economy, making up 4% of New Zealand's GDP in 2003, and that a 10% increase in the efficiency of the construction processes would result in a $1 billion increase in real GDP (Toh, 2003). The value of construction is enormous because it is the foundation of modern society. Construction is what makes it possible to have houses, offices, hospitals and many more facilities. The overall process of construction is split into different phases, with the two main steps being the design phase and the construction phase, with the design phase being completed before construction begins. The design phase is where collaboration between the Architecture, Engineering and Construction Industries is necessary, usually occurring through means of a design meeting. The different parties will bring different sets of expertise and will discuss the needs of the clients and the possible designs (Alarcón & Mardones, 1998).

Collaboration is a vital part of the design process in construction. It is crucial for each party involved with the design to have a clear understanding of the models and drawings to have productive discussions (Tory & S. Staub-French, 2008). However, it is not always possible for there to be a perfect understanding between the different parties regarding the design, especially as they become increasingly complex (Jensen & Heckling, 1995). This is one of the main issues with collaboration. Therefore, there is room for improvement in this area of design meetings.

Another issue is the human's ability to visualise designs and create a mental model. The time taken to visualise a design can vary depending on the individual. However, it has been shown that it takes longer to visualise a design from a 2D sketch of a 3D model than it would take from a 3D model (M. Tory, 2006). These time delays can translate to costs when considering the overall efficiency of the project.

Augmented reality is a technology that may prove to be useful when attempting to visualise and collaborate in design meetings for projects in the AEC industries. This is where virtual objects are combined and mixed in with reality using projections and screens (Calderon-Hernandez & Brioso, 2018). There have already been studies which have looked into using AR in these industries (Behzadan & Kamat, 2007).

An experiment was conducted to assess the potential benefits of using smartphone AR compared to standard paper drawings. The results of the experiment were analysed and compared to a similar experiment conducted using Microsoft HoloLens as the AR device. The primary aim of the research is to evaluate the effectiveness of using smartphone AR in design meetings in AEC industries compared to using paper-based drawings.

The contributions made in this study include:

- The development and implementation of a smartphone AR application to be used for experimentation.
- The evaluation of the improvement in a person's ability to visualise a simple building model using smartphone AR compared with using paper drawings.
- A general comparison of results between the smartphone and HoloLens experiments

2 LITERATURE REVIEW

2.1 Background

2.1.1 Architecture, Engineering and Construction (AEC)

Architecture, engineering and Construction (AEC) are all very significant industries in many countries globally, not just in New Zealand. The value that is provided by construction is a necessity to the modern world, with larger developed cities relying on construction to house other industries and residents (Becerik, 2004). The construction process is not simple and requires collaborations between many different parties and specialisations (Akintoye & Skitmore, 1991). In simplified terms, architects will mainly consult with the client to identify the physical set up that is desired and will be visible once the construction is completed. The Consulting Engineers then will investigate the geotechnical environment and potential structural designs that will accommodate the needs of the client and the required national standards for strength and serviceability. The contractors are then hired to make the designs in reality to the specifications provided by the consulting engineers. It is also often common for there to be multiple engineering consultants and architects for larger, more complex projects (Alarcón & Mardones, 1998). In reality, there would be many people involved each needing and giving specific information to and from others. The number of information exchanges is generally very high, and each of these interfaces are prone to errors and miscommunications (Alarcón & Mardones, 1998).

The design phase consists of technical drawings, models and specifications that are used to identify the client needs. Different parties handle each aspect of the design. For example, the columns and beams of a building will be handled by the structural engineers, while the power and lighting will be managed by the electrical engineers (Alarcón & Mardones, 1998). Once again, these parties will also need to communicate with each other, which leaves room for miscommunications resulting in reduced efficiency and increased costs.

Business Information Modelling (BIM) has increased in popularity. It is a 3D modelling software that allows all the information of a building design to be accessed simultaneously in one place (Calderon-Hernandez & Brioso, 2018).

2.1.2 Virtual Reality

Virtual reality is where the user is transported to a completely different environment that is entirely conjured by the software and shows no signs of their real environment (Bricken & Byrne, 1993). A headset is worn which has a screen and a gyroscope, so when the user moves their head, the screen in the headset also moves accordingly, to give the effect that the user is looking around with their own eyes (Bowman & McMahan, 2007). Using virtual reality provides the user with the ability to experience a new construction site before it even begins. The experience is fundamentally different from a 3D model or a computer screen due to its immersion (Whyte, 2003). Immersion is measured by interactivity and vividness. Vividness is how realistic the environment is and how much the user's senses perceive it. Interactivity is the ability of the user to change and modify things in the new environment and act as if they were actually in this environment (Burdea & Coiffet, Virtual Reality Technology, 2003).

Virtual reality has a range of benefits, especially for education. It provides a way of training someone for something which may not be safe or comfortable to do without some experience, such as riding a bicycle on busy streets (Bowman & McMahan, 2007). Virtual reality would allow someone to 'learn by doing' but without the danger of actually being hit by a car. Depending on how immersive the experience, the VR can provide adequate training to improve performance significantly.

Virtual reality has also been used in the AEC industries to aid with identifying construction errors and helping architects to visualise concept designs (Shang, Whyte, & Ganah, 2005).

The possible downside of Virtual reality is the potential motion sickness that can affect the user, due to a sensory disagreement between actual movement and how much movement the eyes see (Regan, 1995).

2.1.3 Augmented Reality

Augmented reality is where virtual objects are combined with the real environment through either goggles or a camera screen (C. Furmanski, 2002). Essentially, AR is supplementing the real world with virtual objects instead of completely replacing reality (Liuska, 2012). Augmented reality is often called mixed reality for this reason as it is a mix of virtual items and reality. The three main components that make up AR are: combining real and virtual aspects, interactive and real-time, and is registered in 3D. (Liuska, 2012)

AR has many benefits, such as being easier to create. In VR the entire 360-degree environment must be created, but with AR, only the relevant objects that need to be projected are necessary to render. This means that less time would be consumed in the creation of AR, making it a more efficient process. This also means that it is easier to switch on and off the virtual objects without disorientation (Wang & Dunston, 2006).

AR has seen many benefits with many study's showing its usefulness. A study showed that students found it easier to see an object in 3D rather than on a computer screen when working on a construction project (J. L. Perdomo, 2005). AR can also be used on construction site visits to lay the proposed 3-dimensional designs onto the existing buildings.

There are different types of Augmented Reality, some having goggles such as HoloLens, google glasses and many more (Slant, n.d.). Others can be used on certain smartphones and devices with virtual objects projected onto the screen, which shows the real environment through a camera. Many of the goggle devices are very expensive and difficult to carry around unless there is a specific purpose for using it.

Mobile Augmented Reality uses the hardware already available in tablets and smartphones that are widely accessible (Craig, 2013). The advantage of Mobile AR is that it can be used almost anywhere that a capable device can be used. The devices that support Mobile AR are becoming more powerful while technology continues to improve, but also less expensive.

2.2 Design Meeting Issues

The two main issues that arise with design meetings in the AEC industries are visualisation and collaboration. Visualisation is the understanding of the 3D objects or structures in a person's head. Collaboration is the ability for multiple people to interact with drawings and models and communicate this information to each other.

2.2.1 Visualisation

Visualisation is how humans try to picture objects or scenarios in their heads without seeing them. It has been defined as "the mechanisms by which humans perceive, interpret, use and communicate visual information" in the AEC industries (M. Tory, 2006).

Another similar term, "Spatial ability," is explored in a University of Auckland Study (Wong, Yu, & Giacaman, 2019) and is defined as, "the ability to picture and manage 3D shapes within the mind."

It is a considerable portion of AEC industries because it is required when creating and understanding models and designs. The different parties involved must be on the same page to have productive meetings and discussions. Especially when the drawings are all in 2 dimensions, but the actual design is for a 3-dimensional structure (Tory & S. Staub-French, 2008). As the complexity of the projects increases, the difficulty of visualisation also increases. Rohrer found that visualization (2D and 3D displays) improves people's understanding of simulation, but the 3D visualization has a greater realism aspect than the 2D (Rohrer, 2000). The standard method of training spatial ability is through desktop applications or other 2D interfaces, but the communication barrier created by the discrepancy between the 2D interfaces and the 3D concepts of spatial ability diminishes the learning process (Wong, Yu, & Giacaman, 2019).

Traditionally, architectural design is focussed on 3D scale models which can have issues such as having expensive design evolution and limited reusability. The 3D models are also still viewed on a 2D computer screen which does not give a real sense of being in the room (Wang, Wang, Xu, & Shou, 2014). It has been argued that architecture is more than just the layout of the objects in a building (Champion, 2011). The items have a "thingness" to them that appeals to more than just the senses. There is a kinetic aspect to architecture that only occurs when moving through the building or house. The use of computer modelling on a 2D screen does not accommodate this, giving a cold mechanical feeling. Augmented reality can increase this feeling of being a real object, as it will be mixed in with the natural environment (Champion, 2011).

2.2.2 Efficient collaboration

The AEC industries require large amounts of collaboration to be successful. While technical skills are required, effective communication and a complete understanding between involved parties are essential for a successful project (Emmitt, 2010). Therefore, any misunderstandings can have adverse impacts on the project timeline and output quality. Design problems commonly occur due to a lack of coordination or communication between these various involved parties (Alarcón & Mardones, 1998).

In previous years, individual drawings would be made first, which then are brought together for the final drawing. The different components would be done separately, which meant that the designs did not accommodate for all the other aspects that needed to come together for the final design (Wang &

Dunston, 2006). However, in recent times 3D modelling and BIM have improved and become the primary designing tool while 2D drawings have less importance (Azhar, 2011). Advancements in technology have also allowed multiple people to view and work on the same model simultaneously, giving more visibility between the different parties and specialisations of the project (Azhar, 2011). Drawings are still used very often in design meetings as it is challenging to share and collaborate with a 3D model in a meeting environment. 2D sketches are more comfortable to interact within a meeting environment but make it more difficult to visualise more complex projects mentally. (Tory & S. Staub-French, 2008).

3D visualisation has become the primary problem-solving tool for engineering education and practice. The use of 3D CAD models helps to reduce the misinterpretation of special and logical aspects of construction planning information. However, there is a lack of collaborative problem-solving abilities which need to be addressed before 3D visualisation becomes widely accepted. Interaction in a shared workspace naturally and smoothly allows for a collaborative learning process (Dong, Feng, Behzadan, & Kamat, 2013).

2.3 How Augmented reality can solve design meeting issues

Virtual and Augmented Reality may be able to provide solutions and improvements to both the collaboration and visualisation aspects of design meetings. Currently, 3D CAD and BIM are ubiquitous and are gaining popularity. The use of paper 2D sketches in design meetings is still widespread (Tory & S. Staub-French, 2008). AR and VR are both advantageous over 2D sketches and 3D computer models because they provide more interaction capabilities. The reason paper is still commonly in design meetings is because of the ability to draw and interact on the paper to discuss and explain certain ideas and layouts (Foley & Macmillan, 2005). With the use of AR, this would become possible as AR is more intuitive with interaction when compared to VR (H. Regenbrecht, 2002). The interaction would enable a more collaborative design meeting, allowing parties to get more involved with the design process (Dong, Feng, Behzadan, & Kamat, 2013). It is evident that AR technology may be able to help solve both the issues of collaboration and visualisation efficiency (Wang & Dunston, 2006).

2.4 Relevant Work

Transvision system developed aims to create a more collaborative design environment using AR technology. The research states that the issue with CAD-based design is that it lacks intuitiveness (Rekimoto, 1996). The Transvision system would also allow two or more people to share the same computer model, which is made to virtually exist in real space.

Magic Meeting is an augmented reality system that is supposed to support the collaboration of experts when designing a product (H. Regenbrecht, 2002). This system has been used in the automotive industry, where a 3D model could be created on a meeting table, and people can interact with the model as if it was a 3D object. The system also enables users to interact with the model using 2D applications on desktop. The motivation for Magic Meeting came as a result of the necessary variety of expertise for creating designs. Meetings were necessary to discuss parts objects in the automotive industry, where a physical mock-up of the part would be taken to the meeting. Participants were either able to get up close to larger parts or pick up smaller parts to get a closer inspection. With 3D AutoCAD projections on desktops, these mock-up parts would no longer be necessary and would remove the mock-up part cost. However, the object would no longer be tangible or available for closer inspection by all members of the meeting. Using AR would combine the benefit of both by not having to produce the mock parts, but also being able to inspect the part through virtual reality. Augmented reality is preferred as the virtual object can be seen in the real world and compared with drawings and designs on paper.

Tangible Bits is a user interface that focuses on the tangible nature rather than the graphical nature. It is called Tangible user interface (TUI) and is an alternative to Graphical user interface (GUI) (Ishii, 2008). The study focuses on using the hands to manipulate the object in the way the hand would, instead of using generic inputs such as a mouse and keyboard to move and object. The study highlights how TUI would allow for more interaction and learning, likened to how children learn to count more effectively when using an abacus as opposed to just seeing or writing numbers.

Studierstube is a project which is trying to create an interface for manipulating complex 3D information in a powerful way that would be similar to how the desktop is for 2D information (Schmalstieg, et al., 2002). This is to be achieved using augmented reality and would allow multiple 3D tasks to be opened modified simultaneous, like how a computer can have multiple applications open at once.

2.5 Statement of research intent

Past Literature has shown that there is potential is for Augmented Reality to aid in both collaboration and visualisation in design meetings for the AEC industries. There is not a significant amount of research into AR specifically for AEC Industries, but there are studies in different sectors such as the automotive. A previous research paper was conducted looking into how AR can aid with the efficiency of design meetings, using Microsoft HoloLens as their choice of Augmented Reality. The research goal of this paper will be to continue with this research project, but now comparing the use of smartphone AR with the HoloLens AR that was previously tested. A similar application will be developed and tested by participants, and the feedback from the testing will be compared to research conducted with HoloLens. Smartphones are commonly held among most people, so the introduction of Smartphone AR would not require large initial capital investments for businesses in AEC Industries.

3 RESEARCH METHODS

3.1 Experimental Method

The experiment aims to compare the ease of understanding between the paper drawings and the Augmented reality application that was developed. The intention is to compare the results with those of last year and see whether smartphone AR would be a suitable alternative to an eyewear AR device such as the Microsoft HoloLens. Specifically, the experiment aims to analyse any improvements in the user's ability to visualise a model while also checking their ability to communicate in a natural manner. The main portion of the experiment requires the participant to find errors in a model of a house using two mediums; paper drawings and a smartphone AR prototype.

To compare the two different systems; AR and paper, the counterbalanced measures methodology was used (P. S. Jensen, 1999). This meant that the participants were randomly assigned to perform the tasks with one of the systems first. Then they would swap to the other system and repeat the same tasks again. However, if a mistake or error was found in the first system, it would not count as a feature identified while using the second system. This method of experimenting has the benefit of each participant using both systems, and therefore collecting two sets of test data from each. After completing the trial with both systems, the participants will then complete a questionnaire that asks for feedback on both systems using Likert scales, such as which medium they preferred or how easy was it to use the AR application.

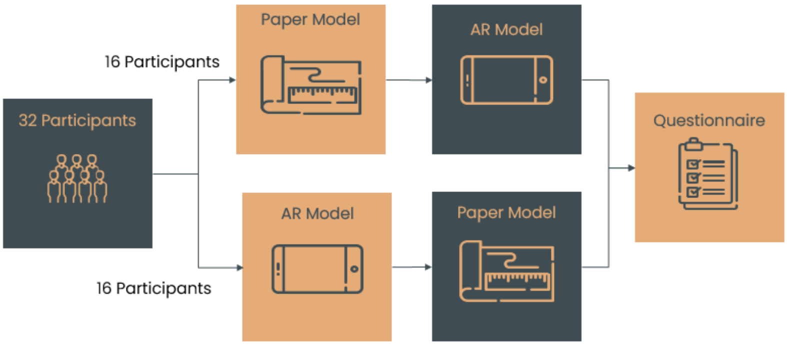

Figure 1: Testing Flow

3.2 Questionnaire

The experiment will be similar to the previous year's and will be made up of three sections.

Section A asks background information such as what they are studying at university, and how much experience they have with AR and AEC industries.

Section B involves the participant performing three tasks that will be related to certain features in the house model, and whether there are any errors such as fewer lighting fixtures than there should be.

The design that is used in the model has inconsistencies built into the model which are visible on both the paper drawings and the AR app. These mistakes are categorised into general and specific. The general errors are things which would not be right in any house. For example, there is a toilet out on the deck in the open; the television is facing the wall, the fireplace is facing the wrong way, along with others. The specific mistakes are where there are more or less particular items that are specified on the specific criteria. This could include things such as there should be more than ten lights in a certain room, or there should be more than ten items to sit on in this room.

This task is used to test the user's ability to visualise the house model and compare how efficiently they can detect the errors using the paper drawings or the AR application. Finding errors would be similar to what stakeholders would be doing in an AEC design meeting, so this task would be an excellent way to measure it. The second task asks the user to delete and highlight a specific window in a room. This task is also carried out on paper by annotating the drawings. It is expected that the ability to see inside the house model in AR freely would make it easier to find the specified window when compared to the orthogonal drawings provided on paper. The third task is to ask the user to explain what they like and what they don't like about the kitchen of the house. This requires the user to visualise for a different purpose than to find specific errors or inconsistencies. The participant will have to visualise what they see in the house and also communicate the different aspects which they like and dislike. This would be an essential part of AEC design meetings as clients would want to be able to communicate with the architects and engineers what they like and what they would like to change about a particular design. The key area to observe in this task is how well the participant is able to communicate through words and gestures while still using the AR system.

In Section C, the participant is asked to answer a series of questions about which medium they found easier and how difficult they found the experiment. These questions are to be answered using a linear scale from 1 to 5, with some questions ranging from very easy to very difficult and others ranging from AR significantly to paper significantly when asked for their preference.

4 SYSTEMS DEVELOPMENT

4.1 Software

The software that was used to develop the prototype was Unity. The Unity software allows the user to create 2d and 3d games and projects, giving easy access to many useful tools and add-ons. This was also suitable because the project that was being continued from 2019, also used the unity software for the HoloLens development. Unity also allows projects on multiple different platforms ranging from PC, to android devices, to iOS devices, to universal windows platforms. This made it possible to import assets from the previous year's project into the current year's project.

The intended target device this project was an android device due to it being easier to upload apps onto the play store, making it easier for trial participants to access.

Initially, AR Foundation was used to develop the software. This was chosen due to it giving the user the ability to create an app that would be compatible with both android and iOS devices (Unity, 2019).

This was essential due to the members in our project group having different devices. After developing the model to a certain extent using AR Foundation, it was found that some devices were better at using their camera to detect surfaces than others. For example, some smartphone devices had multiple cameras which significantly improved their ability to sense depth. As the project was aimed to be usable by anybody with access to a smartphone, it was decided that using AR Foundation would not guarantee a certain level of usability for the user, depending on what type of device they had.

Therefore, a switch was made to Vuforia, which was a unity add-on that allowed the use of image targets for the camera to detect and then produce a model in a position relative to the image target (Vuforia, n.d.). This proved to be much more effective as any device with a camera was able to reliably track the image.

Using Vuforia also provided more resources online due to existing for a more extended time period than AR Foundation (Circuit Stream, 2020). More forums and discussions around certain coding and development subjects proved to be useful.

The model used in the project was imported from the previous year's project so that the trial and experiment results from last year, and this year would be comparable.

4.2 Features

The final application had a variety of features that allowed the user to manipulate the house model by resizing and rotating it about its axis using a two-finger touch mechanism that would be intuitive to the user. A single finger drag allows the user to move the model around relative to the image target. Both the rescale and Rotate functions are intuitive and easy for a smartphone user to understand.

The application also gave the user the ability to highlight, delete and undo the individual components of the house model such as the roof, walls, or pieces of furniture. These functions are turned on and off through the use of UI buttons, and there are also undo buttons to correct any accidental delete or

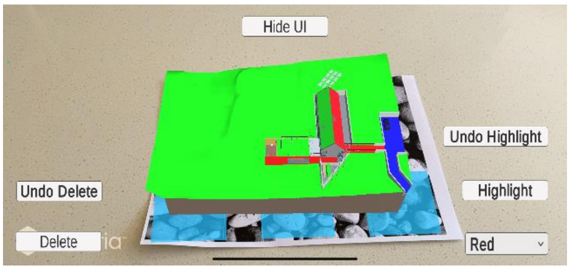

Figure 3: Highlight Function

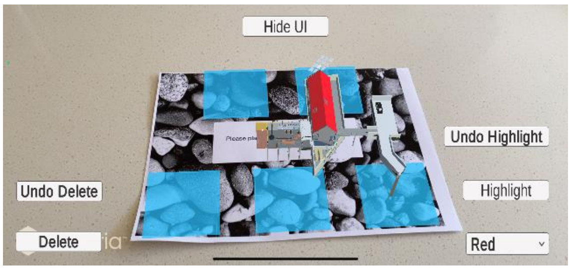

Figure 2: Highlight Function

highlight actions. The delete and highlight functions were developed with C# using Visual Studio's integration with Unity.

Virtual buttons are where the user can hover their finger over a particular portion of the image target which will trigger an event. In this case, the virtual buttons can be used to switch between different versions of the house model. In total there are five virtual buttons on the main image target, which will each cause one of the following to show up; the full house model, the house with the roof lifted upward, the house with the first floor lifted upward, the kitchen and the lounge. This could be useful to the user if they were to be more interested in one particular room or base of the house.

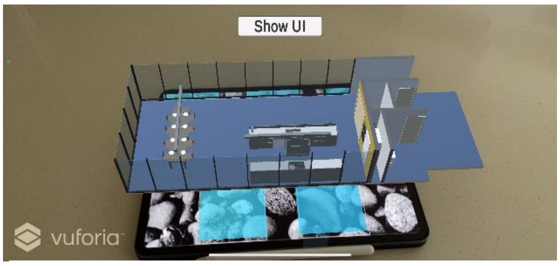

Figure 7: Kitchen

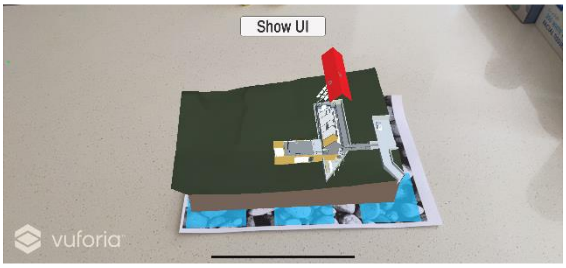

Figure 6: Second Floor

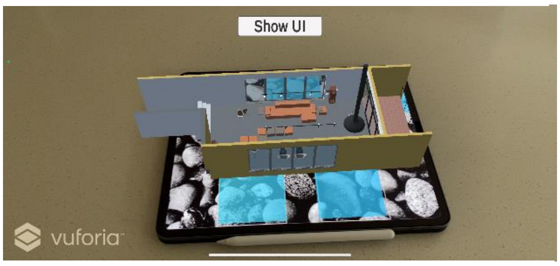

Figure 5: Lounge

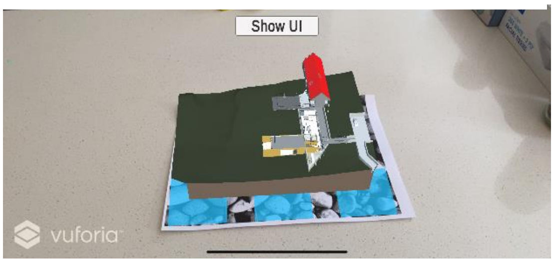

Figure 4:First floor

UI buttons on-screen are used to change between the delete and highlight modes. Another undo button is present for each of delete and the highlight functions. There is also a UI button that can be used to hide the rest of the UI buttons to clear up screen space and give more room to view the model.

All of the features of the applications were intuitive and could be understood without the need for a tutorial. However, one was put in by having a separate image target that would give the reader text to read that would explain how the different features worked. The user can switch between the various blocks of text by using virtual buttons.

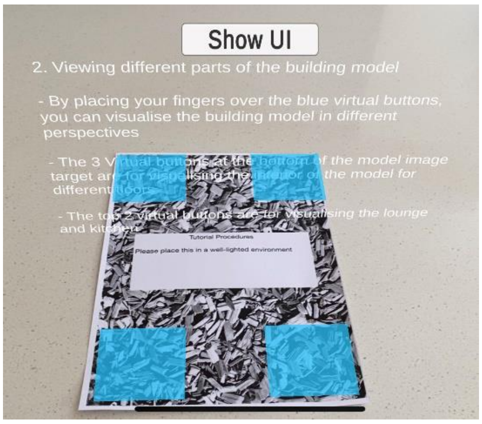

Figure 8: Tutorial Image Target

4.3 Pilot Test

After developing a reasonably usable prototype for the experiment, it was tested on a small number of selected people, who were able to give constructive feedback. It was found that the app was generally usable, although the frame rate would still drop when certain parts of the model were generated.

Another issue identified was related to the undo button. The undo button function was supposed to undo the latest, most recent object that had been deleted or highlighted. However, it was found that the button was undoing the altered objects in the wrong order, with the first deleted or highlighted item being restored first.

An issue was also found where the buttons didn't stop the app from picking up a touch input on the area hidden by the button. This means that if the user wanted to push the highlight button again to turn off the highlight function, it would actually highlight any object that was hidden behind the button before turning the highlight function off.

Users also found that the on-screen UI buttons were overcrowding the screen and making it difficult to view the model. To solve this problem, another UI button was added, which hides and unhides all the other buttons making the screen less crowded.

5 RESULTS

5.1 Section A-General Questions

General information about participants was obtained to ensure that the experiment was well balanced. Majority of participants were in Part IV of Engineering, and there was a large portion of PhD students.

More than half of the participants had minimal or no experience with Augmented reality, while also having between minimal and moderate expertise in AEC industries, as shown in the below table.

Table 1: AR and AEC Experience of Participants

Previous Experience	Augmented Reality	AEC Industries
No Experience	28.1%	6.3%
Minimal Experience	53.1%	53.1%
Moderate Experience	12.5%	37.5%
Substantial Experience	6.3%	3.1%

5.2 Section B – Experiment Questions

5.2.1 Task 1 – Correct Answers and Accuracy

As this experiment consisted of two groups randomly chosen, with independence between and within groups, the Mann-Whitney U test was appropriate to check for statistically significant differences between the two mediums (Statistics Kingdom, n.d.). The totals for AR and Paper were compared, as well as the results from Paper first only and AR first only participants. This is because the number of correct answers found with the second method is heavily influenced by how many were found by the same participant while using the first method. Therefore, comparing the results of the first systems gives a better overall picture of the independent differences. The table below summarizes the results.

Table 2: Summaries of U-Test Output

	Paper First		AR First			Initial				All	
	Paper mean	AR mean	AR mean	Paper mean	Mean difference in Firsts (A-P)	U-value	p-value	All Paper	All AR	U-value	p-value
Average correct Answers	5.63	7.25	10.69	1.81	5.06	7.5	2.60E-07	3.72	8.97	51.5	5.34E-10
Average incorrect answers	1.19	0.44	0.44	0.75	-0.75	195.5	3.40E-03	0.97	0.44	704	5.17E-03
Average confidence (correct)	7.90	8.96	8.76	7.15	0.86	37.5	3.45E-04	7.55	8.86	104.5	1.26E-07
Average confidence (incorrect)	5.63	6.00	6.67	4.33	1.03	28.5	0.367	5.10	6.36	85.5	1.77E-01

There was a clear difference between the average number of correct answers with AR first having a mean value of 10.69 compared to paper first with a mean value of 5.63. Even when the paper medium was used first, there were more correct answers found on average with AR at 7.25 than with paper at 5.63. The number of incorrect responses was slightly larger for paper first at 1.19 on average, and 0.44 for AR. Users also had greater confidence when correctly identifying features while using AR first, with mean confidence of 8.76 compared to paper first with a mean of 7.9.

There were also differences between the two mediums when comparing the 14 features that were correctly identified. The below shows the number of times a feature was found with each of the methods, bearing in mind that once a feature was found in the participants' first method, it would no longer count in the second method. In the table, the features are separated with specific criteria coloured light blue, and general criteria highlighted green. The table shows a trend where general criteria are much more likely to only be found with AR, whereas specific criteria are more likely to be found with either medium.

Table 3: Total Number of Correct Criteria Identified

Criteria/Features	Paper (1st)	AR(2nd)	AR (1st)	Paper(2nd)	AR(1st)-P(1st)
Window numbers	11	5	15	0	4
Windows floor to ceiling	7	5	14	1	7
2 Double doors	8	5	15	2	7
10+ Object to sit	11	5	14	2	3
4 types of seats	3	13	11	2	8
8 lights	10	6	16	0	6
Chair not facing window	8	8	16	0	8
Chairs collision	5	11	16	0	11
Table/Chair Collision	1	15	12	0	11
Table Floating	0	7	1	2	1
Toilet on deck	4	12	15	1	11
TV Orientation	6	10	10	6	4
Furnace Orientation	1	10	5	9	4
Cabinet Orientation	5	11	12	3	7

The McNemnar and Fisher Exact tests were undertaken to determine whether there were any statistically significant differences between the two mediums. The McNemar test shows whether there are any improvements from the participants going from their first medium to their second medium. McNemar was carried out using a 2x2 contingency table (Centre for Clinical Research and Biostatistics, n.d.). Therefore, using the test results, it can be determined whether there was a more significant improvement going from AR to Paper, or from Paper to AR The McNemar test is appropriate to use in this situation because there are two nominal categories, found and not found which are mutually exclusive as well as an independent variable of AR first or paper first; and the participants are assumed to be random. Participants showed significant improvements when switching from Paper to AR for all objects, as the p-value is lower than 0.05. The only two items which participants were able to identify more effectively after switching from AR to paper were the TV and furnace orientation.

Table 4:McNemar Test Results

	Paper first		AR first	
Feature/Criteria	Test statistic	p-value	Test statistic	p-value
Window numbers	3.20	0.037	inf	0.000
Windows floor to ceiling	3.20	0.037	0.00	0.500
2 Double doors	3.20	0.037	0.50	0.240
10+ Object to sit	3.20	0.037	0.50	0.240
4 types of seats	11.08	0.000	0.50	0.240
8 lights	4.17	0.021	inf	0.000
Chair not facing window	6.13	0.007	inf	0.000
Chairs collision	9.09	0.001	inf	0.000
Table/Chair Collision	13.07	0.000	inf	0.000
Table Floating	5.14	0.012	0.50	0.240
Toilet on deck	10.08	0.001	0.00	0.500
TV Orientation	8.10	0.002	4.17	0.021
Furnace Orientation	8.10	0.002	7.11	0.004
Cabinet Orientation	9.09	0.001	1.33	0.124

The Fisher exact test was used to determine if there were any statistically significant differences between the two first systems used, and the participants' ability to identify each feature. Fisher Test was carried out using a 2x2 contingency table to assess the independence of the different mediums for each feature (GraphPad, 2018). The test is appropriate when considering the mutual exclusivity of the two frequency-based nominal variables 'found' and 'not found', the independence of the AR-first and Paper-first groups, the single data point used from each participant, and the small values present in each 2x2 contingency table generated. There was a significant difference in the participants' ability to correctly identify all features with their first system used except for the floating table, furnace and TV orientation, window numbers and 10+ objects to sit on.

Table 5: Fisher Exact Test Results

Criteria/Feature	T Stat	p-value
Window numbers	1.000	>0.05
Windows floor to ceiling	0.023	<0.05
2 Double doors	0.016	<0.05
10+ Object to sit	0.394	>0.05
4 types of seats	0.011	<0.05
8 lights	0.043	<0.05
Chair not facing window	0.002	<0.05
Chairs collision	0.001	<0.05
Table/Chair Collision	0.000	<0.05
Table Floating	1.000	>0.05
Toilet on deck	0.000	<0.05
TV Orientation	0.289	>0.05
Furnace Orientation	0.172	>0.05
Cabinet Orientation	0.032	<0.05

5.2.2 *Speed and Timing of Correct Answers*

A clear difference was seen between the times taken to find the criteria and identify whether they were met. Figure 9 below shows the differences in the gradients of the graphs. The AR section had a greater slope than the paper method, regardless of which method was undertaken first. The overall number of criteria identified correctly was higher when the AR method was used second, shown as the point of intersection of the two lines.

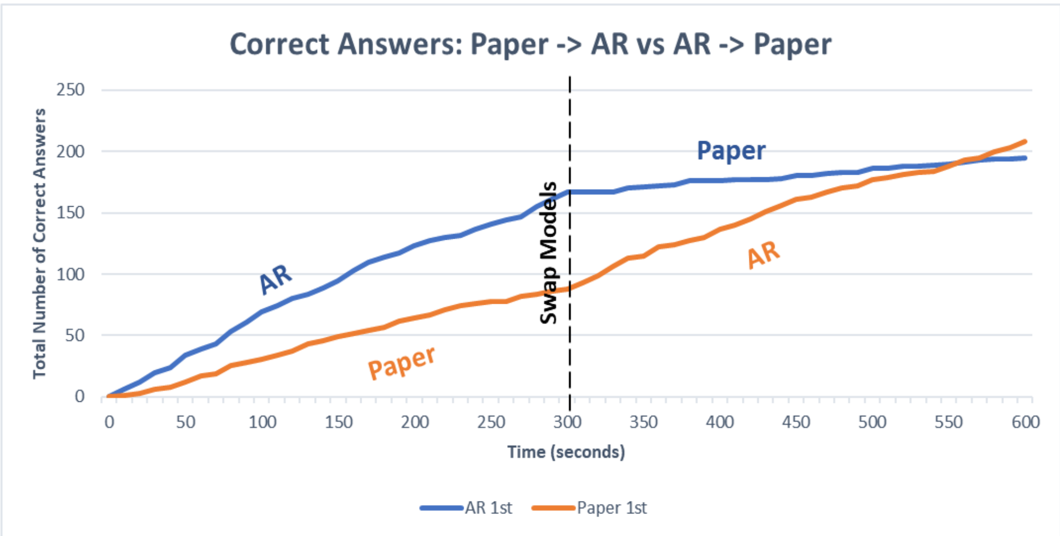

Figure 9: Cumulative number of features correctly identified

5.2.3 Task 2 and 3

When asked to annotate both faulty and removed windows on the Paper medium, participants often seemed slightly hesitant at first but then either shaded or crossed the windows, while drawing an arrow from to say either remove or faulty. When using the AR system, people were able to quickly highlight and delete the specified windows as part of the task. The post questionnaire also asked which method the participants preferred to use to make changes to the model and 81% said AR or AR significantly, while only 6% chose the paper system, with the remaining 13% having neutral stance.

Task 3 asked the participants to express their likes and dislikes about the kitchen. Many trialists stated that it was difficult to get a feel for what the kitchen looked like with only the paper drawings, while the AR made it much more apparent. In the post questionnaire, 100% of the participants stated that they felt more affinity for AR when viewing the house. Question 4 and 8 of the post questionnaire asked how easy it was to express what they liked and didn't like about the kitchen for each system, and 100% said it was either easy or very easy using the AR system, and only 9.4% said the same with the paper system.

5.3 Section C – Questionnaire

Table 6:Paired question ratings from Questions 1-8

	% Easy or Very Easy	
Question	**AR**	**Paper**
1, 5. How easy would the model be for a non-engineer to understand	100	12.5
2, 6. How easy was it to visualize the room's exterior	90.7	3.1
3, 7. How easy was it to visualize the building's contents	100	6.3
4, 8. How easy was it to express what you liked/didn't like about the kitchen	100	9.4

Table 7: Likert Scale for Questions 10-12

Question	**AR or AR significantly %**	**Paper or paper significantly %**
10. Which system held your attention more?	96.9%	0%
11. Which system was better for making changes?	81.3%	6.3%
12. If this were your new house, would you feel more affinity for it when viewing it in AR or on paper?	100%	0%

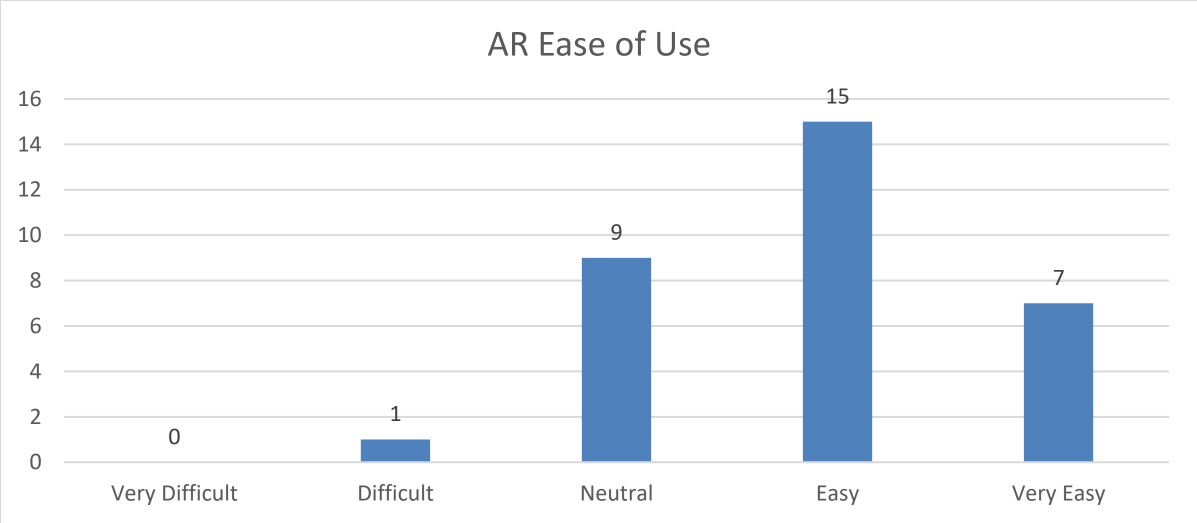

Figure 10: AR Ease of use Bar Chart

The first eight questions of the questionnaire in Section C asked the participant to rate the difficulty of completing various tasks. The results show a greater ease rating with the AR model compared to the paper model. The results were analysed using the Wilcox signed-rank test to determine if there was a statistically significant difference as this test is a paired difference test. This test is appropriate to this situation as the data is paired, dependent and of an ordinal nature. The calculated p-value was less than 0.05 for all pairs, meaning that the difference is statistically significant.

Questions 10 -12 also showed a clear preference for AR, as shown in table 7. The AR systems held the users' attention better, was better for making changes and gave the user a greater feeling of affinity.

Figure 10 shows the participants' responses to question 9, asking how easy it was to interact with the AR model. Results show that a majority found it either easy or very easy; however, there were a fair many who were neutral. This suggests that the intuitiveness of the prototype can be improved. One area where people had difficulty was with the virtual buttons. These buttons were frequently irresponsive and could be improved by increasing the sensitivity settings in Unity.

6 DISCUSSIONS

An interesting point to notice is that participants using AR were much more effective at identifying errors with the general criteria when compared with Paper users. In contrast, the specific criteria were identified more evenly between the two modes. This may be because the specific criteria gave the participants obvious directions and hints as to what to look for, whereas the general criteria could be anywhere in the room. This finding could suggest that the AR method gives the user a more remarkable ability to visualize objects and establish what they are and whether they are in suitable locations or orientations. Participants using the paper model were more likely to have difficulty visualization what the 3-dimensional object would look like from only the multiple 2-dimensional views. The two criteria which seemed to be the most difficult to identify regardless of the medium were the furnace orientation and the floating side table. The furnace orientation was difficult to observe using AR due to the dark colours of both the outer casing and the fireplace. Many participants commented that they did not know what the furnace was and thought that the error was that it was floating. The floating side table was almost impossible to identify using the paper medium, and still very difficult to find on the AR model, as the participant needed to manipulate the model to get the perfect angle to see that it was not on the ground. This was made difficult because the image target needed to be present on the screen for the house model remain present. This issue could be relieved by somehow making the model stay present, even when the image target is not within the camera shot.

After comparing the rate at which the participants correctly identified both the general and specific criteria, the AR medium can be seen to be faster. This indicates the user can more effectively and efficiently visualise objects using AR in real-world applications. Therefore, AR use could reduce the time and cognition cost involved with understanding drawings in AEC industries.

The results of task 2 showed that most participants preferred to use the AR system to make/annotate changes or removals to the house model. This may be because of the clear distinction between highlighting an object and removing it on the AR system. With the paper model, many participants commented that it was challenging to annotate on the paper in such a way that made it very clear whether the object was to be removed or highlighted. In real-life applications, AR has the potential to make it clearer to meeting participants which features are being referred to or changed with the use of highlighting. However, real-life designs are often much more complicated than the model that was used in this experiment. Therefore, the highlighting and deleting functions may not be preferred if the parts are too small or intricate to distinguish from the surrounding elements.

In task 3, the way that participants expressed what they liked and didn't like was similar between both mediums. This involved a combination of pointing at the certain areas on the paper or phone and making eye contact with us, the researchers. However, many people commented that it was much more challenging to get a feel for what the kitchen was like using only the paper drawings. This suggests that AR could be useful in the industry for allowing clients to gain a more thorough understanding of what their house or project would look and feel like once it has been constructed. The AR also has the potential to be a useful tool for collaboration as well, due to the users being able to talk and look at each other while explaining certain aspects of the model.

Section C of the questionnaire also confirms the participants' preference for the AR model when judging how easy it was to express what they liked and what they didn't like about the kitchen. 100% of participants felt that it was either easy or very easy to express their tastes with the AR model compared to only 12.5% with the paper medium.

Another research aim was to compare the results of the smartphone AR experiment with the HoloLens AR experiment that was carried out last year. The overall trends of the results were very similar, with participants performing more efficiently and accurately with AR mediums. The participants preferred using the AR system when highlighting objects, as well as when expressing their judgement of the kitchen. These findings could suggest that the smartphone AR could be a suitable alternative to using the HoloLens or a similar head-mounted AR device. In real-world application to design meetings, the use of smartphones would be much more accessible to people as almost everyone would own a device that can handle some an AR application. In contrast, AR goggles can both be expensive, and time-consuming to set up at the start of a design meeting, resulting in a much higher cost for the parties involved. Therefore, this research has shown the potential for smartphone Augmented reality to aid with the collaborative visualization issues that are faced by the AEC Industries.

7 LIMITATIONS

This application is a significant simplification of what would be occurring in real-life design meetings which should be considered when considering the validity of this research. For example, the simple highlighting and deleting of a window would not be a complete and accurate representation of all possible annotations or comments that could be made in a design meeting.

Another limitation would be that the participants of this study would all be engineering students of the university. Although they may have some experience, they may not be fully competent with the usage of design drawings and AR technology.

Another limitation is the validity of the comparison between the previous year's HoloLens experiment and the current projects smartphone project. Even though both experiments were carried out in a very similar manner, the participants used were different, which is not a statistically accurate method of comparing results. Therefore, general comparisons can be made, but concrete conclusions cannot be drawn between comparing the effectiveness of the two mediums when it comes to visualisation and collaboration potential.

8 CONCLUSIONS AND FUTURE WORKS

The research carried out in this paper has looked at the potential for the use of Augmented Reality on smartphones to aid with collaborative visualization in design meeting in the AEC industries. A prototype application was built that gave the user the ability to view, manipulate and change a model of a house using intuitive screen gestures. An anonymous experiment was conducted on 32 willing participants to compare how they perceive and understand the same model through two different mediums; Paper drawings and the Augmented Reality model. The results showed that people were more accurate and faster when it came to identifying features correctly. Additionally, a significantly significant proportion of participants preferred the AR medium for multiple reasons, as evidenced by the post-experiment questionnaire. These results suggest that AR has the potential to be a useful tool in AEC Industries.

In future, this research could be further investigated by using a more complex and realistic building model. This would give a better indication of how application this technology would be in the industry. Along with this, the model could be developed so that multiple users can view the same model through different devices. This way, collaboration would become more accessible, allowing all meeting participants to understand the changes that are made. Another annotation feature could also be added, which will enable users to attach comments to particular sections of the model, similar to comments on a Google document. The technology would also benefit from becoming more refined, responsive and fluid. Specific improvement areas include the frames per second of the model, virtual button consistency, and some of the bugs with the buttons. Overall, there is still a broad scope that remains to be researched in the future, but smartphone AR shows the potential to improve the effectiveness of design meetings in AEC industries.

ACKNOWLEDGEMENTS

Acknowledgements go out to the two supervisors for this project; Vicente Gonzalez and Nasser Giacaman. Their continued support made this research project possible. The 32 participants who gave up their time to help with the research are also much appreciated.

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