

HOLOSYNC

A comparative study on Mixed Reality and contemporary communication methods in a building design context

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Abstract. The integration of technology into the design process has enabled us to communicate through various modes of virtuality, while more traditional face-to-face collaborations are becoming less frequent, specifically for large scale companies. Both modes of communication have benefits and disadvantages - virtual communication enables us to connect over large distances, however can often lead to miscommunication, while face-to-face communication builds stronger relationship, however may be problematic for geographically dispersed teams. Mixed Reality is argued to be a hybrid of face-to-face and virtual communication, and is yet to be integrated into the building design process. Despite its current limitations, such as field of view, Mixed Reality is an effective tool that generates high levels of nonverbal and verbal communication, and encourages a high and equal level of participation in comparison to virtual and face-to-face communication. Being a powerful communication tool for complex visualisations, it would be best implemented in the later stages of the building design process where teams can present designs to clients or where multiple designers can collaborate over final details.

Keywords. Communication; HoloLens; Mixed Reality; Collaboration; Virtual.

1. Introduction: Research Aims and Motivations

In many ways, the integration of technology in the design process allow more effective communication of ideas and information, overcoming limitations of locations and time difference. Traditionally, Face-To-Face (FTF) meetings have been the dominant method for collaborative projects. Yet, for companies that are large in scale and have non-collocated team members on a common project, this method of communication can be problematic. Everyday contemporary communication increasingly comprise of less FTF interactions and more virtual interactions. Virtual technologies such as Skype, email, and other telecommunications help to overcome geospatial locational communication issues, yet lose some of the important qualities inherent to FTF.

The benefits of using virtual communication technologies include a more equal level of participation within a heterogenous group, and cost reduction for those who would otherwise be required to travel. However, virtual communication can lead to miscommunication through the misinterpretation of body language (Billinghurst et al, 2002). In these situations and in the context of building design decision-making, space is created for weak design decisions to be made by both parties.

Conversely, FTF communication allows for stronger relationships between parties and therefore a sense of trust is formed. Being within another person's social or personal space enables the direct translation of body language and nonverbal cues platform (Blenke , 2013). Nonetheless, technological advances have created a paradigm of computer-mediated humans who are more familiar with social interactions through a virtual.

Mixed Reality (MR) is argued here to reside between FTF and virtual communication. While the device is hands free and you are able to view the environment and people around you, holographic projections and spatial sound make for a unique experience (Microsoft, 2017). The Microsoft HoloLens is a contemporary MR device that uses interactable holograms that are overlaid on to real-world surfaces. It is a device in the form of a portable headset where multiple users can interact with synchronous holograms and real-time feedback of another user's actions.

It is considered conventional for design firms to use FTF and virtual platforms heavily to communicate between design teams that are both co-located and non-collocated. The pattern that often follows the advancement of technology suggests that the integration of more modes of virtuality is likely. MR being a hybridized tool between FTF and virtual communications, provides a fresh platform for designers to utilise. However,

how do we know if this technology is in fact effective? Being in its infancy, it is unclear where MR could be best used within the building design process if at all, and whether it would promote better communication and relationships within a team as FTF does, or if it is another virtual wall that will divide design teams.

2. Research Observations and Objectives

The objective of this research is to address and determine in what ways MR technology is an effective communication method in comparison to current methods. FTF communication and virtual communication are studied through a collection of existing literature. Through this analysis, an argument is created for the use of MR as a beneficial hybrid tool between FTF and virtual communication.

In order to explore the advantages and disadvantages of MR, user-testing is conducted and analysed via video recordings to determine where MR would be best used within the building design process and in what ways it is a successful communication tool.

3. Research Questions

This research explores in what ways MR technology can be an effective communication tool compared to current communication methods and whether it constitutes a viable method of communication for the building design process. To answer this, there are a number of variables that need to be acknowledged. Communication is considered a broad term for the exchange of information of data. Therefore, analysing its effectiveness and success in a way that is non-subjective is something that must be considered.

Communication consists of verbal and nonverbal cues. Body language, facial expressions, and physical gestures can be categorized into nonverbal cues, whereas communication through any type of vocal projection can be considered verbal-cues. Both cues are forms of participation, and it is clear that there is a link between levels of participation and how successful a team of collaborators communicate (Billinghurst et al, 2002).

To answer this research question, both verbal and nonverbal cues are studied. These extensions of the research question help further identify specifically how effective MR could be as a communication tool or where it is lacking. Therefore, the following questions must also be considered:

- (i) Does MR encourage a higher level of participation through nonverbal cues?
- (ii) Does MR encourage a higher level of participation through verbal exchange?

4. Methodology

To evaluate MR as a communication tool, a holographic design review platform is created that allows you to interact and assess models. This application encourages collaboration through a shared MR experience and uses voice commands to explore holographic models. This paper uses Action Research methods where a plan is created for evaluation. User-testing is conducted, data is observed and collected, and the results are analysed (Gabel, 1995).

Through the analysis of existing literature, an evaluation method is proposed for user-testing. Three scenarios using subjects split into pairs in a co-located environment are tested. The first scenario requires the subjects to communicate FTF, the second scenario uses a Computer-Mediated-Communication (CMC) method of communication, and the third scenario uses MR communication using HoloLens devices. The subjects are recorded and observed while performing a problem-solving task to examine the effectiveness of FTF, CMC and MR communication methods.

A quantitative methodology is adopted to measure the outcomes of user-testing and to determine which communication approach is most beneficial in a building design context. The data collected consists of calculating the number of nonverbal communications (pointing gestures and model interactions), and verbal communications (questions and statements) through observation of recorded user-testing scenarios. In addition to observational data, pre- and post- testing surveys are conducted to gather the subject's opinions on which methods would be best for visualisation, communication, focus, and user-friendliness. These results are then reflected upon to determine in what ways MR could be used within the building design process.

5. Background Research

There is an extensive range of existing research looking at how FTF and CMC impact on communication within a group. With the release of new and innovative technology, there are now more communication tools and methods that should be considered.

5.1. FACE-TO-FACE COMMUNICATION METHODS

Before technology was integrated heavily into society and specifically the building design process, FTF meetings and collaborations were the conventional way to exchange ideas and information. There are beneficial aspects to FTF collaborations, mostly involving laying the foundation of a relationship between yourself and your collaborators, however there are also downfalls to relying solely on FTF meetings.

Blenke (2013) identifies key aspects of FTF communication that are neglected through virtual communication such as the observation of nonverbal cues, and the establishment of trust between team members. He claims that “[FTF meetings] are a way to improve understanding, develop trust and provide a basis for future communication” (Blenke, 2013). Collaborating through FTF meetings also opens the opportunity for relationships to develop beyond the professional kind, allowing future collaborations to be more personal and enjoyable.

Previous studies have shown that CMC groups that were given tasks took longer to complete in comparison to the groups who completed the tasks FTF. In 1986, Hiltz et al. reported that some participating groups had to be stopped mid task due to them taking so long. However, factors such as time taken to type may have factored in to the overall time recorded and may have been a factor that slowed subjects down.

However, there have been studies that suggest CMC groups generate more ideas than groups who collaborate FTF. These studies show that non-redundant idea generation was higher in CMC groups in comparison to FTF groups (Bordia, 1997).

The disadvantages of FTF communication arises when there is a team that is non-collocated and would be required to spend money to travel in order to collaborate FTF. Where FTF communication becomes problematic, CMC or virtual communication becomes beneficial.

5.2. VIRTUAL/COMPUTER-MEDIATED COMMUNICATION METHODS

Virtual teams are increasingly becoming conventional with large scale companies and firms having businesses in multiple locations. Communication between these teams are just as critical as co-located teams, however can face more challenges. “Unlike in co-located teams, subtle yet important cues are easily missed in the virtual environment” (Pauleen et al, 2001). Particularly with colleagues and team members who have not met in person, it is quite easy to misinterpret a comment or remark without being able to observe that person’s subtle nonverbal cues and body language (Burgoon et al, 2002). More notably, relationships that are formed through a virtual network tend to be less personal in comparison to a team that works in the same office. This relationship can affect how teams work, making the relationship and experience less personal and more task oriented (Blenke, 2013).

Despite the possibilities for misinterpretation, communicating via technology gives us the ability to connect and network with people we may not have the chance to meet in person. Additionally, we can communicate with others over large distances, regardless of time-zone. Travel costs would

decrease with the increase of virtual communication and opportunities of multidisciplinary collaboration would be endless.

5.3. MIXED REALITY / MICROSOFT HOLOLENS

Mixed Reality (MR) is a hybridization between the tradition FTF and more contemporary methods of virtuality. In 1994, Milgram defined MR as “a subclass of [Virtual Reality] related technologies that involve merging of real and virtual worlds... the most straightforward way to view a Mixed Reality environment, is one in which real world and virtual world objects are presented together within a single display...” (Milgram, 1994). At the time of Milgram’s exploration, the technology was limited and still very experimental. Since then, there has been significant progress in technology.

The Microsoft HoloLens is a non-tethered MR headset that allows the user to roam around their environment freely, allowing interaction with holographic overlays mapped on to real-world surfaces. Although MR has been present in research and development for many years, only recently has the technology become readily available and affordable. Often used for entertainment and gaming, it is a tool that would be effective for rapid visualizing design iterations both within a collaborative team and to clients, as well as communicating model data information (Microsoft, 2017). MR devices currently have limitations such as field of view, however these may be refined and mitigated in the future.

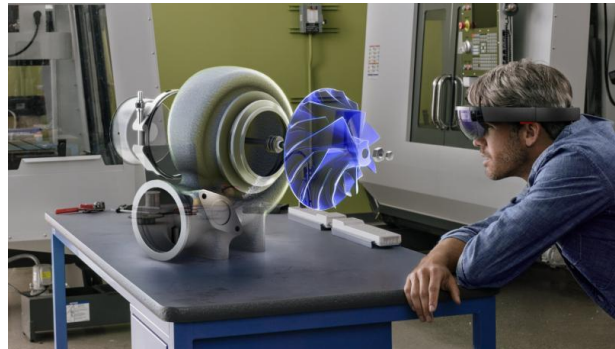


Figure 1. The Microsoft HoloLens (Muchmore, 2016)

5.3.1. Current HoloLens applications

There are a variety of HoloLens applications designed for various modes of entertainment and educational purposes such as model visualisation, gaming, and collaborative long-distance communication such as Skype.



Figure 2. Skype call via the HoloLens (Hachman, 2015)

Skype for the HoloLens is a powerful application for non-located communication. The application can be used between multiple users to interact with one another's space. While making a Skype call using the HoloLens, the companion is able to observe what you see and "as the [companion] sees objects to note, he can annotate items in the space for [you] to see" (Chen et al, 2015). Applications such as this are an example of the power of MR technology and how it could be used for geographically dispersed team members.

5.4. PROPOSING A METHODOLOGY FOR TESTING

Several studies compare FTF and virtual communication methods, while fewer studies address MR. Using the HoloLens, a study is conducted to determine where it sits in relation to FTF and virtual communication methods. By reviewing existing communication studies, approaches can be extracted and compared to then propose the most appropriate way to test MR as a less explored method of communication.

The 2002 study comparing Augmented Reality (AR) interfaces with screen-based projection and FTF interactions conducted by Billinghurst et al, is the primary source for the methodology chosen for this research. The experiment consisted of 3 scenarios (FTF, AR, and screen-based projection), assigning a pair of subjects to each scenario. The pairs were provided with 10 sets of rules which were divided in half. Each subject within the paired team would receive 5 sets of rules each. The subjects were made to organize 9 virtual or physical models on a 3 x 3 grid, using the rules as clues as to where each building needed to be placed. The number of gestures, number of words per phrase, number of speaker turns, and performance time were

observed and compared against the 3 scenarios to conclude how effective the AR interface was. Additionally, video and audio recordings were collected of each scenario. This study used 12 pairs of adults as subjects for testing.

Billinghurst et al’s results showed that the subjects were able to solve their task much faster using FTF communication in comparison to the remaining two methods – AR taking the longest to complete.

[FIGURE 3]

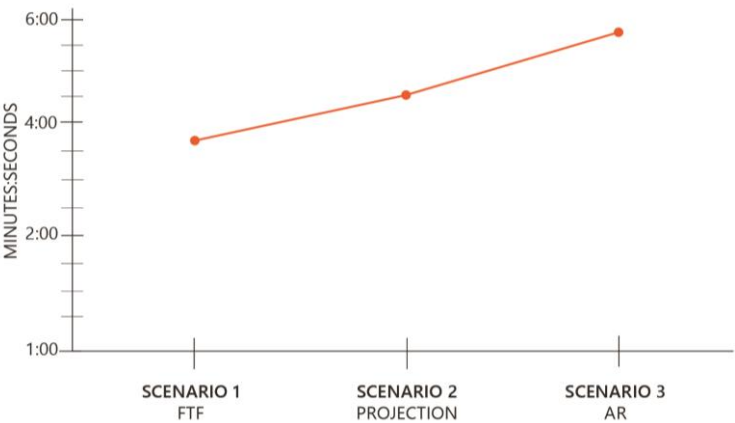


Figure 3. Results of performance time (Billinghurst et al, 2002)

The number of speaker turns and number of words per phrase was also measured during each scenario. Speaker turns was defined as “one user taking control of the conversation and speaking until either the other user interrupted, or he stopped speaking for more than three seconds” (Billinghurst et al, 2002). The summary of these averaged measurements showed that there was not much difference in both average number of words per phrase and average number of speaker turns.

Table 1. Results of verbal communication (Billinghurst et al, 2002)

AVERAGE	FTF	PROJECTION	AR
NUMBER OF WORDS/PHRASE	9.51	8.99	8.24
NUMBER OF TURNS/SECOND	0.30	0.31	0.32

[TABLE 1]

The number of pointing gestures made per minute was also measured, with FTF showing the most amount of nonverbal collaboration and screen-based projection encouraging the least amount of nonverbal communication.

[FIGURE 4]

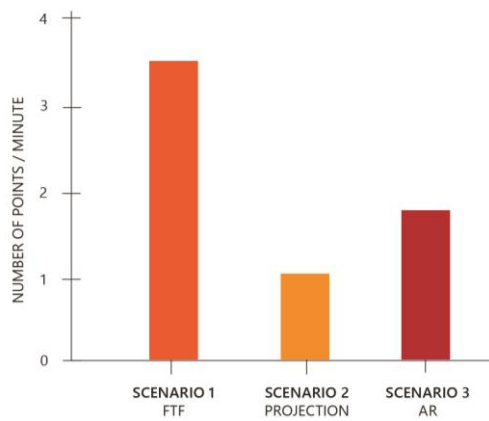


Figure 4. Results of pointing gestures (Billinghurst et al, 2002)

Similar to the results of the number of pointing gestures per minute, FTF subjects showed the highest level of picks, or model interactions, per minute, while AR was recorded to have had the least amount of picks.

[FIGURE 5]

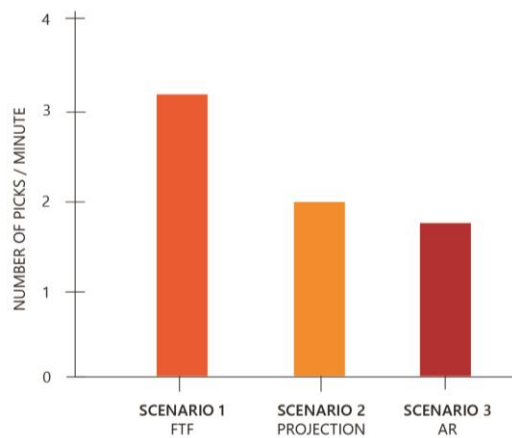


Figure 5. Results of picking gestures (Billinghurst et al, 2002)

A subject's comment that was included in the study depicted what was felt overall by the subjects in the study. "AR'S biggest limit was lack of peripheral vision. The interaction physically as well as spatial movement was natural, it was just a little difficult to see. By contrast in the Projection condition you could see everything beautifully but the interaction was tough because the interface didn't feel instinctive," (Billinghurst et al, 2002). This study provides an insight in to what kinds of quantitative and qualitative data that could be extracted and analysed.

As the case study is now out of date, this methodology has been recycled and modified to suit current technology for this research.

6. Case Study

The holographic design review platform combines a shared experience with voice control interaction. With the capability to have multiple users experience the same holograms, the platform could be used by different design disciplines discussing a common idea/design, or by the designer and the clients.

This paper focuses specifically on establishing a shared connection and conducting user-testing to determine how effective MR is as a communication tool.

For information on holographic interaction through voice control, see Ali Siddiqui's paper.

6.1 ESTABLISHING A SHARED NETWORK

The Microsoft Windows Development Centre website provides a range of MR learning resources that are catered to the Microsoft HoloLens (Microsoft Developer, 2017). In addition, the HoloToolkit includes a variety of sample C# scripts and Unity scenes that you can use or modify for your own purposes (Github, 2017). For the holographic design review platform, the scripts were mildly modified as this was not the main objective of the paper. This paper will therefore not focus on the coding aspects of this exploration and will focus more so on the user-testing.

To establish a shared connection within Unity for the HoloLens, the Sharing prefab was used within the HoloToolkit sample to create a link between the computer's IP address and the additional HoloLens headsets. The Sharing Service was enabled, bringing up the depicted log box (see *Figure 6*) which displayed the computers IP address. This address was then entered into the Server Address where Unity could then connect the incoming HoloLens devices that wanted to join the same shared network.

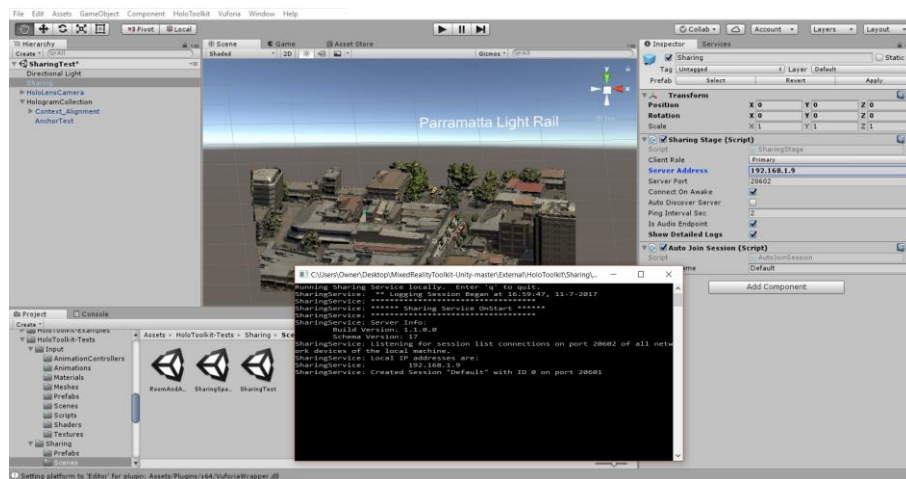


Figure 6. Establishing a shared connection within Unity

AnchorText was another critical prefab element that made the sharing service and hologram sharing successful. The AnchorText prefab was used as a location anchor where its coordinates and location within your environment would be shared via the Sharing Service and communicated to the other HoloLens devices in order for them to see it holograms the exact same location. This was modified to display the appropriate text for the Parramatta Light Rail context environment provided by ARUP, and was adjusted to not interfere with the holograms.

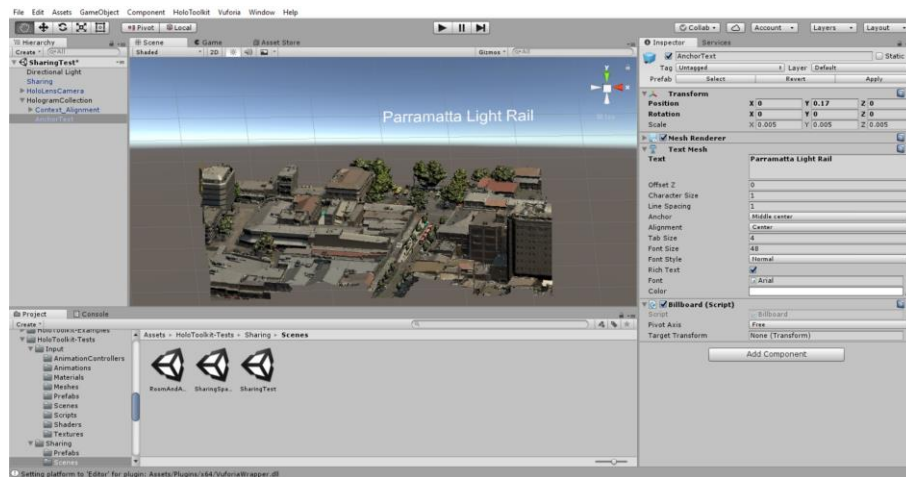


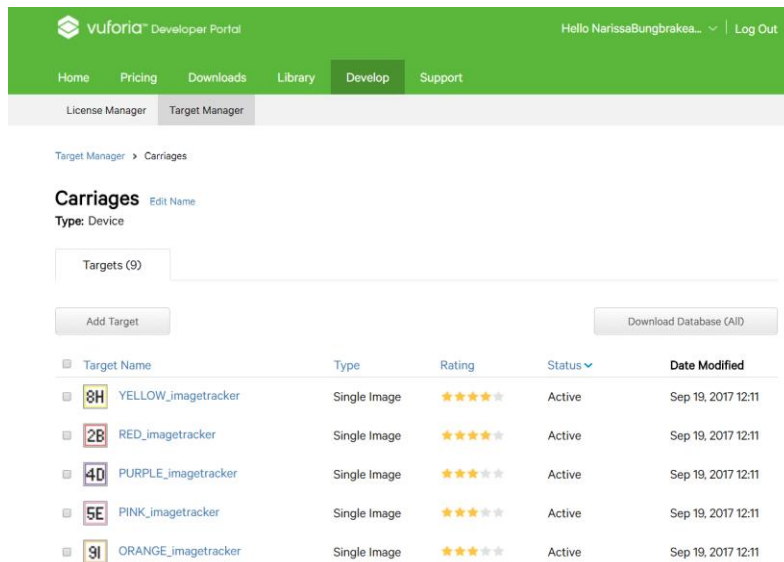
Figure 7. Using the AnchorText prefab to communication hologram location

6.2 INCORPORATING VUFORIA

Certain features of the HoloLens platform such as holographic models and shared connection were included for user-testing. Although a shared connection has been established for the holographic platform, the collection of observational data would be more accurately identified if a physical level of interaction was incorporated in to the experience.

Vuforia is an AR platform that recognizes images as anchors to project holograms on to. It can be used on different platforms such as Android, iOS, tablets, and the HoloLens. This platform enables you to customize the images or symbols that Vuforia can track, which will then act as an anchor for holograms to be projected on to (Vuforia, 2017). Using Vuforia and Unity, a physical level on interaction was added to the HoloLens testing experience.

After creating an account with Vuforia and downloading it into Unity from the Asset Store, a license key was provided for activation within Unity. On the Vuforia Developer Portal, databases can be created that contain folders of tracking objects or images that you wish to upload. One database was created to hold nine tracking images. When uploading a tracking image or object, whether the file is 2D or 3D, must be specified as well as the correct measurements of its height and width. This is to ensure that Vuforia is able to recognize the image and its correct proportions. From here, the database can be downloaded as a Unity package which can then be imported into Unity.



The screenshot shows the Vuforia Developer Portal interface. At the top, there's a green header with the Vuforia logo and 'Developer Portal'. Below the header, there's a navigation bar with links: Home, Pricing, Downloads, Library, Develop, and Support. The 'Develop' tab is active. Below the navigation bar, there's a sub-navigation bar with 'License Manager' and 'Target Manager'. The 'Target Manager' tab is active, showing a breadcrumb 'Target Manager > Carriages'. The main content area is titled 'Carriages' with an 'Edit Name' link. Below the title, it says 'Type: Device'. There's a 'Targets (9)' section with an 'Add Target' button and a 'Download Database (AID)' button. A table lists the tracked targets:

Target Name	Type	Rating	Status	Date Modified
8H YELLOW_imagetracker	Single Image	★★★★☆	Active	Sep 19, 2017 12:11
2B RED_imagetracker	Single Image	★★★★☆	Active	Sep 19, 2017 12:11
4D PURPLE_imagetracker	Single Image	★★★★☆	Active	Sep 19, 2017 12:11
5E PINK_imagetracker	Single Image	★★★★☆	Active	Sep 19, 2017 12:11
9I ORANGE_imagetracker	Single Image	★★★★☆	Active	Sep 19, 2017 12:11

Figure 8. Creating a database on the Vuforia Developer Portal

Sample prefabs and scripts were used from the Vuforia example download. ARCamera was used to link the HoloLens camera for image tracking recognition. The ImageTarget prefab was replicated and modified nine times for nine different models and was placed in the Unity hierarchy as a child of ARCamera.



Figure 9. Assigning 3D models to tracking images

The areas of the ImageTracking prefab that was modified were the options under Image Target Behaviour (Script). Once the online database had been downloaded as a Unity package, it was then imported into the Unity scene. The Database option was changed to “carriages” which was the name of the database created in the Vuforia Developer Portal, and the Image Target option was changed to feature one of the nine target images. The width and height were then specified again, and Extended Tracking was enabled to ensure that Vuforia would be active.

To assign a 3D model to a tracking image, the model is simply placed on top of the image with the same size and ratio of what is depicted in the scene, projected in real life.

6.3 USER-TESTING

Three scenarios were tested using three different forms of communication. Scenario 1 required subjects to work together FTF, Scenario 2 used CMC, and Scenario 3 used MR through the Microsoft HoloLens. Subjects were asked to arrange nine light rail carriage models on to a 3 x 3 grid. These carriages were distinguished by colour and varied in material/medium over the three scenarios. For example, Scenario 1 used nine paper crafted models,

Scenario 2 used nine digital models, and Scenario 3 used nine holographic models (see *Figure 10*). Using Vuforia, nine cards printed with different images were used to project the light rail carriages, making it easier for the subjects to control and move around the holographic models.

[FIGURE 10]

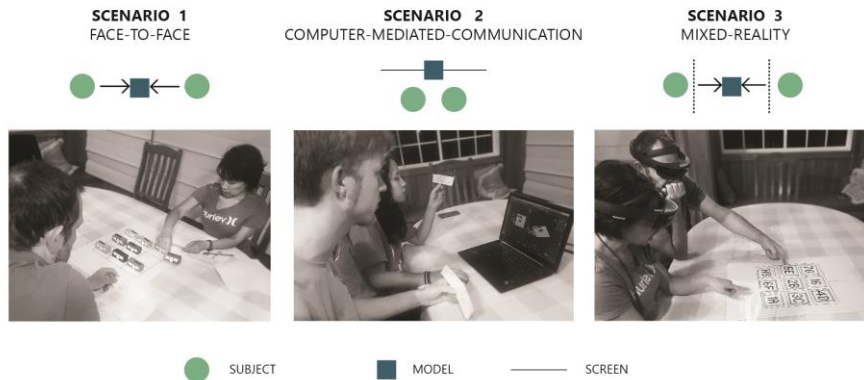


Figure 10. Diagrams and images of the three testing scenarios in a co-located setting

A total of four subjects were tested on each scenario and were split into 2 categories. Category A included two subjects aged 50 – 55, and Category B included two subjects aged 25 – 30. These subjects acted as clients rather than designers, as none had experienced MR before nor were they highly experienced using CMC, but all were comfortable with traditional FTF communication.

Similar to Billingham et al's method of testing, the subjects were given five sets of rules that together would complete a problem-solving task – this task being to place the 9 light rail carriage models in the correct location on the 3 x 3 grid. An example of these rules includes:

The RED carriage is opposite the LIGHT GREEN carriage

The PURPLE carriage is next to the PINK carriage

The task required the pair of subjects to work together and verbally communicate their provided rules in order to successfully complete the activity. Without all 10 rules the task could not be solved correctly.

Both nonverbal and verbal communication is critical to determine how effective communication is within a team. Therefore, the following observational data was collected through the video recording of each subject category completing each task:

- (i) Nonverbal – number of pointing gestures
- (ii) Nonverbal – number of model interactions
- (iii) Verbal – number of questions asked
- (iv) Verbal – number of statements made

6.3.1 Constraints and limitations

During user-testing there were some limitations in terms of time and resources. The number of HoloLenses provided by the university was limited, therefore only two HoloLenses were tested at one time. Additionally, the time constraints meant that there was only enough time to conduct user-testing on four subjects in a co-located environment and not in a non-collocated environment. Time constraints also determined how far the shared network could be developed for the holographic design review platform, without taking time away from user-testing and analysis.

6.4 RESULTS

The data collected was visualised in to graphs to further communicate the results from each participant. The bar graphs depict the outcomes of each subject in each category to show equal or unequal levels of participation.

6.4.1 Pre-test and post-testing surveys

During the testing process, subjects were asked to complete a pre-test and post-test survey. This was used to gauge their initial opinions on FTF, CMC, and MR, by asking the following questions:

- (i) Which method would be best for visualisation?
- (ii) Which method would be best for communicating ideas?
- (iii) Which method is the most user friendly?
- (iv) Which method is the least distracting?

The pre-testing survey shows that FTF was chosen as the best method for all questions. This could be due to subjects being more comfortable and familiar with FTF interactions and not having experienced MR communication before. *Figure 11* shows that all subjects from both Category A and Category B, chose FTF as their preferred method, with the exception of one subject from Category B selecting MR as their choice for visualisation.

[FIGURE 11]

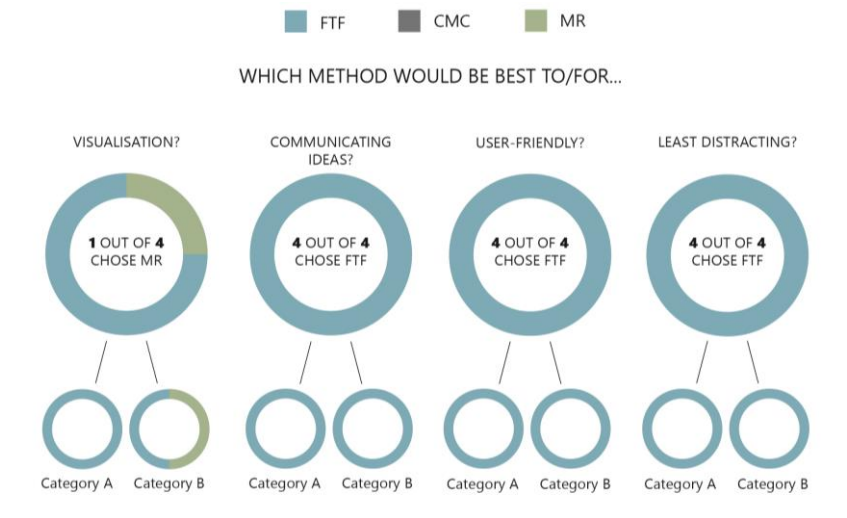


Figure 11. Pre-testing survey results

The post-testing survey results are very different to the pre-testing survey. The data shows that after having experienced MR communication, the subjects were more in favor of MR than before, however some subjects still chose FTF.

[FIGURE 12]

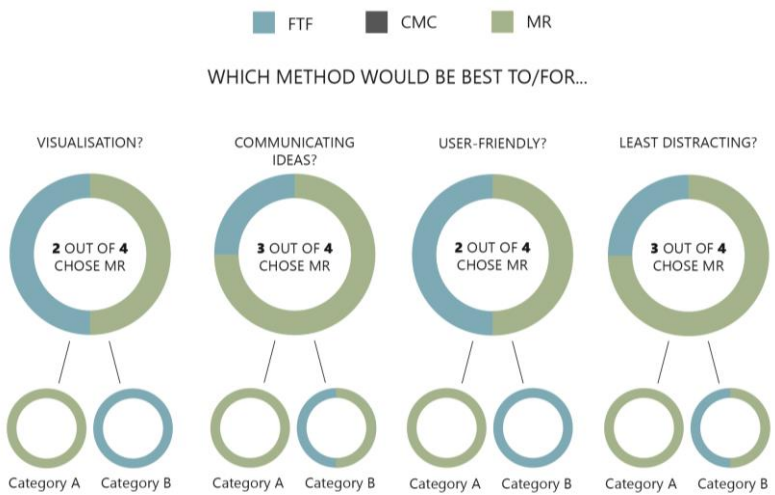


Figure 12. Post-testing survey results

Looking at the results from the specific categories, both of the older subjects from Category A chose MR as their preferred method for all questions, however Category B has mixed reviews on MR and FTF.

In both the pre-testing and post-testing surveys it is evident that CMC was the least preferred method, not being selected at all.

6.4.2 Completion time

Completion time was recorded from the moment subjects began reading their rules to the time of task completion. The graph shows how long subjects took to complete each of the three tasks together as a team.

The results seen in *Figure 13*, indicates that CMC communication takes the longest amount of time to complete, FTF is the quickest method and MR sits in between. These results are unexpected as it was assumed that MR would take the longest to complete due to it possibly being more difficult and less intuitive to use, especially for first time users.

[FIGURE 13]

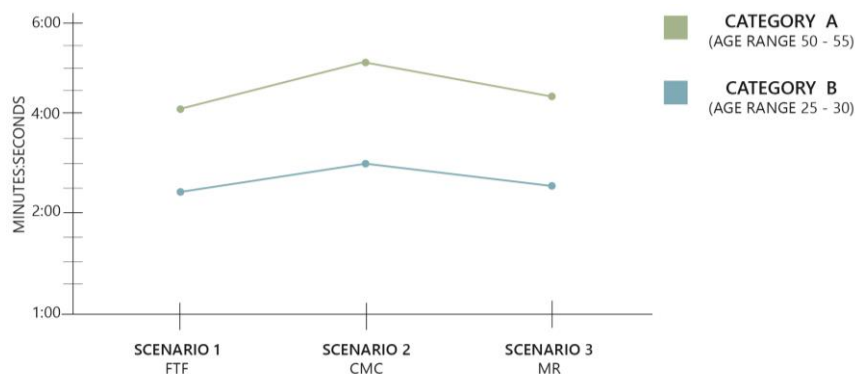


Figure 13. Results of the time taken to complete each task

6.4.3 Nonverbal cues – gestures

Pointing gestures were measured from each subject to identify how much nonverbal interaction occurred during each communication method. Immediately from the graph, it is clear that there was very little pointing gestures while using CMC to complete the task, however for both FTF and MR methods, there was a significant amount of gestures. Although Category A shows a higher level of pointing gestures than Category B, there is still an equal level of participation between both subjects in each category when

looking at the results from MR in comparison to the results from FTF which have a larger ratio of participation. From *Figure 14* we can see that while using CMC, two subjects showed zero gestures.

[FIGURE 14]

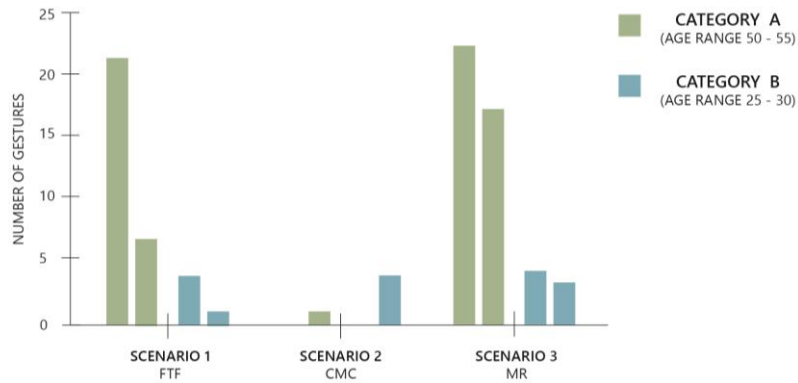


Figure 14. Results of the number of pointing gestures

6.4.4 Nonverbal cues – model interaction

Model interaction was measured any time a subject picked up or moved one of the train carriages. It was observed that during CMC there were common questions asked at the start of the task between the subjects involving who would like to “drive” the mouse and take charge of moving around the train carriages. By doing so there was an immediate designated driver who would take control of most, if not all, of the model interactions. Although there is was a high level of model interaction between the subjects when interacting FTF, there was more of an equal level of participation when using MR as a communication tool. This could be due to the subjects wanting to play and understand the technology better and by doing so, there was more interaction with the holographic train models.

[FIGURE 15]

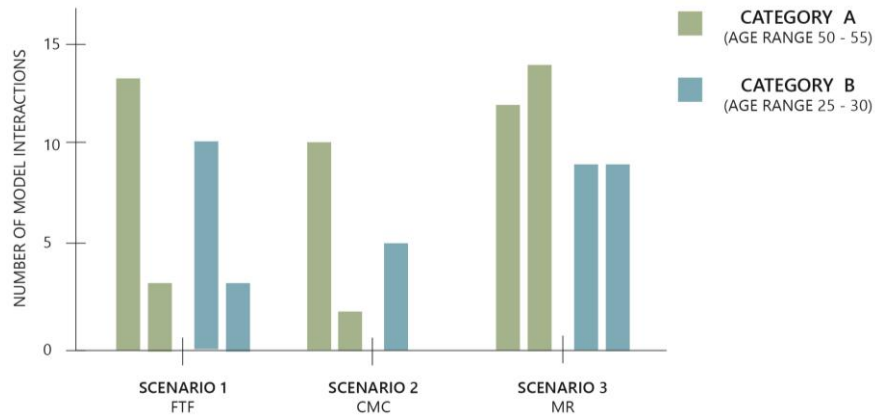


Figure 15. Results of the number of model interactions

6.4.5 Verbal cues – questions

During each task, the subjects communicated verbally, asking each other a variety of questions. Unlike the previous two results of nonverbal cues, it is evident that CMC encourages a high level of questions. Although FTF has a more equal level of participation, the least amount of questions were asked. The unfamiliar MR environment could be what caused such a high volume of overall questions asked during Scenario 3, although unlike the previous results for MR, the participation levels are not equal.

[FIGURE 16]

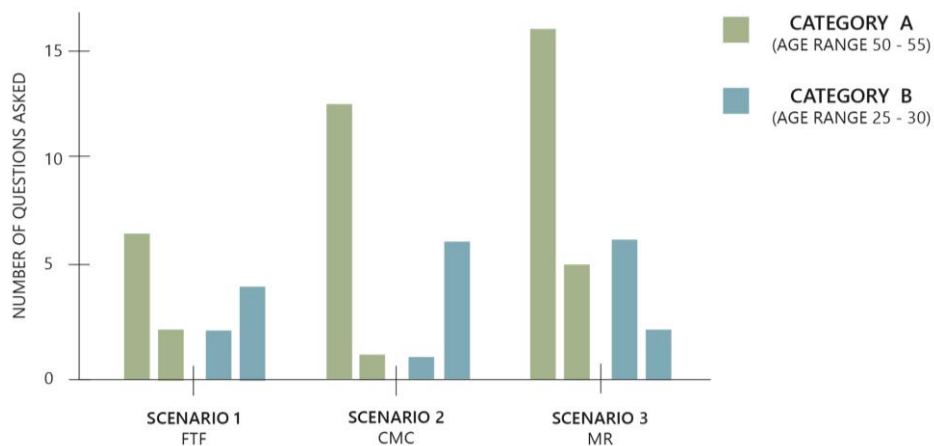


Figure 16. Results of the number of questions asked

6.4.6 Verbal cues – statements

The number of statements, or sentences, were measured during each scenario to evaluate how much discussion there was between subjects in each category. In the Figure !!! it is shown that MR encouraged a wider discussion and subjects participated at similar levels in comparison to FTF and CMC.

[FIGURE 17]

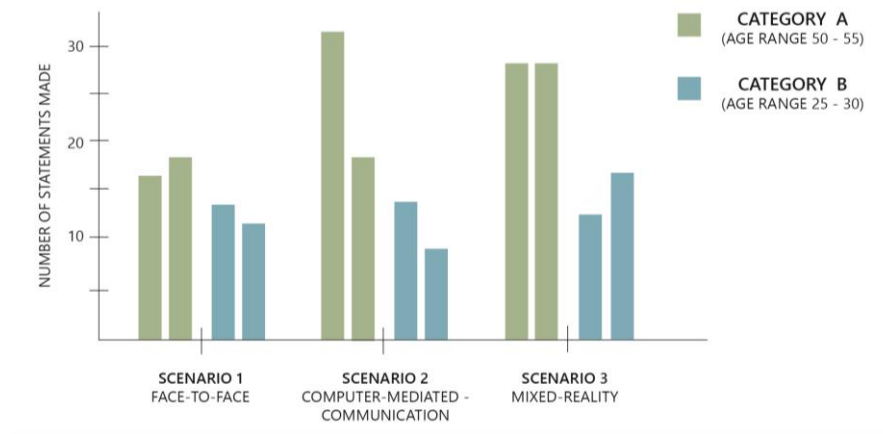


Figure 17. Results of the number of statements made

6.4.7 Results summary

The data collected is valuable for identifying in what ways MR can be useful and where it has downfalls. Averaging the results and comparing them against one another, it is evident that MR is a power platform for collaboration and has fewer disadvantages in terms of communication. MR has shown to excel in all areas of the collected data with the exception of completion time where FTF communication was the fastest. Furthermore, this research has given insight to CMC and how it performed as the least effective method of communication in all areas.

Table 2. Average results of data per minute from this paper

AVERAGE	FTF	CMC	MR
TIME (MIN:SEC)	3:29	3:77	3.34
NUMBER OF GESTURES / MIN	2.3	0.2	3.7
NUMBER OF INTERACTIONS / MIN	2.2	1.1	3
NUMBER OF QUESTIONS / MIN	1	0.7	2.2
NUMBER OF STATEMENTS / MIN	4.5	4.8	6.1

[TABLE 2]

Comparing the results of this paper to Billingham et al's study, we can see a significant difference in the results. Keeping in mind that projection is the equivalent to CMC and AR to MR, the results from the two studies suggests that MR has developed rapidly over the past decade and has improved in both encouraging verbal and nonverbal communication and in completion time.

Table 3. Average results of data from Billingham et al 2002 study

AVERAGE	FTF	PROJECTION	AR
TIME (MIN:SEC)	3:61	4.5	5.66
NUMBER OF POINTS/MIN	3.5	1	1.8
NUMBER OF PICKS/MIN	3.1	2	1.8
NUMBER OF WORDS/PHRASE	9.51	8.99	8.24
NUMBER OF TURNS/SEC	0.3	0.31	0.32

[TABLE 3]

7. Significance of Research

Although MR is not a new concept, is still in its infancy due to its current limitations. Even so, the technology has proven to be able to provide new and innovative ways to share and communicate designs and ideas. This paper explores the concept of MR as a communication tool and where it could be best utilised in the design process.

From user-testing, the data suggests that tasks are performed more quickly when using MR than CMC, and MR encourages a higher and more equal level of nonverbal and verbal communication. Additionally, it would be effective for complex visualisations, however may not be necessary for simple forms. For some, the technology seemed to be on par with FTF visualisations and user-friendliness. The division of method choice came down to the complexity of the models, as it was believed that for simple models such as the light rail carriages, MR would be unnecessary as it would be simpler to physically create the model. However, for more complex forms such as detailed buildings or visualising context environments, MR would be more effective.

Being an unnecessary platform for simple forms, MR would not be best utilised during the preliminary stages of the design process where building forms are visualised through block forms or other rough design forms. Instead, it could be used during the later design stages where the design has been refined and detail has been added. It would be an effective presentation tool to multiple and varying design disciplines or to the client. Overall, the results suggest that we should take advantage of the capabilities of MR and implement them more so in the later stages of the design process.

8. Evaluation of Research Project

This research explored communication within a collaborative setting, focusing mainly on MR as a contemporary communication platform. Furthermore, a shared connection between multiple HoloLens users was successfully established for the holographic design review platform in conjunction with voice controlled interactions.

Although the shared network between multiple HoloLens headsets was created and holograms were successfully anchored in the same location for each user within the holographic design review platform, the interactions for each user has not been synchronized. The consequences of this would mean that if User 1 were to turn off all floors, User 2 would have to turn off floors themselves as the hologram interactions would not sync between them. This is something that could be further explored in the future to create a more finalized product.

It is recommended for future testing that more subjects be included for user-testing to generate a richer set of data. In doing so a more well-rounded conclusion can be drawn.

As mentioned previously, it is common for design teams to be geographically displaced instead of concentrated in one location. Large firms with multiple locations will often have team members on a common project stationed in different locations or even time-zones. Non-located communication user-testing would add to a richer data set and would further explore ways in which MR would be an effective communication tool in a non-located scenario.

These factors should be considered when re-testing and re-analysing data in the future. However, this research acts as a foundation for further complex development and more detailed testing.

9. Conclusion

Through the modification of an existing methodology for testing three different communication methods, five sets of valuable data were collected and analysed to determine in what ways MR is an effective communication tool and where it would be best utilised during the design process. In comparison to Billingham et al's 2002 study using FTF, screen based projection, and AR, it is clear that the technology has advanced over the past decade, with new data suggesting that MR is more effective than FTF in many ways. Despite teams not being able to complete tasks as quickly in MR than in FTF collaborations, the amount of verbal and nonverbal communication is much higher when using an MR device, suggesting that it is successful in terms of information exchange and participation.

Although MR has constraints, it is a powerful visualisation tool and would be best utilised when visualizing complex forms and environments. Additionally, it should be used towards the later stages of the design process where multiple designers can collaborate over final details or teams can present ideas to clients.

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