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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. Mixed Reality; Communication; Hololens; Collaboration; Virtual.

1. Research Aims, Motivations and Question

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 in contemporary offices FTF

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communication can often not be achieved and increasingly comprise of less FTF interactions and more virtual interactions. Virtual technologies such as Skype or email 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, enabled through ie. the Microsoft HoloLens (Microsoft, 2017). 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. Hence 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. 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 Billinghurts 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 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.

- Does MR encourage a higher level of participation through nonverbal cues?
- Does MR encourage a higher level of participation through verbal exchange?

2. 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. In an action research framework 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.

2.1. PROPOSING A METHODOLOGY FOR TESTING

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 organise 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. 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. 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. 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. 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 based on early 2000 technologies, this methodology has been recycled and modified to suit current technology for this research.

3. Background Research

FACE-TO-FACE COMMUNICATION METHODS. 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. 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. 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).

VIRTUAL AND COMPUTER-MEDIATED COMMUNICATION METHODS. Pauleen et al (2001) states "Unlike in co-located teams, subtle yet important cues are easily missed in the virtual environment". 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.

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. At present Microsoft's 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. MR devices currently have limitations such as field of view, however these may be refined and mitigated in the future. A current communication application on the HoloLens is Skype. 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).

4. Comparitive 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. Due to the scope of the paper a detailed explanation of how to establish a shared network and how to incorporate Vuforia, an AR platform that recognises images as anchors, could not be included.

4.1. 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. 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. 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 Billinghurst 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:

- *Nonverbal* - number of pointing gestures
- *Nonverbal* - number of model interactions
- *Verbal* - number of questions asked
- *Verbal* - number of statements made

During user-testing there were some limitations in terms of time and resources. The number of HoloLenses available to the research 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.

4.2. RESULTS

A large number of data was collected and visualised in graphs to communicate the results from each participant, depicting the outcomes of each subject in each category to show equal / unequal levels of participation. Data and visualisations are available on Computational Design Graduation Catalogue (see references).

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 questions:

- Which method would be best for visualisation?
- Which method would be best for communicating ideas?
- Which method is the most user friendly?

- Which method is the least distracting?

The pre-testing survey revealed that FTF was chosen as the best method. This could be due to subjects being more comfortable and familiar with FTF interactions and not having experienced MR communication before. Here all subjects from both Category A and B, chose FTF as their preferred method, with the exception of one subject from Category B selecting MR as their choice for visualisation. 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 favour of MR than before, however some subjects still chose FTF. 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, pre-testing and post-testing surveys it is evident that CMC was the least preferred method, not being selected at all.

COMPLETION TIME Completion time was recorded from the moment subjects began reading their rules to the time of task completion. The results shown 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.

NONVERBAL CUES - GESTURES Pointing gestures were measured from each subject to identify how much nonverbal interaction occurred during each communication method. 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.

NONVERBAL CUES - MODEL INTERACTIONS 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. This could be due to the subjects wanting to play and understand the technology better hence there was more interaction with holographic model.

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.

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. It has shown here that MR encouraged a wider discussion and subjects participated at similar levels in comparison to FTF / CMC.

Table 1. 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. Average results of data from Billinghurst 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

RESULT 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. This research has given insight to CMC and how it performed as the least effective method of communication in all areas. Comparing our results [Table 1] to Billinghurst et al's study (2002) [Table 2], 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.

5. Significance, Evaluation and Conclusion of Research

Although MR is not a new concept, is still in its infancy due to its current limitations. Yet, 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. 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, MR would be unnecessary as it would be simpler to physically create the model. 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 as an effective presentation tool to multiple and varying design disciplines or client. 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. 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. Non-collocated 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-collocated 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. 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 Billinghurts 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 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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