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MULTI-USER INTERACTION FOR LIVING ROOM FURNITURE LAYOUT DESIGN IN HANDHELD AUGMENTED REALITY

Chong Li Ling, Goh Eg Su*, Pang Yee Yong

Faculty of Computing, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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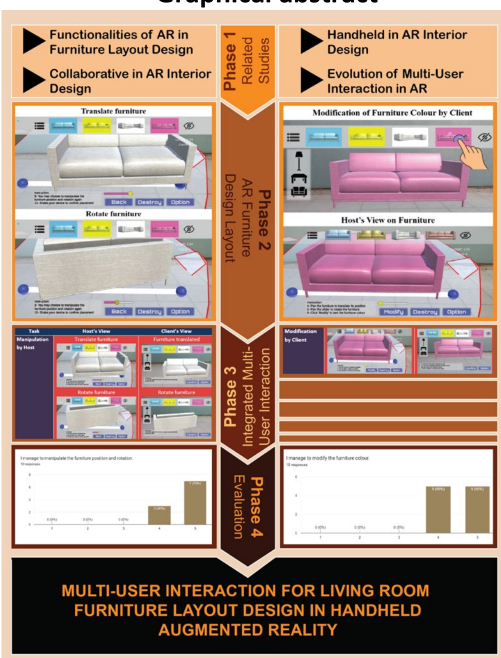
*Corresponding author
eg.su@utm.my

Graphical abstract



Abstract

Augmented Reality (AR) is the most recent popular technology that was developed in many fields. Development of AR is important for living room furniture layout design due to the high expectation of clients for testing design outcomes. Being able to think in three dimensions (3D) and visualizing projects is also a great importance for interior designers. Besides, the interior designer is difficult to collaborate with the clients for collecting furniture layout design ideas by referring the 2D furniture layout. Therefore, this study aims to introduce a multi-user interaction system for living room furniture layout design using handheld AR. The objectives of this study are; firstly, study multi-user interaction for living room furniture layout design in handheld AR. Secondly, develop handheld AR research prototype and multi-user interaction for living room furniture layout design and lastly, to integrate the handheld AR research prototype with multi-user interaction for living room furniture layout design. This study implements and combines the AR living room furniture layout design with multi-user interaction. This study also evaluates the research prototype based on the usability and user acceptance testing. The testing results showed the research prototype works properly. The respondents were overall satisfied with the research prototype and agreed that this research prototype is very interesting, creative and useful for collaborating with multi-user to design the living room furniture layout. This study has successfully established multi-user interaction for living room furniture layout design in handheld AR.

Keywords: Handheld Augmented Reality, Living Room Furniture Layout Design, Multi-user Interaction, Collaborative Augmented Reality, Interior Design

1.0 INTRODUCTION

Living rooms serve as the nexus for day-to-day life, preserving countless cherished memories. As its importance in homes has grown, so has the need to design it impeccably. In recent years, with the rapid development of information technology, the usage of AR and 3D technology by people is increasing [1]. Berryman (2012) had defined that AR places 3D digital information of objects in the real world for the user experience enhancement [2], so AR has the ability to combine digital information with reality and be implemented in art decoration, architecture and numerous other areas. According to Cipresso et al. (2018), AR turns into the more recent technology than VR by superimposing virtual 3D objects into the real world [3].

Although AR has incredible potential, collaborative AR is particularly intriguing. As Yusof & Khairi (2018) pointed out, this advancement emphasizes multi-user engagement [4 - 6]. This allows multiple clients or users to immerse themselves simultaneously in an AR environment. In scenarios like joint homeowners discussing living room designs, this collaborative aspect enhances real-time communication and interaction, facilitating collective decision-making.

The challenge of selecting furniture that perfectly complements a room's size is a puzzle every homeowner faces. However, traditional methods, like 2D layout designs, fall short in providing a comprehensive perspective and the homeowner cannot view a better graphics of visualization with the 2D furniture layout design to refer. This is because 2 dimensions (2D) furniture layout design causes the interior designers often encounter situations in which clients cannot view the scale and size of the real furniture. The clients are not sure whether the furniture scale is suitable to the room or not depend on their requirements. Hence, there should have a way to let clients use the AR technology to view a better graphics of visualization for furniture layout and enhance the testing design experience before starting to renovate their house. In this context, AR technology can help clients to visualize how furniture pieces will look and scale in their desired room space in 3D furniture layout design. The virtual 3D furnishing model with the real visualization will be superimposed in the physical environment for the clients.

The interior designer is also difficult to collaborate with the clients for collecting furniture layout design ideas by referring the 2D furniture layout. Instead of physically delivering 2D furniture layout to the clients, the interior designer can offer a collaborative AR experience with 3D visual furniture layout to collect more ideas about it from them. Based on this backdrop, thereby the aim of this study is to develop the multi-user interaction for living room furniture layout design in handheld AR. The objectives of this study are to study multi-user interaction for living room furniture layout design in handheld AR, develop handheld AR research prototype and multi-user interaction for living room furniture layout design, integrate the handheld AR research prototype with multi-user interaction for living room furniture layout design.

2.0 LITERATURE REVIEW

2.1 Functionalities Of Ar In Furnitrure Layout Design

AR has been extensively researched for various application, including furniture placement in living room [7]. The architecture of living room furniture layout design in AR involves the process of AR plane detection to place 3D virtual furniture on the plane [8]. The process of detecting horizontal and vertical planes using marker-less AR involves the use of anchors and feature points [9]. Anchors utilize the 3D world coordinate system to accurately map the object's location within the real world as the user moves around. When an object is introduced into the environment, it is assigned a value based on its pose, which encompasses both its position and orientation with respect to the world space. Therefore, when anchors are established, the object's pose effectively indicates its relative position and orientation [10]. Anchors rely on the concept of feature points to remain attached to their designated positions. Feature points correspond to distinctive elements within each frame of the system, encompassing various characteristics such as planes, textures, and colors [11].

Although AR placement of virtual furniture are crucial components, there is limited research on how users interact with AR interfaces in the context of furniture layout design. Understanding user preferences, challenges, and the learning curve associated with AR tools in this context is essential for improving user satisfaction. Inaccurate measurements can lead to furniture layout errors. Research can focus on improving the accuracy of AR-based measuring tools. This could involve refining computer vision algorithms for feature point detection and tracking under various lighting conditions and room geometries. Addressing these challenges can enhance the practicality of AR solutions. Interior designers often follow established workflows and processes. Exploring how AR tools can seamlessly integrate with these workflows, and whether they enhance or disrupt the traditional design process, is an area that requires further investigation.

2.2 Collaborative In Ar Interior Design

Collaboration in AR refers to an environment that supports multiple users [4]. The collaborative AR interface developed allows multiple users to share a virtual space projected into their common workspace in face-to-face collaboration [12]. There are two types of face-to-face collaboration in AR which are synchronous and asynchronous [13, 14]. For the synchronous collaboration, collaborators are working together in real time in the same physical space [13]. It enables the exchange of data among nearby handheld devices, resulting in reduced delays and the utilization of combined device computing capabilities to enhance the quality of AR encounters. For the asynchronous collaboration, collaborators work together in real time, but not from the same physical location [13]. AR enables users to attach markers for conveying essential details and instructions related to specific locations. This proves especially valuable when collaborators must share location-based information remotely, without the option of in-person communication [13].

However, previous works were mainly focusing on single user for furniture layout design and did not involve any collaboration in interior design. IKEA Place is one of the AR furniture layout design researches for single user since its research focus is to sell furnishing products for furniture layout only [15]. Houzz is more similar with this research but they also focus on single user to design the furniture layout [16]. Ideally, AR technology should empower collaborative scenarios which involves multiple users interacting with virtual objects in a shared workspace. There is a research gap in exploring the dynamics of multi-user interactions, including issues related to coordination, conflict resolution, and the impact of group size on collaboration effectiveness. Understanding these dynamics can lead to the development of better collaborative AR systems. Collaborative AR interfaces often involve the use of multiple technologies, including AR devices, sensors, and networked devices. Research is needed to investigate how these technologies can be seamlessly integrated to create a cohesive collaborative experience.

2.3 Handheld In Ar Interior Design

A handheld device is a compact and portable computing or electronic device designed for used in one or both hands [17]. This means that handheld device has smaller size with small keyboard and screen, but higher portability compared to other computing devices [18]. Internet connectivity is also one of the significant elements to determine the huge market of handheld device nowadays. Therefore, internet connectivity, smaller size and higher portability of handheld device bring a lot of convenience to users. AR incorporates three main features, the combination of digital and physical worlds, real time interactions, and precise 3D identification of both virtual and real objects. Handheld device gives users see-through virtual object in the real environment for AR experience via powerful processor and various built-in sensors [19]. The graphical display in handheld device is also needed to let user make interaction with virtual object through the device's screen in AR accurately.

Most existing works have shown that handheld devices are popular for mobile AR experiences, but there still requires research in understanding the user experience when interacting with AR content on small screens [20]. The user interfaces need to be designed to maximize user comfort and minimize fatigue during extended AR sessions on handheld devices. Besides, creating AR content that is engaging and user-friendly on handheld devices can be challenging. There is a research gap in exploring efficient methods and tools for creating and distributing AR content specifically tailored to the constraints and capabilities of handheld devices. Handheld devices come in various forms and operating systems. Research could focus on addressing the challenges of creating AR applications that work seamlessly across different handheld devices, ensuring a consistent and high-quality AR experience regardless of the device used.

2.4 Evolution Of Multi-User Interaction In Ar

The interaction is one of the main issues related to the fundamental of AR, so there are more essential researches for AR interaction. Touch-based interaction is widely used in handheld AR due to widespread familiarity with touch-screen inputs on smartphones and tablets. For touch-based interaction, the DOF of 3D object translation and rotation are separated [21]. The user can adjust 3 DOF for object translation and 3 DOF for object rotation with the gesture of two fingers on the touch screen. Before any 3D object manipulation, the object needs to be selected by using touch-screen input. The tap gesture is used to tap and select the object by using one index finger to touch on the screen. If the touch input receives, then the ray cast is generated, and it checked if the ray cast is touching any object [22]. The ray cast will be used to instantiate the selected virtual objects [22]. Besides, the panning gesture is used to translate or rotate the object by using two index fingers to touch on the screen.

While touch-based gestures are widely used in handheld AR, there is room for improvement in gesture recognition accuracy and precision. Research could focus on developing advanced algorithms and sensor technologies that allow for more accurate and reliable gesture recognition, reducing the potential for user frustration and errors. The naturalness of touch-based interaction in AR is crucial for user acceptance and comfort. There is a research gap in understanding how to make touch-based interactions in AR feel more natural and intuitive. This includes exploring haptic feedback, visual cues, and ergonomic considerations. The process of selecting objects in AR through touch input and ray casting can be optimized further. Research can investigate ways to make object selection more efficient and user-friendly, reducing the time and effort required to interact with virtual objects.

3.0 METHODOLOGY

The methodology includes four phases for the research activities of this study in Figure 1.

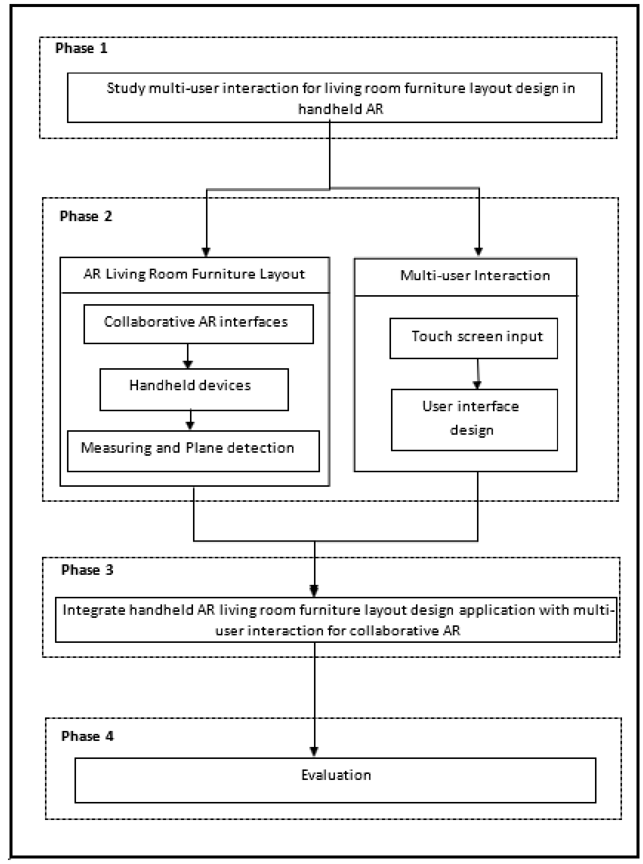


Figure 1 Methodology Flow Chart

3.1 Phase 1: Study Multi-User Interaction For Living Room Furniture Layout Design In Handheld AR.

The first phase begins on comprehensively studying multi-user interaction in handheld AR, emphasizing its fundamental concepts and suitable types for living room furniture layout design through various studies on the literature of AR technology. The study also collects data on the architecture of living room furniture layout design in AR along with its key features that can be implemented into the prototype. Collaborative AR interface and multi-user interaction has been studied while handheld AR is also studied to have a study on collaborative AR application in handheld AR. All information that is gathered in this phase will be the references and used in the following stage of development.

3.2 Phase 2: Develop Handheld AR And Multi-User Interaction For Living Room Furniture Layout Design.

In the second phase, the research task centers around the development of the AR living room furniture layout design and multi-user interactions. The interior designer must open a room for the multi-user AR environment before the indoor decoration in order to achieve the collaboration of interior designer with client. For the collaborative AR interface, both the interior designer and the client can simultaneously access a shared AR environment, enabling joint design of the living room furniture layout. During the whole furniture layout design process, the host and client take turns to become active user and perform collaborative task for living room furniture layout design in the same AR environment.

3.3 Phase 3: Integrate Handheld AR With Multi-User Interaction For Living Room Furniture Layout Design.

The third phase involves the research task to integrate handheld AR research prototype with multi-user interaction for living room furniture layout design. To foster collaboration, the AR living room furniture layout research prototype integrates multi-user functionalities, using Photon Unity Networking (PUN) for seamless user interaction. It should be able to run and execute with the mobile devices to let two AR users collaborate together for decorating the same environment in the same room. The multi-user feature will be integrated into it by having a host and client. The interior designer becomes the host while the client will be the client for the room to access the same AR environment.

3.4 Phase 4: Evaluation.

Lastly is the evaluation phase for assessing the collaborative handheld AR research prototype to design living room furniture layout. Twenty respondents including two interior designers paired with their two clients, and also the public will participate in the research prototype testing. They will be given a Google Form questionnaire after using this prototype based on different roles whether they are assigned to be hosts or clients. This questionnaire contains a pre-test and usability test questionnaire. The pre-test questionnaire is used to get the respondents' background while the usability test questionnaire is to know the user experience when interacting with the research prototype.

4.0 COLLABORATIVE AR INTERFACE AND INTERACTION IMPLEMENTATION

For a good user adoption, the collaborative AR interface is designed to be similar with other applications. The first interface presents a start menu allowing users to enter the prototype. Next, the user must enter the username and room name to create a room as the host or join the room as the client. This collaborative AR interface enables the host and client to enter the same room name for accessing the same AR environment to carry out multi-user interaction on different user interface design. To synchronize the starting position in the chosen empty AR environment, both users need to align their devices side by side and face the plane together at the beginning because the initial position in the AR system, often referred to as the 'zero position', dictates the starting position for the collaboration interaction between two AR users.

Before starting the process of AR living room furniture layout design, there is a need for host to detect the plane by AR plane detection, then select a start and end point to measure the space by the AR measuring to place the furniture on the plane within the measurement as demonstrated in Figure 2. AR measuring plays a crucial role in living room furniture layout design since the interior designers need to work with space for the best furniture layout design [23]. AR measuring measures indoor space by augmentation [24]. Therefore, it can reduce human error for the manual measurement of the space and choose to place the suitable furniture within the measured space [25].

Based on the measurements taken, the host is presented with specific furniture panel options after using AR plane detection and measuring. If the measurement is less than 0.5 meter, the light panel and light colour panel are set active true while other panels are set active false. If the measurement is within 0.5 between l.3 meter, the table panel and table colour panel are set active true while other panels are set active false. If the measurement is more than l.3 meter, the sofa panel and sofa colour panel are set active true while other panels are set active false. These provided ergonomic considerations reduce the time of object selection in AR and optimize the ray casting to increase the accuracy of positioning the selected furniture.

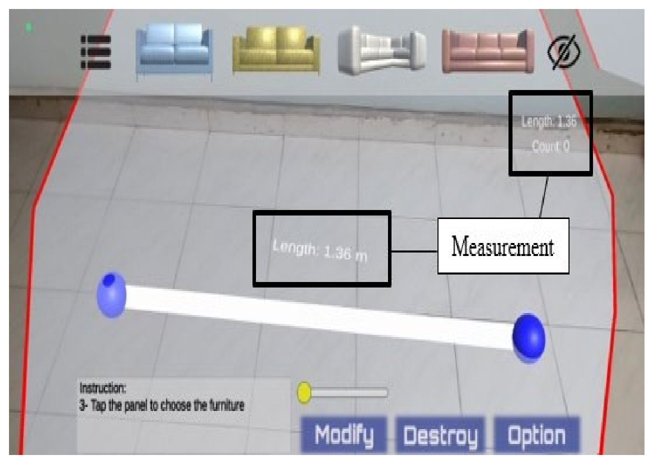


Figure 2 AR Plane Detection and Measuring Implementation

Collaborative AR interfaces are then implemented in handheld devices after the implementation of AR living room furniture layout design with AR plane detection and measuring. There are two tasks that can be done by the user in handheld AR living room furniture layout design. The tasks are manipulating the selected 3D furniture as shown in Figure 3 and modifying its colour as shown in Figure 4. But during the collaborative task, the client has permission to modify the furniture colour only as shown in Figure 5 since the space planning is the main role of host who will be the creator. These collaborative AR interfaces are designed to provide the instructions, place the selection panels and buttons on the side of screen. They are engaging and assisting users to create new AR content with the maximum user comfort while using this research prototype.

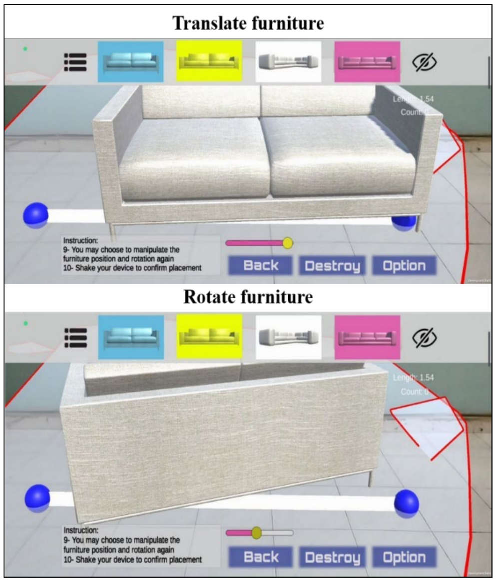


Figure 3 Manipulating Furniture by Host

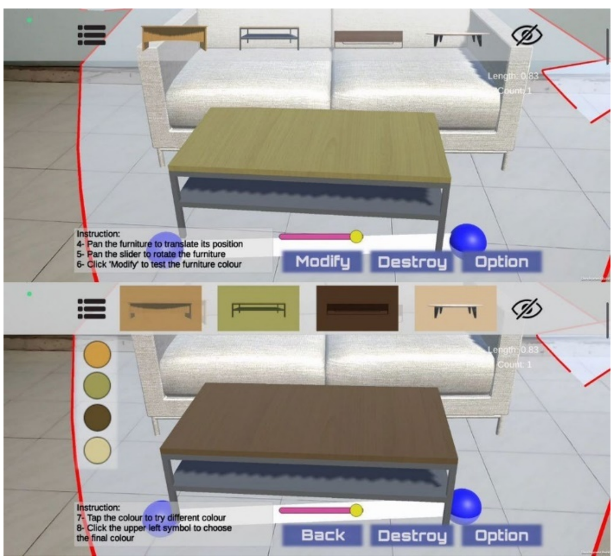


Figure 4 Modifying Furniture Colour by Host

Figure 5 Modifying Furniture Colour by Client

These collaborative AR interfaces allow the client to modify the furniture colour using the colour panel. Then, it allows the host to view the colour changes of furniture done by the client as shown in Figure 6. The client can also view the final furniture colour decided by the host after a discussion through face-to-face collaboration. Besides, the client can view the final furniture position and rotation done by the host in the same AR environment. This can enhance the face-to-face collaboration of the host and client through collaborative AR interfaces. This can also integrate the interior designer workflows of initial consultation, onboarding and concept development with AR technology to save time and improve the traditional design process. Table 1 shows the collaborative AR interfaces during the manipulation and modification of 3D furniture by the active user among them in the same AR environment.

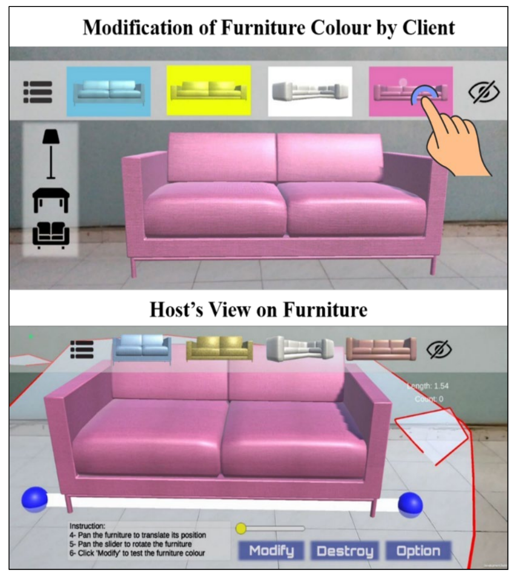


Figure 6 Modification of Furniture Colour by Client and Host's View on Furniture

Table 1 Host and Client's View during Furniture Manipulation and Modification

Task	Host's View	Client's View
Manipulation (Host)	Translate furniture  Rotate furniture 	Furniture translated  Furniture rotated 
Modification (Client)		

This research prototype allows multiple devices with various operating systems to be connected to the same room. It is different with the previous works which are only focusing on single user for furniture layout design. The host can pan the virtual furniture to get the screen touch and translate it within the measured space, and also drag the slider to rotate it within the measured space. It will synchronize the transformation and rotation of the 3D objects across the shared AR environment. The client can tap the colour panel to select a colour in order to modify the furniture colour. It requests the permission from host and changes the furniture colour in the same AR environment. This involves the ownership transfer in Photon Unity Networking (PUN) to modify that same 3D furnishing model colour. The interaction involved in this research prototype is dependent in the collaborative AR environment since multi-user interaction is performed dependently with interrupting the design action that performed by the host. Dependent actions can promote a more structured and synchronized workflow among users. Dependent actions can also reduce conflicts to some extent because users are less likely to interfere with each other's tasks if they understand the dependencies. This will avoid the issues related to coordination and conflict resolution on collaboration effectiveness while designing the furniture layout.

5.0 EVALUATION

To test the usability of research prototype in this study, each respondent will be given a Google Form questionnaire consisting of a pre-test and usability test questionnaire after assessing the Augmented Reality (AR) research prototype for living room furniture layout design based on the assigned role whether the respondent is host or client. The testing and evaluation were carried out with the participation of 20 respondents aged between 22 to 34 involving 16 females (representing 80% of respondents) and 4 males (representing 20% of respondents). 10 respondents are assigned as hosts while 10 respondents are assigned as clients. Two interior designers, along with their respective clients, as well as other members of the public, participated in the prototype testing. Majority of the respondents (65%) have prior experiences with AR and they are further inquired about the experience with handheld AR, and with multi-user interaction in handheld AR. All of the respondents have experience with handheld AR but there are 6 respondents who have no experience with multi-user interaction in handheld AR. The usability test questionnaire provides five response options for respondents which are from Strongly Disagree to Strongly Agree in order to determine the research prototype usability.

5.1 Usability Testing Result By Host

Most of the respondents (7) strongly agree that they could manipulate the furniture position and rotation as this is the main functionality of this research prototype for host. There are only 3 respondents agree that the position and rotation of furniture could be manipulated by them. Half of the total 10 respondents strongly agree (50%) and agree (50%) that they could modify the furniture colour respectively as this is the second functionality of this research prototype for host. Most of the respondents (90%) strongly agree that they manage to view the furniture colour modified by the client while only one respondent (10%) agree that the furniture colour modified by the client could be viewed by them. This statement shows that the host and client successfully access the same AR environment for multi-user interaction in designing the living room furniture layout. The respondents were overall satisfied with the research prototype and agreed that this research prototype is very interesting, creative and useful for collaborating with multi-user to design the living room furniture layout.

5.2 Usability Testing Result By Client

Most of the respondents (8) strongly agree that they manage to modify the furniture colour as this is the main functionality of this research prototype for client. There are only 2 respondents agree that the furniture colour could be modified by them. Majority of the respondents (60%) strongly agree that they manage to view the furniture position and rotation manipulated by the host. The remaining of respondents (30%) agree and (10%) neither agree nor disagree that the furniture position and rotation manipulated by the host is could be viewed by them. This statement shows that the host and client successfully access the same AR environment for multi-user interaction in designing the living room furniture layout. The respondents were overall satisfied with the research prototype and agreed that this research prototype is very interesting, creative and useful for collaborating with multi-user to design the living room furniture layout.

6.0 FUTURE WORKS

This study is suggested to be improved by carrying out some future works. This research prototype can be developed more to allow 3D furniture be placed in the AR environment that has real furniture. Future iterations of this research prototype could collaborate with various furniture stores, integrating a broader range of furniture options directly into the system.

7.0 CONCLUSION

This paper discussed the development and integration of multi-user interaction for living room furniture layout design in handheld AR. This paper also discussed the testing and evaluation for this study. The results show that the research prototype works properly, albeit with certain limitations. Accurately syncing the position of 3D furniture in the same AR environment for both host and client presents challenges due to the environmental variations, latency and device limitations. The research prototype requires an active internet connection for use.

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References

[1] Tang, J., Lau, W., Chan, K. & To, K. 2014. AR interior designer: Automatic furniture arrangement using spatial and functional relationships. *2014 International Conference on Virtual Systems; Multimedia (VSMM)*.

[2] Berryman, D. 2012. Augmented Reality: A Review. *Medical Reference Services Quarterly,* 31(2): 212-218.

[3] Cheng, C.L.Y., Goh, E.S., Ahmad, J.B. & Sutikno, T. 2024. Game-based Augmented Reality Learning of Sarawak History in Enhancing Cultural Heritage Preservation. *Indonesian Journal of Electrical Engineering and Computer Science,* 34(3): 1718–1729.

[4] Yusof, C.S. & Khairi, M. 2018. Collaborative Handheld Augmented Reality for Interactive Furniture Interior Design. *UTM Computing Proceedings.*

[5] Goh, E.S., Sunar, M.S., Ismail, A.W. & Andias, R. 2018. An Inertial Device-based User Interaction with Occlusion-free Object Handling in a Handheld Augmented Reality. *International Journal of Integrated Engineering*, 10(6): 159-168.

[6] Goh, E.S., Sunar, M.S. & Ismail, A.W. 2020. Device-based Manipulation Technique with Separated Control Structures for 3D Object Translation and Rotation in Handheld Mobile AR. *International Journal of Human Computer Studies*, 2020(141). https://doi.org/10.1016/j.ijhcs.2020.102433.

[7] Barbosa, J., Araújo, C., Mateus, R. & Bragança, L. 2015. Smart interior design of buildings and its relationship to land use. *Architectural engineering anddesign management,* 12(2): 97-106.

[8] Sundaram, S. G., Ponmalar, A., Deeba, S., J. A. A, A. S & S. S. 2022. Plane Detection and Product Trail using Augmented Reality. *2022 1st International Conference on Computational Science and Technology (ICCST),* 887-892.

[9] Cheng, J., Chen, K. & Chen, W. 2017. Comparison of Marker-Based and Markerless AR: A Case Study of An Indoor Decoration System. *Lean and Computing in Construction Congress - Proceedings of the Joint Conference on Computing in Construction. 1*

[10] Chaudhry, T, Juneja, A. & Rastogi, S. 2021. AR Foundation for Augmented Reality in Unity. *International Journal of Advances in Engineering and Management (IJAEM),* 3(1): 662-667.

[11] Kumar, D., Srinidhy, P. & Kafle, V. 2021. Enhancing the System Model for home Interior Design Using Augmented Reality. *2021 ITU Kaleidoscope Academic Conference.* 39-46.

[12] Nur Affendy, N.M & Ismail, A. 2019. A Review on Collaborative Learning Environment across Virtual and Augmented Reality Technology. *Joint Conference on Green Engineering Technology & Applied Computing 2019.*

[13] Pidel, C. & Ackermann, P. 2020. Collaboration in Virtual and Augmented Reality: A Systematic Overview. *International Conference on Augmented and Virtual Reality.*

[14] Gasques, D., Johnson, J. G., Sharkey, T., Feng, Y., Wang, R., Xu, Z. R. & Weibel, N. 2021. ARTEMIS: A collaborative mixed-reality system for immersive surgical telementoring. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* 1-14.

[15] Alves, C. and Luís Reis, J. 2020. The Intention to Use E-Commerce Using Augmented Reality - The Case of IKEA Place. *Advances in Intelligent Systems and Computing.* 114-123.

[16] Kasar, S. 2021. Shopping App using Augmented Reality. *International Journal for Research in Applied Science and Engineering Technology.* 9(4): 338-342.

[17] Weiss, S. 2002. *Handheld Usability.* John Wiley & Sons, Ltd.

[18] Myers, B. A., Nichols, J., Wobbrock, J. O. & Miller, R. C. 2004. Taking handhelddevices to the next level. *Computer*, 37(12): 36-43.

[19] Gervautz, M. & Schmalstieg, D. 2012. Anywhere Interfaces Using Handheld Augmented Reality. *Computer,* 45(7): 26-31.

[20] Faria, A. P., Pinto, C. & Sousa, E. 2022. On Mobile Augmented Reality and User Experience: A Reflection and Future Research Agenda. *Usability and User Experience,* 39: 146-152.

[21] Goh, E., Sunar, M. & Ismail, A. 2019. 3D Object Manipulation Techniques in Handheld Mobile Augmented Reality Interface: A Review. *IEEE Access,* 7: 40581-40601.

[22] Fadzli, E., Yusof, M., Ismail, A. & Salam, M. 2020. AR Garden: 3D Outdoor Landscape Design using Handheld Augmented Reality with Multi-user Interaction. *IOP Conference Series: Materials Science and Engineering.*

[23] Falcone, S.M. 2019. Designing Single-Family Residences: A Study of the Positive Impact of Interior Design in Creating New Home Value. *Interior Design Program: Theses,* 17.

[24] Chen, Y., Wang, Q., Chen, H., Song, X., Tang, H. & Tian, M. 2019. An Overview of Augmented Reality Technology. *Journal of Physics: Conference Series,* 1237(2), https://doi.org/10.1088/1742-6596/1237/2/022082.

[25] Bergquist, R. & Stenbeck, N. 2018. Using Augmented Reality to Measure Vertical Surfaces. *Bachelor thesis, Linköping University.*