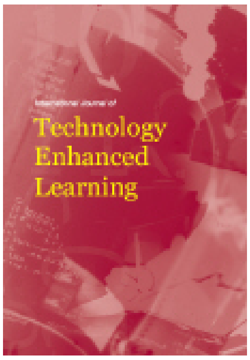

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Augmented reality remote assistance to enhance learning using a novel framework design

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Abstract: Technology is growing expeditiously and the demand for new innovative software and devices is encouraging to design and develop new software to cater to the needs of next-generation interactions. Traditional online meeting platforms do not support immersive AR meetings. To stimulate immersive technology of interactive applications, a software application is designed and developed for conducting a remote meeting through AR glasses and laptop or desktop computers. The aim of this paper is to introduce utility-based immersive web portal 'remote assistance' (RA) results of conducting various performance tests on the immersive web portal to validate the RA application through a novel framework to evaluate user experience in using AR web portal. The RA application is a comprehensive online meeting platform that connects the meeting participants remotely and facilitates the hands-free streaming of critical operations, screenshot sharing, annotations, loading, and interaction of the 3D models.

Keywords: augmented reality web portal; remote assistance; mixed reality; performance testing; online meeting; user experience design; evaluation framework.

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1 Introduction

Augmented reality (AR) technology marks a significant milestone in the world of digital innovation and human-computer interaction. Although the concept of augmenting reality has been explored for decades, it gained significant traction and prominence in the early 2010s. According to the prime market reports, the AR market is projected to grow from the United States Dollar (USD) 15.3 billion in 2020 to USD 77.0 billion by 2025; it is expected to grow at a Compound Annual Growth Rate (CAGR) of 38.1% from the year 2020 to the year 2025. Mixed reality (MR)-based applications are one of the top 10 ranked information and communications technology (ICT) technologies in 2020 (Flavián et al., 2019). Virtual reality (VR) and AR are widely in use across the globe by all enterprise sectors to enhance brand recognition and improve businesses. AR systems have conciliate interest among researchers and the education usage is extensively expanded with the use of the mobile devices that is explained by the author (Dunleavy et al., 2009). However, many challenges and problems in the educational sector are yet to be addressed. The author (De Paolis et al., 2017) identified the Integration of AR systems into the unexplored fields of education. AR meeting room with remote assistance is one such unexplored problem.

Online meeting platforms like 'Team', 'Gmeet', 'Zoom', etc., provide an interface for connecting participants in a meeting room for interactions. Such meeting platforms are in much use during the period of online schooling. Teachers use these platform extensively to connect with students and conduct lectures and practical sessions. The current platforms are in two dimensions and perspective views with features like sharing the screen , zoom out and zoom in features, sharing multimedia files, recording meeting, etc. Currently, the existing meeting rooms offer display of 2D models. But, these 2D models do not offer a feel of immersive experience to users. The 3D model interaction is crucial for online meetings, especially in practical demonstrations of medical and engineering labs for better visualisation and learning. Such 3D AR meeting platforms assist in better real-time visualisation and understanding of the facts and concepts and enhance the student learning outcome. The 3 D enabled meeting platforms provide necessary facilities for 3D model display and control options like scale, translate, and rotate for interaction with the 3D models.

The AR meeting platform is a utility-based immersive software, which enables the participants to have immersive meetings through computers or AR glasses to load, visualise and interact with 3D objects by creating different meeting rooms. This AR meeting room provides remote assistance to the meeting participants for hands-free participation with real-time video streaming of the critical operations, to seek guidance from the other meeting participants, capture snapshots of real-time operations, annotate and guide the participants working on critical operations. A RA meeting conducted through computers and AR glass on an AR web portal is a helpful application and can serve as a constructive training and learning application in any domain where guidance and assistance from experts is crucial in training the novice users.

Software testing plays a crucial role in the development and deployment of quality applications across industries. Performance testing, both functional and non-functional, is conducted on the AR meeting platform. This comprehensive testing approach evaluates the platform's ability to perform its intended functions accurately and efficiently, as well as assesses its performance in terms of speed, responsiveness, scalability, and reliability. The visualisation and experience of 2D applications are different from that of 3D AR applications. It is observed that a systematic process is the need of the hour to evaluate the functionality, reliability, performance, and usability of 3D AR applications, to ensure that it meets the intended requirements and optimal performance.

By conducting performance testing, the AR meeting platform ensures optimal functionality and a seamless user experience. This paper introduces an AR meeting application and suggests quality testing with respect to user experience, user-centric design, usability, customer satisfaction, competitive advantage, interaction rates, and cost savings. By prioritising user experience and incorporating user feedback throughout the development process using the proposed framework, companies can test the applications that meet user needs, drive engagement during development stage and ultimately achieve business success.

2 Literature survey

AR technology enriches user experiences by overlaying digital content onto the real world, seamlessly blending virtual and physical elements. It offers interactive and immersive experiences that engage and captivate users, enabling them to visualise and interact with information in new and exciting ways AR finds application in various domains such as gaming and entertainment, retail and e-commerce, healthcare, tourism, manufacturing and maintenance, architecture and design, and education and training. The introduction of AR, VR, and MR is changing the impact of teaching and learning in the education sector. These technologies promote an interactive and extraordinary teaching-learning experience. Much research is in progress to design and develop AR and VR software to alleviate the teaching-learning process in the education and training sectors. In this section, we give a brief summary of some of the recent VR, AR, and MR Softwares used in the education sector.

VR is more interesting, the present-day classrooms are full of computers, digital boards, and tablets. VR has been described as the learning aid of the 21st century. VR, a technique that takes students to a different reality, the VR glasses replaces the visible reality with computer-generated images. (Smutný et al., 2019), the author present an overview of the uses of VR in education, specifically on the Oculus Rift platform. Their study explores the current use of VR to support teaching and learning. The best VR applications rated by users are presented in the work. A detailed study of types of immersive VR technologies used in higher education by Radianti et al. (2019) shows that 76% of high-end head-mounted devices are used in higher education. The study by Flavián et al. (2019) highlights the influence that recent technological breakthroughs in virtual realities can have on customer experience. Various VR glasses support several VR apps for classroom teaching. Some of the popular apps are ‘ocean rift’, an app for a fun intermezzo in biology class or natural sciences. ‘the body VR’, an app to visualise how disease and treatment affect the human anatomy.’ ImmerseMe’, an academic language tool, and ‘Mondly’, for learning languages in VR.

AR software for learning and business experiment by the authors (Minaudo, 2019), concluded that an immense sea of the virtual elements enriched the human sensory perception with information conveyed electronically and which otherwise would never have been perceived by the senses. ‘3D AR software solution for mechanical engineering education’ by Aliev et al. (2017) contains a description of AR technology application in the education and training of mechanical engineers. An approach for designing a textbook with 3D models of cutting tools, measuring tools, and special equipment, visualised using AR. The article by Tongprasom et al. (2021) focuses on an AR system for forensic medicine education in Thailand, where drowning is one of the main causes of death. With the aim of a comparative study and selection, the AR-type is suitable for use in creating an AR system for teaching forensic medicine. The authors Lopez Benito et al. (2014) proposed the development of AR software to help computer engineering students understand concepts and processes in embedded systems during laboratory exercises. There are many AR applications and mobile apps designed for specific applications in the education domain. Many popular AR learning apps do not facilitate the feature of meeting rooms and RA communication.

One of the technologies that have been showing possibilities of application in educational environments is the MR comprising of both AR and VR in addition to its application to other fields such as tourism, advertising, and video games, among others. In an experiment conducted by authors Beyoglu et al. (2019), the majority of the students stated that MR applications should be employed in all courses and expressed that they are excited about the use of these applications and feel motivated in science learning. The benefits of applications developed for MR over the traditional teaching methods and the basic user reactions to them are presented in a paper by the authors Pridhvi Krishna et al. (2019). The effectiveness of VR and AR has been analysed in terms of various variables in different fields by various authors such as speed reading by Rau et al. (2018), medical education by Maniam et al. (2020), education by Maebell and Lawrence (2021) biology by Garcia-Bonete et al. (2018), higher education by Delello et al. (2015), mathematics and geometry education by Buchori et al. (2017) and Voronina et al. (2019), and teacher education by Salmi et al. (2012). The insights from these related works, along with the emerging immersive technologies helped us to understand the requirement of a RA cog, especially during pandemic times to explore and provide support to the teaching and learning community under the umbrella of immersive technology.

AR technology plays a crucial role in transforming the education and training sector by creating immersive and interactive learning experiences. It enables students to visualise intricate concepts, conduct virtual experiments, and engage in hands-on simulations, thereby enhancing understanding and knowledge retention. Consequently, the user experience within the education and training domain becomes pivotal as it needs to be captivating and engaging, ensuring that complex concepts are learned in an interesting and interactive manner.

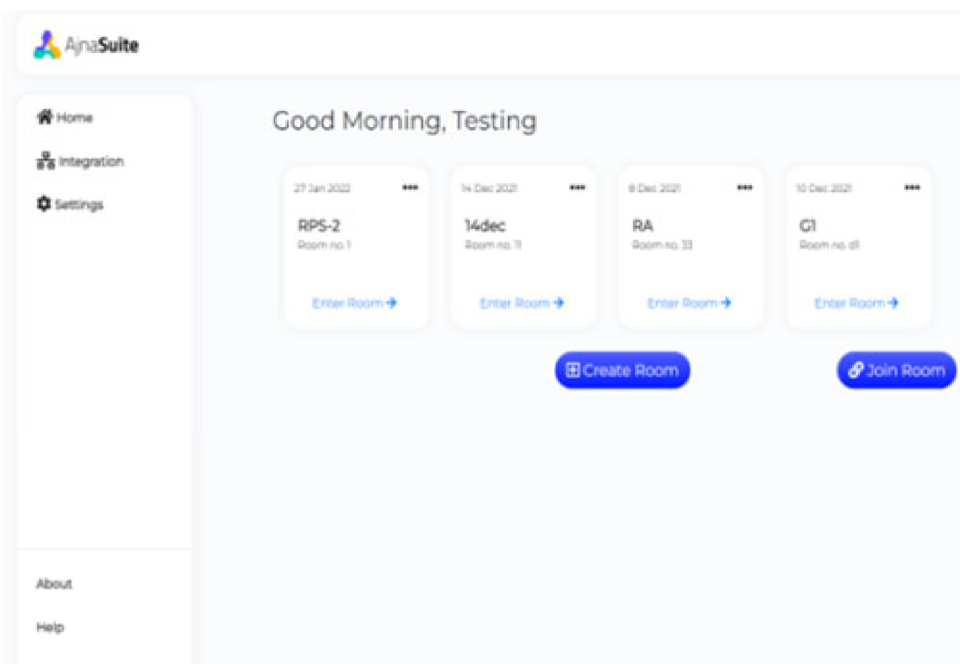
Throughout our thorough investigation of VR, AR, and MR meeting applications, we discovered a notable gap in the market. Specifically, we did not find any application that focuses on the 3D visualisation of objects, particularly by creating dedicated meeting rooms. Recognising this opportunity, we embarked on the development of an AR meeting platform for online meetings, which would effectively address several challenges related to training and learning within the education sector. In the subsequent section, we have provided a comprehensive explanation of the features offered by the RA on the AR meeting platform.

While AR technology continues to advance rapidly, understanding and optimising the user experience remain ongoing challenges. Obtaining meaningful and timely user feedback in AR can be challenging. As AR often involves real-time interactions and immersive environments, capturing user feedback during the experience itself can be complex. Presently, the evaluation methods followed include heuristic evaluation given by Nielsen and Molich (1990). These methods do not give us a clear root cause of user pain points. Traditional UX research methodologies may not fully capture the unique aspects of AR experiences. There is a need for tailored research methods that consider the spatial and interactive nature of AR, including methods for capturing user interactions, context, and environmental factors. Developing innovative techniques and tools for collecting user feedback in AR scenarios is crucial to gain insights into user preferences, pain points, and overall satisfaction. By recognising the specific pain points of users, the developers can create more intuitive and user-friendly AR experiences and continuously advance UX research in AR to enhance the overall user experience, increase user satisfaction, and unlock the full potential of AR technology in various domains. The proposed novel framework provides a comprehensive understanding of the specific pain points experienced by users, effectively mapped with various design parameters in AR applications. This framework offers clarity by identifying the areas where users encounter difficulties or challenges and aligning them with the corresponding design elements of AR. By leveraging this framework, developers and designers can gain valuable insights into user pain points and make informed decisions to optimise the design parameters, resulting in an improved user experiences in AR applications. The novel framework provides a structured approach for assessing and evaluating the UX aspects of AR applications, enabling researchers and developers to gain valuable insights into user perception, satisfaction, and usability.

3 Remote assistance

RA is a unique AR web portal that facilitates teaching and learning on an online platform by using immersive AR and VR technologies. The RA web application 'AjnaSuite' and the AR glasses 'AjnaX' are the software and hardware products respectively, which aid the immersive online meetings. RA has both, the web page and an app designed for conducting online AR meetings to provide assistance and receive assistance by joining the AR meeting room. The app version is designed to join the meeting room using the AR glasses, and thereby enable users to load, visualise and interact with the 3D models in a meeting room. Using this AR glass app, the user can communicate with the experts joining the meeting room from various remote locations and seek guidance through visualising the 3D models, videos, and files displayed on the AR glass screen. The participant joining the meeting room with AR glasses is provided with hands-free streaming of the critical operations. The other meeting participants joining the meeting room through AR glasses or computers can monitor the real-time critical operations and provide assistance to the participant performing the critical operations. The RA application is best suited for professional education like a medical fellowship programme in the medical science field to connect with expert doctors and fellowship candidates on an online platform. RA applications would also be supportive in industrial applications to connect the experts and the trainee in the same meeting room for 3D interactions and communication, helpful in remote maintenance, repair, and service as well as remote tours and inspection.

Figure 1 Web page on web portal to create AR meeting rooms (see online version for colours)



The basic audio and video features of the online meeting platform are apparent and inclusive in the RA meeting interface. Figure 1 shows the web application interface to join the online meeting through computers and the initial home page screen to create meeting rooms. Participants can create a meeting room and join respective rooms from the AR glasses and also laptop or desktop computers.

The meeting environment has screen elements that help participants connect with their peers in the meeting room, freedom to move around in the environment, and facilitate loading and interaction with 3D objects and other relevant audio and video files required for the meeting. The environment and the screen elements screenshot are depicted in Figure 2. The meeting room can be experienced by visiting the link https://ajnasuite.ajnalens.com/login

Figure 2 Virtual meeting environment with screen elements (see online version for colours)

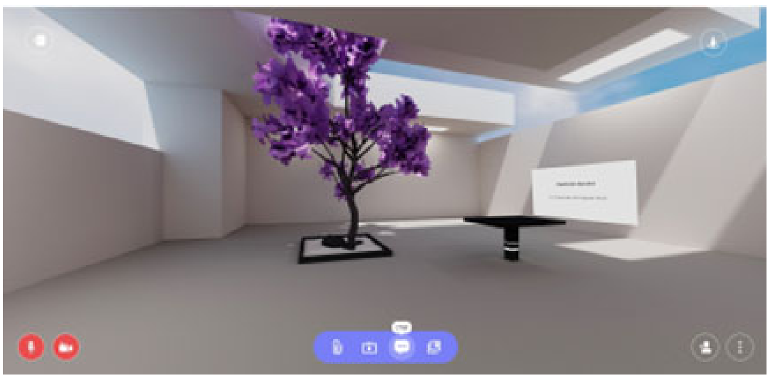
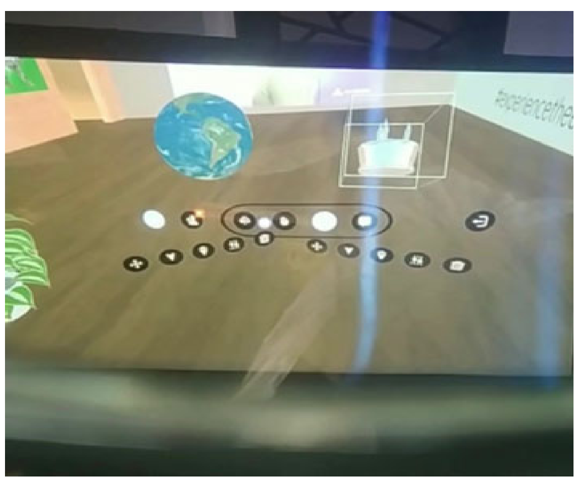


Figure 3 Screenshot of user screen seen through AR glass (see online version for colours)



The app interface is visualised through AR glasses. The screenshot of the interface seen through the AR glasses is depicted in Figure 3. Multiple numbers of such AR glasses could be used to join and connect with the peers in the same AR meeting room. The AR glasses for visualising the RA are available at AjnaLens (www.ajnalens.com) for interested readers to understand the immersive meeting room experience. The AR glass offers a wide focus of view which allows superimposing a 200-inch screen in a real-world environment just a few feet away. The screen elements consist of the default environment, icons to mute, unmute, and share the view, teleport, chat, and record sessions.

4 Testing the remote assistance

Software testing plays a significant role in the software development life cycle. To test the working of features and functionalities supported by the RA application, basic functional tests (Sawant et al., 2012) white box testing is conducted to test all the corner cases of the immersive software. An automated script to cover each node of the system architecture to test the RA functionality and to provide specific feedback based on the varied inputs was designed. During black box testing an automated tool, 'Selenium' was used to test the functionalities, irrespective of the backend logic. This test was prepared to test the functionalities to ensure the working of different modules by accepting the input from the users. Unit testing was performed to examine the working of each unit component of RA, such as creating users, uploading assets, capturing snapshots, annotating, creating, and joining the meeting rooms. Database testing of each collection was done to check the consistency and integrity of the database, in checking users' credentials for authenticating users joining the meeting room. These basic functional testing results inveterate the functional requirements of the RA application are met. The testing was continued as a study experiment to test the non-functional requirements of RA.

A total of fifteen participants eleven on computers and 4 with AR glasses participated in the study experiment to perform the non-functional test on RA application. The details of the user participants are given in Table 1. The participants had no history of working with such an immersive interface. Every participant was provided an opportunity to experience RA on web and AR glasses. The user participants involved in the study experiment were mostly computer engineering students and working professionals. The RA finds suitable applications in higher training and education sectors. Hence, the study experiment was conducted with such sample population, familiar with using some smart devices.

Table 1 Profile of participants involved in the study experiment

Profile	*Experience of using AR glasses*		*Age*	
	Yes	*No*	*15–30 years*	*30 to 45 years*
Students	-	10	10	-
Working professionals	-	05	-	05

RA is an AR meeting room with a non-traditional way of interaction and requires rigorous testing with several devices. The set of non-functional performance tests is conducted to test response time, reliability, scalability, and speed of the RA application with several devices. Test cases were carefully planned to perform the load testing, stress test, endurance testing, spike testing, and scalability testing on RA application as listed by the author (Anwar and Kar, 2019). A novel framework was designed to test and analyse the user experience element. Table 2 tabulates the different non-functional test cases performed on RA.

Table 2 Different non-functional tests performed on RA

Type of test	*Description*
Communication testing with different devices	To test the application's ability to communicate through audio & video functionalities with different devices. The participants tested to check if they could communicate with the media devices and change media devices during communication
Bandwidth testing	Bandwidth testing is to test the performance of the application and its audio/video streaming quality over varied bandwidth levels. The participants tested the applications on different networks at different places such as University Campus WIFI, Home WIFI, and Cellular Networks
Load testing	To test the application's ability to perform under anticipated user loads. The participants connected with several others through laptop/ desktop computers and AR glasses
Stress testing	To test the RA application under extreme workload by varying session data such as loading images, videos, and PDFs while communicating in a meeting room. The participants uploaded and loaded various media objects into the room randomly and tested the application's performance
Endurance testing	To test the RA application to handle the expected load such as multi-user communication, sharing of snapshots, and loading objects for a longer period of time. The participants set a session between different other participants in the meeting room and recorded the time frame for each activity till the maximum limit it would perfectly work without any failure
Spike testing	Spike testing is performed to test the application's reaction to a sudden large spike in the load generated by the users. The participants were asked to load files (glb, .jpeg, .mp4, .pdf) of larger sizes at a random point during the RA meeting and thereby noted the loading time and any other performance issues
User experience	A novel framework is designed to frame the research questionnaire to measure the overall user experience of using the RA on AR glasses and laptop/desktop computers. The novel framework is explained in the next section

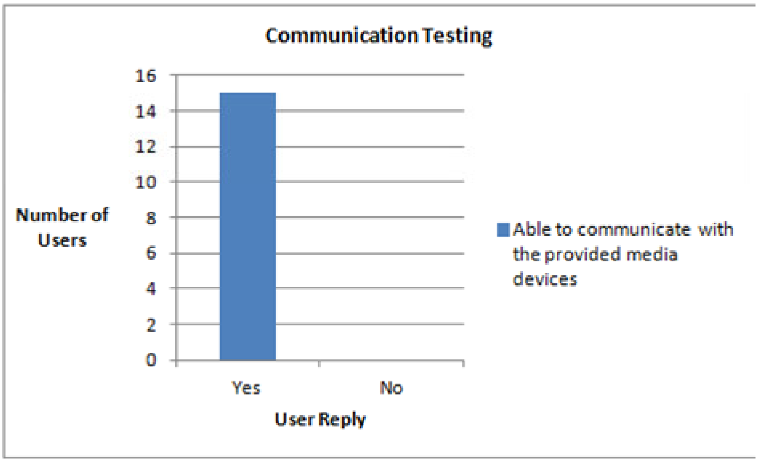
5 Results

The performance testing of the RA application, listed in Table 2 was conducted. A survey feedback form was shared with all the participants. The participants conducted the RA meetings and recorded their observations and comments in the feedback form. The response graphs generated by the survey form are presented in this section.

5.1 Communication testing

The communication test to check video stream from AR glasses to desktop/laptop computers and the option to change media devices during communication was tested on various laptops and devices. The feedback result of the communication test shows that all the participants were able to join the meeting room easily from different devices. Figure 4 is the graph depicting the results of the survey questionnaire – users were able to communicate with the provided media devices? All 15 user participants were able to join the meeting room and communicate well in the meeting room with AR glasses and laptops.

Figure 4 Screenshot of user screen seen through AR glass (see online version for colours)



5.2 Bandwidth testing

The bandwidth test of testing the RA on different networks at different places such as university campus Wi Fi, home Wi Fi, and cellular networks is conducted and the test results is shown in Figure 5 to Figure 7.

The insights drawn from bandwidth testing is that the RA meetings work best between 30–50 Mbps and 5–10 Mbps with different networks and different locations.

Figure 5 University campus bandwidth testing performance graph (see online version for colours)

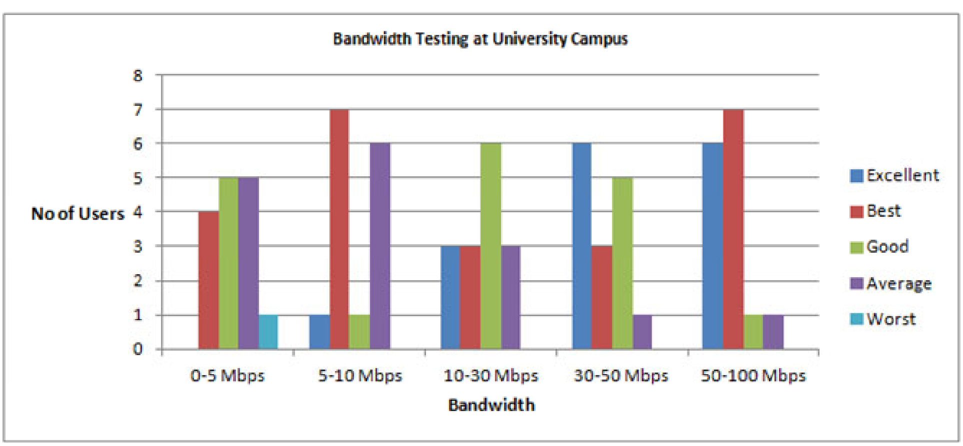


Figure 6 Home bandwidth testing performance graph (see online version for colours)

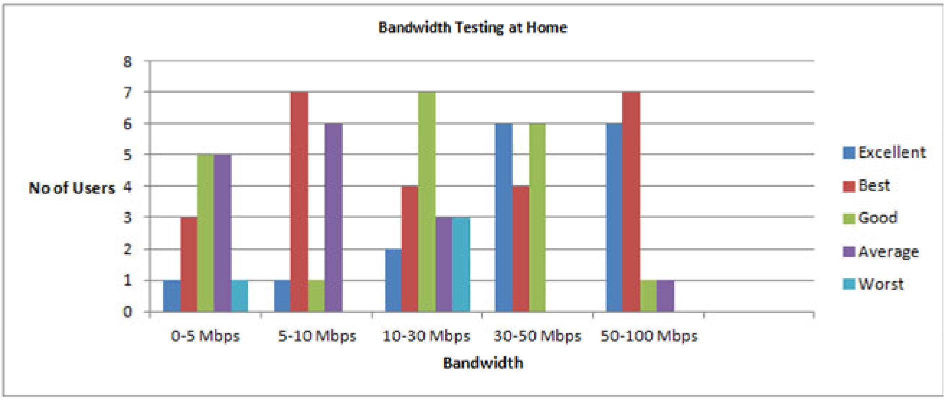
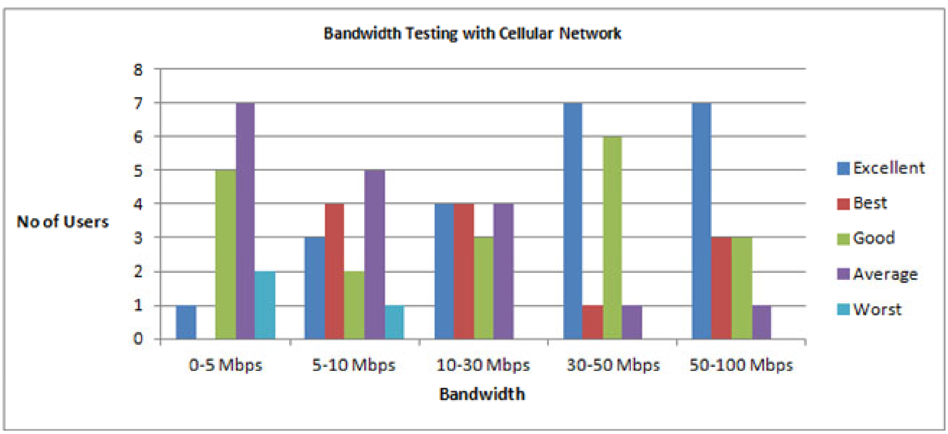


Figure 7 Cellular network bandwidth testing performance graph (see online version for colours)



5.3 Load testing

A load test was conducted to assess the performance of the RA application's ability to perform under anticipated user load. The load is in terms of the number of users joining the meeting room. The load test is performed by gradually increasing the participants from four web users and two AR glass users to 11 web users and 4 AR glass users. The RA application worked well with stable connections and the users interacted in the meeting room without any difficulties. Since the AR glass interface and 3D room interface is being experienced by new users, the count of users in the meeting room was limited to 15. This count can be gradually improved based on the expertise of the users and their comfort in using this immersive interface.

5.4 Stress testing

While communicating in an online meeting room, stress testing is performed by testing the RA application under extreme workload by varying session data such as loading images, videos, PDFs, 3D models, and television (TV) elements. The TV element is a screen to load images and videos which enable scaling, rotation, and other 3D user interactions. The users randomly uploaded various media objects in the meeting room to test the application's performance. The result of the stress test is shown in Figure 8. Stress testing of snapshots and annotation is also performed. The participants clicked a few random snapshots during the meeting and annotated the screenshots with a message, saved the annotated snapshots, loaded the annotated snapshots, and deleted the annotated snapshots randomly for around 10 snapshots. The stress testing performance graph of snapshots and annotations is shown in Figure 9.

Figure 8 Stress testing performance graph for loading media objects (see online version for colours)

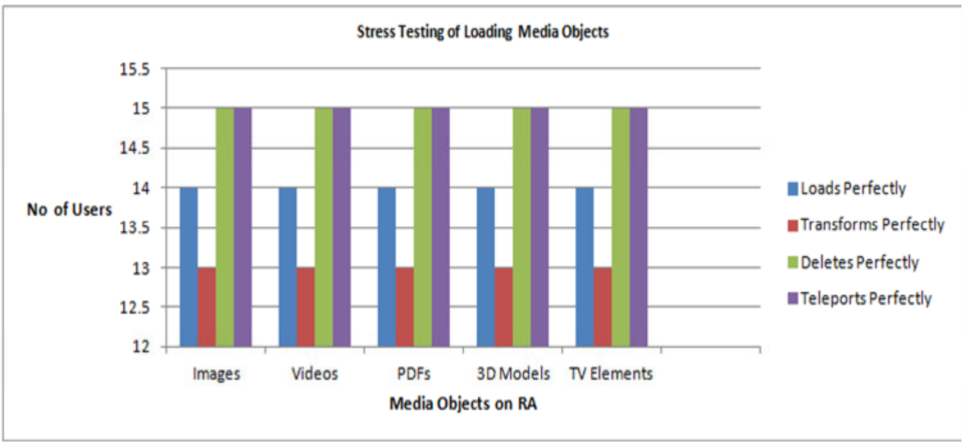
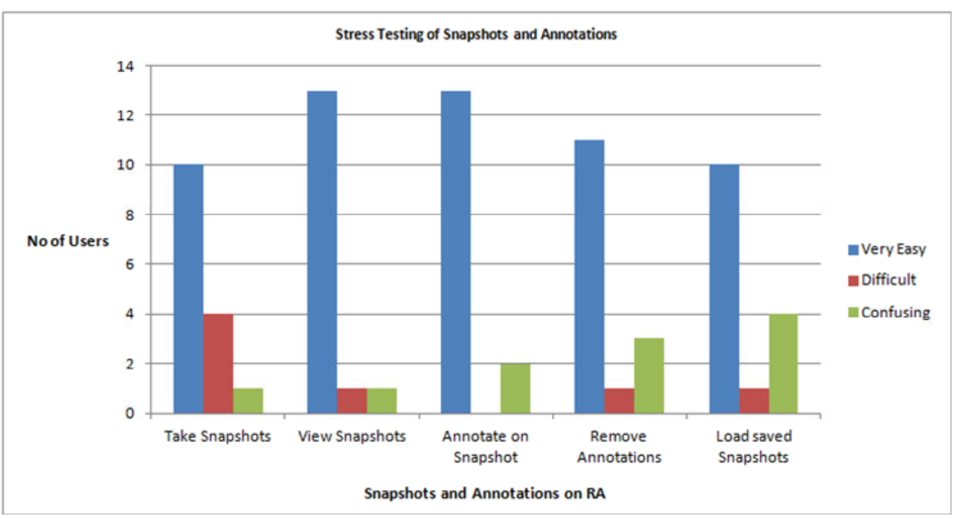
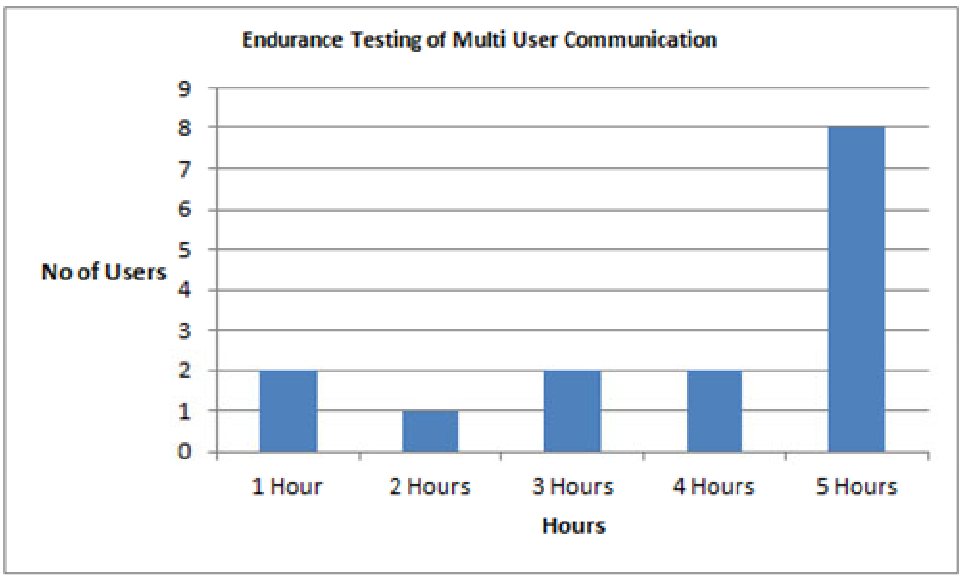


Figure 9 Testing performance graph for snapshots and annotations (see online version for colours)



The insights drawn from the stress test show that the user participants could load images, videos, pdf files, and 3D models in the meeting room. The majority of the user participants could transform the objects, delete the objects and teleport the objects perfectly. This is an un-moderated study and the participants were using immersive technology and devices for the first time. It was observed that very few of the participants had some difficulty in performing the task. Providing some help and guidance on the RA interface would help solve this problem. Snapshots and annotations operation was very easy for a few participants, but two to four users found it difficult and confusing to use the snapshot and annotations of RA. This would be further studied as part of our user experience research to iterate and enhance the interface usability by rearranging and redesigning the screen elements.

Figure 10 Endurance test graph for multi user communication (see online version for colours)



5.5 *Endurance testing*

Endurance testing was performed to test the RA to check the expected load such as multi-user communication, sharing of snapshots, and loading objects for a longer time. The user participants set a session between different testers and recorded the time frame for each activity – multiuser communication, taking snapshots and annotations, and interacting with objects. The maximum limit set for endurance testing was five hours. The user participants set the time limit in the range of one hour to five hours in the meeting room. The insights from endurance testing confirm the perfect working of RA for the maximum limit set. The graphical representation of the endurance testing by user participants is shown in Figures 10 to Figure 12. The endurance test for multiuser communication is tested by different participants setting time duration between one to five hours. The RA application performed well and proved to be a stable online meeting platform. The endurance test for multiuser communication is shown in Figure 10.

The endurance test for multimedia interaction was tested by different participants setting the time duration between one to five hours. The RA application performed well and proved to be a stable online meeting platform to share multimedia files. The endurance test for multimedia interaction is shown in Figure 11.

Figure 11 Endurance test graph for multimedia interaction (see online version for colours)

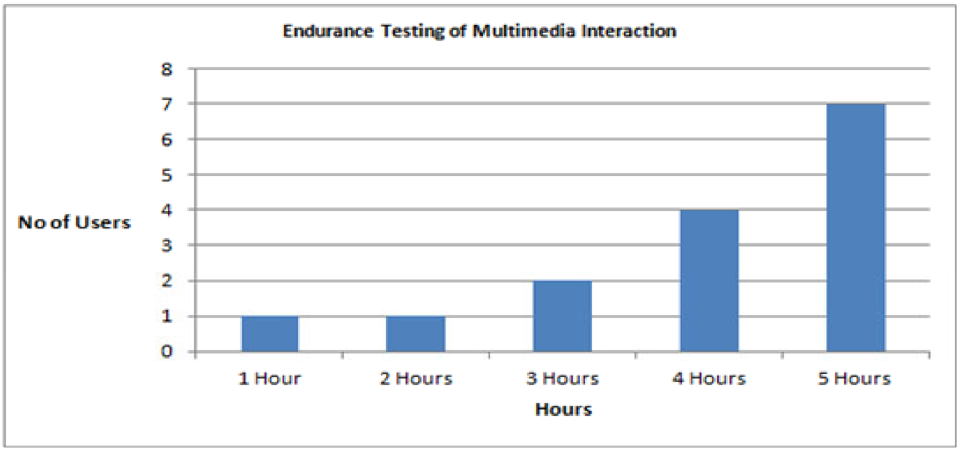
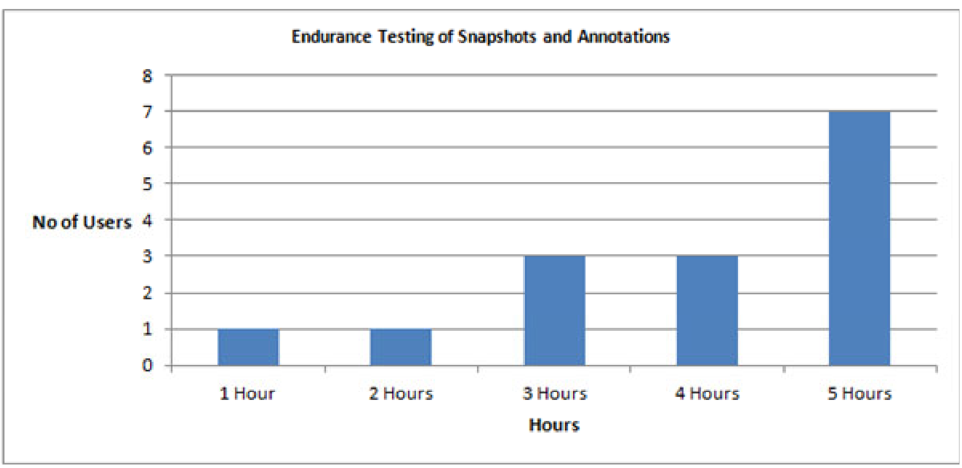


Figure 12 Endurance test graph for snapshots and annotations (see online version for colours)

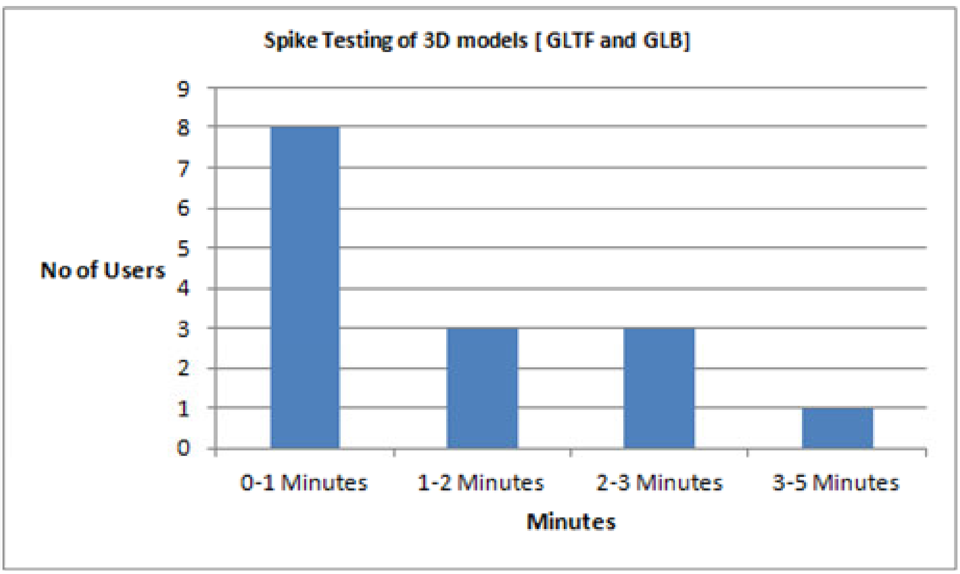


The endurance test for capturing snapshots and annotations was tested by different participants setting time duration between one to five hours. The RA application performed well and proved to be a stable online meeting platform to capture snapshots and annotate and explain the snapshots to all the meeting participants. The endurance test for multimedia interaction is shown in Figure 12.

5.6 Spike testing

A spike test is conducted to test the RA application's reaction to a sudden large spike in the load generated by the users. The participants loaded different files of larger sizes at a random point, thereby noting the loading time and any performance issues. The spike test feedback results of participants and the time to load various files are shown in Figures 13 to Figure 16. The insights drawn from the spike test elucidate the participants were able to load the files randomly within a few seconds. Few participants noted two to three minutes and three to five minutes loading time. Otherwise, the participants successfully loaded the different media files into the meeting room. There were around twenty media files loaded at once in the same room, the system performed well and facilitated the visualisation of all the loaded files.

Figure 13 Spike testing performance graph for 3D models (see online version for colours)



5.7 User experience design

RA is a new application with an AR online meeting interface. Usability and ease of using a RA play vital importance along with innovative technological growth. To understand the usability of the system, focus was placed on user experience research. We designed a framework to evaluate the user experience of the online AR meetings. Table 3 describes the framework to outline the user experience research questionnaire based on the user environment, view zone of model visualisation, interaction design and the interface design. This framework is based on our user experiments using AR glasses and the underlying theory of user interface design principles given by authors Todorovic (2008), Fitt's law, and the task wise heuristic evaluation given by authors Nielsen and Molich (1990) to understand the common usability issues of the RA.

Figure 14 Spike testing performance graph for images (see online version for colours)

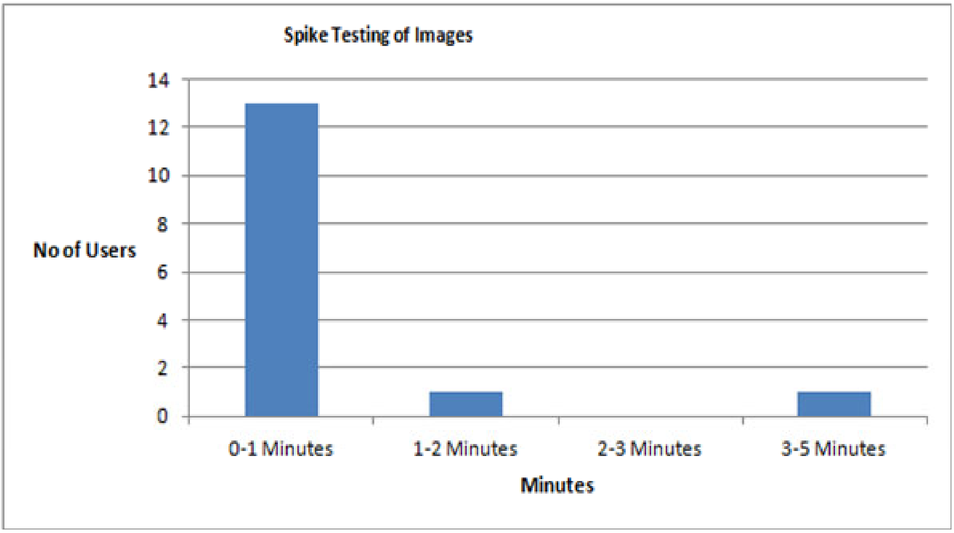
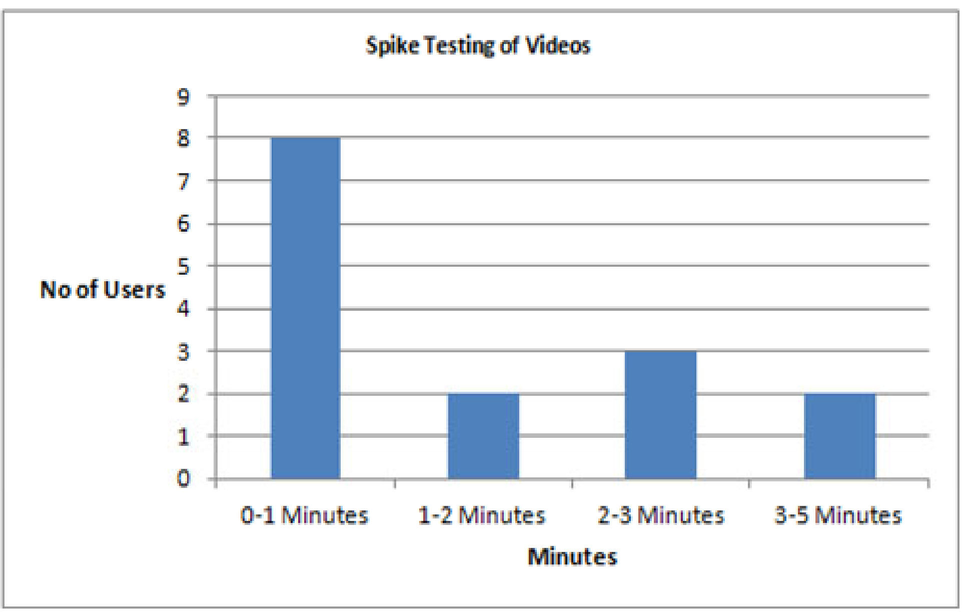


Figure 15 Spike testing performance graph for videos (see online version for colours)



User experience on AR glasses depends on interaction design, interface design, environment design and the view zone in which the user visualises and interacts with the 3D objects. The framework is divided into six columns to evaluate the user experience. Each column of the framework in Table 3 is explained in the below section.

- Research questions: Research questions is application dependent and Nielsen's ten heuristics (Nielsen and Molich 1990) is referred to frame the research questions.

Heuristic evaluation, developed by Nielsen and Molich, is a method for structuring the critique of a system using a set of relatively simple and general heuristics.

- Interaction design: Interaction design is all about how the users interact with the screen elements in the given user context or environment. These interactions take place on the screen or the viewfinder of the AR glasses, where three-dimensional objects are present. The context will also drive the possible interactions that users use to touch and experience the augmented object. The interaction design aspects look at situation feasible for possible touch interactions, checks for some contexts in which only voice commands would be safer, and considers the duration, and whether users have a long or short time to interact. The foremost interactions that can be used to interact on AR applications are tap, swipe, pinch, rotate, air tap (Hololense specific), voice, hover, and facial expressions. The best fit interaction method for respective elements is again a factor determined during the usability study. Also, there are different screens that can be designed for AR glasses, like flat screens, curved screens, folded screens, and detached screens. All screens floating around the users. There is a huge scope to explore the relationship between the type of screens and the interaction methods. Fitt's law focuses on human motor skills and assumes all interaction methods to behave the same (Fitts, 1954). The interaction method used in RA is gaze and tap, these interaction methods are experienced and evaluated by the user participants.
- Interface design: Interface design includes parameters like the visual design and ergonomics in designing the screen interface on smart glasses. The relevant image captures in the book '*Human Dimension and Interior Space*' by Julius Panero and Martin Zelnik, the ergonomic studies facilitate understanding of the range of motion, comfort, and natural postures for the users, and also the importance of the different levels of accessibility in space. Apparently, the field of ergonomics deals with the efficiency of humans in their working environment, and how humans can use tools more naturally when their design considers the human form. The RA interface is designed carefully by following all the interface design principles, user participants experienced and evaluated the RA interface for ease of usability.
- Environment design: Environmental design is the context of user surroundings engaging with the application. The context users are currently in is the environment. The environment of users using AR glasses may be anything from walking down the lane, attending the training sessions, or driving in an unknown city. Environment design considers user's context in mind, with comportment on things like user interface placement, colour, and size. To categorise the possible user environments when using applications of AR glasses, the user context was studied to understand the factors that influence and affect the usability of AR glasses. From the design perspective, we observed the areas and the probable context in which the users experience and use AR glasses. From the observation, the context of the environment referred to as users' real-time physical space falls into one of these categories or they may intersect between two of these categories. The first category of physical environments is classified as highly disturbed, user's context outdoors, public areas like shopping malls, stations, and markets with more crowded people and noise. The second category of the physical environment is a medium disturbance. This context was in the laboratory and workshops where the users make use of AR glasses for

expert guidance and need to focus on both real-world objects and also the smart glasses. The third category of physical environment observed is an environment with no disturbance or minimal disturbance. Such minimal disturbance observations were noted in users' context which involved classroom teaching, watching the 3D video, and playing games where the environment is static and users can fix up the screen location. Classifying the environment under study is essential to measure the user experience in their respective environment (Sumithra et al., 2022).

- View zones: The proximal relationships with distance, a feeling like things are personal or public , kind of substance can be used for things like implying whether the content is publicly visible or not. Users have slightly different visceral relationships to these areas around the bodies and feel more in charge of things below the gaze and are subject to things above that make them think that they normally have no control and cannot change. The distance of objects on smart glasses is related as intimate for distance less than 5 metres, personal for the distance up to 5 metres, 10 metre as social, and 15 metre as public zones. From our observations and intuition, we classify the user environment, and the surrounding space of users into the foreground, which includes the intimate and personal zone, mid-ground which includes the social zone, and background as a public zone. Measuring user experience in visualising the 3D models on different view zones is crucial for the usability study.
- Overall experience: The last column, overall experience is a summation of the user experience in interaction design, interface design, user environment and view zone of experiencing the 3D models. We have used five point likert scale for measuring the user experience.

Figure 16 Spike testing performance graph for PDF (see online version for colours)

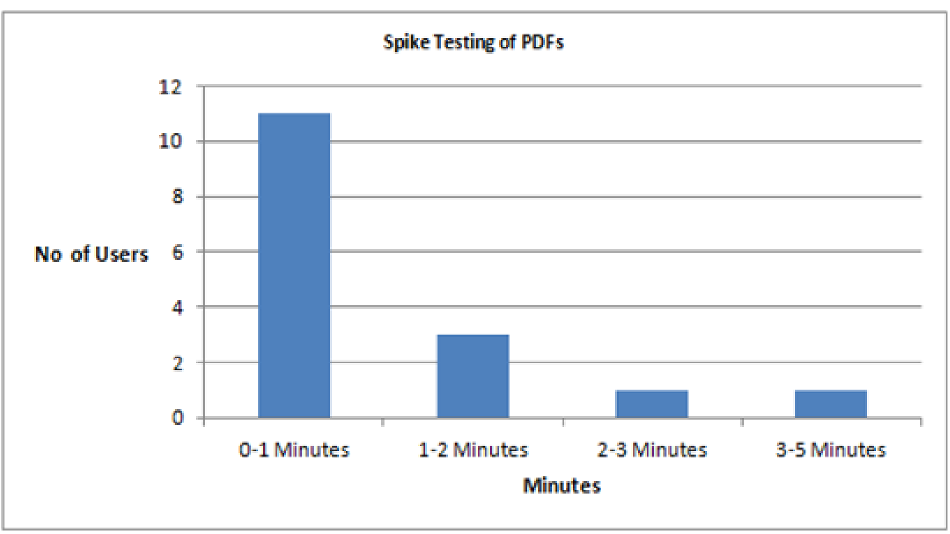


Table 3 Framework for conducting user experience research on AR glasses

Research questions	*Interaction design*	*Interface design*	*Environment design*	*View zones of model visualisation*	*Overall experience*
Heuristic evaluation questions (Nielsen and Molich, 1990)	Swipe Tap Gaze	Principle of proximity Principle of closure Principle of similarity Principle of continuity Principles of perception Principle of organisation Principle of symmetry (Todorovic, 2008)	No/minimum disturbance, medium disturbance and high disturbance	Intimate, Personal, Social and Public zone	Average of user feedback measured using five point likert scale

Table 4 Percentage of total known usability problems found in 100 analysis samples

No. users	*Minimum % found*	*Mean % found*
5	55	85.55
10	82	94.686
15	90	97.050
20	95	98.400
30	97	99.00
40	98	99.600
50	98	100.00

User experience feedback was collected from students and professionals for the research questionnaires mentioned in Table 5, in using the RA meeting. The questionnaires were identified based on the task the users need to complete during the conduction of the RA meeting. Five-point rating scale ranging from higher-end 5 to 1 with a neutral point in the middle was used to obtain responses to the research questions. The five-point scale to measure the agreement of research question statements is, 5 – strongly agree, 4 – agree, 3 – neutral, 2 – disagree, and 1 – strongly disagree. The summative evaluation of the RA application was conducted with potential users who had a desire to learn and use immersive technology. The number of participants in the study was limited, and a majority of them are students. Although, increasing the number of user participants could have produced more significant results. Faulkner (2003) showed that the mean 97% of the usability problems could be identified by 15 participants. A summary of the percentage of total known usability problems found in 100 analysis samples is presented in Table 4. However, the study was conducted with 15 participants as an initial step forward before the application can be used by a large number of users. The main concern of this study is to get valuable feedback on usability to improve various screen elements and the contents of the RA application.

Table 5 Research questions to measure user experience in experiencing online AR meetings

Research questions	*Interaction design (method – eye gaze and tap)*	*Interface design (Considering all design principles)*	*Environment design (No/minimum disturbance)*	*View zones of model visualisation (social)*	*Overall experience*
It was clear and easy to login to the system through AR glasses	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
It was easy to create and join meeting room	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
It was easy to land on main page	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
It was easy to load objects	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
It was easy to interact with objects	5 points (10 participants) 4 points(5 participants)	5 points (9 participants) 4 points(5 participants)	5 points (12 participants) 4 points(3 participants)	5 points (14 participants) 4 points(1 participants)	4.75
It was easy to move around the meeting room	5 points (10 participants) 4 points(5 participants)	5 points (9 participants) 4 points(6 participants)	5 points (12 participants) 4 points(3 participants)	5 points (14 participants) 4 points(1 participants)	4.75
It was easy to teleport on any object	5 points (8 participants) 4 points(7 participants)	5 points (9 participants) 4 points(6 participants)	5 points (12 participants) 4 points(3 participants)	5 points (14 participants) 4 points(1 participants)	4.71
It was easy to exit the meeting room	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
Annotation icons for different functionalities is justified for their actual usage and easy to use	4 points (13 participants) 3 points(2 participants)	4 points (13 participants) 3 points(2 participants)	4 points (13 participants) 3 points(2 participants)	4 points (15 participants)	3.98
Attachment icons for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
Deleting icons for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants)	4.9
Translating icon for different functionalities is justified for their actual usage and easy to use	5 points (11 participants) 4 points(4 participants)	5 points (12 participants) 4 points(3 participants)	5 points (12 participants) 4 points(3 participants)	5 points (14 participants) 4 points(1 participants)	4.81
Rotating icon for different functionalities is justified for their actual usage and easy to use	4 points (12 participants) 3 points(3 participants)	4 points (13 participants) 3 points(2 participants)	4 points (13 participants) 3 points(2 participants)	5 points(1 participant) 4 points (14 participants)	3.9
Scaling icon for different functionalities is justified for their actual usage and easy to use	5 points (14 participants) 4 points(1 participants)	5 points (12 participants) 4 points(3 participants)	5 points (9 participants) 4 points(6 participants)	5 points (8 participants) 4 points(7 participants)	4.7
Teleporting icon for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9

Table 5 Research questions to measure user experience in experiencing online AR meetings (continued)

Research questions	*Interaction design (method – eye gaze and tap)*	*Interface design (Considering all design principles)*	*Environment design (No/minimum disturbance)*	*View zones of model visualisation (social)*	*Overall experience*
Capturing snapshot icon for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
Saving snapshots icon for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	4.9
Loading snapshots icon for different functionalities is justified for their actual usage and easy to use	4 points (11 participants) 3 points(4 participants)	4 points (10 participants) 3 points(5 participants)	4 points (13 participants) 3 points(2 participants)	4 points (15 participants)	3.81
Chatting icon for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	4 points (13 participants) 3 points(2 participants)	4 points (15 participants)	4.4
Exit meeting room icon for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	5 points (15 participants)	4.93
More option icons for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	5 points (15 participants)	5 points (15 participants)	4.93
Play/pause video icon for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	4 points (13 participants) 3 points(2 participants)	4 points (15 participants)	4.4
T V element icon for different functionalities is justified for their actual usage and easy to use	5 points (13 participants) 4 points(2 participants)	5 points (13 participants) 4 points(2 participants)	4 points (13 participants) 3 points(2 participants)	4 points (15 participants)	4.4
Previous and next icon in PDFs for different functionalities is justified for their actual usage and easy to use	4 points (5 participants) 3 points(10 participants)	4 points (4 participants) 3 points(11 participants)	4 points (12 participants) 3 points(3 participants)	5 points (1 participant) 4 points (14 participants)	3.6

Research questions to measure the user experience is listed in Table 5. There were 24 main questions identified to measure the user experience and follows the same structure of the framework as mentioned in Table 3. The task wise user experience, value of five point likert scale and the number of participants in using the AR online meeting through AR glasses is tabulated in Table 5.

6 Discussion

AR technology offers an engaging and interactive experience, but any usability issues can impede the user's immersion experience. The Immersive RA application is specifically designed with the user in mind, providing guidance to AR designers and developers on how to design and conduct usability tests. This approach takes into account various factors, such as interaction design, interface design, environment, and view zones, to ensure a user-centric design. Our user experience findings have reliably shown that adopting this design approach leads to a superior immersive experience for users. The results of the summative evaluation of the user survey for identified 24 research questions, establish the fact that the majority of the users agree that they could easily log in, participate, interact and exit the RA meetings through AR glasses and computers. The insights drawn from user experience survey show that majority of the participants found the RA application features to be very easy to use for the very first time. Interacting with objects, the rotating functionality, saving snapshots, and loading the annotated snapshots were difficult and confusing for nearly 30% of the user participants. Gradually, with a help of a moderator, participants were able to get familiar and found it easy and interesting to use the RA. The overall performance has a mean of 4.61 on a 5 point likert scale with a variance of 0.16. The user interviews illustrated that the majority of the participants have a strong opinion that the RA application has the potential to encourage new users to use the immersive application in professional courses by further improving the screen design. User experience design is an iterative process. The user experience survey has encouraged further redesigning of the screen elements on the AR glasses for a much better user experience.

7 Conclusions

Existing industry testing methods commonly involve traditional tests such as functional and non-functional tests, accompanied by heuristic evaluation. However, the proposed testing methods for the remote assistance application using an AR web portal go beyond these conventional approaches. They encompass a diverse range of tests aimed at validating the application's stability and functionality. Additionally, a novel evaluation framework is introduced, specifically tailored for conducting usability studies and assessing the user experience in online AR meeting rooms. This framework draws upon the design theory of AR applications, incorporating elements such as interaction design, interface design, user context, and view zones to provide a comprehensive evaluation of the AR meeting room experience.

Overall, the immersive technology online meeting platform, AR web portal looks promising to hasten the training and education sectors. The novel RA application was tested to check for the performance of the system under immersive technology usage to ascertain the fact that the software and devices work as expected and is ready for conducting the heuristic evaluation. The insights derived from the performance testing have proved that the system is stable and functional and would gradually scale up to adapt to the minor glitches of bandwidth issues. A novel framework is constructed to frame the user experience research questionnaire. The research questionnaires and heuristic evaluation to evaluate the RA application under a specific use case has assured the users comfort and ease of operability in using the RA as an innovative immersive web portal for conducting online meetings. Task wise rating mapped with various design factors, give a clear understanding of the usability issues and guide us to focus on a specific design parameter for developing an application with the emphasis on user centric design.

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