ECTI Transactions on Computer and Information Technology
Journal homepage: https://ph01.tci-thaijo.org/index.php/ecticit/
Published by the ECTI Association, Thailand, ISSN: 2286-9131

Mixed Reality Application for Virtual Tourism: Annah Rais Longhouse

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ABSTRACT

The tourism industry worldwide has faced unprecedented challenges recently, which has increased the need for innovative solutions to showcase destinations sustainably. Virtual tourism has emerged as a transformative response to these challenges, allowing individuals to explore destinations remotely through immersive digital experiences. Malaysia is renowned for its breathtaking natural landscapes and diverse cultural heritage, such as the Annah Rais Longhouse in Sarawak. Despite the decline in tourist numbers, there are concerns about the degradation of Sarawak's natural sites. Furthermore, individuals with disabilities often encounter barriers when trying to access these locations, which can exacerbate feelings of exclusion and isolation. This research focuses on developing a mixed reality (MR) application that leverages immersive technology to provide virtual tourism experiences, preserve natural attractions, and enhance accessibility for all types of visitors in response to these issues. The research adopted the multimedia development life cycle encompassing five key stages: concept, design, data gathering, assembly, and testing. The developed MR application offers users two modes: Explore Mode and Virtual Tour Mode. With the integration of interactive elements, the MR application allows users to delve deeper into the history and significance of the cultural heritage, which positively contributes to the tourism industry in Sarawak. The developed MR application was evaluated using the constructs of perceived ease of use (PEOU), perceived usefulness (PU), perceived interaction (PI), and telepresence (TP). Descriptive analyses of the constructs were conducted. The results demonstrated that the MR application is well-accepted.

Article information:

Keywords: Mixed Reality, Immersive Technologies, Virtual Tourism, Culture Heritage

Article history:
Received: October 11, 2024
Revised: January 24, 2025
Accepted: March 22, 2025
Published: April 19, 2025 (Online)

DOI: 10.37936/ecti-cit.2025192.258793

1. INTRODUCTION

Sarawak is a state of Malaysia on Borneo Island, which contains an extensive area of completely protected regions, gazetted national parks, wildlife sanctuaries, and nature reserves rich with flora and fauna [1]. Most of these natural attractions are in remote areas, posing accessibility difficulties for tourists who cannot physically reach these destinations due to health issues, disabilities, or geographical constraints. One significant potential way to improve accessibility to remote tourist attractions is through technological advancements such as mixed reality.

Another primary concern for tourism destinations worldwide is the degradation of natural attractions, sites, infrastructure, antiquities, and habitats. The

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degradation results from various human and environmental factors, including tourist activity, natural occurrences, and insufficient policy, planning, and management [2, 3]. Therefore, sustainable tourism solutions are essential for minimizing the environmental impacts and preserving cultural heritage, particularly in delicate or vulnerable sites that may suffer from physical tourism. Virtual tourism offers a way to protect these locations while still allowing people to explore them remotely. The need for such alternatives became especially apparent during the Coronavirus disease (COVID-19) pandemic, when public safety concerns led to widespread travel restrictions, leaving many people with limited and monotonous experiences at home. In this context, the United Nations World Tourism Organization (UNWTO) promotes accessible tourism to make sure that tourism and travel are attainable to all people, with disabilities or not. Despite a growing interest in accessible tourism, delivering high-quality tourism experiences to people with disabilities remains a significant challenge [4].

This research aims to address various challenges and opportunities within virtual tourism. This research is motivated by the increasing demand for alternative tourism solutions that enable users to engage with cultural sites without physical travel, which are affected by sustainability issues and technological advancements in immersive experiences. The objective is to implement a mixed reality (MR) application that enhances virtual tourism experiences by leveraging immersive technologies. In tandem with this, the research also aims to preserve natural attractions in Sarawak digitally, emphasizing the importance of conservation and sustainability in virtual tourism initiatives. These objectives collectively form a comprehensive approach to developing a mixed reality application for the Annah Rais Longhouse, with the motivation to align with the broader goals of enhancing visitor experiences, conserving natural resources, and promoting accessibility for all users.

In this study, the multimedia development life cycle is adopted, and the MR application is designed with the integration of different interactive elements, which allows users to actively engage with the content developed, thereby enhancing their tour experience. The paper is organized as follows: the first section discusses the study's introduction; the following section provides an extensive literature review on virtual tourism and immersive technologies, while the third section offers a detailed explanation of the methodology employed in the design and development of the mixed reality application. The fourth section presents the study's results accompanied by an in-depth discussion, leading to a conclusive summary and implications in the final section.

2. LITERATURE REVIEW

Tourism is an important global industry that encounters several challenges. The COVID-19 pandemic, which has disrupted travel, is one reason for the increased demand for innovative solutions to showcase destinations sustainably [5, 6]. Virtual tourism has emerged as a creative response to these problems, allowing travelers to visit locations virtually through immersive digital experiences.

2.1 Virtual Tourism

Virtual tourism (VT) has risen in recent years with the advent of new technologies [7]. VT is exploring nature, attractions, ruins, and travel destinations via a remote application without physically visiting them. The simplest form of VT can be a video on a tourist attraction site where users can watch and hear the content using their computer devices such as smartphones, tablets, or desktops [8]. VT, which is also known as digital or cyber tourism, refers to the use of virtual environments with digital technologies to simulate real-world destinations and experiences for tourists [5].

A survey was conducted by M. S. Siddiqui et al. [9] on the willingness of people to experience VT. 534 respondents from four generational groups of Gen Z, Millennials, Gen X, and baby boomers participated in the survey. The overall statistic showed that 184 individuals responded with "maybe," 53 individuals responded with "no," and 297 individuals responded with "yes" regarding their willingness to experience virtual tourism. The result showed insights into the varying levels of willingness among different generational cohorts towards virtual tourism. It highlights the overall positive inclination towards virtual tourism, with variations and differences observed across various age groups.

As technology continues to develop, VT is likely to become even more popular in the future. It has the potential to revolutionize the tourism industry and make travel more accessible to people worldwide. With the advancement of technology, the virtual world's imagination can be diversified with the real world to provide more realistic experiences.

2.2 Immersive Technologies

Immersive technologies such as augmented reality (AR), virtual reality (VR), and mixed reality (MR) have been adopted and implemented in VT. These technologies integrate the virtual world and the real world to provide a surrogate experience that can be used to convince potential visitors to travel to a tourist attraction's destination with a low risk of environmental damage [10]. Table 1 shows some examples of research on designing, developing, and implementing applications based on immersive technologies for VT purposes. Each technology possesses distinctive features and offers different contributions, as explained by D. Buhalis and N. Karatay [11].

Table 1: *Research on Immersive Technologies for Virtual Tourism.*

Technology	Authors	Location	Platforms
AR	I. Cibilić *et al.* [13]	Pazin, Istria	Smartphone
AR	H. Pranoto *et al.* [14]	Lawang Sewu, Indonesia	Smartphone
VR	M. M. Amin *et al.* [17]	Bukit Puteri, Terengganu, Malaysia	Smartphone, Google Cardboard
VR	H. Yu *et al.* [20]	Changchun University History Museum	Computer
MR	D. Tresnawati *et al.* [21]	Bandung, Indonesia	Smartphone, computer
MR	Y. C. Chu *et al.* [22]	Taichung Train Station and Taichung Broadcast Studio, Taiwan	Mixed reality smart glasses

Augmented reality (AR) combines virtual objects with the actual environment in the presence of a trigger such as a QR code, an image, a real object, or a device location as a stimulus to activate the augmentation of virtual objects on the device [10]. AR technology overlays virtual information in the real-world environment. It integrates computer-generated and real-world content to augment the user's perception of the real world. AR can be experienced through various devices such as smartphones, tablets, and smart glasses. The device captures the user's view of the physical world and overlays digital content to enhance the user's experience. The digital content is anchored to a specific object in the real world, such as a building, product, or sign, using markers, a global positioning system (GPS), or other tracking technologies [12]. For example, I. Cibilić *et al.* [13] created a mobile AR tourism application that enables overlapping old photos with the current views. They claimed that the AR application provides users with more detailed information about the destinations through the AR application. H. Pranoto *et al.* [14] developed an AR application that serves as a guide to assist users in exploring and locating places of interest within the historical site. The guide could appear in the form of text, images, or other multimedia elements, based on the user's location within the designated range of locations within the historical site. Although the AR application can potentially draw tourists to the visited destination, it might cause undesired degradation to the site [3].

Virtual reality (VR) simulates a computer-generated artificial environment wherein the user can enter a virtual environment with a VR headset, controllers, or other input devices. The digital environment can be entirely fictional or based on a real-world location or situation [2]. Users immerse themselves in the VR experience and have a sense that they appear in the virtual world as the virtual environment blocks the user's real-world view [10]. One of the current trends in VR for VT is the use of 360-degree videos and photos, which can transport users to real-world locations and provide a more realistic and immersive experience [15, 16]. For instance, M. M. Amin et al. [17] developed a mobile-based VR application with Google Cardboard. Their application used text, graphics, 3D models, audio, and other interactive multimedia elements in their application. However, the issue of VR sickness, which has been linked to nausea, disorientation, and eye fatigue, may affect the VR experiences, as claimed by E. Chang *et al.* [18].

Mixed reality (MR) combines real-world and virtual objects, and scenes can be emulated to provide a more realistic experience [12]. MR allows the virtual and real worlds to blend to create a new environment where real and virtual objects can coexist and interact in real time. MR requires smart glasses, such as HoloLens 2, with lenses that have transparent screen features [11]. In MR, the virtual content is not just anchored to specific objects, but it can interact with and respond to real-world objects [2]. Therefore, users can concurrently engage with actual and virtual objects [19]. MR applications merge the virtual and physical worlds, providing an augmented experience that enhances the physical environment with digital information, creating a mixed reality that offers a new perspective on reality. These applications provide a more engaging and interactive experience for tourists, which enhances their understanding and appreciation of their destinations. Hence, this technology can potentially provide tourists with an even more realistic and engaging experience of VT.

However, the use of MR in VT is still in its infancy, and there is a lack of research on designing and developing practical MR applications for VT. Based on the review reported by E. H. Pratisto et al. [10] on AR and VR in the context of VT, they also suggested researching the implementation of MR to enhance the user experience as one of the potential future works.

3. METHODOLOGY

This section discussed the processes involved in the methodology phase, which consisted of designing the content, collecting data, specifying the necessary software and hardware, describing the features and assets incorporated in the design, and developing the mixed reality application.

Design thinking (DT) and the multimedia development life cycle (MDLC) are commonly used approaches in creating immersive technology content. [21, 23, 31, 32]. However, DT is a user-centric problem-solving methodology that closely aligns development with specific user requirements [32]. Conversely, MDLC is a framework specifically designed for multimedia and software development, offering a structured approach for integrating diverse media elements and emphasizing the systematic development of interactive applications [25, 26]. Hence, this specificity makes MDLC particularly advantageous for immersive technology projects, where the seamless integration of multimedia components is crucial.

The proposed MR application has been developed using the MDLC method. This method has been used by S. Solehatin *et al.* [23] for their study on the advancement of AR in educational media and by D. Tresnawati et al. [21] for their research on the deployment of a prototype of MR application as promotional media for tourist destinations. The MDLC shares fundamental similarities with the Software Development Life Cycle (SDLC), but it differs in its focus on the development and use of multimedia components [24].

The MDLC is a structured framework for developing multimedia applications, comprising five essential stages: concept, design, data gathering, assembly, and testing, as illustrated in Fig. 1. Generally, the concept stage defines the project's goals, target audience, and primary features. Meanwhile, the design stage focuses on developing the application's blueprint, including the user interface (UI) and interaction elements. During the data gathering stage, all multimedia materials, including text, audio, and images, are gathered. In the assembly stage, the multimedia components are then integrated and programmed to create a functional application. Finally, in the testing stage, the application is thoroughly tested to ensure functionality and collect user input for product refinement. This structured approach facilitates systematic and user-centric development of multimedia applications, offering both engagement and functionality [29].

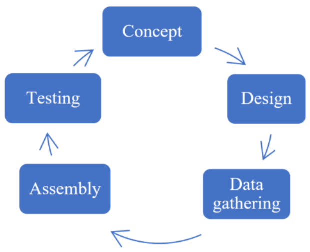

Fig.1: *Multimedia Development Life Cycle.*

The MDLC framework, with its structured and well-defined stages, served as a valuable guide in developing the mixed reality application for virtual tourism. This process is not only limited to the tourism industry, but it can be generalized and adapted to various fields such as education, healthcare, and entertainment, where multimedia applications are increasingly important. Despite its effectiveness, its inflexible stage-based design may impede adaptation when addressing unexpected challenges during the development process. To mitigate this, an iterative approach was incorporated within each MDLC stage, allowing greater adaptability while maintaining the structured development flow. This flexibility enabled the MR application to be tailored to various tourism contexts, each with unique cultural and geographic elements [30].

3.1 Concept

During the first stage, the team conducted a literature review on current related mixed reality applications. Activities are carried out to determine the objectives of application development, identify the target users, and clarify development and implementation requirements. It includes identifying the software and technological tools that will be utilized to create the application. The hardware and software involved in this study are listed in Table 2 and Table 3, respectively. The usage of the hardware and software are discussed in the following stages.

Table 2: *Hardware.*

No.	Hardware	Description
1.	Insta360 Pro 2	It is used to capture 360 videos and images.
2.	Dell XPS Workstation	It is used to perform development work for the application.
3.	iPhone 13 Pro	It is used to scan 3D objects.
4.	Microsoft HoloLens 2	It is used to deploy and test the MR application.
5.	Insta360 X3	It is used to capture 360° videos and images.

Table 3: *Software.*

No.	Software	Description
1.	Unity3D	It serves as a platform for designing elements required for the application.
2.	Insta360 Stitcher	It performs 360° video and image stitching for the Insta360 Pro 2 camera.
3.	Visual Studio 2019	It is a platform to deploy applications on HoloLens 2.
4.	Mixed Reality Feature Toolkit (MRTK) 2	It provides a set of components and features used to accelerate cross-platform MR app development in Unity.
5.	Polycam – LiDAR & 3D Scanner	It performs 3D object scanning.
6.	Adobe Premiere Pro, Wondershare Filmora	It performs 360° video editing.
7.	Insta360 Studio	It is a stitching and editing platform for the Insta360 X3 camera.

3.2 Design

In the design phase, the team defined the specifications for the application's storyboard, visual aesthetics, user navigation map, interface design, and overall user experience. In virtual tourism, as highlighted by D. Ye *et al.* [25], the utilization of digital devices hinges significantly on the quality of content and interaction provided to tourists. The content's caliber plays a pivotal role in engaging and satisfying tourists, necessitating accurate, up-to-date information, visually captivating multimedia, engaging narratives, and authentic representations of destinations. Simultaneously, the quality of interaction between tourists and digital platforms is crucial, requiring a seamless, intuitive interface, real-time feedback, personalization options, interactive features, and responsive navigation. User interaction and digital storytelling are the two content design features identified in addition to the 3D environment.

The key interaction tasks for designing a mixed reality application for virtual tourism are selection, manipulation, navigation, and system control [26, 27].

- Selection: Users should be able to easily select and choose virtual objects, landmarks, or experiences to interact with and retrieve information about. It could involve pointing, gazing, or using hand gestures to select items of interest. The application was designed to allow users to choose various options from the menu provided.
- Manipulation: Users should be able to manipulate the size, position, or other characteristics of virtual tourism elements. Such interaction allows them to customize their experience and better understand the environment. Techniques like pinching, dragging, or resizing could enable this. This application was designed so that users can interact with 3D objects by manipulating the size, position, and sound.
- Navigation: The application should facilitate smooth navigation and exploration of the virtual tourism environment. This could involve walking, flying, or teleporting through space to change one's position and orientation. This application implemented a teleport function, allowing users to navigate throughout the village from one scene to another scene.
- System Control: Users should be able to control various settings and parameters of the mixed reality system, such as adjusting menus, toggling information overlays, or switching between different virtual tourism experiences. The application was designed to allow users to turn off the main menu user interface (UI) "follow-me" mode to allow an unobstructed view of the village.

By designing the content and interactions around these key tasks, the mixed-reality tourism application can provide immersive, engaging, and customizable virtual experiences for users. Additionally, the goal of including interactions in the design is to close the gap between the physical and digital realms, allowing users to interact with virtual tourism content naturally. As for digital storytelling, a factual narrative is formed by integrating various distinct components. The narration for this research was constructed from the information obtained from local experts.

Eight proposed scenes were designed for the application. The content components and description of each scene are summarized in Table 4. The navigation structure design for the proposed scenes is illustrated in Fig. 2. The navigation structure highlights the application's flow, detailing the relationships inside each scene to establish the overall development of the designed application. The application was designed to start with a main menu. This menu contains three main application selections: Virtual Tour, Hotspring, Explore Mode, and a selection to exit the application.

The content of these three primary options was delivered to users in different formats. The first option, the Virtual Tour, presented the village's story by directing users to discover distinctive locations: the Village Entrance, Skullhouse, and Sugarcane Crusher site, accompanied by voice narrations and caption displays. The second option, Hotspring, offered a natural setting where users could observe and appreciate the sound of nature. The third option, named Explore Mode, enabled an alternative for users to independently revisit the village without a narrative guide while still having access to text dialogue pop-ups for further details. Besides that, Explore Mode also provides an environment for users to interact with 3D instruments. Fig. 3 shows the graphical illustration of the storyboard design.

Table 4: *Proposed Storyboard Design.*

No.	Scene	Content Component	Description
1.	Main Menu	Assets: 360-degree image, 3D menu Interaction: selection, navigation	This is the first scene when users load the application. There will be a menu that shows the primary selections for the applications. Users can navigate to different scenes using the options given.
2.	Virtual Tour	Assets:360-degree image, 3D menu, narrations, caption displays Interaction: selection, navigation	This is the first option on the Main Menu. It leads users to the 3rd, 4th, and 5th scenes, respectively, for exploration.
3.	Village Entrance	Assets: 360-degree video, 3D menu, narrations, caption displays Interaction: selection, navigation	This is the first scene in Virtual Tour, which shows the front entrance to the village.
4.	Skull house	Assets: 360-degree video, 3D menu, narrations, caption displays Interaction: selection, navigation	This is the second scene in Virtual Tour, which shows the skull house of the village.
5.	Sugarcane Crusher site	Assets: 360-degree video, 3D menu, narrations, caption displays Interaction: selection, navigation	This is the third scene in Virtual Tour, which shows the site of the traditional sugarcane crusher.
6.	Hotspring	Assets: 360-degree video, 3D menu, narrations, caption displays Interaction: selection, navigation	This is the second option on the Main Menu. It shows the hot spring near the village.
7.	Explore Mode	Assets: 360-degree video, 3D menu, text dialogue pop-ups, music Interaction: selection, navigation	This is the third option on the Main Menu. Users could freely explore the scenes without narrative guides but with buttons to access text dialogue for details.
8.	3D Instruments	Assets: 3D scanned objects Interaction: selection, navigation, manipulation	This is an extended scene from Explore Mode, where users can interact with the scanned 3D instruments.

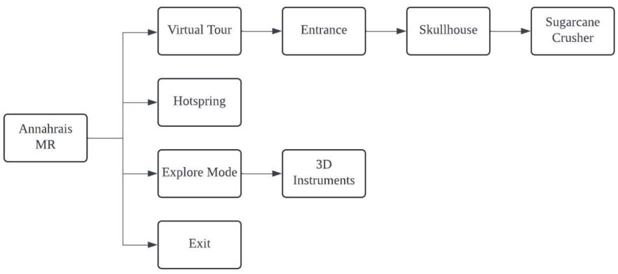

Fig.2: *Proposed Scenes and User Navigation Map.*

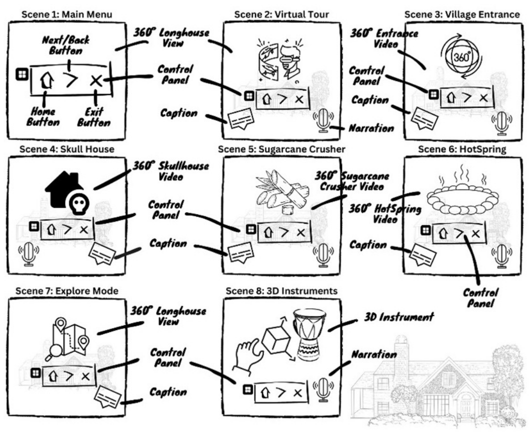

Fig.3: *Storyboard Illustration of the Proposed MR Application.*

The storyboard illustration, as shown in Fig. 3, visually represents a sequence of eight scenes depicting a traditional longhouse experience, enhanced with augmented and mixed-reality elements. The experience begins in Scene 1, where users load the application and access a main menu with navigation options. Scene 2 represents the Virtual Tour Mode, guiding users sequentially through three inner scenes: Scene 3 (the Village Entrance), Scene 4 (the Skullhouse), and Scene 5 (the traditional Sugarcane Crusher site). Scene 6 is an independent option that showcases the Hotspring near the village. Scene 7 introduces Explore Mode, allowing users to freely navigate all scenes without a guided narrative, with interactive buttons providing textual information. Scene 8 expands this experience, enabling direct interaction with scanned 3D instruments within the environment. This structured storyboard offers a clear progression from guided exploration to interactive engagement, enhancing cultural heritage immersion through mixed-reality technologies.

3.3 Data Gathering

The selected location for the study is Annah Rais Longhouse, one of the major tourist attractions in Sarawak. It is the largest and most famous Bidayuh Longhouse, which houses around 80 families. It is located 60 kilometers from Kuching, the capital of the Sarawak state in Malaysia. The Annah Rais Longhouse stands on the same site where its original longhouse first stood 200 years ago and is built in the same manner using bamboo as its primary construction material, along with timber and nipah palm leaves.

The primary data gathered from the site consists of videos, images, and audio. 360-degree videos and pictures are required data for developing the MR application. During the site visit, the data was captured using the Insta360 Pro 2 and Insta360 X3 cameras. The output videos are recorded in MP4 format with a resolution of 7680 × 3840 at 30 fps HDR (8K 2D). The output images are captured in JPEG format with a resolution of 7680 × 3840 (2D). Unique objects were scanned using the software Polycam installed on an iPhone 13 Pro. The generated 3D objects, such as musical instruments named "gaduak" in the Bidayuh language, were exported as an object (.obj) file format. The audio sounds of the music performance, nature, and surroundings were recorded directly from the Insta360 Pro 2, which supports spatial audio format. Additional audio was recorded using smartphones in MP3 format and WAV format.

3.4 Assembly

The stage of assembly involves asset preparation and product development. A variety of design tools and software, as shown in Table 2, were employed to generate and prepare the 2D/3D assets, as well as to cultivate engaging and immersive user experience for the MR application. The development was constructed according to the design created during the design stage.

Assets may appear in several formats, including polygons, textures, photographs, music, movies, 3D models, and animations. UI elements, such as menu navigation, are modified from the standard asset packages provided by the Mixed Reality Feature Toolkit (MRTK). It is an open-source software development kit developed by Microsoft. However, custom 3D object creations offer a higher level of control and fidelity in representing the virtual elements, as stated by T. Louis *et al.* [28]. Hence, on-site captured photographs, 3D objects, and videos incorporating the recorded nature sound along with narration audio were used in this research, which is believed to bring a sense of realism and authenticity to the virtual environment and further enhance the overall user experience. Fig. 4 illustrates asset instances of a modified menu navigation and a scanned 3D object for the application use. Narration was added to deliver valuable and exciting information, to navigate people through the virtual tour, and to provide insights into the environment they experienced. The combination of recorded audio and narration enhances the virtual experience, fostering a more immersive and instructive environment for user exploration. Besides that, the 360-degree footage for each scene and supporting assets such as background music were prepared for the development. Fig. 5 shows an example of raw 360-degree video footage on the scene of Skullhouse.

Fig.4: *Examples of Assets.*

In addition to the MRTK, the software utilized for this research comprises Unity3D, Insta360 Stitcher, and Visual Studio 2019. The integration of MRTK and Unity3D supported the development of the application's required functionalities. For example, as shown in Fig. 6, RadialView and FollowMe toggle are components from MRTK, which can be set in the Unity3D environment. The application development was mainly done using Unity3D, a widely used game engine, to accommodate all required files, such as the 360-degree videos, 360-degree images, and 3D objects in the scene, as shown in Fig. 7. Additional scripts,

Fig.5: *Raw Footage of Scene on Skullhouse.*

such as scripts for scene management and caption displays were written using Visual Studio 2019 as the editor and then imported into Unity3D. An example of user interaction implemented was the orientation of 3D scanned objects, which can be changed based on the response received from the user's hand motions. The object interaction and manipulation features, as shown in Fig. 8, were controlled through the setting of features ObjectManipulator, NearInteractionGrabbable, and Box Collider.

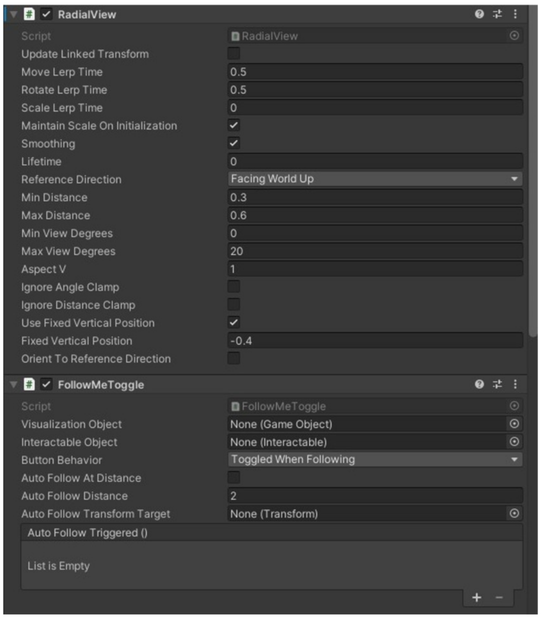

Fig.6: *An Example of MRTK Components Loaded in Unity3D.*

3.5 Testing

Visual Studio 2019 was utilized to compile and deploy the application on HoloLens 2. Upon the development of an application, it undergoes testing to evaluate its existing features and identify any existing problems. According to D. Tresnawati *et al.* [21], Alpha testing is conducted by the development team to find and rectify any flaws or faults in the application. The team performed alpha testing on

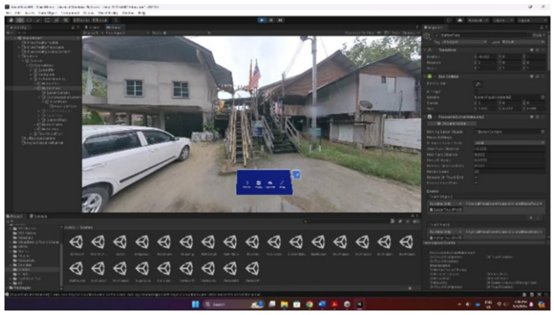

Fig.7: *An Example of 360-degree Video Imported into the Unity3D Environment.*

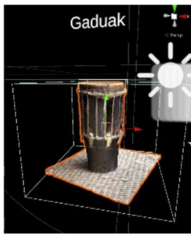

Fig.8: *The Interaction and Manipulation Construction for 3D Object.*

the application deployment and launch, appearance, button functionalities, narrations, music, sound, dialogue pop-ups, and object manipulation. The deployed MR application is then evaluated by a convenience sample of respondents, including students and faculty staff. The data collection was conducted in a university laboratory. The respondents viewed a tutorial video that introduced the HoloLens 2 device and how it is used before the application trial. Data was collected via a questionnaire immediately after the respondents had experienced the MR application. The questionnaire is divided into two sections: Section A seeks demographic profiles; Section B evaluates the MR application on usability and user experience. Respondents rate their evaluation using a 7-point Likert scale, ranging from (1) indicating strongly disagree to (7) strongly agree. The result of the alpha testing and the user evaluation will be addressed in the subsequent section.

4. RESULTS AND DISCUSSION

The Annah Rais MR application is implemented into an actual prototype. The content environment is built using 360-degree videos and images. It is developed based on the two identified content design features: interaction and storytelling. The application successfully implemented the interaction tasks on navigation and selection by presenting users with the menu options illustrated in Fig. 9 and transporting them to the chosen scene. Users can interact with the virtual environment through hand gestures. The main menu serves as the entry point for users to access the various components of the application. It includes selection options to start the Virtual Tour, engage the Explore Mode, access the Hotspring scene, and exit the application. The narrations in the virtual tour represent the narrative of the village as the storytelling component.

Fig. 9: *The Main Menu When the Application Launches.*

The application exhibited the caption of the narrative, as shown in Fig. 10. For example, users will be briefed on the village entrance, offering a realistic first impression, where the modern wood staircases and traditional notched log staircases at Annah Rais Longhouse are unique. As the entrance scene goes on, users can observe another distinctive feature of Annah Rais Longhouse, the bamboo strip flooring used throughout the village, as shown in Fig. 10.

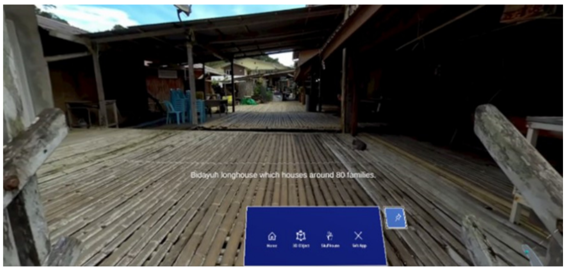

Fig. 10: *The Caption Displayed at Village Entrance Scene.*

The application also implemented the interaction task on navigation and selection in the Explore Mode with a responsive environment. The application enables users to personalize their tour experience by adjusting the scenes at their own pace according to their preferences with the availability of text dialogue pop-up as depicted in Fig. 11. Users can activate the text dialogue pop-up as required. In this case, the dialogue pop-up description serves as the component of the storytelling feature. For instance, users can revisit the Skullhouse scene in the Explore Mode, highlighting Annah Rais Longhouse's cultural landmark. They can review its details and learn about its significance by triggering the dialogue pop-up.

Additionally, the application executed the interaction task on manipulation inside a specially designed scene of interactive 3D instruments, as illustrated in Fig. 12. For example, users can engage with the scanned 3D instrument "gaduak," not just regarding

Fig. 11: *Text Dialogue Pop-up at Skullhouse Scene.*

scale, position, and rotation, but also in terms of the original acoustic response from the instrument.

Fig. 12: *3D Instrument Interaction.*

The Hotspring scene depicted in Fig. 13 exhibits a natural phenomenon resulting from underground water heated by geothermal energy, which emerges at the surface and empties its thermal waters into Sungai Semadang, also called Sungai Sarawak Kiri. Spatial audio is an immersive sound technology that simulates real-world sound behavior by creating a 3D sound experience. The nature sounds at the hot spring area are delivered to users through spatial audio, simulating a real-life auditory experience. The spatial audio enhances depth and realism in the virtual environment, hence augmenting immersion in experiences.

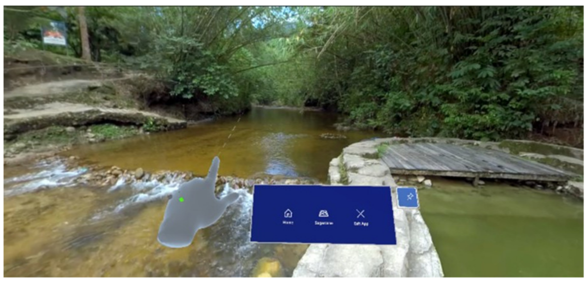

Fig. 13: *The Nature Sound Through Spatial Audio.*

4.1 Results of Alpha Testing

After completing development, the research technical team members executed the application to test its functionality. Eight items were evaluated in the alpha testing. The result of the alpha testing is shown in Table 5. The testing encompasses the deployment of the application onto the HoloLens 2 device and the subsequent launch of the installed application. The testing findings demonstrate that the developed application is installable on the HoloLens 2 device and can be successfully activated by the research team.

Table 5: *Alpha Testing Result.*

No.	Test Class	Test Scenario	Result	Conclusion
1.	Deploying application	Deploying the application onto the HoloLens 2 device.	The application was successfully deployed on the HoloLens 2 device.	Appropriate
2.	Launching application	Launching the application that has been installed on the device.	The application was successfully launched.	Appropriate
3.	Navigation and selection	Pressing the option on Virtual Tour.	The application proceeds to showcase the Virtual Tour scenes. The entrance, skull house, and sugarcane crusher site scenes were automatically loaded and played sequentially. Narrations and captions displayed were played effectively.	Appropriate
4.	Navigation	Pressing the option on Hotspring.	The application continues displaying the Hot Spring scene. The narrations and captions were presented well.	Appropriate
5.	Navigation and selection	Pressing the option on Explore Mode.	The application proceeds to deliver the scenes upon users' selection. The text dialogue pop-ups can be accessed. The music was played successfully.	Appropriate
6.	Navigation and manipulation	Pressing the option on 3D instruments.	The 3D instruments scene was loaded. Users can engage with the 3D instruments, produce corresponding sounds, and adjust their size and orientation.	Appropriate
7.	Navigation	Pressing the option on Exit.	The action of closing the application was successful.	Appropriate
8.	System Control	Pressing the "follow-me" toggle on the menu.	The menu stops following the user around.	Appropriate

Besides that, the testing also involves verifying the implementation of interactions in the application, such as establishing suitable navigation links, functional selection options, reliable manipulation features, and uninterrupted operation of control settings. The selection on the menu functioned correctly. The navigation links for each scene were evaluated and worked properly. The digital content, caption, and narrations are coherent and executed well. The music and sound are appropriately played. The text dialogue pop-ups are accessible. The 3D instruments were loaded successfully and could be manipulated accordingly.

4.2 Results of User Evaluation

41 respondents aged 18 and older participated in the user evaluation. The sample consists of 56.1% females and 43.9% males. The ethnicity distribution of the respondents is shown in Table 6. The Malay ethnic group forms the most significant proportion at 41.5% (17 respondents), followed by the Chinese at 22% (9 respondents). The Bidayuh and Melanau groups represent 14.6% (6 respondents) and 12.2% (5 respondents), respectively. The Iban group constitutes 7.3% (3 respondents), while the Peranakan community is the least represented, comprising only 2.4% (1 respondent).

The quantitative data obtained from the questionnaire is analyzed by using descriptive statistics. The descriptive statistics include frequency, percentage, mean, and standard deviation. The usability aspect

Table 6: *Ethnicity Distribution.*

Ethnic	Frequency	Percent
Bidayuh	6	14.6
Chinese	9	22.0
Iban	3	7.3
Malay	17	41.5
Melanau	5	12.2
Peranakan	1	2.4
Total	41	100.0

is assessed using two constructs: perceived ease of use (PEOU) and perceived usefulness (PU). Furthermore, two additional constructs, perceived interactivity (PI) and telepresence (TP), are employed to evaluate the user experience of the MR application. The items used in the questionnaire are shown in Table 7. The items are derived from validated questionnaires in past related research [33, 34, 35, 36, 37].

Table 8 presents a descriptive analysis of the four constructs. Overall, the respondents exhibited positively towards the usability and experience of the implemented MR application, with mean scores exceeding 5.0 out of 7 and minimal standard deviation values. The constructs of perceived utility and perceived ease of use, with mean values of 6.0569 and 6.0122, respectively, obtained the highest evaluations, suggesting that the system is significantly regarded as effective and user-friendly. The construct regarding perceived interaction, with a mean score of 5.8699, has a slightly lower mean than the preceding two constructs. Nonetheless, it received a comparatively high score, indicating that respondents found interactions within the system satisfactory. The telepresence concept has the lowest mean score and the highest standard deviation, indicating that respondents have varied experiences about their sense of presence or immersion while utilizing the application.

Table 7: *Usability and User Experience Evaluation.*

Construct	Item	Questionnaire
Perceived ease of use (PEOU)	PEOU1	Learning to operate the MR application is easy for me.
	PEOU2	I find it easy to get the MR application to do what I want.
	PEOU3	My interaction with the MR application is clear and understandable.
	PEOU4	Overall, I find the MR application easy to use.
Perceived Usefulness (PU)	PU1	I think the MR application is useful to me.
	PU2	The MR application enables me to get access more quickly.
	PU3	I find the MR application saves me time.
Perceived Interactivity (PI)	PI1	I felt I had complete control over my experiences with the MR application.
	PI2	Gaining information through the MR application was very fast.
	PI3	I think the 3D elements in the MR application were enjoyable.
Telepresence (TP)	TP1	I forgot about my immediate surroundings when I used MR to experience VT.
	TP2	After using this MR application, I felt like I return to the "real world" after a journey.
	TP3	I can fully concentrate while I'm using this MR application.

Motion sickness was not explicitly included as a construct in the questionnaire. But respondents were asked if they experienced discomfort, such as dizziness or nausea, while performing navigation or manipulation tasks. This approach facilitated a more

Table 8: *Descriptive Analysis of Constructs.*

Constructs	Mean Std.	Deviation
Perceived Ease of Use	6.0122	0.82718
Perceived Usefulness	6.0569	0.82967
Perceived Interaction	5.8699	0.67855
Telepresence	5.2683	1.01440

comprehensive evaluation of user discomfort without directly attributing it to motion sickness. Notably, none of the respondents reported experiencing any issues. This finding implies that the developed MR application offers a comfortable user experience, minimizing potential motion-related discomfort during interaction.

4.3 Discussion

The results of this study demonstrate that mixed reality (MR) applications have significant potential to bring about a revolution in the field of virtual tourism by providing immersive user experiences and sustainable tourism solutions. Our results correspond with previous studies that highlight the transformational impact of immersive technology on tourism experiences [30]. In particular, user engagement was improved by the capacity to adapt MR apps to various cultural and geographic contexts, especially in situations where physical travel posed accessibility or sustainability challenges.

This study indicates that the developed MR application facilitates greater engagement than AR applications [13, 14], which enhance the tourist experience through visual stimuli and necessitate physical presence at the sites. This study also demonstrated that MR applications facilitate interaction with real-world environments, providing a more authentic experience compared to VR applications [17, 20], especially if utilizing created 3D virtual environments. Furthermore, this study offers interactions with actual scanned artifacts from the sites, which will help to boost the enthusiasm of tourists.

Despite these encouraging results, the research was subject to some restrictions, including a constrained field of view (FOV), sensitivity to room brightness, and external noise distractions, all of which hampered the quality of the immersive experience. Future studies should explore using advanced MR devices with wider FOVs, improve adaptability to different lighting conditions, and incorporate noise-cancellation features to ensure a seamless user experience. In addition, further insights into user engagement could be obtained through long-term research on the behavioral impact of MR applications in tourism.

Finally, this study adds to the developing area of MR in tourism by offering a scalable and adaptable framework that can be implemented in other sectors, including education and healthcare. The findings highlight the necessity of ongoing innovation in immersive technology to create sustainable, accessible, and engaging virtual experiences.

5. CONCLUSION

The MR application has been successfully developed using appropriate software. The development process involves integrating assets, optimizing the content designed, and ensuring that the application is compatible with the selected hardware. The quality of the content and interactions are two fundamental factors that affect tourists' use of digital devices for virtual tourism. MR technology allows users to experience a blend of the real world and virtual objects. Overall, the MR application is well-accepted in terms of ease of use and usefulness but could benefit from improvements in interaction quality and immersion. Other interactive features, such as voice commands and customized background music, could be incorporated as future works. More advanced analyses could be employed to evaluate the nature of the relationships between the constructs more accurately.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Sarawak Digital Economy Cooperation (SDEC) for the financial support and provision of resources under the Translational Research Grant 2022 (100-TNCPI/PRI 16/6/2 (032/2022)). The authors also thank the Research Management Centre (RMC) Universiti Teknologi MARA for their support throughout the study.

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