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RESEARCH ARTICLE

AR Mobile Application for Enhancing National Museum Heritage Visualization

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ABSTRACT - This study explores the integration of mobile Augmented Reality (AR) applications within the context of the National Museum of Malaysia, focusing on enhancing the educational experience for visitors. The project aims to address the challenge of enhancing museum experiences through innovative technologies. The research problem centers on designing an AR application for the National Museum of Malaysia to enrich the visitor engagement and understanding, as stemmed from the decline in museum visitors, with the National Museum of Malaysia experiencing a staggering 70% drop in income in 2020 and 2021. Utilizing Unity Editor and other libraries, the project developed the National Museum AR App, featuring four distinct AR experiences corresponding to different exhibits within the museum. Methods involve AR content creation, user testing, and data analysis. Overall, findings suggest that the AR application effectively meets visitors' learning needs and enhances the educational value of museum exhibits by providing unique AR features. The significance of the project lies in its potential to transform cultural heritage tourism by bridging the gap between traditional museum experiences and digital engagement. The study also serves as a preliminary investigation to guide the future development and deployment of AR applications within the museum setting.

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1.0 INTRODUCTION

Cultures, communities, and histories are often preserved and showcased through museums, allowing visitors to engage with the rich heritage of a nation. Museums serve as valuable educational institutions, offering deep insights into a country's historical matters [1]. However, like many cultural institutions worldwide, the National Museum of Malaysia faced unprecedented challenges during the COVID-19 pandemic. According to the Visitor Figures 2021 annual survey conducted by the Art Newspaper, the number of visitors to the world's most famous art museums fell by 77% in 2020 compared to 2019 [2]. The biggest museum in Malaysia, the National Museum, also suffered a drop in income by over 70% due to a lack of visitors, highlighting the need for museums to develop a digital strategy to maintain their connection with visitors [3]. A survey conducted in Italy in 2020, with around 7,000 participants, revealed that 91% of respondents acknowledged the necessity for museums to continue offering new digital content even after reopening [4]. This collective sentiment underscores museums' need to develop a digital strategy, utilizing digital resources to share the culture globally. Museums around the world found themselves compelled to shut down during the COVID-19 pandemic, which caused severe financial impact [5]. The pandemic has underscored the significance of digital resources in maintaining cultural engagement and embracing digital acceleration in the museum sector. Studies from Croatia and Greece also emphasize the importance of museums embracing digital acceleration to ensure continued engagement with audiences after the COVID-19 pandemic happened [6, 7]. In Croatia, half of the museums were active online during the pandemic, with social media being a commonly used platform. Similarly, Greek museums experienced positive and negative effects from the pandemic, with digital technology proving useful in maintaining cultural engagement.

However, while digital technology offers benefits in terms of accessibility and user experience, it cannot fully replace the live interaction and immersion provided by physical visits [7]. Instead, the emphasis should be on leveraging digital tools to complement and enhance traditional museum experiences [8]. Therefore, while digitalization is crucial for promoting cultural heritage and ensuring accessibility, it should complement rather than replace in-person experiences. This research explores methods to implement digital visualization of museum exhibits, utilizing digital tools to promote cultural heritage while preserving the unique experience of visiting museums in person.

To ensure the recovery of the tourism and culture sectors from the effects of the COVID-19 pandemic and to continue serving historical values, it is crucial to enhance the museum tourism experience and encourage the public to visit the National Museum as soon as possible. As the Malaysia Tourism, Arts, and Culture Minister Datuk Seri Nancy Shukri said, her ministry intends to ensure that the museum industry recovers by holding exhibitions and the ministry's slogan, "Coming Back Stronger" [9]. Meanwhile, previous researchers also suggest that the existing cultural museums in Malaysia can enhance visitor satisfaction and engagement by incorporating more activity and workshop [10]. It is being proven that museums can better cater to visitors' needs for a more engaging and restorative experience by enhancing interactivity.

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AR has emerged as a groundbreaking tool with the potential to revolutionize the way we experience and engage with our surroundings. By superimposing digital elements onto the physical environment, AR enables visualizing virtual objects within the real world. AR's effectiveness is due to its use of detected environmental features to integrate virtual objects with shadows, physics, and occlusion to create a seamless integration with the natural world [11]. This technology combines computer-generated graphics, audio, and other sensory inputs to provide an immersive and interactive experience. It provides an immersive and interactive experience, which has shown promising results in enhancing learning in various contexts, including museum tourism experiences [12]. For example, the previous study demonstrated how AR can improve learning abilities and offer an alternative solution to conventional learning methods. This finding extends beyond traditional educational contexts to encompass museum tourism experiences. The output applies to the context of the National Museum, as one of the objectives of the National Museum is to utilize historical artifacts to educate communities on identity building and the national development of Malaysia [13].

At the same time, tourists seek unique and enriching experiences that go beyond traditional guidebooks and static information displays. The concept of “Intelligent Tourism” was introduced by Kontogianni et al., which can be characterized as a progression of conventional tourism to modern technology that evolved continuously [14]. Hence, the approaches to implementing digitization on museum exhibits and historical sites have become a popular trend in the field of heritage visualization [15]. From the aspect of tourism industry view, by offering extensive and specialized marketing opportunities, digitalization benefits the tourism sector and encourages the development of new mediums of distribution for historical events to tourists, such as Extended Reality technology (consisting of Augmented, Virtual, and Mixed Reality) and more [16]. Previous researchers also encourage the developers and studies to delve deeper into exploring digital tools and technologies to participate in crafting interactive exhibitions [17]. By leveraging AR technology, the proposed AR application aims to offer an immersive and interactive experience, arousing visitors' enthusiasm and providing a more immersive observation of the heritage [18].

The proposed AR application is expected to showcase tangible and intangible benefits to the cultural heritage preservation sector by leveraging AR technology. The benefits proven to exist by previous research such as increased visitor engagement, increased revenue, positive reviews and attitude, and educational impact [19, 20, 21, 22]. By offering an interactive and immersive experience, the application aims to attract more museum visitors, encourage extended visits, and word-of-mouth publicity. Additionally, it is an innovative educational tool, making history and culture more accessible and exciting for students and learners of all ages. The goal is to rejuvenate tourism, engage visitors, and preserve cultural heritage through digital visualization.

In response to this, the primary objective of this study is to design and evaluate an AR mobile application that seamlessly integrates with the National Museum's exhibits. By incorporating virtual content, interactive 3D models, and informative multimedia content, the application aims to enhance visitor engagement and provide a deeper understanding of Malaysia's cultural heritage. At the later stage of the research, the authors will focus on analyzing and implementing the impact of AR technology on the heritage visualization for the National Museum, evaluating the study's significance in the context of cultural heritage visualization. The key contributions of this work are summarized as follows:

- Investigate the effectiveness of AR technology in enhancing visitors’ understanding of historical and cultural context in Malaysia.
- Develop an AR mobile application that integrates real-time information, interactive virtual content, and immersive animations to provide visitors with engaging experiences.
- Evaluate the impact of AR applications on visitors’ overall satisfaction and engagement.

This research aims to contribute to the growing knowledge of AR technology in cultural heritage preservation and museum experiences by achieving these objectives. The findings of this study will provide valuable insights for the National Museum of Malaysia and other cultural institutions interested in implementing AR applications to enhance visitor experiences.

The remainder of this paper is organized as follows: Section 2 highlights related work on various aspects of AR. Section 3 presents the methodology based on Research and Development (R&D). Section 4 discusses the application's development results and testing phase and provides an analysis. Finally, Section 5 presents the discussion of limitations encountered and the conclusion.

2.0 RELATED WORKS

AR, or Augmented Reality, is a technology that overlays virtual information or digital content onto the real world, enhancing the user's perception and interaction with their environment [23]. This technology combines computer-generated graphics, audio, and other sensory inputs to provide an immersive and interactive experience. This is typically achieved through AR-enabled devices like smartphones, tablets, AR glasses, or headsets. According to Ronald Azuma, a notable researcher in computer graphics and augmented reality, the foundational understanding of AR involves computer displays that overlay virtual content onto a real-world view. The primary objective of AR is to enhance the user's experience by seamlessly integrating virtual elements with the physical world. Azuma's definition emphasizes the integration of real and virtual worlds, their alignment, and real-time interaction [24]. The AR technology applications are

vast and continue to expand across various domains. Industries like healthcare, architecture, education, and manufacturing have embraced AR for training, design, and maintenance purposes, enhancing efficiency and accuracy [25, 26, 27].

Several types of AR systems exist, each with unique characteristics and applications. These include Marker-based AR, Markerless AR, Projection-based AR, Superimposition-based AR, Outlining-based AR, and Location-based AR [28]. In the context of the AR App developed in this study, the selection of Marker-Based and Markerless AR technologies was based on their compatibility with the museum's exhibits and visitor experience. Marker-based AR is an approach that heavily utilizes image recognition [29]. The display of computer-generated content is triggered by a camera and a visual marker [30], which can be categorized into non-figurative markers, such as a QR code, or figurative markers, such as a piece of the printed static image. Marker-based AR is typically chosen for the accuracy and efficiency in analyzing content that contains too much information. The low computation requirements on how a marker-based AR is tracked make it suitable for use on almost every mobile device regardless of the model, brand, operating system, and more [31]. However, the implementation of a visual marker restricts the flexibility of the AR system because it requires a highly accurate camera sensor for the user to identify the marker [32]. Conversely, markerless AR is a form of augmented reality that displays computer-generated content without the need for a visual marker [33, 34]. Instead, it uses computer vision algorithms to identify and follow surfaces and objects in the real world. It does not rely on any specific image to display the content so it can be used in nearly any location and setting. In e-commerce, markerless AR allows customers to view products in their physical space before purchasing, providing a personalized and accurate representation of 3D objects [35], using Simultaneous Localization and Mapping (SLAM) to visualize building structures without the need for printed markers [36]. However, compared to marker-based AR, it does rely on computer vision algorithms that may only sometimes be accurate enough to track real-world surfaces, which also requires higher computational power. By leveraging Marker-Based and Markerless AR technologies, the AR app aims to cater to diverse exhibit types and visitor preferences within the National Museum of Malaysia.

In exploring the landscape of AR applications within cultural institutions, previous studies have shed light on the potential and challenges of integrating digital technology into museum settings. Li et al. researched the development of 3D virtual museums, emphasizing the importance of distance-driven user interfaces (DUI) to facilitate collaborative exhibit viewing [37]. Their findings underscored the need for user-centric design approaches to enhance engagement and accessibility within museum environments. Similarly, Ferretti and Quattrini investigated using digital data and virtual reality (VR) technology to enhance tourist experiences at cultural heritage sites. Their study highlighted the immersive and interactive nature of VR experiences, which contribute to a deeper understanding and appreciation of historical artifacts and landmarks [38].

Based on the interviews conducted by E.E. Cranmer et al. with fifteen tourism experts, the study found that AR has the potential to create value for the tourism industry in various ways, such as enhancing the tourist experience, increasing revenue, and improving marketing effort [39]. This finding can be further supported by other research projects, including the user study by M. Noreikis et al., where the paper involved 176 participants who visited the "Heureka" Science Centre in autumn 2018. After the participants had experienced the gamified AR app provided, ARQuiz, the visitors enjoyed the exhibition more and felt more social after visiting the exhibition. The results indicate that a well-designed AR game can boost the overall satisfaction of an exhibition visit and increase players' sociability [40]. Besides, the research shows that the AR's interactive nature has provided a compact and stable mobile experience that is both engaging and minimally intrusive to the art gallery experience. The application loads relevant models onto the painting in the world space, allowing users to directly interact with the model and get information about the painting. The results of the project showed that the participants found the application to be engaging and informative and that it added an extra layer of interaction to the art gallery experience [41].

The research, preservation, dissemination, and presentation of cultural heritage data all include the use of various visual media, such as 3D models, images, videos, and technologies for the visualization of that heritage [42]. Cultural heritage visualization aims to preserve historic structures by constructing photorealistic 3D models and evaluating how visible the heritage elements are regarding tourist exposure. In line with this, research conducted on the e-Tracer AR Application, designed for a Silversmithing museum in Greece, underscores the effectiveness of AR technology in enhancing historical learning experiences. By incorporating gamification and educational elements within the museum setting, the e-Tracer Application successfully enhances visitors' on-the-spot experiences, leading to a better understanding of historical events depicted in the exhibits [43].

In recent scholarly discourse, the application of AR technology in the domain of cultural heritage preservation and enhanced museum experiences has garnered significant attention. Through a systematic review, the paper underscores the transformative potential of AR in rendering cultural artifacts and heritage sites more accessible and engaging to the public [44]. Meanwhile, the study by Boboc et al. through a rigorous analysis of documents collected from databases (n = 1201) underscores the significant impact of AR in enhancing the cultural heritage sector by improving accessibility, engagement, and the educational value of cultural artifacts and sites. The authors advocate for future research to focus on developing more efficient real-time digitization techniques and user-friendly AR applications that accommodate diverse technical skills [45]. Previous researchers also suggest further development to support location-based information access, which can enrich the tourist experience by providing critical information and increasing awareness of the destination. To enhance

outdoor AR experiences, they advocate for improving hybrid tracking approaches that combine marker-less monitoring with mobile device sensors [46].

3.0 METHODS AND MATERIAL

This section outlines the methods employed in developing and evaluating the National Museum AR App in several sub-sections through research and development (R&D). The development process involved several key stages, beginning with a thorough analysis of the project requirements and objectives, with the preliminary study conducted. Following this, the appropriate software tools and platforms were selected for application development. These tools were chosen based on their suitability for creating marker-based and markerless AR applications. After that, the AR contents for the National Museum AR App are created accordingly, focusing on showcasing various historical artifacts and exhibits in a visually engaging and informative manner. Last, prototype testing was conducted to test the application developed using unit and user access acceptance testing methods. The data and feedback collected from the participants will be analyzed to evaluate whether the application successfully fulfills the research's objectives. Figure 1 shows the flowchart for the overall research methodology in this study.

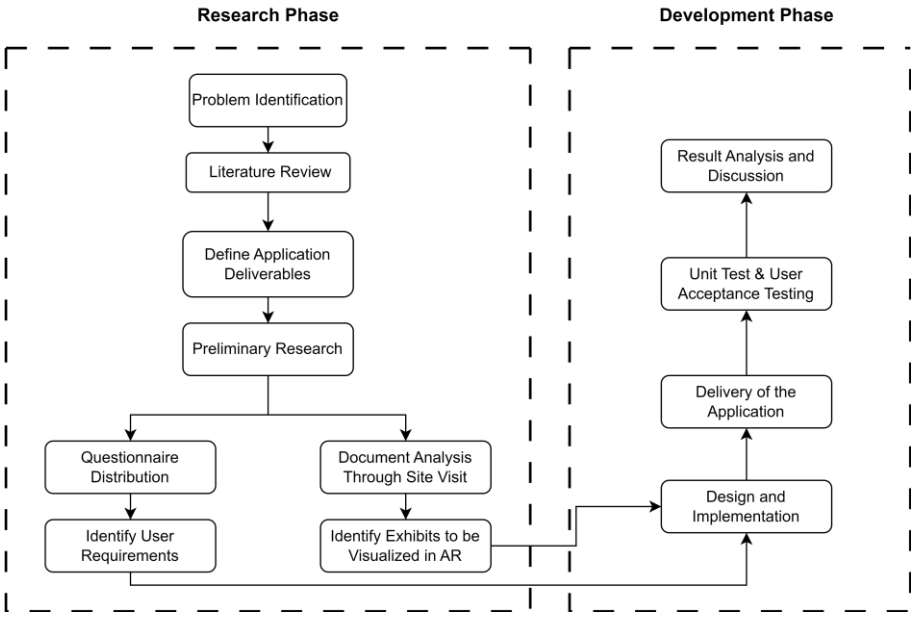

Figure 1. Research Methodology Flowchart

3.1 Preliminary Study – Online Questionnaire

The preliminary study was a crucial first step in understanding user preferences and requirements for the development of the National Museum AR Application. The research team conducted an online questionnaire survey to gather feedback from a diverse set of potential users. The survey questionnaire consisted of a total of 23 questions, encompassing various question formats, including closed questions such as list-based inquiries, rating questions employing a Likert scale ranging from 1 to 5, and other types. Given the intention to collect generalized and non-specific data from a diverse range of potential users, there were no predefined criteria, such as age, limiting the selection of respondents. Instead, the researchers utilized a stratified sampling approach, where the participants were segmented into different groups to enable the collection of diverse feedback for subsequent analysis [47]. For example, respondents might have different preferences regarding AR functionalities or user interface styles based on their gender and age. This technique allowed the researchers to gather opinions and intentions that were essential for creating an AR experience that resonates with museum visitors from different backgrounds.

In total, the researchers received 50 responses from participants with varied demographic profiles, as shown in Table 1. The respondents included individuals from the 18-24, 25-34, and 35-44 age groups, with a balanced gender representation of 56% male and 44% female. The participants' educational qualifications ranged from high school to master's degree and Ph.D. levels. Additionally, 58% of the respondents had previous experience visiting the National Museum, while 84% had prior exposure to AR technology.

Table 1. Respondents' demographic profile for the online questionnaire

Demographic Profile	Frequency	Percentage
Age		
18-24	43	86%
25-34	4	8%

35-44	3	6%
Gender		
Male	28	56%
Female	22	44%
Educational Qualification		
High School or lesser	8	16%
Pre-U (Diploma, Foundation, etc.)	20	40%
Bachelor's Degree	19	38%
Master's Degree	1	2%
Ph.D.	2	4%
Visited National Museum before		
Yes	29	58%
No	21	21%
Experienced AR before		
Yes	42	84%
No	8	16%

Several significant findings emerged from the analysis of the questionnaire responses, directly informing the design of the AR application:

- The presentation of artifacts and historical objects was identified as the critical factor contributing to a positive impression of the National Museum, with 68% of respondents highlighting this aspect. This finding suggested a need to implement visually appealing and well-presented exhibits in the AR application.
- Only 16% of respondents agreed that the interactivity and engagement were well-implemented during their museum visits, indicating potential areas for enhancement through the incorporation of AR features.
- A strong interest in technology-enhanced experiences was evident, with 86% of respondents identifying it as a factor that would encourage future visits to the museum. This underscored the importance of integrating interactive and immersive AR elements into the application.
- Overwhelmingly, 80% of respondents expressed a preference for the AR app to provide additional content and information beyond what is available in traditional exhibit information boards. This highlighted the need to incorporate supplementary digital content and multimedia experiences to enrich the visitor's understanding of the museum's exhibits.

Table 2 shows the questions related to the responses received. The detailed findings from the preliminary study provided valuable insights that directly informed the design and development of the National Museum AR Application. By understanding user preferences and pain points, the research team aims to tailor the AR features and content to meet the target audience's needs.

Table 2. Significant findings from online questionnaire conducted

No.	Question	Percentage	
		Yes (%)	No (%)
1.	What specific aspects of the National Museum contributed positively to your overall impression?		
	Quality and diversity of exhibits	46	54
	Presentation of artifacts and historical objects	68	32
	Well-implemented interactivity and engagement	16	84
	Informational content and descriptions	56	44
	Interesting cultural events and activities	46	54
2.	What factors would influence your decision and encourage you to visit the museum in the future?		
	Enhanced use of technology, such as AR features	86	14
	Interactive applications for exploring cultural exhibits	66	34
	New types of exhibits or collections	52	48
	Positive reviews from other sources	18	82

	Improved accessibility and convenience	28	72
3.	Would you prefer the AR app to provide additional content and information beyond what is available on the traditional exhibit information board?	80	20

3.2 Preliminary Study – Document Analysis

In addition to the online questionnaire, the research team conducted a document analysis by visiting the National Museum of Malaysia located in Kuala Lumpur. The purpose of this site visit was to capture detailed information about the museum's exhibits, including visual documentation, text on information boards, and the overall exhibition format.

During the site visit, the researchers systematically documented the selected exhibits using a camera to record images and video footage. The exhibits chosen for this analysis were:

a) The Royal Throne of Perak (Singgahsana Kesultanan Perak) as shown in Figure 2(a).

b) Tin Mining (Bijih Timah) as shown in Figure 2(b).

c) Baju Melayu in Hari Raya Aldilfitri as shown in Figure 2(c).

d) Centre Gallery as shown in Figure 2(d).

Figure 2(a, b, c, d). The photo collection of the exhibits selected

The researchers thoroughly examined and recorded the presentation methods, spatial arrangements, and contextual information for each of these exhibits. This detailed documentation allowed the team to gain a deeper understanding of the museum's exhibit design and the opportunities for integrating AR technology to enhance the visitor experience.

Table 3 presents the findings from the document analysis, outlining the specific information gathered for each exhibit and the corresponding AR visualization approaches that were considered for the application development.

Table 3. Document analysis of the exhibits selected

Exhibit Name	Information	Located at	AR Visualization Approach
The Royal Throne of Perak	The exhibit is enclosed by a protective barrier that limits visitor access.	Gallery B	Implement an AR Portal feature that would allow users to virtually step into a digital recreation of the throne room and explore the exhibit in greater detail.
Tin Mining	The tin exhibit is situated beneath a corridor, featuring a transparent display with a glass floor.	Gallery C	Implement an AR Historical Diorama that would enable users to observe the historical events and processes of tin mining through a window-like virtual display.
Baju Melayu	The exhibit comprises traditional costumes and props related to Hari Raya Aldilfitri in glass showcases.	Gallery D	Implement an AR Coloring that would allow users to digitally customize the appearance of the Baju Melayu garment in real-time.
Centre Gallery	The interior look of the National Museum of Malaysia holds temporary exhibitions.	Lobby (Centre Gallery)	Implement an AR Video Player that would enable users to access a montage video presentation highlighting the National Museum's history and significance.

3.3 Design

In the design phase of the National Museum AR App, the research team carefully selected the appropriate software tools and platforms to ensure the effective development of the AR experiences.

Unity was chosen as the primary game engine for the project, as it offers seamless integration with the AR Foundation package. This provided cross-platform development capabilities, simplifying the creation of interactive AR experiences

compatible with both Android and iOS devices. The integration of the Vuforia Engine within Unity further enhanced the application's AR functionalities, facilitating the development of marker-based AR experiences. The use of C# as the main programming language allowed the researchers to leverage Unity's extensive capabilities and customization options, enabling them to create highly interactive and responsive AR features. In addition to the game engine and programming language, the team utilized Blender for the creation of detailed 3D models of artifacts, exhibits, and interactive objects within the museum. Blender's comprehensive 3D pipeline, including features such as sculpting, texturing, rigging, and UV unwrapping, enabled the researchers to develop high-quality 3D assets that could be seamlessly integrated into the Unity-based AR application.

The implementation and structure of the application were outlined, focusing on the key features representing four galleries within the National Museum: A markerless AR portal showcasing the Royal Throne of Perak, allowing users to virtually step into a digital recreation of the exhibit space in Gallery B, marker-based AR Historical Diorama depicting scenes of economic events during the colonial era such as tin mining in Gallery C, an AR Coloring feature enabling users to digitally paint traditional Malay attire on a physical marker, with the changes reflected in real-time on an AR avatar in Gallery D, and an AR Video Player presenting the history of the National Museum through a montage video in Centre Gallery.

3.4 Conceptual Framework for AR Content Generation

The processes of AR content generation for each AR content are being developed based on the block diagrams of the framework design below.

a) AR Portal Flow Chart.

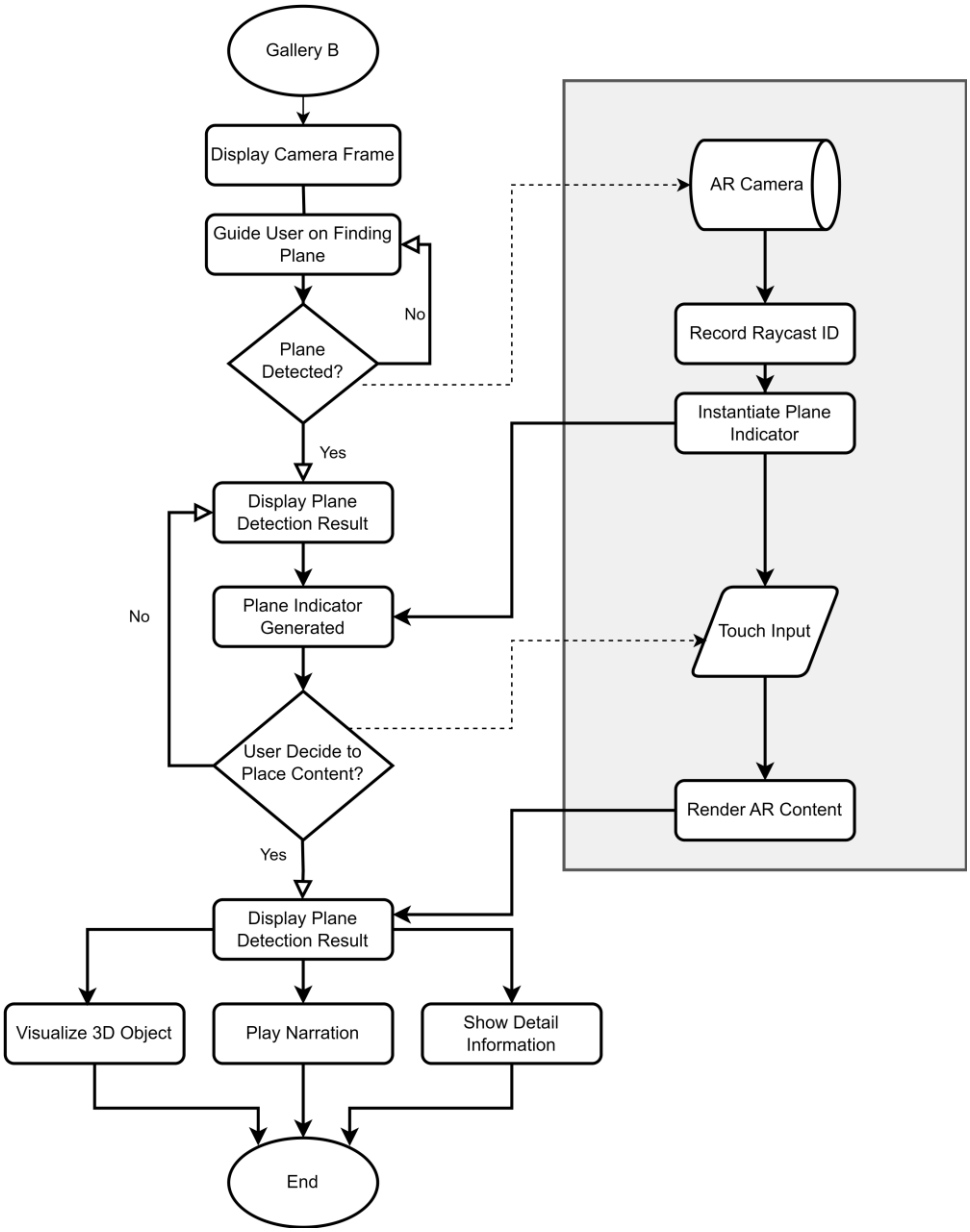

Figure 3. Flow Chart of the AR Portal

In the conceptual framework for the AR Portal feature, as shown in Figure 3, the device camera will initiate upon a user entering the Gallery B category, displaying a camera frame to indicate activation. Subsequently, the ARFoundation library will be utilized to continuously detect planes in the environment. Upon successful plane detection, a plane placement indicator will be displayed on the screen, delineating areas suitable for AR content placement. Following user input, such as a tap on the screen, the indexed AR content will be rendered and visualized in the designated area. This will result in the display of 3D objects positioned on the detected plane, accompanied by corresponding narration and exhibit descriptions based on the index.

b) AR Portal Flow Chart.

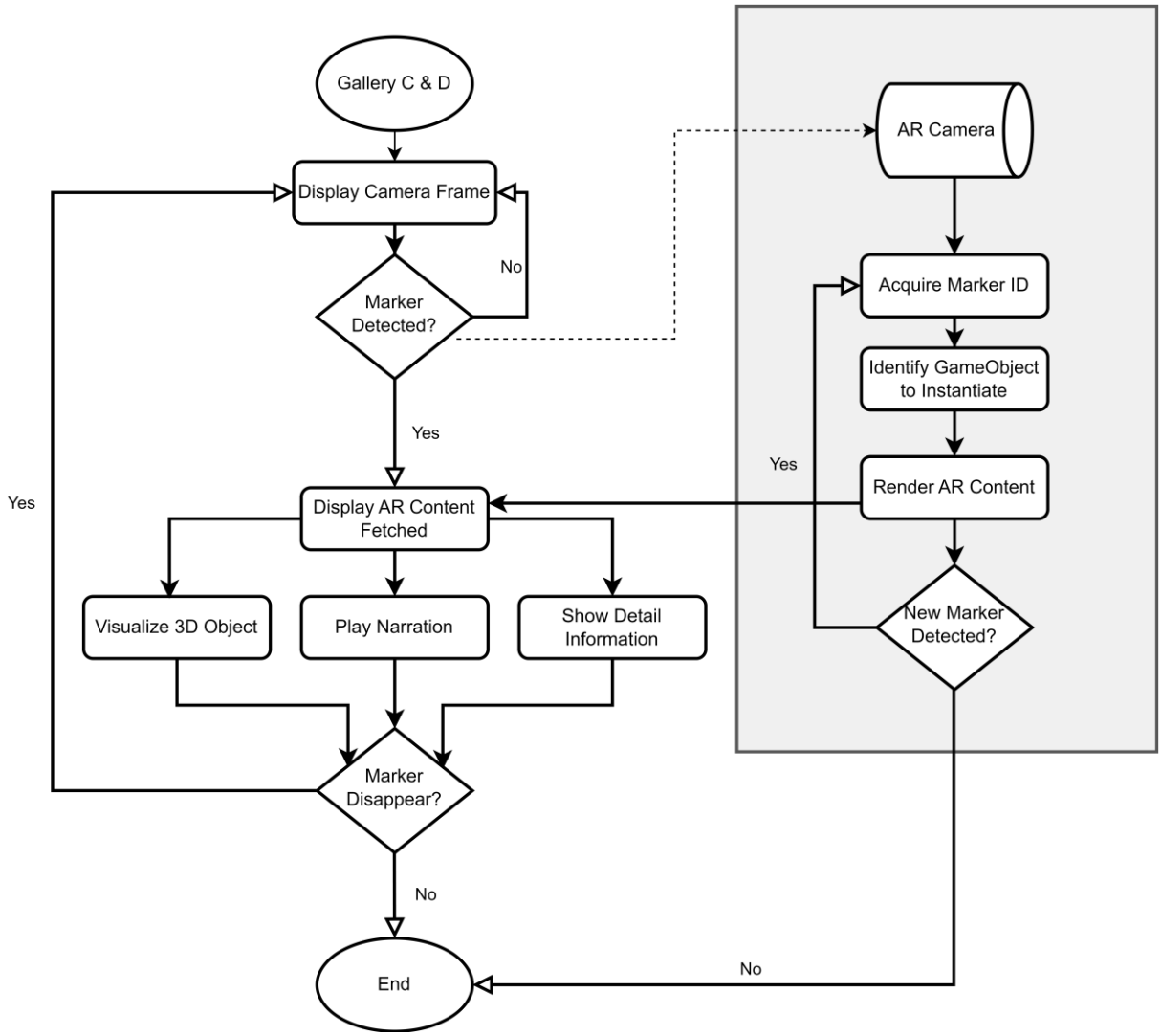

Figure 4. Flow Chart of the AR Coloring and AR Historical Diorama

Meanwhile, the AR Coloring and Historical Diorama's conceptual design shown in Figure 4 begins with the camera's activation, which displays a camera frame to indicate its functionality. The camera will continuously detect predefined image markers stored within the Vuforia Engine database. Upon detection of an image marker, the camera will identify its marker ID and determine which GameObject to instantiate and render. Like the AR Portal flowchart, the visualized 3D object, narration, and exhibit descriptions will be displayed. If the user moves the camera to focus on a new marker, detecting the marker ID will be initiated again to identify it, and new AR content will be rendered based on the index. Only one content will be rendered at a time. Users can then interact with the rendered content, such as applying color to the image marker for AR coloring, with changes reflected in real-time on the rendered AR content texture.

c) AR Video Player Flow Chart.

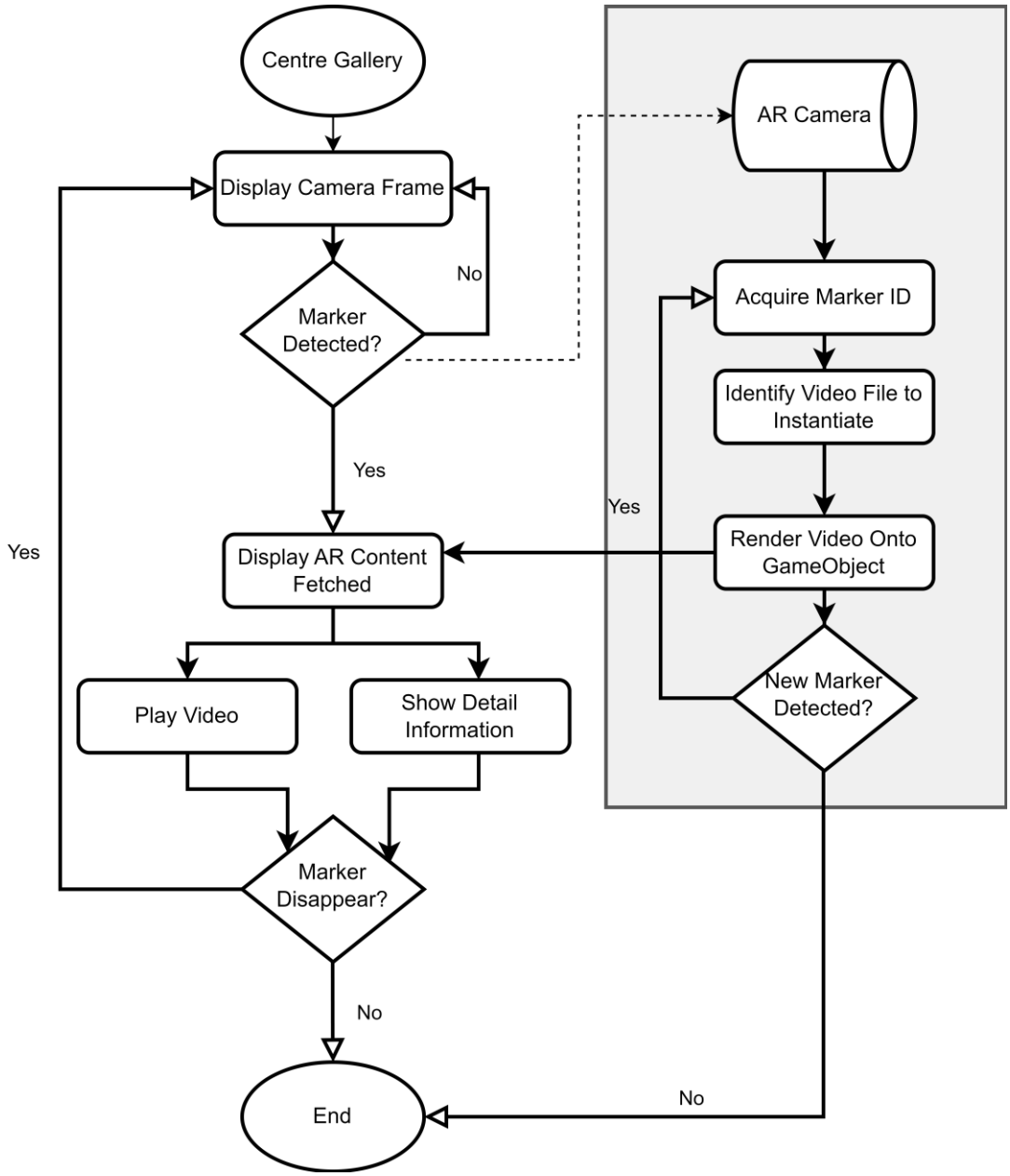

Figure 5. Flow Chart of the AR Video Player

The process closely mirrors the previous one for the conceptual design of the AR Video Player as shown in Figure 5. However, in this case, a GameObject representing the video player is added to the scene, and the video is rendered within it upon detection of the image marker.

3.4 Implementation

The development of the National Museum AR Application involved a multi-faceted implementation process, drawing upon the various software tools and techniques selected during the design preparation phase.

The 3D models and animation clips were created using Blender, an open-source 3D modeling software. This included the development of the 3D model for the Royal Throne of Perak, an animated 3D avatar for the AR Coloring feature, and an animated 3D model of a tin mining worker for the AR Historical Diorama. The wireframe and rendered version of the model is shown in Figure 6. The researchers ensured that these 3D assets were high-quality and visually appealing to enhance the overall user experience. The tin mining worker animation rigging was done using Blender's built-in rigging system, with the team adding an inverse kinetic bone for the knee and foot to animate the crouch position accurately, as shown in Figure 7.

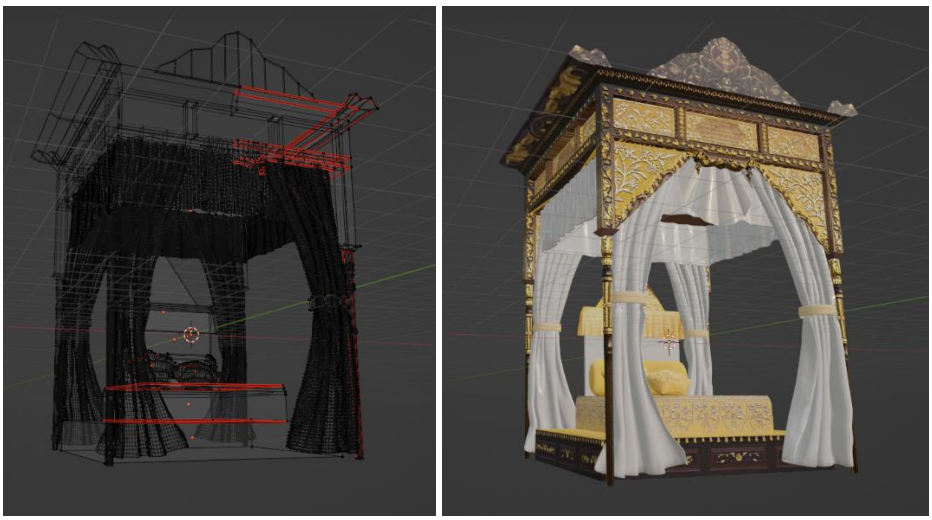

Figure 6(a, b). The wireframe view and rendered view of the 3D models

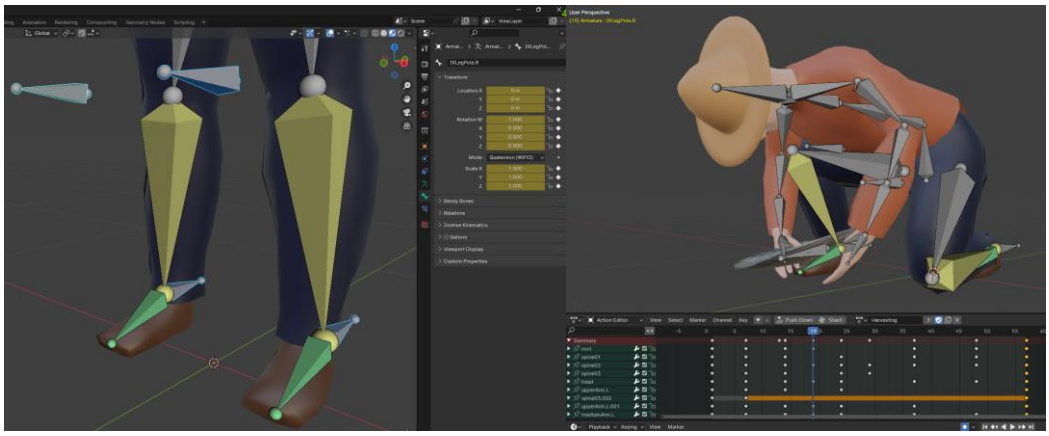

Figure 7(a, b). The animation was created for tin mining workers, to be imported inside the AR Historical Diorama scene

After creating the 3D models, the team focused on preparing them for integration into the Unity-based AR application. The base version was rendered and then transferred to Adobe Photoshop. In Adobe Photoshop, the outline of the image was refined to prepare it for use as a coloring page. The image texture is transferred to the Blender software and used for UV Mapping for the 3D avatar. The procedure required configuration as every vertex created needed to move to an accurate position for reflecting the color applied to the AR coloring page later, as shown in Figure 8.

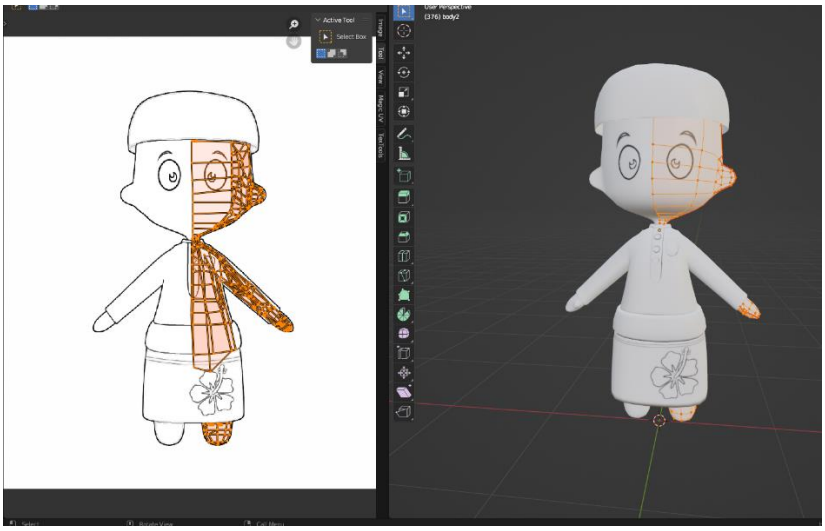

Figure 8. The material preview of the 3D avatar used in AR Coloring after UV Unwrapping

The game engine chosen for developing the proposed system mentioned above, Unity Editor, is being utilized with the implementation of the AR Foundation package and Vuforia Engine. Unity provides a common API for both ARCore and ARKit, the development of cross-platform AR applications has been simplified as it unifies Android and iOS

platform-specific intricacies. Additionally, Unity integrates with Vuforia Engine, which provides features that align with the requirements of the proposed system to create an interactive and immersive AR experience. Besides, the Universal Render Pipeline (URP) in Unity Editor is used to streamline the integration of various assets into the project and create advanced graphics and visual effects using Shader Graph. C# was chosen as the main programming language for developing the National Museum AR App because it is fully compatible with Unity Editor.

For the marker-based AR features, such as the AR Historical Diorama and AR Video Player, the team designed custom image markers using Adobe Photoshop. Upon the unique characteristic of each marker image, a frame is added to all markers for better readability which eases the process of detecting the marker on the device. These markers were then uploaded to the Vuforia Developer Portal, where the platform generated binary images with feature point computations, enabling the AR application to accurately identify and track the markers during runtime, as shown in Figure 9. The markers are now available to be used inside any AR scene.

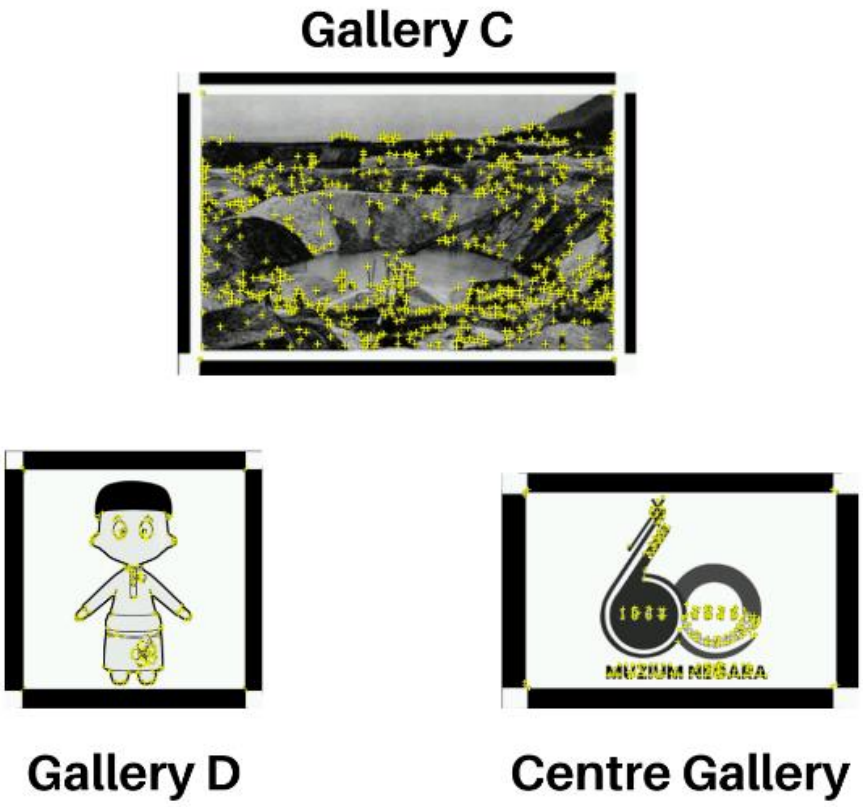

Figure 9. The result of image markers generated with feature points after uploaded to the Vuforia Developer Portal

The implementation of the markerless AR Portal feature utilized the AR Foundation libraries within Unity. AR Foundation offers a universal API for AR functionalities like camera tracking, plane detection, and interaction in Unity Editor. The plane detection allows the application to identify horizontal and vertical surfaces in real-world settings and, hence, superimpose the AR content to the physical environment, which creates a portal effect through the usage of the device camera. A custom shader is applied to specific meshes inside the prefab to control visibility, ensuring that certain areas remain hidden until the player walks into the portal. Additionally, a plane mesh is placed on the door to maintain visibility when the user looks through before walking into it. A custom C# script is attached to the AR Session Origin to detect planes in the AR environment and spawn the portal prefab at the detected position upon user interaction. This script also ensures the portal is oriented to face the camera and maintains its position in the AR world as a child of an anchor. Lastly, collision detection between the user and the portal door is implemented using colliders and kinematic rigid bodies attached to the AR Camera. Another C# script modifies the stencil value of meshes with the shader, which means hiding certain areas' visibility upon collision, making the previously hidden content visible to the user. Figure 10 shows the outcome of the AR portal feature developed.

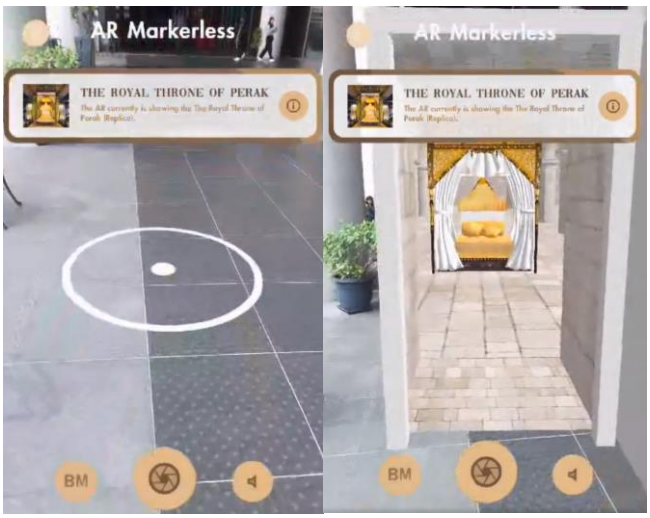

Figure 10. After the plane detection is finished, the AR Portal can be placed on any detected area

Meanwhile, The AR Coloring feature in Gallery D involves real-time capture of the video background rendered from the device camera onto the AR avatar material, which is UV unwrapped and mapped to the corresponding coloring page in Blender. Firstly, the AR avatar material mapping is facilitated by importing the 3D model into the Unity scene and ensuring correct material assignment. A C# script is attached to relevant meshes, capturing the rendered image from the AR camera and applying it as the texture to enable dynamic texture changes. Additionally, the script defines the area of the coloring page and is attached to a plane mesh positioned on the location of the coloring page image marker. This script handles real-time capture of the coloring page area using the render camera, updating the material texture based on user modifications on the physical coloring page image marker. Figure 11 shows the outcome of how the AR Coloring feature works.

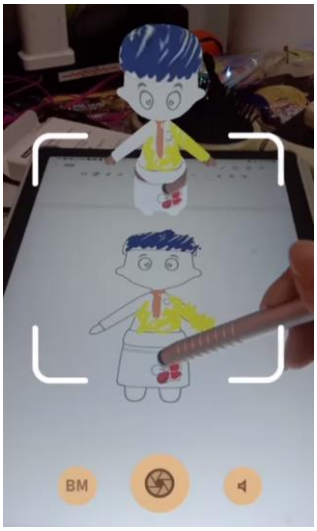

Figure 11. When the user applies colors to the marker, the marker with the customized look will be mapped to the texture of the AR avatar in real-time

4.0 RESULTS AND DISCUSSION

4.1 Delivery of the Application

The National Museum AR Application, developed by the National Museum, offers users access to four distinct galleries, each featuring unique AR content and experiences. To operate the application, users begin by selecting a gallery from the main menu. Upon selection, the app prompts the user to point their device's camera at a predefined marker or a flat surface to detect a plane for markerless operation.

In Gallery B, which showcases the Malay Kingdoms, users can access an AR Portal by pointing their device's camera at the floor and initiating the plane detection process. Once a suitable plane is detected, the user can tap on the screen to spawn the AR Portal. This markerless AR feature allows users to virtually step into a digital recreation of the Royal Throne of Perak exhibit, providing an immersive and up-close exploration of the artifact as shown in Figure 12.

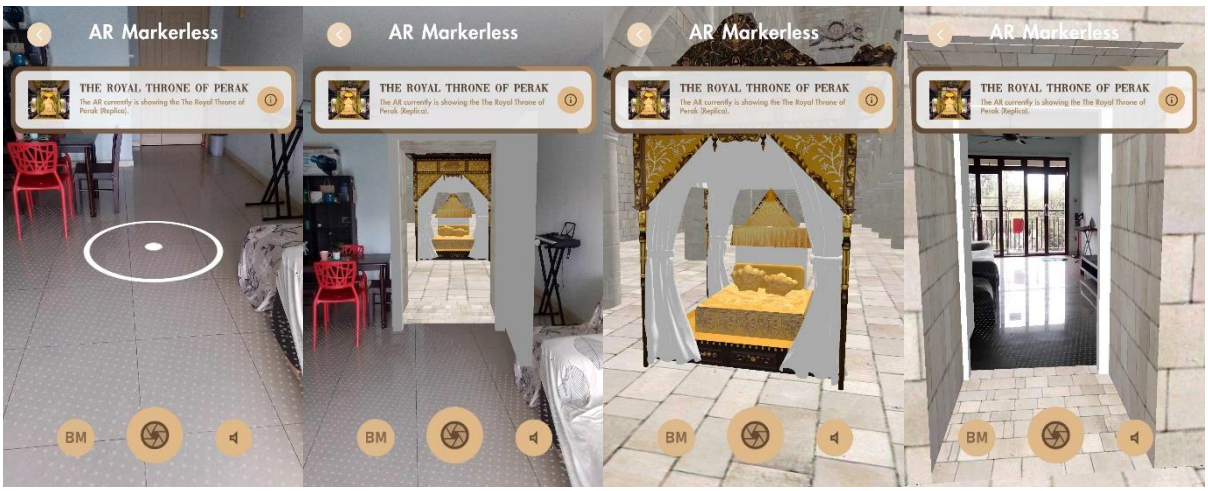

Figure 12. The user can physically walk into and out of the portal door while holding their device camera

Gallery C, representing the Colonial Era, features marker-based AR portals that depict scenes of economic activities, such as tin mining. Users can point their device's camera at the designated image markers to trigger the AR content, which includes interactive 3D models and animations showcasing the historical events that are shown in Figure 13. Additionally, Figure 14 shows the screenshot for both Galley D and Centre Gallery. The AR Coloring feature in Gallery D, highlighting Malaysia Today, enables users to engage with a marker-based AR experience. With customized texture updates displayed by pointing the camera at a coloring page marker, users can digitally paint the traditional Malay attire on an AR avatar in real-time. Finally, the Centre Gallery showcases an AR Video Player that plays a montage video highlighting the history and significance of the National Museum. Users can access this feature by focusing their device's camera on the corresponding image marker. Throughout the AR experiences, users can access additional information, such as descriptions and narrations, by tapping on the informational panels associated with the virtual exhibits. The user can also screenshot the current AR content and save it to their device’s image gallery.

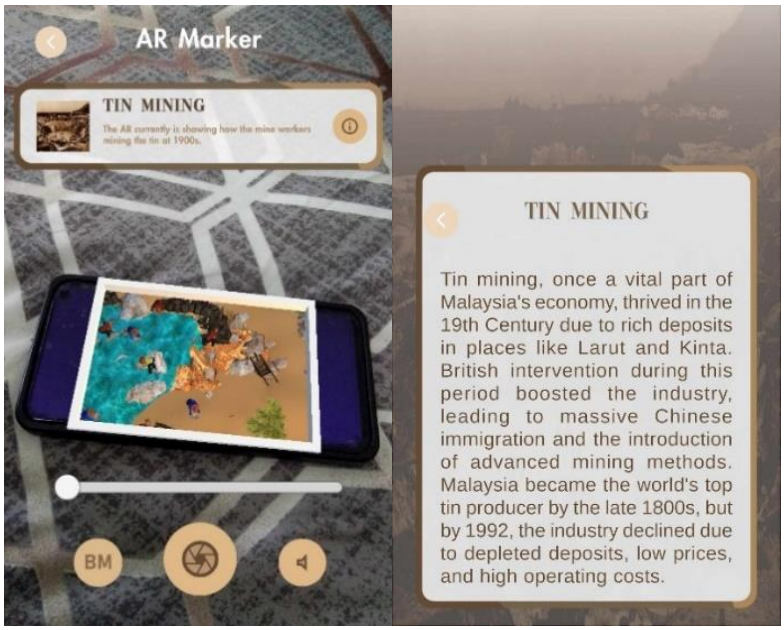

Figure 13. The user can look through the white frame window to see the historical diorama playing inside, with animation played in Gallery C

Figure 14. The user can play the AR Coloring feature in Gallery D while watching the AR Video Player in Centre Gallery

4.2 Unit Testing

A comprehensive testing phase was undertaken to improve and polish the National Museum AR Application, employing Unit Testing techniques. Unit testing involves testing individual units or components of the software in isolation to ensure they perform as intended [48]. The unit testing focused on validating the technical reliability and stability of the AR features, ensuring precise marker detection, tracking, and content rendering. The researchers addressed issues identified during this phase to improve the application's operational performance. Table 4 presents the outcomes of the unit testing performed on the National Museum AR App, outlining its operational performance compared to the anticipated results.

Table 4. Unit Testing Result.

Test case ID	Description/ Actions	Expected output	Actual output	Test Result
1	Home Page			
2-1	Users can see a scrollbar holder containing four gallery image buttons.	Users should be able to scroll horizontally on the screen, either left or right to view the next or previous buttons.	As expected	Pass
2-4	The user selects the gallery to experience and presses the button.	The scene should be redirected to the Gallery Launch Page, where the panel will show the information about a specific gallery relatively based on which button is pressed.	As expected	Pass
3	Gallery B – AR Portal Events			
3-1	Upon launching, the system starts to access to camera for initializing the plane tracking.	The UI should pop up a window stating that the plane tracking is initializing. When the script is loaded and finished, the UI will show the animated logo stating ‘Move your device slowly’ to guide the user in efficient plane tracking.	As expected	Pass
3-2	The system successfully tracked the plane using AR Raycast.	The animated logo fades slowly, and the user should notice the plane's appearance with the dot pattern covering the floor or surface surroundings.	As expected	Pass
3-3	The user places their device camera centered on the AR plane generated.	A white rounded indicator should appear on the center of the screen. The indicator's size and rotation will follow the axis of the AR plane generated like stuck on the AR plane. The indicator will disappear if the user’s device camera center is being moved and does not focus on the AR plane anymore.	As expected	Pass
3-4	The white placement indicator is currently on the screen.	The AR Portal will be spawned on the indicator’s position when a user clicks anywhere on the screen.	As expected	Pass
3-5	After the AR Portal spawned, the user	Users should start seeing the full appearance of the hidden building beneath the portal when they enter the door. The	As expected	Pass

	walks through the portal door.	building will always remain visible when the user is still inside the portal space.		
3-6	The user returns to the original position where he/she spawned the portal before.	The portal will remember the anchor point of the AR world, which will remain the same as at the beginning. Once the user quits the portal, the appearance of the portal space becomes hidden again; only the part where the door is open remains visible.	As expected	Pass
4	Gallery C, D, and Centre Gallery			
4-2	The user points the camera's center to any of the image markers in Gallery C.	The system should be able to detect the image marker if the lightning is enough for the device's camera to recognize the patterns on the image marker. The white camera frame disappears, and the information panel appears with real-time tracked information from the marker. The narration button below will play the corresponding audio track related to the AR content shown.	As expected	Pass
4-3	The user drags on the slider located slightly above the buttons.	The 3D model will rotate itself based on the slider value, minimum 1° maximum 360°.	As expected	Pass
4-4	The user removes the current image marker from the camera sight and points to a new marker.	When a marker is not detected, the system returns to the initial state, and the information about the new marker will appear correspondingly in the information panel.	As expected	Pass
7-1	The user pressed on screenshot button located in the middle below.	The system will hide all existing UI assets and freeze the screen to show the screenshot captured. A panel will pop up stating that the screenshot was captured successfully and that the image has been stored inside the device's photo gallery. When the user checks their device's photo gallery, a new album named 'MuseumAR' will be generated, and the screenshot image will be stored inside.	As expected	Pass

4.3 User Acceptance Testing

The User Acceptance Testing (UAT) involving five users from various demographics, including teenagers, young adults, and parents, who represent the target audience for the National Museum AR Application is being conducted. The UAT aims to gather diverse insights into the application's user experience, examining aspects such as its objectives, AR content design, ease of use, and overall user satisfaction. By incorporating feedback from different perspectives, the testing process seeks to identify strengths and areas for improvement. Overall, the feedback was largely positive, with participants finding the application intuitive and engaging. They appreciated the variety of AR features available across the different galleries and noted that the application effectively enhanced their museum experience. However, some participants encountered minor issues with marker detection accuracy and occasional glitches in AR content rendering. The research team acknowledged these challenges and identified areas for improvement in future iterations of the application. Despite these minor issues, the majority of the UAT participants expressed a high level of satisfaction with the National Museum AR Application. 100% of the participants strongly agreed that the AR visualization of cultural heritage had increased their satisfaction with the exhibits showcased in the National Museum. Table 5 shows the result of UAT outcomes.

Table 5. Document analysis of the exhibits selected.

Participant	The AR App is user-friendly and integrates interactive content.	The AR App impacts overall satisfaction and engagement with the cultural heritage showcased in AR form.	The AR App enhances understanding of the historical and cultural context in Malaysia.
	Grade (1 – Poor, 5 – Outstanding)		
A	5	5	4
B	4	5	3
C	5	5	5
D	4	5	5
E	4	5	3

4.4 Discussion

Based on the research results, the National Museum AR Application project has successfully achieved its initial objectives and deliverables. The creation of four distinct AR experiences, each representing different exhibits across various galleries, demonstrates the project's capability to make otherwise inaccessible items, such as the Royal Throne of Perak, approachable in a virtual space. The incorporation of interactive features, like the AR Coloring activity, received positive responses from both children and adults, enhancing user engagement and satisfaction. However, the project encountered several challenges during the development and evaluation phases.

One notable challenge was the use of plane detection in the AR Portal feature, which relied on the AR Foundation and ARCore SDKs. This dependency limited the application's compatibility with certain devices, posing a consideration for future implementations. The research team acknowledged the need to explore alternative interactive elements or wait for more stabilized AR SDKs to address this limitation. The screenshot function in AR Portal experienced issues with the texture rendering of game objects, resulting in distorted and transparent appearances. This limitation was likely due to the camera's inability to accurately capture the transparent textures that mapped on the hidden object behind the door.

Additionally, the application's cultural sensitivity must be considered at all times. One of the UAT testers pointed out concerns about potential misrepresentation in the AR coloring of traditional attire featuring songkok. As a national institution, the National Museum of Malaysia requires careful consideration of cultural nuances to ensure the appropriate representation of traditional elements.

Despite these challenges, the application passed all the unit tests, indicating its technical robustness and successful development. Furthermore, the overall positive response from the UAT indicates the successful fulfillment of the project's objectives. To improve the application in the future, the author will consider addressing compatibility issues and refining the plane detection functionality to ensure a smoother user experience.

Moving forward, the research team has identified key recommendations for enhancing the National Museum AR Application based on user feedback from the UAT. These recommendations include providing a clearer tutorial for the AR Portal, refining the AR Coloring feature for improved accuracy, enhancing stability in camera movement, exploring additional interaction features with AR avatars, and addressing compatibility issues with alternative interactive elements or waiting for AR SDK stabilization. These suggestions aim to elevate the application's immersive and user-friendly experience, emphasizing the importance of continuous improvement in innovative projects. The positive feedback from the UAT underscores the application's potential, inspiring ongoing efforts to expand and enhance its capabilities. Future researchers are encouraged to consider these recommendations as a roadmap for refining and advancing augmented reality experiences in cultural and educational contexts.

5.0 CONCLUSIONS

In conclusion, the National Museum AR Application project has successfully achieved its objectives by creating engaging and informative augmented reality experiences for visitors. The project's ability to make museum exhibits accessible in virtual space, including the Royal Throne of Perak and AR coloring activities, demonstrates its capacity to enhance user engagement and satisfaction. While encountering challenges such as compatibility issues and the need for cultural sensitivity in content design, the positive responses from user testing indicate the project's success in fulfilling its goals. Moving forward, incorporating the identified recommendations for future improvements, such as enhancing tutorials, refining AR features, and addressing stability and compatibility issues, will further elevate the application's immersive and user-friendly experience.

This study paper also has demonstrated the workflow of creating immersive AR content for museums, providing a valuable guideline for future researchers to enhance visitor experiences through innovative technologies. The project's success in developing AR features for the National Museum of Malaysia serves as a foundation for unlocking creativity in content design within the cultural sector. The utilization of observation methods, such as site visits and document analysis, proved crucial in gathering insights into exhibit popularity and real visitor engagement. These methods can inspire future researchers to create multimedia content that resonates with visitors and enriches their museum experience. By leveraging these insights and methodologies, future researchers can further innovate and elevate the digital representation of cultural heritage in museum settings.

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AUTHORS CONTRIBUTION

Khor Chin Yee (Conceptualization; Methodology; Resources; Software; Writing – original draft)

Siti Azreena Mubin (Writing – review & editing; Supervision; Project Administration)

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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