ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

DEVELOPING A MARKER-BASED AR APPLICATION TO INTRODUCE TEMPLES AND CULTURAL HERITAGE TO YOUNGER GENERATIONS

Oka Sudana[1], Ngurah Adi[2], Agung Cahyawan[3]

[1,2,3]Jurusan Teknologi Informasi, Universitas Udayana

email: agungokas@unud.ac.id[1], ngurah.adi006@unud.ac.id[2], agung.cahyawan@unud.ac.id[3]

Abstract

Preserving Balinese cultural heritage is crucial for sustaining community identity. In Bali, temples (*pura*) are central to spiritual and cultural life. However, younger generations, especially temple caretakers of Pemerajan Agung Sakti Padangsambian, are increasingly losing knowledge of these sacred spaces, weakening their sense of belonging, to preserve cultural traditions. Current media efforts has failed to engage this demographic. This research addresses this challenge by developing an application-integrated images compiled into books and Android-based AR technology. The application employed a user-centered design approach involving analysis, design, development, testing, and evaluation phases. Results show AR effectively bridges the knowledge gap, with usability scores and a significant increase in user knowledge of 42.43%. This research demonstrates AR's potential for preserving and transmitting cultural heritage, including the reconstruction of damaged historical objects through 3D modeling with the marker detection technology, to ensure seamless integration between the real and virtual worlds.

Keywords : Augmented Reality, Temple, Android, Marker Based

Received: 03-03-2024 | **Revised:** 19-07-2024 | **Accepted:** 15-08-2024
DOI: https://doi.org/10.23887/janapati.v13i3.76126

INTRODUCTION

Preserving cultural heritage is crucial, yet it often faces challenges in engaging the younger generation. In Indonesia, Hindu temples, known as *'pura'* or *'pemerajan'* in Bali, are central to cultural and spiritual life. One such example is the Pemerajan Agung Sakti Padangsambian Lanang Dawan Pemecutan. Currently, the younger generation has increasingly limited knowledge about the history and significance of these sacred sites, resulting in a diminished sense of ownership and connection to the temples. This disconnect threatens the sustainability of cultural heritage and erodes the sense of belonging to these temples [1].

The ignorance of the residents of Pemerajan Agung Sakti Padangsambian Lanang Dawan Pemecutan regarding the history and information about the *pelinggih* and *pratima* has resulted in a loss of insight into their sense of ownership of this temple. According to A.A Made Arjana, *pemerajan* or temple owner, this is due to the increasing difficulty of accessing the history of Pemerajan Agung Sakti Padangsambian Lanang Dawan Pemecutan especially since there are no digital documents or archives so it is still limited to the memories of the ancestors and is not passed down to future generations (personal communication, 20 September 2023).

Several factors contribute to this issue, including the lack of interest among the younger generation to seek out this information themselves. Figure 13 was confirmed through surveys and direct interviews conducted with 128 respondents, including 12 individuals categorized as "caretakers" (the next generation of Pemerajan Agung Sakti Padangsambian) who are between 18-24 years old. The survey revealed that the majority of these young respondents lacked knowledge about detailed records and showed little initiative to seek out this information. Furthermore, there is no access to engaging information for citizens, especially the younger generation, because information is still stored only in the memories and records of a few individuals. The limited number of sources who know the complete information makes it difficult to pass on to the public, particularly through digital media.

Current media efforts aimed at introducing and educating the public about these temple structures have proven insufficient in effectively capturing interest and conveying information, especially among the temple administrators themselves. To address this challenge, this research focuses on developing an innovative approach using Augmented Reality (AR) technology to bridge this gap. AR's ability to integrate virtual objects with the real world environments offers a unique opportunity to enhance interactiveness and comprehension of complex information compared to traditional media. Furthermore, AR's interactive nature aligns with the preferences of younger demographics, making it a promising tool for bridging the knowledge gap.

To preserve Balinese culture heritages structures, especially ones damaged due to natural disasters, Made Bunga Anindya, Padma Nyoman Crisnapati, I Made Gede Sunarya, and Made Windu Antara Kesiman conducted research using the System Development Life Cycle (SDLC) waterfall method to develop an Augmented Reality Book application for introducing and archiving Balinese culture, specifically Pura Luhur Batukaru. Their application, which displays 3D objects of the Pura Luhur Batukaru Temple building and its layout, is tested able to serves as a learning medium and visual information tool for preserving Balinese culture [2].

Based on these previous researches, this study introduces an effective Augmented Reality application for Pemerajan Agung Sakti Padangsambian Lanang Dawan Pemecutan. The application utilizes a marker-based AR system, integrating images into an AR book with Android-based technology, supported with Unity 3D, Vuforia SDK, and Blender for 3D modeling. This approach not only increases engagement but also provides an interactive platform for learning about the temple to educate and involve the public in preserving the cultural heritage of Hindu temples in Indonesia.

THEORITICAL REVIEW

A. Augmented Reality

Augmented Reality (AR) is a technology that incorporates two-dimensional and/or three-dimensional virtual objects into a three-dimensional real-world environment and projects those virtual objects in real time. As defined by R. T. Azuma (1997), augmented reality as a combination of real and virtual objects in a real environment. This happens interactively in real time and there is integration between objects in three dimensions, or what is called the term virtual objects are integrated into the real world, meaning able to add virtual or remove existing objects to the real world [3]. While AR applications can be accessed anywhere using a smartphone or tablet, they often rely on marker-based tracking for accurate object recognition and interaction. Markers, such as QR codes or specific images, are essential for the AR system to anchor digital elements to real-world locations, to ensures a stable and coherent augmented experience.

A number of studies regarding Augmented Reality (AR) have shown positive results in contexts relevant to cultural heritage and education [4]. F. A. Purnomo et al. designed an AR application for museums using the 3D markerless method Vuforia, highlighting the potential of AR in cultural preservation and interactive learning [5]. Noveria Anggraeni Fiaji and her team created AR-CA to document the reliefs of Candi Jago, demonstrating the effectiveness of AR in capturing and presenting historical artifacts [6]. Similarly, Sarah Olivia Meily's use of GPS, digital compass, and accelerometer in AR for Taman Ayun underscores AR's capability to provide an immersive experience in outdoor cultural sites [7].

Research by M. F. Syahputra and his colleagues on the use of AR in a North Sumatran traditional house further supports the application of AR in preserving and showcasing traditional architecture [8]. Banu Nur Affan et al. designed AR for Dieng tourism, which successfully enhanced visitor engagement and provided detailed information about the site [9]. Saputro's assessment of AR with wireless sensor networks in a museum setting illustrated how AR can integrate with modern technologies to offer enriched educational content [10].

B. Augmented Reality Book

Augmented Reality (AR) books provide a direct or indirect view of the real world enhanced with computer-generated graphics, audio, or video elements [11]. These books offer an interactive and in-depth learning experience. When users point a smartphone or tablet camera at the book’s pages, static images come to life, move, and produce sound. This technology allows users to virtually explore locations like Pemerajan Agung Sakti Padangsambian Lanang Dawan Pemecutan, gain a deeper understanding of Hindu history and culture, and enjoy an entertaining learning experience. AR books effectively bridge the gap between the real and virtual worlds, enhancing comprehension and interest in cultural heritage.

Kadek Agus Jayadi Putra, Padma Nyoman Chrisnapati, Made Windu Antara Kesiman, and I Gede Mahendra Darmawiguna conducted research on AR applications to introduce temple buildings and their natural landscapes. Their findings indicate that the application can display 3D objects based on book markers, though the rendering time for these objects increases with distance [12].

Putu Yoka Angga Prawira, Padma Nyoman Crisnapati, I Made Gede Sunarya, and I Gede Mahendra Darmawiguna used the waterfall model for system development and testing. The outcome was an Android-based AR book application that presents 3D models of Pulaki Temple and Melanting Temple, complete with explanatory narration [13].

Further research by I Made Endra Wiartika employed software analysis and testing methods to develop an AR book application showcasing traditional Balinese house structures. This application includes appropriate narrative content and provides an interactive learning experience, albeit dependent on smartphone hardware. The study concluded that AR books are effective for understanding traditional Balinese houses based on Asta Kosala-Kosali principles [14].

C. Marker Based Tracking

Marker-based tracking is a fundamental aspect of AR, where the system detects and interprets specific visual markers to anchor digital content in the real world [8]. This technology performs its function by relying on the identification of images specified by the user in the form of markers. Generally, the markers used are in the form of QR codes or special logos. A view of the physical environment of the real world with superimposed computer-generated images, thereby changing the perception of reality, is AR. These markers can be anything from simple QR codes to more complex images.

When the camera recognizes the marker, it triggers the augmentative system to overlay digital elements onto the physical world. This process involves capturing the marker's image, processing it to identify its unique features, and then aligning the digital content accordingly. The augmentative system activation is straightforward simply scan the marker with a camera that supports AR technology.

This type of AR experience is tied to a specific marker or code assigned, meaning the presence of digital elements depends on the location of the AR marker code. Marker-based AR is crucial because it ensures stability and accuracy in the placement of digital content. The markers provide a reference point, allowing the AR system to consistently render virtual objects in the correct position and orientation relative to the real world.

In addition to accuracy, marker-based AR offers several advantages that enhance the user experience. Firstly, it is less susceptible to environmental factors like complex backgrounds or varying lighting conditions, which can disrupt markerless tracking. Secondly, marker-based AR can function effectively on a wider range of devices, including those with lower specifications. Finally, physical markers like AR books can provide a tangible element for users to interact with, potentially fostering deeper engagement with the presented material.

D. Unity 3D

Unity 3D technology is a cross-platform based game engine. Unity can be used to create games that can be used on computers, Android smartphones, iPhone, PS3, and even X-BOX. Unity is an integrated tool for creating games, building architecture and simulations. Unity can be used for PC games and online games. Online games require a plugin, namely Unity Web Player, the same as the flash player in the browser. Unity is not designed for process design or modeling. Some of the features of Unity are audio reverb zone, particle effects and Sky Box.

E. Target Manager Vuforia

Vuforia is a library used to create Augmented Reality (AR) and Virtual Reality (VR) applications. Developers can easily add advanced computer vision functionality to Android, iOS, and UWP apps, to create AR experiences that interact realistically with objects and environments. Vuforia employs several digital image processing techniques to achieve this functionality. These techniques include feature detection, tracking, and recognition, which are critical for identifying and interacting with real-world objects.

The Target Manager in Vuforia allows developers to create and manage databases. This involves uploading images (markers) that the AR system will recognize and track. The creation of a database in the Vuforia library, such as 'Merajan Agung', involves registering these markers. The Vuforia engine processes these images using feature extraction algorithms to identify unique points or patterns in each marker. These features are then stored in the database for real-time recognition during the AR experience.

When the camera captures an image, Vuforia compares it to the stored features in the database. If a match is found, the system can accurately overlay digital content onto the physical marker. This process involves complex image processing tasks like edge detection, keypoint identification, and descriptor matching, ensuring robust and precise AR interactions. By describing the mechanism within Vuforia, we understand how digital image processing techniques are essential to its operation, enabling the seamless integration of virtual elements into the real world.

G. Android

Android is a mobile operating system (mobile operating system) for running AR applications because this platform offers a variety of features and technological support that allows developers to create rich and interesting AR experiences. Android creates accessibility features and products that are compatible with the many ways people want to experience the world. Screen readers, noise cancellation, even a hands-on guide to AR.

METHOD

A. Multimedia Development Life Cycle (MDLC)

At the design stage in creating an AR application is to use the Multimedia Development Life Cycle (MDLC) design method. Following are the stages.

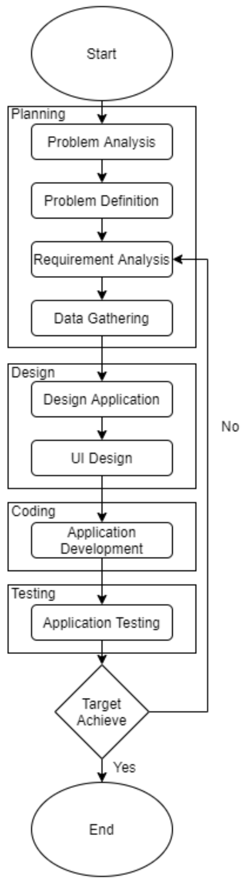


Figure 1. Multimedia Development Life Cycle

Figure 1 is the MDLC design method consists of several phases to guide the development of multimedia applications.

1. It begins with Planning, which involves problem analysis, problem definition, requirement analysis, and data gathering to ensure a thorough understanding of the project's scope and user needs.
2. Next, in the Design phase, the overall application framework and user interface are created, including wireframes and prototypes.
3. The Coding phase follows, where the actual development and integration of multimedia elements occur.
4. Once development is complete, the Testing phase ensures the application functions correctly through various tests. The process concludes with an Evaluation phase, assessing if the application meets its objectives before deployment, followed by ongoing maintenance to address any future issues and updates. This structured approach ensures the creation of high-quality, user-centric multimedia applications.

B. Functional Requirements

Researchers already know what the strengths, weaknesses, opportunities and threats are. The researcher will determine the functional requirements in which there are various stages that the researcher will carry out in the AR system that will be developed.

Based on the system analysis that has been carried out, a flowchart is used to describe the application process flow. The flowchart for the application use case diagram is shown in Figure 2. Figure 2 is a use case diagram that illustrates various functions within an AR application, encompassing two main modes AR Book Mode and Tri Mandala Mode.

1. The AR Book Mode includes marker detection, displaying 3D objects, providing floor plan descriptions, and initiating narrative voiceovers.
2. The Tri Mandala Mode comprises three primary sub-menus: Utama Mandala, Madya Mandala, and Nista Mandala, each capable of marker detection and displaying relevant 3D objects and pelinggih names.

Additionally, the diagram includes supplementary functions such as controlling background music, displaying application information, providing AR guides, and social media contacts. These features are designed to offer a comprehensive and interactive user experience.

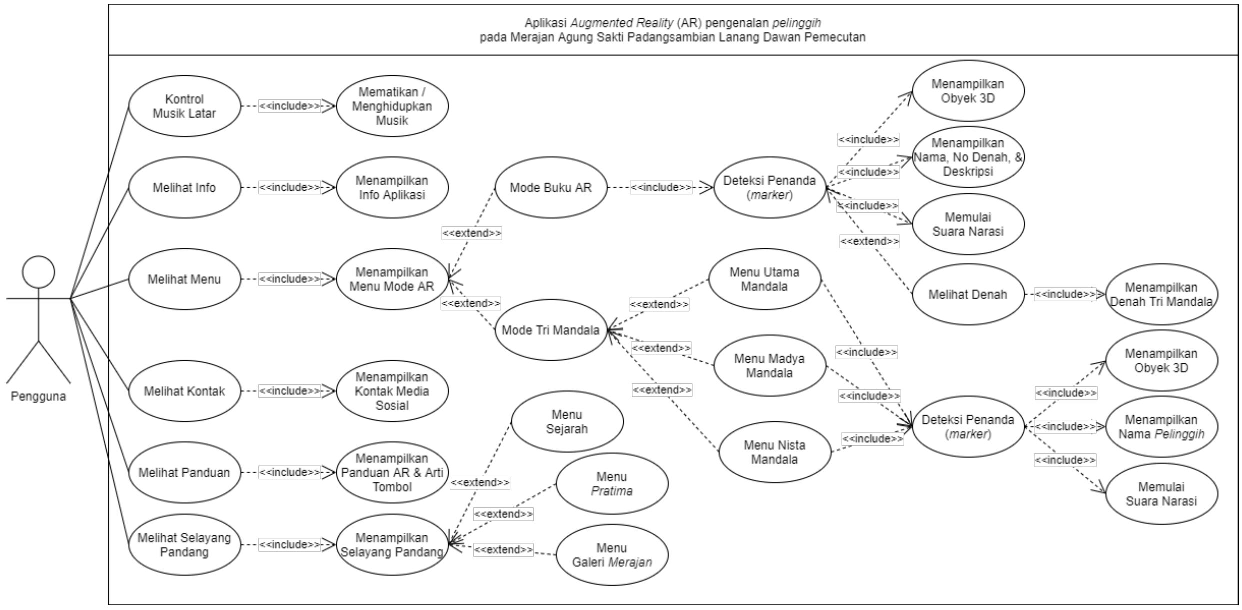


Figure 2. Application Use Case Diagram

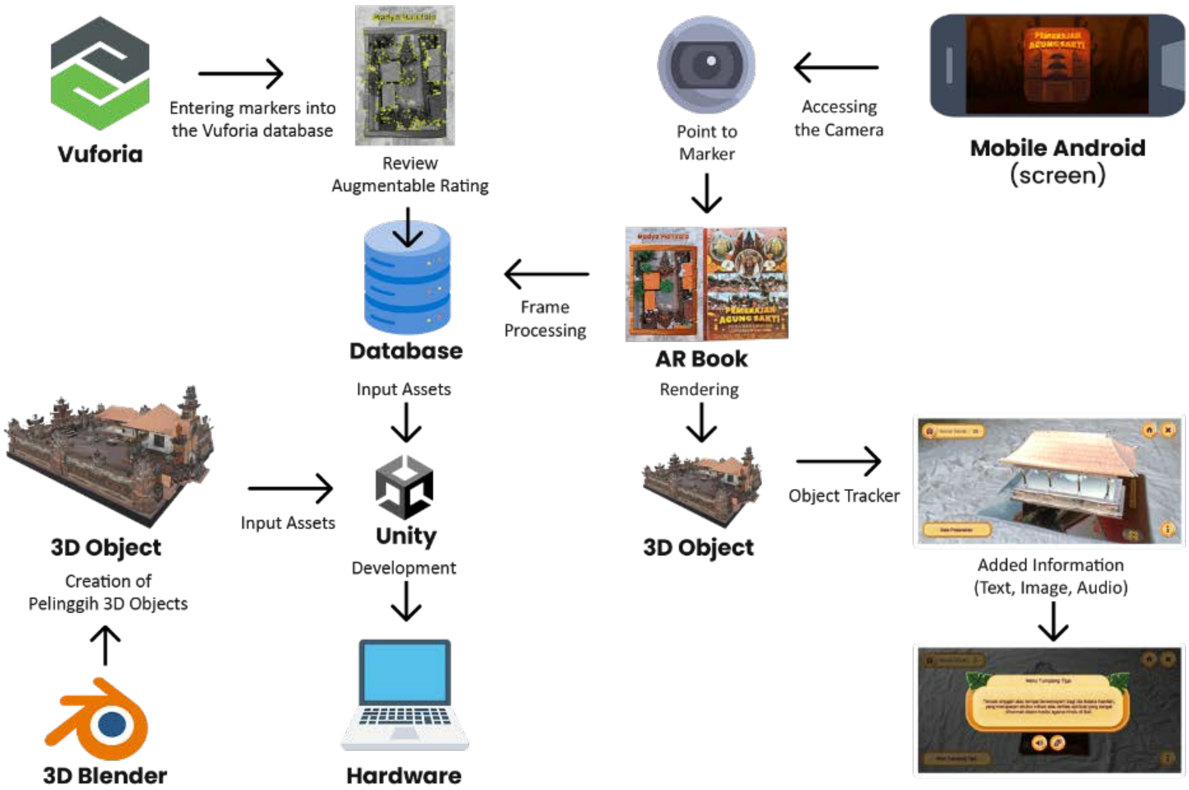


Figure 3. Application Overview

Figure 3 illustrates the overall architecture and workflow of the AR application, detailing the integration of various components such as Vuforia for marker detection, Unity for development, and the use of 3D Blender for creating Pelinggih 3D objects. It showcases the process from entering markers into the Vuforia database, reviewing augmentable ratings, accessing the camera on mobile devices, to the final rendering and object tracking in the AR Book mode. Additionally, it highlights the input of assets into Unity and the involvement of hardware for processing and rendering the 3D objects within the AR environment.

C. Usability Testing

Usability testing is carried out by distributing questionnaires to application users. All of these questions are structured using a Likert scale with ratings between 1 and 5 which are made in the form of choices[15].

Table 1. Likert Scale Value Weights

Description	SS	S	N	TS	STS
Value	5	4	3	2	1
Formula Total	Weight of X Value of Total				

Table 1 has details including strongly disagree (STS), disagree (TS), neutral (N), agree (S), and strongly agree (SS). Device testing is a crucial element in developing a program. It is important to perform testing as part of the process of identifying potential problems in the system and ensuring that the system meets the requirements set out in the initial plan. The eligibility of the application was categorized based on the percentage scores obtained from the usability testing results, as shown in Table 2.

Table 2. Application Eligibility Categories

No	Score (%)	Eligibility Category
1	< 21%	Totally Not Worth It
2	21 - 40 %	Not feasible
3	41 - 60 %	Decent Enough
4	61 - 80 %	Worthy
5	81 - 100 %	Very Worth It

Furthermore, the results of the feasibility percentage scores obtained are adjusted to the media eligibility criteria adopted by [16] can be seen in the table 3. The following is a detailed explanation of the usability testing results.

RESULTS

For computer needs, researchers will use requirements that have been determined by the Unity 3D developer. Researchers used specifications provided by Unity 3D itself. The computer specifications needed to run Unity 3D where researchers created it using the Windows operating system.

Windows operating system used are Microsoft Windows 11 Home Single Language Operating System, using Android 5.1 OS (API level 22), then the supporting softwares such as Blender 2.70, Vuforia, Unity4.2.0f4, Android SDK Tools, Figma, Visual Studio Code, and Adobe Photoshop CC 2024. The hardware used are ZenBook UX462DA Laptop (Processor AMD Ryzen 7 3700U with Radeon, RAM 8.00 GB (5.95 GB usable), System type 64-bit operating system) and Oppo A7 smartphone (Android Operating System Version 5.1 (API level 22)+).

A. 3D Models

The implementation of this 3D model is carried out according to the number of requirements required.

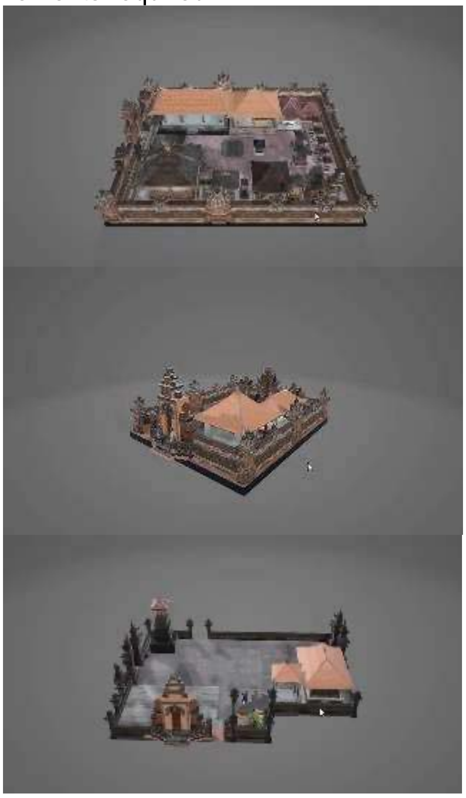


Figure 4. 3D Model

See Figure 4 to determine the three categories of 3D model floor plan mapping used in this application. The top image is Main Mandala, the middle image is Madya Mandala, and the bottom image is Nista Mandala.

Figure 5. Digital Reconstruction

Figure 5 is showing how AR technology offers as a powerful tool for reconstructing damaged historical objects, by utilizing detailed 3D models from available data and historical records, to virtually complete and visualize the

ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

original appearance of these structures. Once these models are built, AR seamlessly overlays them onto the real-world environment. This allows users to experience a captivating reconstruction of the damaged structure, offering a glimpse into its past glory.

Two methods used are marker-based tracking and markerless tracking. Marker-based tracking utilizes physical markers placed around the damaged object, acting as reference points for precise location and orientation information within the AR system. This contrasts with markerless tracking, which relies on existing environmental features like textures and edges. Both methods achieve alignment of the 3D model with the damaged object, ensuring an accurate overlay of the reconstructed image.

This research emphasizes the use of marker-based tracking due to its superior accuracy and stability, providing a more reliable foundation for the reconstruction process. By employing this method, it is possible to achieve highly detailed and accurate reconstructions, allowing future generations to appreciate the original appearance of damaged historical sites and understand their historical significance.

B. Design

The implementation of the software interface was meticulously designed based on wireframe prototypes and user feedback. The design process included several stages, each involving potential users to ensure the interface met their needs and expectations.

1. Wireframe Design Process
a. User Research and Requirement Gathering

Figure 6. User Research

Figure 6 initial user research was conducted to understand the needs, preferences, and behaviors of the target audience, which includes the caretakers of the Pemerajan Agung Sakti Padangsambian Lanang Dawan Pemecutan and the general community interested in cultural heritage. Surveys and interviews were used to gather detailed requirements and insights into user preferences.

b. Wireframe Prototyping

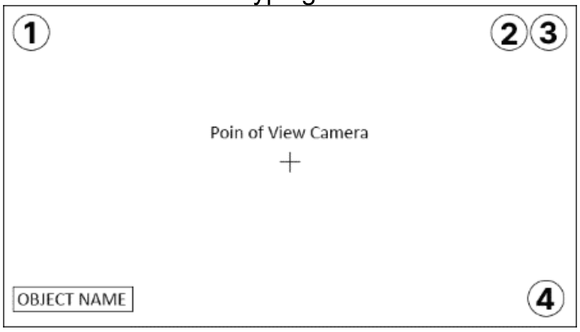


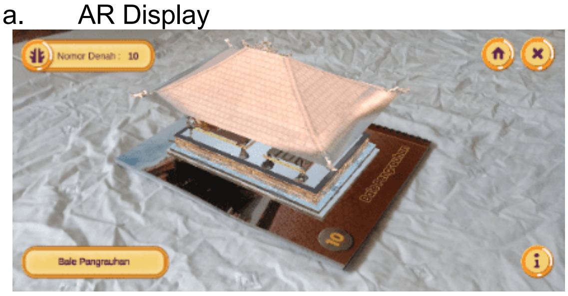
Figure 7. AR Wireframe

Figure 7 based on the gathered requirements, wireframes were created to visualize the layout and functionality of the application. The wireframes focused on simplicity, ease of navigation, and clarity of information to ensure an intuitive user experience. In this wireframe, the top left icon provides information about the object's layout, while the top right contains buttons for returning to the home screen and exiting the application. The bottom right button offers detailed information about the detected object, and the bottom left displays the object's name. The central area is dedicated to the camera's point of view, where the augmented reality content is displayed. This design ensures a user-friendly interface that meets the needs of the target audience.

2. Final Implementation:

The final design, as shown in Figures 8 and 9, reflects the culmination of the wireframe design process and the iterative feedback from potential users. Each interface element was carefully considered and implemented to support the educational goals of the application and provide an enjoyable user experience.

a. AR Display



ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

Figure 8. AR Implementation

Figure 8 AR mode allows users to explore 3D representations of objects by pointing their mobile device's camera at markers in the AR book. After detecting a marker, the app places a detailed 3D model of the object onto the physical book, as illustrated in the image. The interface includes important controls such as a home button, exit button, and object name information button, providing easy navigation as the floor plan number of the object location and additional detailed information about the displayed object pop up when touched. The central area displays augmented reality content from the detected objects as per the mechanism that has been designed in the wireframe in Figure 7.

b. Application Display

Figure 9. Application Display

C. Distance Strength Testing

Distance testing is essential to establish the operational limits of the AR system, ensuring that the application performs effectively under different conditions. It helps in identifying the maximum and minimum distances at which the system can accurately detect and track objects, thereby informing the design parameters for practical usage scenarios. Understanding these limits enhances user experience by ensuring reliable and consistent performance within the specified range.

The results of this test are that several factors can hinder the effectiveness of AR technology at different distances:

1. The size of the marker directly impacts the detection range. Larger markers are detectable at greater distances, while smaller markers require closer proximity for accurate detection.
2. Higher resolution cameras can capture more detail, improving marker detection accuracy at longer distances.
3. Inadequate or inconsistent lighting can affect the visibility and clarity of the marker, reducing detection reliability.
4. The clarity and contrast of the marker play a significant role in detection. Poor-quality markers can hinder the system's ability to recognize and track objects.

5. Physical obstructions, reflections, and varying backgrounds can interfere with marker detection.

The Vuforia system used in this research is designed to accommodate variations in distance, as detailed in their guidelines. Vuforia recommends using larger markers for greater detection distances. For instance, a 20-30 cm wide target should be detectable up to about 2-3 meters, which is approximately ten times the target size. This principle guided the choice of using A4-sized markers in this study, ensuring a balance between marker size and detection range.

Figure 10. Application Testing by Participants

Figure 10 is the distance strength testing was conducted by a team of researchers under controlled conditions. The AR system was set up with a fixed camera and lighting conditions to ensure consistency across tests. A4-sized markers were placed at predetermined distances (5 cm, 10 cm, 30 cm, 120 cm, 150 cm) from the camera. The system's ability to detect and track the 3D object associated with the marker was observed and recorded. Each test was repeated multiple times to ensure accuracy and reliability of the results. The detection success rate and any deviations were documented, providing a comprehensive understanding of the system's performance at each distance. The results obtained by AR were successfully tested as they should be.

D. Augmentable Rate & Marker Area Testing

The markers used in this research were printed on A4 sized paper with matte surface lamination. Based on testing although using glossy surfaces generally does not cause problems in ambient lighting, glossy surfaces can cause major problems at certain angles when light sources (such as lamps or sunlight) cause reflections. These reflections can obscure large portions of the marker texture, causing detection and tracking problems similar to those caused by partial occlusion of the marker.

Figure 11. Augmentable Rate Testing

Figure 11 focuses on analyzing each marker, with a total of 34 markers tested. The main goal of this testing is to determine the extent to which each marker can provide a good level of augmentability, which directly impacts the ability of 3D objects to be displayed and tracked accurately.

Figure 12. Comparison of Marker Based Testing

Figure 12 shows a comparison of two images and note the lack of feature points in the first image. It is always advisable to design and find images that show a large number of points. Feature point alignment also improves the tracking and robustness of the augmentation so that augmented 3D objects are more stable when placed over feature-rich marker areas. Vuforia provides a star rating for image targets, ranging from 1 to 5 stars, which indicates how well an image can be detected and tracked. Higher-rated images, typically with 4 or 5 stars, have more features, better contrast, and a balanced distribution of features, leading to superior detection and tracking performance.

Based on this test, results were obtained where there were several factors that influenced marker detection:

1. The size of the marker and the percentage of its surface area that remains visible significantly impact the system's ability to detect and track it. Larger visible areas result in better detection performance.
2. Glossy print surfaces can reflect light in a way that obscures the marker's texture. This reflection can impede the system's ability to detect the marker accurately,

ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

similar to having parts of the marker physically covered.
3. High contrast between the marker and its background is crucial for accurate detection. Poor contrast can make it difficult for the system to distinguish the marker from its surroundings.
4. The clarity and quality of the print can affect detection. Poor print quality, such as blurred edges or faded colors, can reduce the system's ability to recognize the marker.
5. Consistent and appropriate lighting is essential. Inadequate or excessive lighting can create shadows or reflections that obscure the marker.

E. Usability Testing

1. Respondent Category

To evaluate the usability of the AR application, questionnaires were administered to a sample of 128 potential users, which was initially aimed at individuals ranging from the age 16-30 years old. The questionnaires were distributed online, ensuring a diverse and geographically dispersed sample.

This sample included individuals from both the general public and the Pengempon category, the family members responsible for the temple's upkeep. While the Pengempon category is crucial for understanding the temple's cultural context, their limited numbers necessitated a broader representation from the general public.

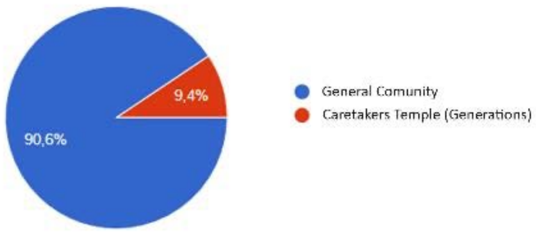


Figure 13. Respondent Category

The results of the analysis of respondent categories are based on 128 answers obtained within 3 days of the interview process with application users. Figure 13 it can be concluded that the majority of respondents fall into the general category, with a total of 116 people or reaching 90.6%. Meanwhile, there were 12 respondents, or around 9.4%, who were included in the pemempon category, namely the *Pemerajan* Agung Sakti Padangsambian family. This category of respondents provides a deeper understanding of the diversity and distribution of participation in the research or survey conducted.

2. Respondent's Age

The following is data on the ages of respondents from the results of filling out the questionnaire given to potential application users. This image provides an overview of the age distribution of respondents based on the results of analysis of the questionnaire data obtained.

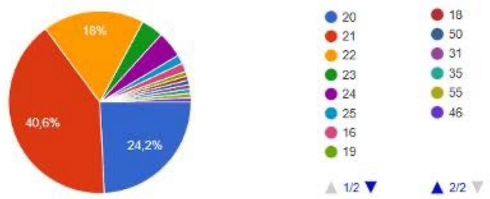


Figure 14. Respondent's Age

Figure 14 from a total of 128 respondents, the 21 year old age group is the majority group with 52 respondents, or 40.6%. Meanwhile, the 20 year age group reached 31 people (24.2%), followed by the 22 year age group with 23 people (18%). A smaller number of respondents were distributed in higher age groups, such as those aged 23 years (5 people or 3.9%), aged 24 years (6 people or 4.7%), and aged 25 years (2 people or 1,6%). There was also one respondent in the 19 year age group (0.8%), 2 people in the 16 year age group (1.6%), 1 person aged 18 years (0.8%), 1 person aged 50 years (0.8%), 1 person aged 31 years (0.8%), 1 person aged 35 years (0.8%), 1 person aged 55 years (0.8%), and 1 person aged 46 years (0.8%).

$$\text{Usability} = \frac{\text{Total Score}}{\text{Total Respondents x Total Questions x Highest Weight}} \quad (1)$$

The formula used to calculate the score for each aspect is as seen on Formula 1. The usability is calculated by dividing the results of the weighted values per usability aspect by the number of respondents, and then dividing again by the number of questions for each aspect.

Usability testing was conducted to evaluate various aspects of the application. The testing involved distributing questionnaires to 116 respondents, including craftsmen and the general public, aged between 16 and 30 years. The questionnaires used a Likert scale with ratings from 1 to 5. The aspects evaluated included learnability, efficiency, satisfaction, memorability, and errors.

Table 3. Application Usability Aspect Results

Aspect	Score (%)	Results
Learnability	98,62%	Very Worth
Efficiency	96,60%	Very Worth

Satisfaction	97,06%	Very Worth
Memorabilit	94,52%	Very Worth
Errors	93,01%	Very Worth

Table 3 applications achieved high scores across all aspects of usability, indicating effectiveness and ease of use. The high learnability score of 98.62% shows that new users can quickly adapt to using this AR application. An efficiency score of 96.60% shows the application's ability to effectively support temple recognition productivity. User satisfaction reached 97.06%, highlighting the positive user experience and interest in this innovation supported by interactive multimedia assets. A memory score of 94.52% shows that users can easily remember how to use the application after a period of not using it. Finally, the error aspect obtained a score of 93.01%, which shows a relatively low error rate during use and even no special competence is required in use in almost all age groups.

F. Increased User Knowledge

To evaluate the effectiveness of the AR application in increasing knowledge about Pemerajan Agung Sakti Padangsambian among the younger generation, pre-test and post-test assessments were conducted with 128 respondents. The goal was to measure the change in knowledge before and after using the AR application.

1. Pre-Test Results

The pre-test was administered to assess the initial knowledge level of the respondents. The results are shown in Table 4.

Table 4. Pre-Test Results

Score	Frequency (User)	Total Score
1	5	5
2	8	16
3	15	45
4	18	72
5	22	110
6	19	114
7	14	98
8	10	80
9	10	90
10	7	70
Total	128	700

2. Post-Test Results

After using the AR application, a post-test was administered to measure any increase in knowledge. The results are shown in Table 5.

Table 5. Post-Test Results

Score	Frequency (User)	Total Score
3	2	6
4	5	20
5	10	50
6	15	90
7	20	140
8	22	176
9	25	225
10	29	290
Total	128	997

3. Analysis of Results

The percentage increase in the total scores from the pre-test to the post-test is calculated as follows:

$$\text{Increase} = \left(\frac{\text{Post}-\text{Test Total Score}-\text{Pre}-\text{Test Total Score}}{\text{Pre}-\text{Test Total Score}}\right)x100 \quad (2)$$

The percentage increase formula is as seen on Formula 2. The calculation is use to assess the impact of the AR application on users' knowledge, we calculated the percentage increase in total scores from the pre-test to the post-test. The formula involves subtracting the total pre-test score from the total post-test score, dividing the result by the total pre-test score, and then multiplying by 100 to obtain the percentage increase. This metric quantifies the improvement in users' knowledge after interacting with the AR application.

Table 6. Analysis of Results

Test Type	Total Score	Increase (%)
Pre-Test	700	-
Post-Test	997	42.43%

Table 6 showed a significant increase in total score from pre-test to post-test of 42.43%. This shows that the application of AR is effective in increasing respondents' knowledge about Pengerajan Agung Sakti Padangsambian.

CONCLUSIONS

According to data analysis from 128 respondents and various stages of testing the Augmented Reality (AR) application as an introduction medium at Pemerajan Agung Sakti Padangsambian Lanang Dawan Pemecutan, it can be concluded that the developed AR application successfully operates on the Android OS platform, accurately tracks 3D objects with a minimum distance detection of 5 cm and a maximum of 150 cm, and achieves high usability scores across various dimensions. Notably, the application significantly enhanced users' knowledge of the temple's sacred spaces, as evidenced by the substantial increase in post-test scores with the details; learnability of 98.62%, efficiency of 96.60%, satisfaction of 97.06%, memorability of 94.52%, and errors at 93.01%, achieving the significant score increase of 42.43% from the 700 score of pre-test to 997 score of post-test. These findings underscore the potential of AR technology in revitalizing cultural heritage education and fostering a deeper connection to the temple among younger generations.

Based on these findings, several recommendations are also proposed for further development and evaluation of AR applications such as focusing on expanding platform compatibility (e.g. iOS), enhancing accessibility through multilingual support for international audience purposes, optimizing performance across various devices with extensive specifications to ensure richer experiences, and developing robust systems for marker database maintenance to maintain accuracy and relevancy in response to real-time changes.

REFERENCES

[1] K. Miura, “A dilemma of World Heritage ideals and challenges in Southeast Asia,” *International Journal of Cultural Property*, vol. 29, no. 4, pp. 433–457, Nov. 2022, doi: 10.1017/S094073912200025X.

[2] M. B. Anindya, P. N. Crisnapati, I. Made, G. Sunarya, M. Windu, and A. Kesiman, “Augmented Reality Book Pengenalan Tata Letak Bangunan Beserta Landscape Alam Pura Luhur Batukaru,” *Jurnal Nasional Pendidikan Teknik Informatika (JANAPATI)*, vol. 3, no. 3, 2014, Accessed: Sep. 22, 2023. [Online]. Available: https://ejournal.undiksha.ac.id/index.php/janapati/article/view/9823/6246

[3] R. T. Azuma, “A Survey of Augmented Reality,” 1997. [Online]. Available: http://www.cs.unc.edu/~azumaW:

[4] K. Dewangga, K. Widhiyanti, P. Nastiti, and U. Atma Jaya Yogyakarta Yustus Eko Oktian, “Arthibition: Designing Augmented Reality For Art Exhibition,” 2023.

[5] F. A. Purnomo, P. I. Santosa, R. Hartanto, E. H. Pratisto, and A. Purbayu, “Implementation of Augmented Reality Technology in Sangiran Museum with Vuforia,” in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Apr. 2018. doi: 10.1088/1757-899X/333/1/012103.

[6] N. A. Fiaji, K. Candra Brata, P. Zulvarina, and P. Korespondensi, “Aplikasi Ar-Ca (Augmented Reality Relief Candi Jago),” *Jurnal Teknologi Informasi dan Ilmu Komputer (JTIIK)*, vol. 8, no. 4, pp. 815–822, 2021, doi: 10.25126/jtiik.202184447.

[7] W. Buana and S. O. Meily, “Augmented Reality Application using Dynamic Location-Based Tracking of Taman Ayun Temple,” *Lontar Komputer : Jurnal Ilmiah Teknologi Informasi*, vol. 12, no. 1, p. 24, Mar. 2021, doi: 10.24843/lkjiti.2021.v12.i01.p03.

[8] M. F. Syahputra *et al.*, “Augmented Reality for Presenting Local Wisdom: Sumatera Utara Traditional House,” in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Jul. 2019. doi: 10.1088/1742-6596/1235/1/012102.

[9] B. N. Affan, A. Suryanto, and A. Arfriandi, “Implementation of augmented reality as information and promotion media on Dieng tourism area,” *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 16, no. 4, pp. 1818–1825, Aug. 2018, doi: 10.12928/TELKOMNIKA.v16i4.7759.

[10] A. K. Saputro, S. Sumpeno, and M. Hariadi, “Performance of the IEEE 802.15.4 Protocol As the Marker of Augmented Reality in Museum,” in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Apr. 2018. doi: 10.1088/1742-6596/1007/1/012020.

[11] J. Elektronik, I. K. Udayana, I. B. Mahendra, and A. Muliantara, “The Application of Augmented Reality in Introducing Temples in Denpasar”.

[12] I. Gede *et al.*, “Augmented Reality for the Documentation of Cultural Heritage Building Modelling in Bali, Indonesia,” 2014. [Online]. Available: https://www.researchgate.net/publication/295908053

[13] P. Yoka *et al.*, “Augmented Reality Book Pengenalan Tata Letak Bangunan Pura Pulaki dan Pura Melanting,” *Jurnal Nasional Pendidikan Teknik Informatika (JANAPATI)*, vol. 4, no. 2, 2015, Accessed: Sep. 22, 2023. [Online]. Available: https://ejournal.undiksha.ac.id/index.php/janapati/article/view/9777/6201

[14] I. Made *et al.*, “Augmented Reality Book Sistem Rumah Tradisional Bali Berdasarkan Asta Kosala-Kosali,” *Jurnal Nasional Pendidikan Teknik Informatika (JANAPATI*, vol. 2, no. 3, 2013, Accessed: Sep. 22, 2023. [Online].

Available: Augmented Reality Book Sistem Rumah Tradisional Bali Berdasarkan Asta Kosala-Kosali

[15] S. A. Putu, A. Pratiwi, A. Wafal An’am, and O. Hardiyantari, “Aplikasi Pengenalan Rumah Adat Jawa dan Bali Berbasis Augmented Reality untuk Anak Sekolah Dasar,” *Prosiding SEMNASA*, 2021, Accessed: Jan. 22, 2024. [Online]. Available: https://ojs.amikomsolo.ac.id/index.php/semnasa/article/view/8

[16] S. Aulia, “Uji Kelayakan Media Pembelajaran Interaktif Berbasis Android Menggunakan Articulate Storyline 3,” *Natural Science Educational Research*, 2022, Accessed: Jan. 22, 2024. [Online]. Available: https://journal.trunojoyo.ac.id/nser/article/view/11854