

**Development of a Marker-Based Augmented Reality
Application for Interactive Tourism
at the Ratu Boko Heritage Site**



Compiled by:

N a m e : Anggito Sulistyo Adi
NIM : 21523200

**INFORMATICS STUDY PROGRAM – UNDERGRADUATE PROGRAM
FACULTY OF INDUSTRIAL TECHNOLOGY
UNIVERSITAS ISLAM INDONESIA
2026**

THESIS SUPERVISOR APPROVAL PAGE

**Development of a Marker-Based Augmented Reality
Application for Interactive Tourism
at the Ratu Boko Heritage Site**

UNDERGRADUATE THESIS



Yogyakarta, 25 May 2026

Supervisor,


(Arrie Kurniawardhani, S.Si., M.Kom.)

THESIS EXAMINERS APPROVAL PAGE

Development of a Marker-Based Augmented Reality Application for Interactive Tourism at the Ratu Boko Heritage Site

UNDERGRADUATE THESIS

This thesis has been defended before the Board of Examiners as a partial requirement for the degree of Bachelor of Computer Science in the Undergraduate Program of Informatics,

Faculty of Industrial Technology, Universitas Islam Indonesia.

Yogyakarta, 25 May 2026

Board of Examiners

Chair

Arrie Kurniawardhani, S.Si., M.Kom.



Examiner 1

Kurniawan Dwi Irianto, S.T., M.Sc.



Examiner 2

Dr. Nur Wijayaning Rahayu, S.Kom.,
M.Sc.

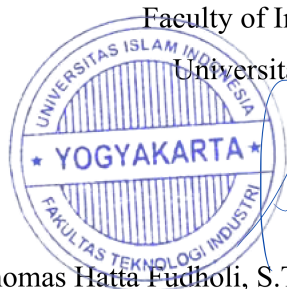
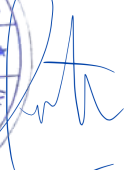


Acknowledged by,

Head of Informatics Study Program – Undergraduate Program

Faculty of Industrial Technology

Universitas Islam Indonesia

(Ir. Dhomas Hatta Fudholi, S.T., M.Eng., Ph.D., IPM., ASEAN Eng.)

DECLARATION OF ORIGINALITY

The undersigned:

Name : Anggito Sulistyo Adi

NIM : 21523200

Undergraduate Thesis entitled:

Development of a Marker-Based Augmented Reality Application for Interactive Tourism at the Ratu Boko Heritage Site

I hereby declare that all components and contents of this undergraduate thesis are entirely my own work. Should it later be proven that certain parts of this work are not my own, I am willing to have this thesis, which has been submitted as my own work, withdrawn and to accept any risk and consequences arising therefrom.

Thus, this statement is made in good faith for its intended purpose.

Yogyakarta, 25 May 2026



(Anggito Sulistyo Adi)

DEDICATION

Alhamdulillahirabbil'aalamin, all praise is due to Allah SWT for His blessings, mercy, and guidance, which have allowed me to complete this final project. May peace and blessings always be upon Prophet Muhammad SAW, along with his family, companions, and followers.

This work is dedicated to my beloved parents, my father, Maryadi, and mother, Astri Triyatmi, S.P., whose unwavering support, prayers, and encouragement have been a constant source of strength throughout my journey. Your sacrifices and care have made this achievement possible, and I hope this accomplishment can bring you happiness. With the extent of my heart, as my mouth may not speak of it, I love you both with all my heart. My brothers, whom I care of, that became the best companions on navigating through the hurdles of life. I would also dedicate this work to my late grandfather, Sarwanto Soeripto, for his guidance and love. May Allah grant him eternal peace and widen his grave, Aamiin.

I would like to sincerely thank my thesis supervisor, Mrs. Arrie Kurniawardhani, S.Si., M.Kom., for the guidance, patience, and valuable insights provided throughout the completion of this research. Your support has greatly contributed to both my academic and personal growth.

My appreciation also goes to Mrs. Septi Indrawati Kusumaningsih, S.S., M.A, and Mr. Yulianto for their cooperation and assistance during this research. I am equally thankful to my friends, Chrisna Maulana, Fikri Sitorus, Naufal Ardiyanto, Farrel Fajra, Alvianto Fauzan, Abdullah Yahya, Mahendi Putri, Chyntia Rejka, Naufaliana Zahrah, Saarah Muthiah, Miftahul Jannah and many others who have accompanied me throughout my academic journey. Thank you for the shared experiences, encouragement, and meaningful moments that have made this journey memorable.

MOTTO

Bismillahirrahmanirrahiim

"Do or die, you'll never make me
Because the world will never take my heart
We'll carry on, we'll carry on"
Welcome To The Black Parade – My Chemical Romance

"Even if you try to be perfect, nobody's perfect. So of course I try to learn from every mistake."
Ayrton Senna – Formula 1 World Champion

"Blood is the debt I bear from my mother's travail,
Sweat is the tribute I owe to my father's toil.
Thus stands my life, wrought of sacrifice and grace,
An heir to love, endured through time and soil."
— *The Author's Random Night, 2025*

FOREWORD

Alhamdulillah, all praise is due to Allah SWT for His blessings, mercy, and guidance, which have enabled the author to complete this final project report. May peace and blessings always be upon Prophet Muhammad SAW, who serves as a role model for all mankind.

This final project report is prepared as one of the requirements for completing the undergraduate study in the Informatics Study Program at Universitas Islam Indonesia. This research is entitled **“Development of a Marker-based Augmented Reality Application for Interactive Tourism at the Ratu Boko Heritage Site”**. During the preparation of this report, the author encountered various challenges, including data collection constraints and technical difficulties. However, with the support and encouragement from many parties, this research was successfully completed. The author realizes that this report still has limitations; therefore, constructive criticism and suggestions are highly appreciated for future improvement.

With sincere respect, the author would like to express gratitude to:

1. Allah SWT, for granting health, strength, and smooth progress throughout the research and writing process.
2. My beloved parents, Maryadi and Astri Triyatmi, S.P., for their endless prayers, support, and trust in helping me complete this academic journey.
3. Mr. Prof. Fathul Wahid, S.T., M.Sc., Ph.D., as the Rector of Universitas Islam Indonesia.
4. Mr. Prof. Dr. Ir. Hari Purnomo, M.T., as the Dean of the Faculty of Industrial Technology.
5. Mr. Dr. Raden Teduh Dirgahayu, S.T., M.Sc., as the Head of Informatics Department.
6. Mr. Dthomas Hatta Fudholi, S.T., M.Eng., Ph.D., as the Head of the Informatics Undergraduate Program.
7. Mr. Irving Vitra Paputungan, S.T., M.Sc., Ph.D., as the author's Academic Supervisor.
8. Mrs. Arrie Kurinawardhani, S.Si., M.Kom., as the author's Thesis Supervisor. For her knowledge, patience, and dedication guiding the author throughout the completion of the final project.
9. All informatics lecturers, for the knowledge and insights during the author's academic journey.
10. Mrs. Septi Indrawati Kusumaningsih, S.S., M.A., and Mr. Yulianto, for their support and cooperation during this research.

11. My friends and colleagues, who have supported and accompanied the author through his studies.
12. All parties who have contributed, directly or indirectly, to the completion of this research.

Finally, the author hopes that this research can provide benefits and contribute to the development of knowledge, particularly in the field of interactive digital applications.

Yogyakarta, 25 May 2026



(Anggito Sulistyo Adi)

ABSTRACT

The Ratu Boko Heritage Site possesses significant historical and cultural value. However, many of its remaining structures exist only as fragmented architectural elements, making them difficult for visitors to interpret using conventional informational media such as signage and brochures. This research aims to develop a marker-based Augmented Reality (AR) application as an interactive tourism medium to support visitor understanding of selected architectural elements within the Pendapa area of Ratu Boko. The research adopts the ADDIE development model consisting of Analysis, Design, Development, Implementation, and Evaluation phases. Data collection was conducted through field observation, literature review, analysis of existing informational media, and discussions with an archaeological and a professional tour guide. The application was developed using Unity, Vuforia SDK, and Android Studio. The system integrates marker-based AR features, audio narration, textual explanations, and point-of-interest information. System evaluation consisted of black-box testing, compatibility testing, content validation by experts, and usability evaluation using the System Usability Scale (SUS). The results indicate that the application functions according to its intended design and operates across multiple Android devices with acceptable performance. Expert validation confirmed that the presented content is accurate, relevant, and suitable for visitors, while usability evaluation produced a SUS score of 82.916, which falls within the “Excellent” category. These findings demonstrate that marker-based AR can effectively support the interpretation of fragmented heritage structures and enhance visitor engagement within cultural heritage tourism environments. Furthermore, the study highlights the potential contribution of AR technology as a tool for cultural heritage interpretation and education tourism at the Ratu Boko Heritage Site.

Keywords : augmented reality, cultural heritage, interactive tourism, marker-based AR, usability

GLOSSARY

ADDIE	An instructional design model consisting of five phases: Analysis, Design, Development, Implementation, and Evaluation, used to guide systematic application development.
Android	A mobile operating system used as the platform for developing and running the AR application in this research.
Augmented Reality (AR)	A technology that overlays digital content, such as images, text, or 3D objects, onto the real-world environment in real time.
Black-box Testing	A software testing method that evaluates system functionality based on inputs and outputs without considering internal code structure.
Compatibility Testing	A type of testing conducted to ensure that an application operates correctly across different devices, operating systems, and hardware configurations.
Image Target	A predefined visual marker used in marker-based AR to trigger and align virtual content with real-world objects.
Interactive Tourism Media	A digital medium that enables user interaction to enhance engagement and understanding in tourism experiences.
Marker-based AR	A type of Augmented Reality that uses predefined visual markers to detect and display virtual content in alignment with real-world objects.
Points of Interest (POI)	A specific location within the application that contains relevant information, such as descriptions, images, or coordinates, for user exploration.
System Usability Scale (SUS)	A standardized questionnaire consisting of ten items used to measure the perceived usability of a system.
Unity	A cross-platform game engine used in this research to develop AR content and integrate interactive features.
Usability	The degree to which a system is easy to use, efficient, and satisfying for users in achieving specific goals.
Vuforia	A software development kit (SDK) used to enable marker-based AR tracking and recognition within the Unity environment.

TABLE OF CONTENTS

THESIS SUPERVISOR APPROVAL PAGE.....	ii
THESIS EXAMINERS APPROVAL PAGE.....	iii
DECLARATION OF ORIGINALITY.....	iv
DEDICATION.....	v
MOTTO	vi
FOREWORD.....	vii
ABSTRACT	ix
GLOSSARY	x
TABLE OF CONTENTS.....	xi
LIST OF TABLE	xiii
LIST OF FIGURES	xiv
CHAPTER I INTRODUCTION.....	1
1.1 Background	1
1.2 Problem Formulation.....	2
1.3 Scope and Limitations	2
1.4 Research Objectives	3
1.5 Research Benefits	3
1.6 Writing Systematic	3
CHAPTER II LITERATURE REVIEW	5
2.1 Augmented Reality in Cultural Heritage.....	5
2.2 Mobile-based AR and Design Considerations	6
2.3 ADDIE Method.....	7
2.4 System Testing	9
2.4.1 System Usability Scale (SUS).....	10
2.4.2 Compatibility Testing	11
2.4.3 Black-box Testing.....	11
2.5 Previous Studies	12
2.6 Existing Digital Heritage Platforms	14
2.7 Research Gap.....	16
CHAPTER III RESEARCH METHODOLOGY	18
3.1 Research Methodology	18
3.2 Analysis Phase	19
3.3 Design Phase	19

3.4 Development Phase	20
3.5 Implementation Phase	21
3.6 Evaluation Phase	21
CHAPTER IV RESULTS AND DISCUSSIONS	27
4.1 Analysis	27
4.2 Design.....	32
4.2.1 Use Case Diagram.....	32
4.2.2 System Flowchart.....	33
4.2.3 Marker Design and AR Interaction	35
4.2.4 Content Design.....	37
4.2.5 Low-Fidelity Interface Design	40
4.2.6 High-Fidelity Interface Design	52
4.3 Development	64
4.3.1 AR Development using Unity and Vuforia.....	65
4.3.2 Android Application Development (Kotlin)	69
4.3.3 Integration between Unity and Android Project	74
4.4 Implementation.....	77
4.5 Evaluation.....	80
4.5.1 Black-box Testing	80
4.5.2 Content Validation	83
4.5.3 Compatibility Testing	87
4.5.4 SUS Evaluation	89
CHAPTER V CONCLUSION AND SUGGESTIONS	94
5.1 Conclusion	94
5.2 Suggestion.....	94
REFERENCES	97
APPENDIX.....	102

LIST OF TABLE

Table 2.1 Comparison of Previous Studies	13
Table 2.2 Comparison of Existing Digital Heritage Platforms and Proposed System	15
Table 3.1 Planned Testing Scenario	22
Table 3.2 Black-box Testing	22
Table 3.3 Compatibility Testing	24
Table 3.4 Validation Aspect Table for Expert Archaeologist	24
Table 3.5 Validation Aspect Table for Tour Guide.....	25
Table 4.1 User Needs and System Requirement Mapping.....	31
Table 4.2 Marker Details of Pendapa	35
Table 4.3 POI Content Display	38
Table 4.4 AR-based Content Display.....	39
Table 4.5 Non-AR Content Presentation.....	40
Table 4.6 Black-box Testing	81
Table 4.7 Content Validation with Archaeologist Score.....	83
Table 4.8 Likert Scale Validity Criteria	83
Table 4.9 Evaluation Aspects of Tour	85
Table 4.10 Suitability Categorization.....	86
Table 4.11 Compatibility Testing.....	88
Table 4.12 System Usability Scale (SUS) Statements	90
Table 4.13 SUS Score of Respondents.....	91

LIST OF FIGURES

Figure 2.1 Phases on the ADDIE methodology	8
Figure 2.2 Ten Statements in The System Usability Scale Instrument	10
Figure 2.3 Example of a Black-box Testing Scenario.....	12
Figure 3.1 ADDIE Methodology.....	18
Figure 4.1 Printed Brochure Provided in the Entrance.....	27
Figure 4.2 Older Version of the Brochure for Ratu Boko	28
Figure 4.3 On-site Informational Signage	28
Figure 4.4 Use Case Diagram of the Application.....	32
Figure 4.5 System Flowchart of the Application.....	34
Figure 4.6 Onboarding View	41
Figure 4.7 Main Menu View	42
Figure 4.8 Map View.....	43
Figure 4.9 Point of Interest List View	44
Figure 4.10 Detail POI View	45
Figure 4.11 How To Use View.....	46
Figure 4.12 Overview View	47
Figure 4.13 Profile View	48
Figure 4.14 Standby Mode	49
Figure 4.15 Marker Detected View	50
Figure 4.16 Information Panel Opened View.....	51
Figure 4.17 Map Detail Opened View	52
Figure 4.18 Onboarding View	53
Figure 4.19 Main Menu View	54
Figure 4.20 How To Use View.....	55
Figure 4.21 Overview View	56
Figure 4.22 POI List View	57
Figure 4.23 POI Detail View	58
Figure 4.24 Map View.....	59
Figure 4.25 Profile View	60
Figure 4.26 Standby Mode View.....	61
Figure 4.27 Marker Detected View	62
Figure 4.28 Information Panel Opened View.....	63
Figure 4.29 Map Detail Opened View	64

Figure 4.30 Vuforia's Licence Key	65
Figure 4.31 Vuforia's Database for Image-targets.	66
Figure 4.32 Unity Inspector with Attached Scripts	67
Figure 4.33 AR Scene Displaying Marker Detection with Active Audio Control.....	68
Figure 4.34 Information Panel Displayed After Marker Detection.....	69
Figure 4.35 Onboarding Interface	70
Figure 4.36 Main Menu Interface.....	71
Figure 4.37 POI List Interface.....	72
Figure 4.38 POI Detail Interface	73
Figure 4.39 Map Interface	74
Figure 4.40 Unity Build Settings configured for "Export Project" with Android.....	75
Figure 4.41 Exported Unity Project Structure UnityLibrary and Launcher Modules	75
Figure 4.42 Android Studio Project Structure with UnityLibrary Imported	76
Figure 4.43 AR Marker Detection as Integrated Application View.....	77
Figure 4.44 Respondent Scanning the Batu Umpak.....	78
Figure 4.45 Respondent Scanning the Jaladwara	78
Figure 4.46 Respondent Scanning the Notched Stone	78
Figure 4.47 Expert Validation with Mrs. Septi Indrawati Kusumaningsih, S.S, M.A	85
Figure 4.48 Documentation with Tour Guide, Mr Yulianto	87
Figure 4.49 SUS Evaluation Procedure.....	89
Figure 4.50 Final SUS Score of the Application.....	93

CHAPTER I

INTRODUCTION

1.1 Background

Keraton Ratu Boko, widely known as Ratu Boko Heritage Site, is a site constructed around the 8th century influenced greatly by Buddhist and Hindu traditions. The site holds significant historical and cultural value based on inscriptions and archaeological findings found on site. Ratu Boko is in Dawung and Sambirejo villages in Prambanan District, Special Region of Yogyakarta, covering a total area of approximately 160,898 square meters (Soenarto et al., 1993).

Unlike many other ancient sites in Java that function as temple or places of worship, Ratu Boko is believed to have served as a secular settlement, likely used for royal, administrative, or daily activities rather than ritual purposes. Its physical layout of Ratu Boko reflects this uniqueness, consisting of a main gate, terraces, an audience hall, bathing areas, and a women's quarter. The uniquely adapted architectural design to the natural contours of the hill by leveling the ground, constructing retaining walls to prevent landslides, and developing water reservoirs for rainwater collection demonstrates how past civilizations adapted to their settlement environment (Worosetyaningsih, 2019).

Despite its historical significance, compared to nearby sites such as Borobudur and Prambanan, the number of visitors to Ratu Boko remains relatively low. In 2024, visitors to Ratu Boko accounted for only 3.2% of the total heritage park visitors, while Borobudur and Prambanan attracted 33.5% and 63.4% respectively (InJourney Destination Management, 2024). Several factors contribute to the condition, including limited facilities, accessibility challenges, and the lack of attractions to encourage visitors to stay longer.

In addition, based on preliminary observations, one of the key issues is the limited availability of interactive and informative media that effectively communicate the historical context and function of the site. Most information at Ratu Boko is delivered to static signages, printed brochures, or optional guided tours. Furthermore, the remaining structures of Ratu Boko that are in the condition of ruins and foundations made many visitors find it difficult to visualize or understand the original function of each area within the site. This condition indicates that existing informational media are not sufficient to support visitors in interpreting the site effectively.

To address this limitation, interactive technology such as Augmented Reality (AR) can be utilized as a medium to enhance visitor understanding. AR enables digital content, including visualizations, images, and textual information, to be overlaid onto the real environment in real time, allowing users to perceive additional contextual information within the site. Rather than reconstructing the site with full archaeological accuracy, this approach focuses on providing simplified and contextual visual explanations that complement the existing physical remains.

Therefore, this research focuses on the development of a marker-based Augmented Reality application as a medium to support visitor understanding of selected elements in the Pendapa area of Ratu Boko. The application aims to present contextual information through visual and interactive representations, thereby bridging the gap between the existing physical structures and their historical interpretation.

1.2 Problem Formulation

Based on the issues described in the background, the research problems are formulated as follows:

- a. How can a marker-based Augmented Reality (AR) application be developed for the Ratu Boko heritage site?
- b. How can the AR application present information at Ratu Boko site?
- c. How usable is the developed AR application based on user evaluation?

1.3 Scope and Limitations

The scope and limitations of this research are defined as follows:

- a. The developed AR application utilizes marker-based Augmented Reality (AR) tracking.
- b. The AR content focuses on the Pendapa area of Ratu Boko, specifically covering five elements: Notched Stone, Batu Umpak, Jaladwara, Stone Materials, and Makara.
- c. The visualization is presented in a simplified form to explain the function of selected elements of Pendapa, due to limited archaeological data and technical constraints.
- d. The application is developed for Android devices and is limited to the English language. The limitation was introduced to maintain the scope of the research and focus on the implementation and usability evaluation of the marker-based AR system. Therefore, multilingual support is not included in this study.

1.4 Research Objectives

The main objective of this research is to develop a marker-based AR application that functions as an interactive media for introducing historical heritage site. Specifically, this research aims to:

- a. Design and develop a marker-based AR application for the Ratu Boko site using the ADDIE development method.
- b. Present information regarding the function and historical context of selected elements on the Pendapa area through AR-based visualization and textual content.
- c. Evaluate the usability of the developed AR application based on user testing using the System Usability Scale (SUS).

1.5 Research Benefits

The benefits of this research are as follows:

- a. To assist visitors in understanding the function and historical context of the Pendapa area of Ratu Boko through interactive visualization.
- b. To demonstrate the application of Augmented Reality technology as a supporting medium in cultural heritage tourism.
- c. To provide an alternative digital learning medium that enhances user engagement and interaction at the Ratu Boko site.

1.6 Writing Systematic

This research is organized into five chapters, each of which is structured as follows:

a. Chapter I – Introduction

This chapter presents the background of the research, problem formulation, scope and limitations, research objectives, research benefits. This chapter serves as the foundation for understanding the context and direction of the study.

b. Chapter II – Literature Review

This chapter discusses the theoretical foundations relevant to the research, including concepts of Augmented Reality, its application in cultural heritage, development methodologies, and usability evaluation. In addition, this chapter reviews previous studies related to AR-based media to support the research framework.

c. Chapter III – Research Methodology

This chapter explains the detailed methodology used in this research, including the application of the ADDIE model, system design, data collection techniques, application development process, and evaluation methods.

d. Chapter IV – Results and Discussions

This chapter presents the results of the AR application development, including the system implementation and features. It also discusses the results of usability testing and analyzes the findings in relation to the research objectives.

e. Chapter V – Conclusion and Future Work

This chapter summarizes the conclusions derived from the research and provides recommendations for future development and improvement of the AR application.

CHAPTER II

LITERATURE REVIEW

2.1 Augmented Reality in Cultural Heritage

Augmented Reality (AR) is a technology that enables the integration of digital elements into the real-world environment in real time, allowing users to perceive virtual content as part of their physical surroundings (Arena et al., 2022). Through this integration, AR can overlay various forms of media, including text, images, and three-dimensional objects, onto real-world contexts, thereby enhancing how information is delivered and experienced (Mendoza-Ramírez et al., 2023). Due to this capability, AR has been increasingly adopted across multiple domains such as education, entertainment, and tourism (Boboc et al., 2022).

In the context of cultural heritage, AR has emerged as a promising medium for improving the delivery of historical information (Bachiller et al., 2023). Conventional methods such as printed brochures, static information boards, and guided tours often rely heavily on textual explanations, which may limit user engagement and accessibility (Awan et al., 2024). In contrast, AR enables the presentation of historical content in a more interactive and visual manner. Several studies have shown that AR can enhance user understanding by providing contextual visualizations, such as 3D reconstructions and interactive overlays, which help users interpret historical environments more effectively (Khor & Mubin, 2024; Md Nor et al., 2021).

Beyond visualization, AR also contributes to increased user engagement and learning motivation. Research conducted by (Lin et al., 2024) indicates that interactive digital experiences encourage active exploration, allowing users to interact with content rather than passively receive information. This interactive nature has been shown to foster deeper cognitive engagement compared to conventional media, particularly among younger audiences who tend to prefer visual and immersive forms of learning (Cho, 2025; Hirsch et al., 2022). These findings suggest that AR functions not only as a visualization tool but also as a medium that supports more effective knowledge construction.

However, despite its advantages, the implementation of AR in cultural heritage also faces several challenges. Technical issues such as tracking instability, hardware limitations, and environmental factors can affect the performance of AR applications. Lighting conditions, occlusions, and camera quality significantly influence AR reliability, particularly in outdoor environments (Boboc et al., 2022). These limitations highlight the importance of selecting appropriate AR techniques and system design strategies.

Based on these considerations, AR presents a promising approach for enhancing cultural heritage experiences, particularly in sites where physical remains are incomplete or difficult to interpret. This is especially relevant to Ratu Boko, where many structures exist only as foundations and fragmented elements, making it challenging for visitors to understand their original function through conventional media alone. Therefore, the use of AR as an interactive learning medium has the potential to bridge the gap between existing physical remains and their historical interpretations.

2.2 Mobile-based AR and Design Considerations

In mobile-based implementations, AR is primarily delivered using smartphones which are widely accessible and equipped with integrated sensors such as cameras and motion tracking capabilities. These capabilities enable the system to detect user position and orientation, supporting the delivery of context-aware and interactive experiences. As a result, this makes mobile AR a suitable approach for supporting interactive experiences in tourism and cultural heritage contexts (Cao et al., 2023).

From a technical perspective, AR systems rely on tracking methods to determine the position and orientation of virtual objects relative to the real world. Common tracking approaches include marker-based tracking, markerless tracking, and location-based tracking using GPS (Syed et al., 2022). Marker-based tracking utilizes predefined image targets to anchor virtual content. In contrast, markerless tracking uses natural features in the environment and provides greater flexibility. Location-based tracking relies on GPS data and is suitable for large-scale navigation (Syed et al., 2022).

In outdoor environments, several factors may affect AR tracking performance, including lighting variations, large spatial areas, and the lack of distinct visual reference structures. These conditions can reduce tracking stability and accuracy (Magrini et al., 2022; Zhang et al., 2023). Making it necessary to carefully select an appropriate tracking approach for the intended application.

For mobile AR development, platforms such as Android are widely used due to their large user base and accessibility, accounting for 70% of mobile operating system globally (Statista, 2025). Development tools such as Unity provide a flexible environment for integrating AR content, while software development kits (SDKs) such as Vuforia support tracking and real-time object recognition. These technologies are commonly utilized in AR application development due to their compatibility with mobile devices (Simon, 2023).

In terms of AR application design, visual elements play an important role in guiding user interaction and enhancing understanding. Directional indicators such as arrows, are commonly used as visual cues to highlight specific points of interest and assist users in focusing their attention within the AR environment (Wang et al., 2023). Additionally, information presented in AR can provide contextual descriptions related to observed object by overlaying digital content to the real-world environment. The design of these visual elements should emphasize clarity, readability, and usability, particularly in outdoor environments where visual distractions may affect user perception (Ghaemi et al., 2023). Furthermore, the information is presented concisely to avoid cognitive overload as excessive information may reduce user comprehension and interaction efficiency.

Based on the concepts described above, this research adopts mobile-based AR due to its accessibility and practicality for on-site use, allowing visitors to access AR content directly through smartphones. Marker-based tracking using image targets is selected for its stability and accuracy in aligning virtual objects with real world references, making it suitable for presenting information at specific points of interest. The Android platform is used due to its widespread adoption, while Unity and Vuforia are utilized to support efficient development of image-based AR features and 3D content integration. For interface design, directional arrows and 3D text are implemented to guide users and present information clearly, supporting a minimized cognitive overload in outdoor environments.

2.3 ADDIE Method

The ADDIE model is an instructional design framework consisting of five systematic phases: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). This model is widely used in the development of educational media and interactive learning systems due to its structured and iterative approach in guiding both design and evaluation processes (Soraya, 2022). Figure 2.1 shows the iterative phases on the ADDIE methodology.

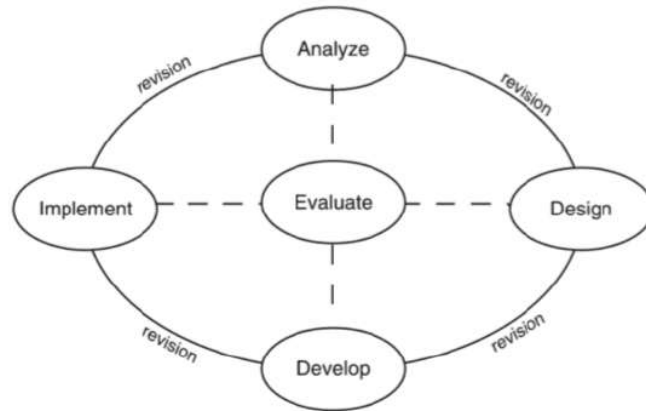


Figure 2.1 Phases on the ADDIE methodology

Source: (Branch, 2009)

One of the main advantages of the ADDIE model is its clear and sequential structure, which allows developers to approach system development in a logical and organized manner. Each phase is carried out in a structured order, ensuring that the development process remains aligned with user needs and system objectives. In addition, ADDIE supports continuous improvement through evaluation and feedback, enabling progressive refinement of the developed system (Adeoye et al., 2024).

Compared to other development models such as the Waterfall model, which tends to follow a linear and sequential process, ADDIE provides greater flexibility through its structured yet iterative design process. When the waterfall model requires each phase to be completed before moving to the next, ADDIE incorporates evaluation across multiple stages, allowing continuous refinement during development. Furthermore, ADDIE emphasizes instructional design principles and user-centered approaches, making it particularly relevant for developing applications that aim to deliver content effectively (Wan Ali & Wan Yahaya, 2023).

In the context of interactive technologies, particularly those integrating multimedia elements such as AR, the ADDIE model offers a structured approach between technical development and content design. AR applications incorporate multimedia elements such as text, audio, video, and graphics, requiring not only proper system functionality but also effective presentation and user interaction. Through its systematic phases, the ADDIE model supports the identification of user needs, the design of content and interaction, and the evaluation of usability and functionality in a structured manner (Suhaizal et al., 2023).

Based on these advantages, the ADDIE model is considered a suitable framework for developing interactive media that require both technical implementation and user-centered design. Its flexibility, systematic structure, and emphasis on evaluation make it particularly appropriate for supporting the development of AR-based applications in cultural heritage contexts.

In the context of this research, the development of AR application for the Ratu Boko heritage site requires not only technical system implementation but also careful structuring of educational content and user interaction. The application is designed to present contextual information for fragmented and partially preserved site elements, which demands a development approach that integrates both content design and usability considerations. AR applications also involve interactive visualization, requiring the system to be both functionally reliable and intuitively understandable for users.

2.4 System Testing

System testing is a process conducted to evaluate a developed application in terms of its functionality and non-functional aspects such as usability and reliability to ensure that it meets the specified requirements (Washizaki, 2025). This process is essential in verifying that the application operates according to its intended design while also delivering a satisfactory user experience in real-world conditions (International Organization for Standardization & International Electrotechnical Commission, 2023). In software quality evaluation, these aspects are commonly associated with broader quality characteristics such as functional suitability, usability, and portability (International Organization for Standardization & International Electrotechnical Commission, 2023).

In the context of mobile-based AR applications, system testing becomes particularly important due to the interactive nature of the system and its dependency on both user interaction, device capabilities, and environmental conditions, which can influence system performance (Mohammadhossein et al., 2025; Suter et al., 2023). Therefore, multiple testing approaches are commonly used to comprehensively evaluate different aspects of the system, as each method targets specific performance characteristics under varying conditions (Pargaonkar, 2023).

Testing methods such as System Usability Scale (SUS), compatibility testing, and black-box testing are commonly used to assess usability, technical adaptability, and functional correctness (Izzat & Saleem, 2023). These methods are relevant in evaluating AR-based

tourism applications, as they address key challenges related to user experience, device variability, and system reliability.

2.4.1 System Usability Scale (SUS)

The System Usability Scale (SUS) is a standardized instrument used to measure users' perceived usability of a system. It consists of ten statements evaluated using a five-point Likert scale ranging from "strongly disagree" to "strongly agree" and produces a single score ranging from 0 to 100 that represents the overall usability (Brooke, 1996). Figure 2.2 Shows the ten statements in the SUS Instrument by (Brooke, 1996).

	Strongly disagree						Strongly agree
1. I think that I would like to use this system frequently	☐	☐	☐	☐	☒	☐	
2. I found the system unnecessarily complex	☐	☐	☐	☒	☐	☐	
3. I thought the system was easy to use	☐	☒	☐	☐	☐	☐	
4. I think that I would need the support of a technical person to be able to use this system	☒	☐	☐	☐	☐	☐	
5. I found the various functions in this system were well integrated	☐	☒	☐	☐	☐	☐	
6. I thought there was too much inconsistency in this system	☐	☐	☒	☐	☐	☐	
7. I would imagine that most people would learn to use this system very quickly	☐	☒	☐	☐	☐	☐	
8. I found the system very cumbersome to use	☐	☐	☐	☒	☐	☐	
9. I felt very confident using the system	☐	☐	☐	☐	☒	☐	
10. I needed to learn a lot of things before I could get going with this system	☐	☒	☐	☐	☐	☐	

Figure 2.2 Ten Statements in The System Usability Scale Instrument

Source: (Brooke, 1996)

SUS provides a simple and efficient approach for assessing usability, as it is designed to be administered quickly while maintaining reliability in capturing users' subjective evaluations of systems interaction (Brooke, 1996). Due to its practicality, low cost, and technology-independent nature, the SUS is commonly applied in evaluating interactive systems to obtain a general measure of perceived usability and user satisfaction (Vlachogianni & Tselios, 2022).

In the context of mobile-based AR applications, usability plays a crucial role in shaping user experience and technology adoption. AR technologies significantly influence tourism experiences as they provide interactive and immersive environments that affect users' perceptions and behavioral intentions. Furthermore, factors such as ease of use and facilitating conditions have been shown to influence users' acceptance indicating that poor usability may hinder user engagement and reduce the effectiveness of the application (Wen et al., 2023).

2.4.2 Compatibility Testing

Compatibility testing is a type of software testing that aims to ensure that an application can build and function properly across different configurations and environments, which may consist of multiple components with varying versions and dependencies. Such environments are often heterogeneous, making compatibility testing essential to verify that software behaves correctly under different conditions (Yoon et al., 2008).

This testing is particularly important in mobile application development, especially within the Android ecosystem, where a wide variety of devices are developed by different manufacturers, resulting in differences in hardware specifications and system behavior. This phenomenon, commonly referred to as Android fragmentation, causes application to behave differently depending on the device, making compatibility an important issue for developers (Ham & Park, 2011).

In this context, compatibility testing is used to identify differences in application behavior across various environments and configurations, ensuring that the system can operate correctly under diverse conditions. In mobile AR applications, compatibility becomes more critical because system performance depends on device capabilities and hardware configurations. Variations in these components may influence how the application operates across devices. Therefore, compatibility testing plays an important role in ensuring that AR applications remain functional and accessible across a wide range of devices.

2.4.3 Black-box Testing

Black-box testing is a software testing method that focuses on evaluating system functionality based on inputs and outputs without considering the internal structure or implementation of the code. This approach is used to verify whether the system behaves according to its specified functional requirements (Khan, 2021).

Test Case	Procedure to test	Expected Outcome
Registration Module		
Invalid sign up to the system	Inserting invalid details to the system.	A warning message will appear to show the error.
Check Strength of the Password	Insert passwords with different lengths or with passwords only with letters and password with mix of characters and letters	Show password strength

Figure 2.3 Example of a Black-box Testing Scenario

Source: (Paranagama, 2016)

In practice, black-box testing involves designing test cases based on system requirements and observing whether the outputs produced match the expected results. Since this method does not require knowledge of the internal workings of the systems, it allows tester to evaluate system behavior independently of its implementations (Khan, 2021).

In this context, black-box testing is useful for identifying functional errors and ensuring that the system produces correct outputs for given inputs. In interactive applications such as AR systems, this approach can be applied to test whether application features function as expected under different input conditions.

2.5 Previous Studies

Previous studies have demonstrated the growing use of AR in cultural heritage as a medium to enhance visualization, engagement, and learning experiences. Based on the comparison in Table 2.1, these studies can be broadly categorized into three main approaches: immersive large-scale visualization, marker-based educational applications, and location-based AR systems.

Table 2.1 Comparison of Previous Studies

Study	Tracking	Content	Focus	Result	Limitations
(Adhitama et al., 2025)	Marker-based (QR)	High-detail 3D reconstruction (photogrammetry + LiDAR)	Digital preservation & immersive visualization	Functional AR system; supports conservation and education	High loading time (8 sec – 11 min) heavy computation
(Adi et al., 2024)	Marker-based	AR Book + 3D temple models	Educational learning for younger generation	Knowledge increased by 42.43%	Limited interaction scope; depends on physical markers
(Tsabita & Nurrisqa, 2025)	Marker-based	AR Book with historical monument content	Learning media (structured educational content)	High feasibility (89% user score, expert validation)	Focus limited to classroom context; lacks real-site integration
(Suyuti & Setyanto, 2023)	Marker-based & Markerless	3D objects + tourism information	Cultural tourism & user understanding	Positive user acceptance (87% UTAUT)	Less emphasis on structured content delivery
(Kleftodimos et al., 2023)	Location-based (GPS)	Multimedia (text , 3D, interaction)	Navigation + cultural education	Strong engagement & learning outcomes (large-scale evaluation)	Depends on location accuracy; less object specific explanation

Studies focusing on immersive visualization, such as the research by (Adhitama et al., 2025), utilized high-detail 3D reconstruction techniques combined with marker-based tracking to recreate heritage structures. These approaches provide rich visual experiences and support digital preservation. However, they often require high computational resources, resulting in performance limitations such as long loading times and reduced efficiency on mobile device (Adhitama et al., 2025).

Other studies adopt a marker-based approach to develop AR application as educational media. Research by (Adi et al., 2024) and (Tsabita & Nurrisqa, 2025) integrates AR with book-based markers to present 3D objects and structured learning content. These application have been shown to improve user understanding and learning outcomes, with measurable increases in knowledge and high usability scores (Adi et al., 2024; Tsabita & Nurrisqa, 2025).

Nevertheless, these systems are generally limited to controlled environments and often lack contextual integration with real-world heritage sites.

In addition, several studies implement AR for cultural tourism using either marker-based or location-based tracking. For example, (Suyuti & Setyanto, 2023) developed an AR application to enhance visitor understanding of cultural sites, achieving positive user acceptance. Similarly, (Kleftodimos et al., 2023) utilized location-based AR to guide users through heritage environments, combining navigation and educational content with strong engagement results. However, these approaches tend to emphasize exploration and navigation, with less focus on structured, object-specific explanation that support deeper understanding (Kleftodimos et al., 2023; Suyuti & Setyanto, 2023)

Based on these comparisons, it can be identified that previous studies predominantly emphasize either immersive visualization, educational content delivery, or navigation-based interaction. However, limited attention has been given to the development of AR applications that focus on simplified, object-based explanations designed to improve user understanding, particularly in heritage sites with incomplete or fragmented physical structures. Furthermore, the integration of stable marker-based tracking with structured content design and systematic usability evaluation remains insufficiently explored.

2.6 Existing Digital Heritage Platforms

In recent years, various digital platforms have been developed to improve public access to cultural heritage information in Indonesia. These platforms provide historical descriptions, documentation, and cultural data that support educational and tourism activities. Among the prominent examples are Jogja Cagar and DAPOBUD (Data Pokok Kebudayaan), which serve as official sources of cultural heritage information at regional and national levels respectively.

Jogja Cagar is a digital platform managed by the Special Region of Yogyakarta Government that provides information regarding cultural heritage sites, historical buildings, and cultural assets within Yogyakarta. The platform presents descriptions, photographs, location information, and historical backgrounds of registered cultural heritage objects. Through its web-based interface, users can access information about heritage sites, including Ratu Boko Heritage Site, before or during their visits. However, the information is primarily delivered through text and image-based content, requiring visitors to independently relate the presented information to the physical object observed at the site.

At the national level, DAPOBUD (Data Pokok Kebudayaan) functions as an integrated cultural database managed by the Ministry of Culture of the Republic of Indonesia. The platform provides comprehensive information regarding cultural heritage assets, cultural heritage organizations, cultural actors, and other cultural resources throughout Indonesia. Similar to Jogja Cagar, DAPOBUD emphasizes information accessibility and documentation through a database-oriented approach. While it serves as an important reference source for cultural information, the platform does not provide contextual interpretation directly linked to physical heritage objects in real-world environments.

Compared to these existing platforms, the proposed system in this research focuses not only on information delivery but also on contextual interpretation through AR technology. By utilizing marker-based AR, the application enables visitors to access information directly while observing physical objects at the heritage site. This approach aims to bridge the gap between fragmented physical remains and their historical interpretation by providing visual, textual, and audio-based explanations integrated in the application. Table 2.2 presents a comparison between existing digital heritage platforms and the proposed system.

Table 2.2 Comparison of Existing Digital Heritage Platforms and Proposed System

Aspect	Jogja Cagar	DAPOBUD	Proposed AR Application
Heritage Information	✓	✓	✓
Historical Description	✓	✓	✓
Image Documentation	✓	✓	✓
Mobile Accessibility	✓	✓	✓
Audio Narration	x	x	✓
Interactive Features	Limited	Limited	✓
Object-Specific Interpretation	Partial	Partial	✓
Direct Integration with Physical Objects	x	x	✓
AR Visualization	x	x	✓
Marker-based Recognition	x	x	✓

Designed for On-site Interpretation	Limited	x	✓
-------------------------------------	---------	---	---

Based on the comparison, existing digital heritage platforms gave access to cultural heritage information through digital documentation and information dissemination. However, these platforms primarily rely on conventional text and image-based presentation methods. In contrast, the proposed application extends beyond information access by providing contextual and interactive interpretation through marker-based AR, allowing visitors to obtain explanations directly while observing heritage objects in their physical environment.

2.7 Research Gap

Although AR has been widely implemented within cultural heritage contexts, existing studies reveal several limitations. Research focusing on high-fidelity reconstruction primarily emphasizes immersive visualization and digital preservation. While such approaches provide rich visual experiences, they often require substantial computational resources and place less emphasis on helping visitors understand the function of specific architectural remains (Adhitama et al., 2025). Other studies have employed marker-based AR as educational media through books and classroom-oriented learning materials. These approaches have demonstrated positive learning outcomes and usability results. However, they are generally conducted in controlled environments and not specifically designed for direct interaction with heritage objects in real-world tourism settings (Adi et al., 2024).

Meanwhile, tourism-oriented AR applications commonly utilize markerless or location-based approaches to support navigation and site exploration. Although these systems improve visitor engagement, they tend to focus on movement and orientation throughout the site rather than providing detailed object-level explanations that assist visitors in interpreting fragmented architectural remains (Kleftodimos et al., 2023; Suyuti & Setyanto, 2023).

Based on this review, a research gap can be identified. Limited studies have investigated the use of marker-based AR as a medium for delivering contextual, object-focused explanations directly linked to fragmented heritage structures within real-world environments. Furthermore, previous studies rarely combine marker-based tracking, expert-validated cultural heritage content, object-level interpretation, and systematic usability evaluation within a single application (Kleftodimos et al., 2023; Suyuti & Setyanto, 2023; Tsabita & Nurrisqa, 2025). This gap is particularly relevant in the context of the Ratu Boko Heritage Site, where many architectural elements survive only as foundations or partial structures. Visitors often encounter

difficulties in understanding the original function and significance of these remains through conventional informational media alone. Therefore, this research develops a marker-based AR application that emphasizes simplified visual explanations and contextual information for selected architectural elements within the Pendapa area of Ratu Boko.

Unlike previous studies that focus primarily on reconstruction, navigation, or classroom-based learning, this research focuses on supporting visitor interpretation of specific heritage object through direct interaction with physical remains. In addition, the developed content is validated by domain experts and evaluated through usability testing using the System Usability Scale (SUS), contributing a practical and user-centered implementation of AR for cultural heritage interpretation.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Methodology

This research adopts the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model as the primary development methodology. The ADDIE model was selected because it provides a systematic framework for developing interactive learning and information systems while maintaining a strong focus on user needs and evaluation. The model is particularly suitable for this study because the developed application combines technological implementation, heritage interpretation, multimedia content design, and user interaction. The ADDIE model supports structured development processes and continuous refinement through iterative evaluation stages. Figure 2.2 displays the ADDIE methodology.

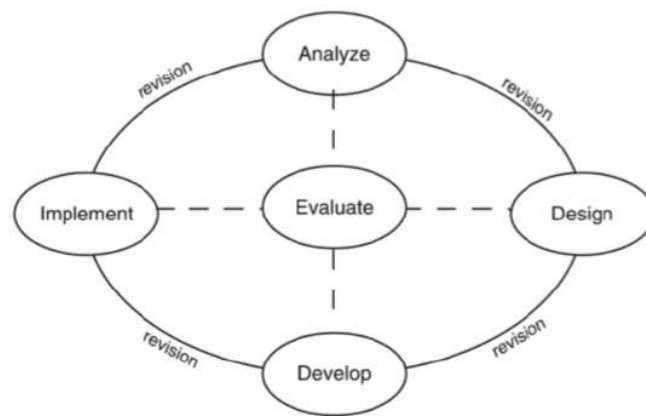


Figure 3.1 ADDIE Methodology

Source: (Branch, 2009)

Through the Analysis phase, user needs, site conditions, and content requirements are identified. The Design phase focuses on defining system architecture, user interaction, interface design, and content structure. The Development phase involves the implementation of the application using Unity, Vuforia, and Android Studio. The implementation phase focuses on deploying and utilizing the application in a real-world environment, while the Evaluation phase assesses the system through functionality testing, compatibility testing, content validation, and usability evaluation.

3.2 Analysis Phase

The analysis phase was conducted to identify the gap between the current condition of information delivery at the Ratu Boko Heritage Site and the expected visitor experience. This phase is aimed to determine the information needs of visitors, identify the limitations of existing informational media, and define the requirements for the proposed AR application. To support the analysis process, three data collection methods will be employed: literature review, field observation, and stakeholder discussions. The literature review is conducted to gather historical information regarding the Ratu Boko Heritage Site, particularly the Pendapa area and its architectural elements. In addition, references related to AR technology, cultural heritage interpretation, and mobile-based AR applications is reviewed to support the development of the proposed system.

Field observations will be conducted at the Ratu Boko Heritage Site to examine the existing informational media available to visitors. The observation focused on printed brochures, informational signage, and the physical condition of selected heritage objects. This activity is intended to identify potential limitations in the current information delivery approach and determine opportunities for digital enhancement. Stakeholder discussions are conducted with individual directly involved in heritage interpretation at the site. Discussions with archaeologist will be conducted to identify historically relevant objects and determine appropriate content for the application. Discussions with a tour guide, is conducted to understand visitor information needs and common interpretation challenges encountered during guided tours.

3.3 Design Phase

In the design phase, the structure and behavior of the system are planned prior to implementation. This phase defines how users will interact with the application and how information will be delivered through AR features. The design aims to ensure that the system is intuitive, efficient, and aligned with user needs identified in the analysis phase.

A use case diagram will be developed to represent the interaction between the user and the system, illustrating the main functionalities of the application. In addition, a system flowchart will be designed to describe the sequence of processes from application launch to AR content display, including decision points such as marker detection and user interaction flow. These diagrams are intended to provide a clear representation of system behavior and functionality.

The interface design is developed in the form of low-fidelity layouts to define the placement of key interface elements and ensure simple navigation. This design focuses on usability and clarity, allowing users to access features with minimal effort. The layout includes key components such as the main menu, AR interface, map view, and POI list.

Content planning will also be conducted in this phase to ensure that each selected object will be associated with digital content, including visual representations and explanatory descriptions that are concise and easy to understand. This structured approach is intended to support user comprehension while avoiding cognitive overload.

3.4 Development Phase

The development phase focuses on implementing the system based on the design specifications established in the previous stage. The application will be developed as an integrated mobile that combines AR functionality with supporting features such as point-of-interest (POI) data and map integration. This phase aims to ensure that all planned components are realized into a functional application.

The AR functionality is planned to be developed using Unity, with Vuforia utilized to enable marker-based tracking. Image targets will be defined and configured to trigger digital content when detected by device camera, allowing virtual elements to appear in alignment with real-world references. Each marker will be associated with specific objects within the Pendapa area to provide contextual information.

In addition to AR features, a structured POI system will be implemented to allow users to access information without relying solely on AR interaction. A map feature will also be integrated into the application to support spatial understanding by displaying the layout of the site and the location of points of interest. These supporting features are intended to enhance usability and navigation within the application.

The integration between the AR module and the Android application will be carried out by exporting the Unity project as an Android-compatible module and incorporating it into the main application. The development process is planned to be conducted iteratively to ensure that all components function cohesively and meet the defined system requirements. This approach allows for adjustments to be made during development to improve system performance and usability.

3.5 Implementation Phase

In the implementation phase, the developed application will be prepared for deployment and initial use on Android devices. The system will be installed and configured to ensure that all required features, such as camera access and sensor functionality, operate properly under expected conditions. This phase is intended to transition the system from development to actual usage.

A usage scenario will be defined to describe how users are expected to interact with the application. This includes steps such as launching the application, accessing the AR feature, scanning markers, and viewing the displayed information. These scenarios are designed to represent realistic user interaction within the application.

Furthermore, the implementation process considers the environmental conditions in which the application will be used. Since the application is designed for outdoor use, factors such as lighting conditions and device positioning will be considered. This ensures that the system can function effectively in real-world usage contexts.

3.6 Evaluation Phase

The evaluation phase is conducted to assess whether the developed application meets the intended objectives in terms of functionality, usability, and performance. This phase is essential to determine the effectiveness of the system and identify potential areas for improvement. The evaluation will be carried out using multiple testing approaches to ensure comprehensive assessment.

Usability evaluation will be conducted using the System Usability Scale (SUS), where users will be asked to interact with the application by performing predefined tasks. After completing the tasks, users will fill out a questionnaire consisting of ten statements using a Likert scale to measure their perception of system usability. The results will be processed to obtain an overall usability score.

According to (Nielsen, 1994) usability testing with a small number of users, typically around five, is sufficient to identify the majority of usability issues, as early participants tend to reveal the most critical problems. Based on this principle, this study adopts a usability evaluation approach with a relatively limited number of respondents. However, to provide a more representative evaluation, this study involves more respondents than just five. It is considered adequate for obtaining a more stable usability score while still maintaining efficiency in the evaluation process.

The SUS score is calculated using a standardized procedure. For odd-numbered items, the score contribution is obtained by subtracting 1 from the user response. For even-numbered items, the contribution is calculated by subtracting the response from 5. The adjusted scores are then summed and multiplied by 2.5 to obtain the final SUS score ranging from 0 to 100.

$$SUS\ Score = \left(\sum adjusted\ scores \right) \times 2.5$$

The interpretation of the SUS score will follow standard usability benchmarks, which will be presented in Chapter IV.

Before conducting the SUS questionnaire, a testing scenario is prepared to guide user interaction with the system.

Table 3.1 Planned Testing Scenario

No.	Task Description
1	Launch the application and access the main menu
2	Use the AR feature to scan a marker
3	View AR content and read object information
4	Access the POI feature and explore object details
5	Use the map to identify object locations

Functional testing will be conducted using black-box testing approach, where the test scenarios are prepared based on system requirements. Each feature will be evaluated by comparing the expected outputs with the actual system behavior to ensure system functioning as expected. In addition, compatibility testing will be performed across different Android devices to assess system performance under varying hardware conditions.

To support the functional testing process, a set of planned test cases is defined. The black-box testing plan is shown in Table 3.2.

Table 3.2 Black-box Testing

No	Feature	Test Scenario	Expected Result
1	Main Menu	User selects AR feature from main menu	AR view with camera is activated successfully

2	AR View	User scans a valid marker	Corresponding AR content (3D Text, audio, Info panel) is displayed correctly
3	AR View	User opens AR map (marker position guide)	Map displays positions of available markers in the Pendopo area
4	AR Marker Detection	User taps information panel in AR view	Information panel appears with correct object description
5	AR Marker Detection	User plays audio narration	Audio plays clearly and matches the detected object
6	AR Marker Detection	User pauses audio narration	Audio pauses
7	POI Access	User navigates from Overview to POI list	POI list is displayed correctly
8	POI Access	User selects a POI from the list	POI detail page (image, description, coordinates map) is displayed
9	How to Use	User opens “How to Use” page	Instructional content is displayed clearly
10	Onboarding	User launches app for the first time	Onboarding screens are displayed sequentially
11	Navigation	User navigates between pages (Back/Home)	Application transitions between pages without errors

In addition to functional testing, compatibility testing is conducted to ensure that the application performs properly across different Android devices with varying specifications. This testing is important to evaluate system stability and performance under different hardware conditions. The planned compatibility testing configuration is presented in Table 3.3.

Table 3.3 Compatibility Testing

No	Device	OS Version	RAM	Expected Performance
1	Samsung	Android 10	3 GB	Excellent
2	Xiaomi	Android 11	4 GB	Good
3	Vivo	Android 12	6 GB	Good
4	Samsung	Android 13	6 GB	Bad

To evaluate system performance, this study employs a four-point ordinal rating scale: 4 (Excellent), 3 (Good), 2 (Fair), and 1 (Poor). This classification is based on direct observation of technical behavior, assessing metrics such as AR rendering and tracking stability. This approach aligns with (International Organization for Standardization & International Electrotechnical Commission, 2023) standards, where performance is categorized into defined levels.

Furthermore, a ordinal four-point scale enhances consistency by requiring a clear distinction between 'Good' and 'Fair' performance, reducing rating ambiguity and ensuring the results accurately reflect stability across different devices (Sauro, 2016).

To ensure the accuracy and reliability of the presented information, content validation will be conducted with domain experts, such as archaeologist or cultural heritage practitioner. The experts will review the AR content, including visual representations and explanatory descriptions, to evaluate whether the information is appropriate, accurate, and aligned with historical context. Feedback obtained from this validation process will be used to refine the content to ensure its credibility and relevance. The validation aspects used to guide expert evaluation are summarized in Table 3.4.

Table 3.4 Validation Aspect Table for Expert Archaeologist

No	Aspect
1	Historical Accuracy
2	Clarity of Information
3	Audience Suitability
4	Narrative Flow
5	Context Relevance
6	Language Style (Audio Guide)
7	Engagement
8	Narrative Length

9	Information Clarity
---	---------------------

To support a more structured evaluation, the validation process utilizes a rating-based assessment. Each aspect is evaluated using a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The final validation score is calculated by averaging the scores across all aspects evaluated by the experts.

$$Validation\ Score = \frac{(\sum scores)}{(number\ of\ items)}$$

While the archaeologist focuses on evaluating the historical accuracy of the content, the tour guide evaluates the clarity and interpretability of the information from how real tours are conducted. The combination of expert roles ensures that the content is evaluated from both academic and practical perspectives. The aspects used to guide the tour guide evaluation are summarized in Table 3.5

Table 3.5 Validation Aspect Table for Tour Guide

No	Aspect
1	Content matches explanation
2	Covers important points
3	No contradictions with field practice
4	Matches tour flow
5	Easy to understand
6	Interesting delivery
7	Not too long/confusing
8	Helps independent understanding
9	Supports guiding activity
10	AR adds value

A dichotomous (Yes/No) approach was selected to evaluate the functional requirements of the AR content. This format was chosen because it has been proven to be equally reliable, quicker, and perceived as less complex than traditional Likert-type scales (Dolnicar et al., 2011). By using a binary format, the evaluation focuses on decisive, actionable judgments

regarding whether each technical aspect is sufficiently fulfilled for real-world guiding activities.

The results of this evaluation are then quantified by calculating the proportion of affirmative responses, allowing the overall suitability of the application to be expressed as a percentage.

The results obtained from these evaluation methods will be analyzed in Chapter IV. This analysis will be used to determine whether the system meets the defined objectives and to identify improvements for future development. Through this process, the overall quality and effectiveness of the application can be systematically assessed.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Analysis

The development of the AR application is based on the gap between the current condition of the Ratu Boko site and the expected visitor experience. Due to fragmented and incomplete nature of the remaining structures, many architectural elements are difficult to interpret visually. As a result, visitors often struggle to understand the original function and meaning of the site using only existing media such as static signage and printed information.

Examples of these existing informational media are presented in Figure 4.1, Figure 4.2, Figure 4.3, which illustrates on-site signage, printed brochures used at the Ratu Boko site. The media primarily have limited visual support, making it difficult for visitors to directly relate to provided information to the observed physical structures.



Figure 4.1 Printed Brochure Provided in the Entrance

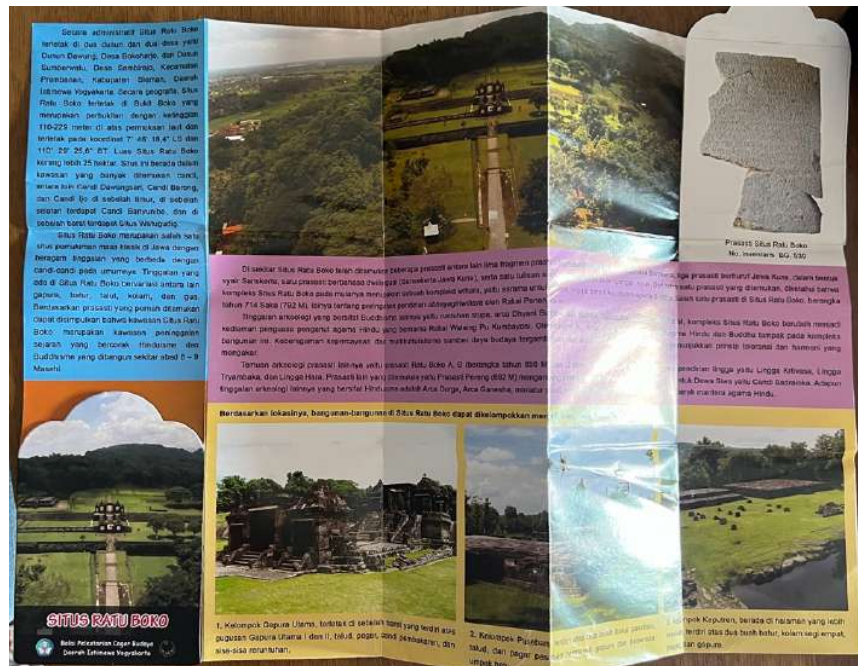


Figure 4.2 Older Version of the Brochure for Ratu Boko

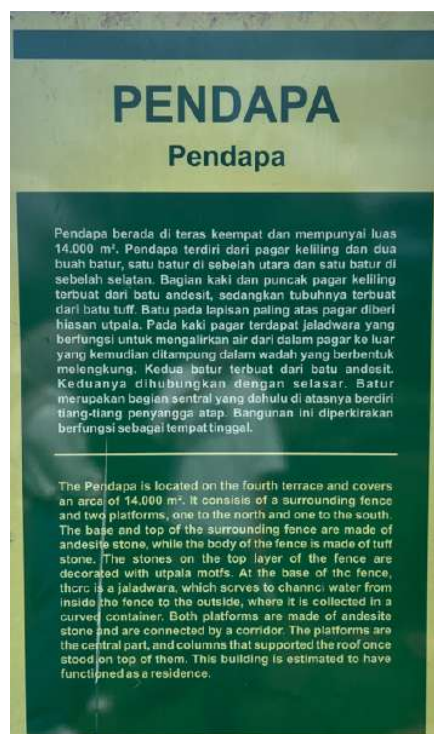


Figure 4.3 On-site Informational Signage

As shown in Figure 4.1-4.3, the information is predominantly delivered through text-heavy formats with limited visual support, while on-site informational signage is often placed

several meters away from the corresponding structures. This condition may reduce visitors to directly associate the provided information with the physical remains being observed, particularly for the first-time visitors.

To further investigate the issue, discussions were conducted with Mrs. Septi. Indrawati Kusumaningsih, S.S., M.A., an archeologist at the Ratu Boko Heritage Site, and Mr. Yulianto, a local tour guide. In addition, interviews were conducted with several visitors to obtain direct feedback regarding their experiences when exploring the site. These activities aimed to identify common interpretation challenges and determine the type of information support needed by visitors.

The discussions and interviews revealed that visitors frequently experience difficulties in understanding. The original function and significance of several architectural remains due to their fragmented condition. Although brochures and informational signage provide historical information, visitors often struggle to relate textual descriptions to the observed physical objects. This challenge is particularly evident for independent visitors who explore the site without assistance from a tour guide.

Furthermore, feedback from informally interviewed visitors of Ratu Boko indicated a preference for information presented in a more visual and interactive manner. 3 visitors reported that understanding the purpose of individual architectural elements would be easier if explanations were directly connected to the observed objects rather than being presented separately through brochures or signage. Similar observations were highlighted by the stakeholders, who noted that visual demonstrations and contextual explanations are often required during guided tours to help visitors interpret the site.

The analysis phase also considered the language used within the application. Although the majority of visitors at the Ratu Boko Heritage Site are domestic tourists, the application was developed in English to maintain a manageable development scope and focus on evaluating the functionality and usability of the proposed AR system. Furthermore, English is commonly used in tourism-related contexts and allows the content to remain accessible to both domestic visitors with basic English proficiency and international visitors.

Based on these findings, it was concluded that the existing informational media were not sufficient to fully support independent interpretation of the heritage site. Therefore, a digital medium capable of providing contextual explanations directly alongside physical objects was considered necessary. AR was selected as a suitable approach because it enables digital

information to be integrated with the real-world environment, allowing visitors to access visual, textual, and audio-based explanations while observing heritage objects on-site.

The analysis also identified the primary content focus of the application. Based on recommendations from the archaeologist and the historical relevance of the objects within the Pendapa area, five architectural elements were selected for implementation: Notched stone, Batu Umpak, Jaladwara, Stone Materials, and Makara. These objects were chosen because they represent important components of the site's architecture while also being suitable for object-based interpretation through AR. The findings obtained during this phase were subsequently translated into system requirements. The application was required to support marker recognition, real-time AR content display, object-specific information presentation, audio narration, point-of-interest (POI) information and map-based navigation. The relationship between identified user needs and the resulting system requirements is presented in Table 4.1

Table 4.1 User Needs and System Requirement Mapping

No	User Needs	System Requirement	Implementation in System
1	Easy to use interface	Simple navigation with minimal interaction	Main menu with clear buttons
2	Understand object meaning	System must display AR content	3D overlay + text descriptions
3	Guidance on what to see	System must provide visual cues.	Directional arrows in AR
4	Access without AR	System must provide non-AR info	POI feature
5	Works in outdoors	System must ensure stable tracking	Marker-based AR
6	Detect Object interaction	System must ensure stable tracking	Camera + image target detection
7	Display correct content	System must ensure stable tracking	Target database
8	Navigate site	System must ensure stable tracking	Map feature

The identified user needs are translated into system requirements. This mapping ensures that each feature implemented in the system directly addresses real user problems observed during the analysis phase.

4.2 Design

Based on the analysis phase, the system design is developed to ensure that the application can be effectively support user understanding through structured interaction and clear information delivery. This phase defines how the system operates, how users interact with it, and how content is presented within the application.

4.2.1 Use Case Diagram

The use case diagram illustrates the interaction between the user and the system. In this application, the user acts as the primary actor who interacts directly with all system features. The main functionality of the system is represented by the “Scan Marker” use case, which enables the user to interact with the AR feature. When a marker is successfully detected, the system displays the AR objects and corresponding information. In addition, the system provides audio narration for each object.

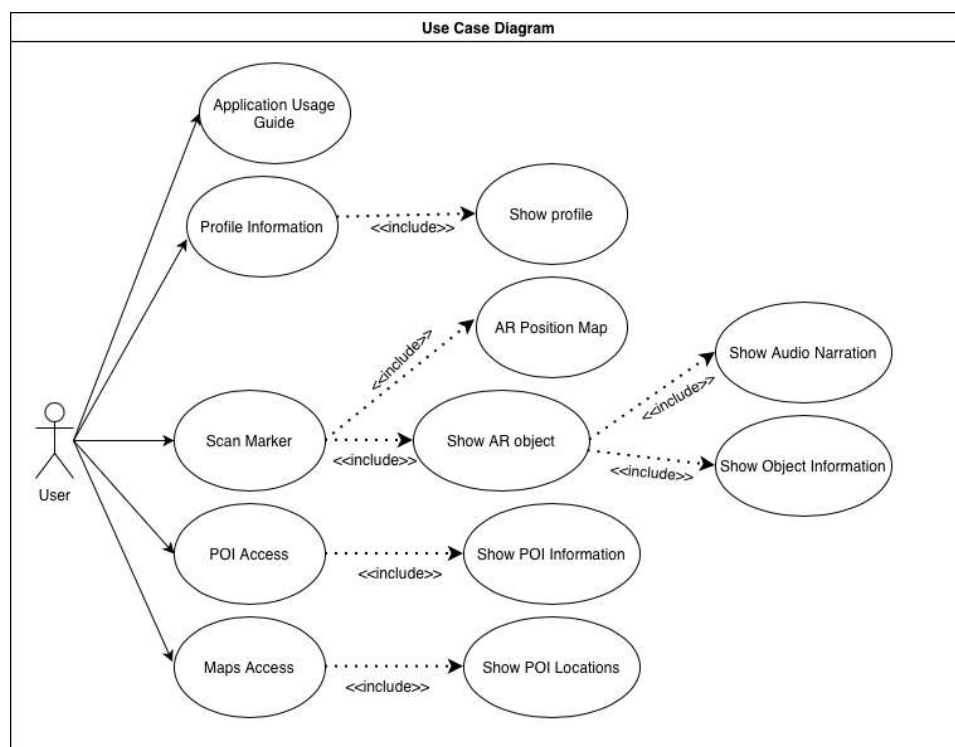


Figure 4.4 Use Case Diagram of the Application

Besides AR interaction, the system also provides supporting non-AR features like “POI lists Access” for exploring other POI at the Ratu Boko site other than the Pendapa area. The

system provides two types of map functionality “Maps Access” represents a standalone map that allows users to explore the location of points of interests across the Ratu Boko site. In contrast, within the AR interaction, the system provides a map that displays the position of predefined markers specifically in the Pendapa area. This feature is integrated as part of the AR interaction to assist users in locating markers more efficiently. In “Profile Information” feature, allow users to view information about the application developer. For new users, a “Application Usage Guide” is accessible to assist users on how to operate the application before interacting with its main functionalities.

The relationships between use cases are modeled using the “<<include>>” relationship. Indicating that certain functionalities are always executed as part of the main process.

4.2.2 System Flowchart

The system flowchart describes the overall process of the application, starting from when the user launches the application until the system displays the corresponding content. The process begins when the user opens the application and accesses the main menu to select a desired feature. The overall system workflow, including the AR marker detection process and alternative navigation through POI and map features, is illustrated in Figure 4.2.

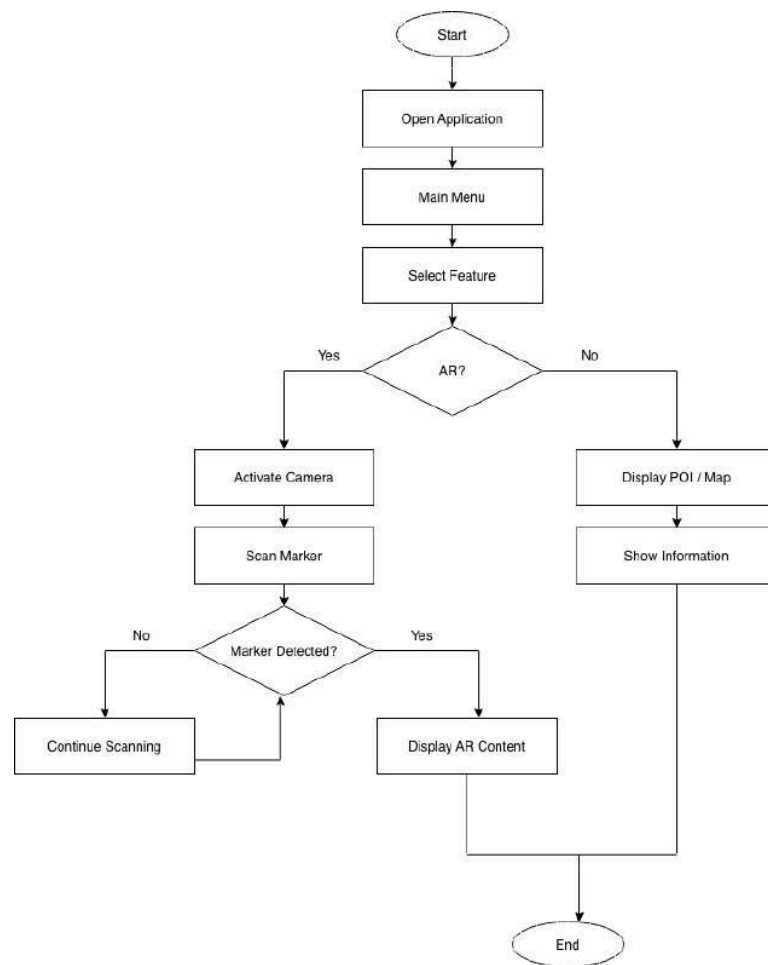


Figure 4.5 System Flowchart of the Application

If the user selects the AR feature, the system activates the device camera and initiates the marker scanning process. The system then attempts to detect a predefined marker to trigger the corresponding digital content. When the marker is successfully detected, the system displays AR content aligned with the detected marker, while if the marker is not detected, the system continues scanning until a valid marker is recognized.

In addition to AR interaction, users can access information through the POI and map features. These features allow users to explore content and navigate the area without relying solely on AR capabilities as AR is only available on selected POI. This flow ensures a simple and guided interaction process, enabling users to interact with the application efficiently and intuitively.

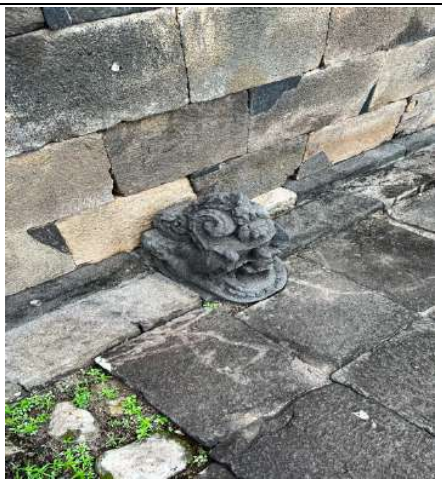
4.2.3 Marker Design and AR Interaction

The application utilizes a marker-based AR approach, where each marker functions as an image target that triggers the appearance of digital content. Each marker is associated with a specific object within the Pendapa area, enabling the system to align virtual elements with real-world references accurately. This approach allows users to directly relate the displayed information to the physical structures present at the site.

The selection of marker-based tracking is based on its stability and reliability in outdoor environments, where lighting conditions and spatial variations may affect tracking performance. Especially in scenarios with limited environmental features. Each marker is chosen to represent selected elements, including Parit, Batu Umpak, Batuan Penyusun, Jaladwara, and Makara. Each of these object as markers is based on their visual distinctiveness and contextual relevance within the site. The marker designs used in the application are presented in Table 4.2.

Table 4.2 Marker Details of Pendapa

Marker	Object	Purpose
	Stone Material	To describe the different materials used in construction of the Ratu Boko Pendapa outer wall.
	Pedestal Stone	A pedestal stone, used as a foundation to hold wooden columns of the building structure.

	Notched Stone	A set of stones that are carved into forming a line , speculated to align the inner walls that covered the pendapa area.
	Jaladwara	An ornanement that functions to flow water out of the building area, serves as a drainage.
	Kala Makara	An ornament that is believed by Hindu-buddhist traditions, to expel negative spirits / energy / dangers from entering the building.

These objects exhibit clear structural features that are easily recogniziabale, making them suitable for stable image-based detection. In addition, these elements represent key

architectural components that are directly related to the physical environment within the Pendapa area, which is selected as the focus of this study as it serves as a central architectural space within the Ratu Boko complex.

This selection is also driven by the intention to emphasize smaller architectural details that are often overlooked by visitors. Rather than presenting broad explanations of larger structures in Ratu Boko area, the application focuses on specific elements that may not be immediately visible or easily interpreted. This approach enables the system to deliver more focused and contextual information, enhancing user understanding of the site's finer architectural details.

The marker design considers visual distinctiveness and detectability to ensure accurate recognition by the system. Unique visual features are used to improve detection performance and reduce the possibility of misidentification. This design approach helps maintain stable tracking and ensures that AR content appears consistently when the marker is scanned.

The AR interaction is designed to be simple and intuitive to accommodate a wide range of users. Users only need to point their device camera toward the marker to access the content, without requiring complex gestures or navigation steps. Once the marker is detected, the system displays visual overlays such as directional indicators, textual descriptions to support user understanding.

4.2.4 Content Design

The content presented in the application is designed based on insights obtained from literature review and expert discussions. The information is structured to prioritize clarity, relevance, and ease of understanding, particularly for users with diverse backgrounds. Rather than presenting detailed historical explanations, the content is simplified into concise descriptions that focus on function and context of each object.

This approach is adopted to reduce cognitive overload and to address the observed difficulty among visitors in connecting complex historical narratives with physical structures. The content is designed to be short, direct, and supported by visual cues to help users.

Table 4.3 POI Content Display

Object	Photos	Description in Detail
Gapura		Gate I is located on the second terrace. This gate complex, designed in the form of a paduraksa, consists of three gates positioned close to one another. The central gate serves as the main gate and is larger in size, with a floor level higher than those of the two flanking gates.
Pendapa Agung		The pendapa structure is located on the fourth terrace and covers an area of approximately 14,000 m². The pendapa complex consists of an enclosing fence and two batur (stone platforms), one situated to the north and the other to the south. The base and roof of the surrounding fence are made of andesite stone, while the wall section is constructed from white stone.

The content in the application is delivered through different interaction contexts to support both immersive and exploratory experiences. In the AR mode, the context focuses on specific architectural details such as Makara and Jaladwara, which are presented through visual overlays, 3D text and audio guidance.

Table 4.4 AR-based Content Display

Object	AR Content Display
Makara	 The image shows a stone structure with a Makara (carved animal head) and a Kala (bell-shaped finial). A purple arrow points to the Makara, and another purple arrow points to the Kala. The labels 'Makara' and 'Kala' are overlaid in brown text.
Jaladwara	 The image shows a stone structure with a Jaladwara (carved animal head). A purple arrow points to the Jaladwara, and the label 'Jaladwara' is overlaid in brown text.

Table 4.4 presents the AR-based content display for selected objects within the Pendapa area of the Ratu Boko site, specifically focusing on the Makara and Jaladwara elements. The figure illustrates how the developed application overlays contextual information directly onto real-world objects using marker-based AR.

In the first section, the Makara object is shown along with its associated architectural elements, including the Kala. The AR system highlights these components using visual cues in the form of directional arrows and labeled text. These overlays are designed to guide the user's attention to specific parts of the structure, enabling clearer identification of each element. The combination of arrows and labels helps users distinguish between the Makara and Kala, which may otherwise be difficult to interpret due to the fragmented condition of the structure. This approach supports object-based explanation by linking digital annotations directly to the corresponding physical features.

In the second section, the Jaladwara object is displayed with a similar AR-based approach. The system uses directional arrows and text labels to indicate the exact location of

the Jaladwara within the structure. This is particularly important as the object is relatively small and positioned at a lower level, making it less noticeable to visitors without guidance. The AR overlay enhances visibility and ensures that users can accurately recognize the object in its physical context.

Table 4.5 Non-AR Content Presentation

Object	Map Coordinates	Photo
Pendapa Agung	"latitude": -7.771531, "longitude": 110.490353	
Gapura	"latitude": -7.769386, "longitude": 110.488493,	

In contrast, the non-AR features such as POI and map provide more general site information, including images of the location, descriptive explanations, and spatial data such as coordinates. This information is structured to support navigation and broader exploration of the site without requiring marker detection.

4.2.5 Low-Fidelity Interface Design

The low-fidelity interface design is developed to define the layout and structure of the application before visual refinement. This stage focuses on the placement of key interface elements and user interaction flow without emphasizing visual details. The main interface

consists of several primary screens, including the main menu, AR interface, map view, and POI list.

At this stage, the design prioritizes usability and clarity to ensure that the users can navigate the application intuitively. Each interface component is arranged to support the interaction flow defined in the System design, minimizing unnecessary complexity. The interface design is divided into two main interaction contexts, consisting of non-AR interfaces and AR interfaces. The non-AR interfaces include the main menu, POI list, map view, and “how to use”. These features are designed to support navigation and structured information access. In contrast, the AR interface focuses on immersive interaction by presenting content through a camera-based view with the placement of text, buttons, and visual overlays.

To illustrate the interface structure, the low fidelity design of the non-AR interfaces is presented below.

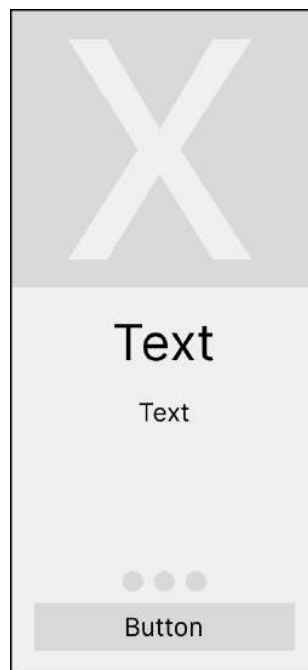


Figure 4.6 Onboarding View

The onboarding view is intended to introduce users to the application and provide initial guidance regarding its main functionality. This view consists of a placeholder image at the top, followed by a title and short descriptive text to explain the purpose of the application. Additionally, indicator dots are included to represent multiple onboarding slides, allowing users to understand their progress within the introduction sequence. A primary button is placed

at the bottom of the screen to enable users to proceed to the next step, ensuring a simple and guided user experience from the beginning.

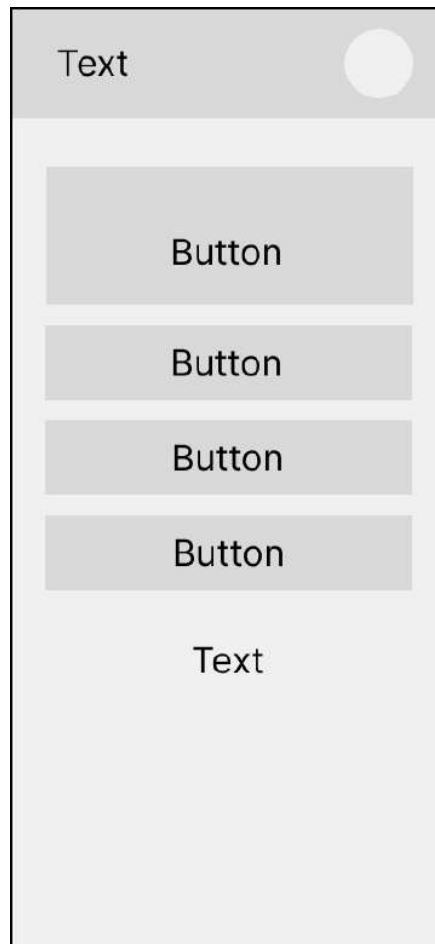


Figure 4.7 Main Menu View

The Main Menu View serves at the central navigation interface of the application, where users can access all available features. This view is structured with a header section at the top, followed by several button placeholders representing different functionalities within the system. These buttons are arranged vertically to provide clear and accessible navigation for users.

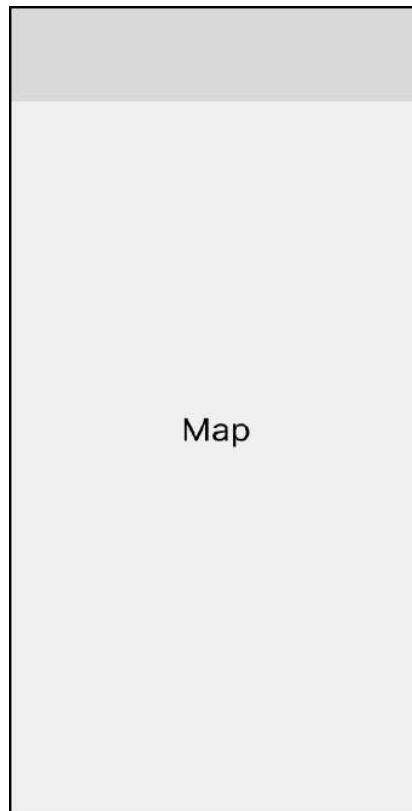


Figure 4.8 Map View

The Map View represents the feature that allows users to explore location-based information within the application. This design emphasizes simplicity by minimizing additional interface elements, allowing users to concentrate on spatial navigation. This layout ensures that the map feature remains clear and functional, supporting the application's objective of providing location-based guidance to users.

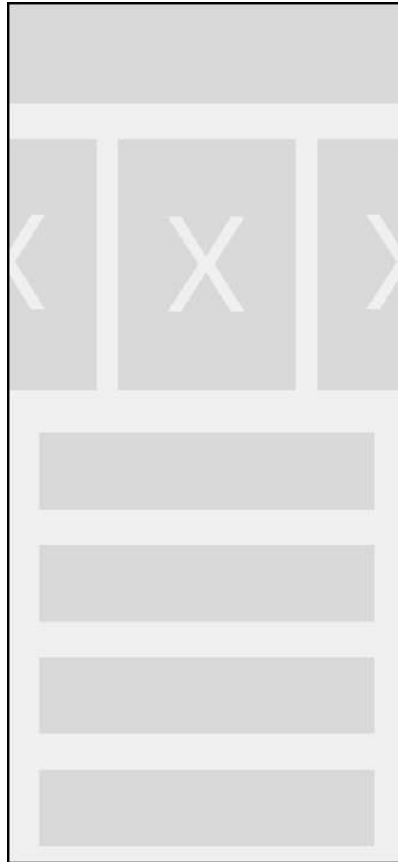


Figure 4.9 Point of Interest List View

The POI List View is designed to display a collection of available points of interest that users can explore within the application. This view is represented using a horizontal image slider at the top, followed by a vertical list of content. The slider allows users to quickly browse highlighted locations, while the list provides additional items in a structured format. This layout supports easy exploration and ensures that users can access multiple POIs efficiently.



Figure 4.10 Detail POI View

The Detail POI View presents detailed information about a selected point of interest after user interaction from the list. This interface includes a large image placeholder at the top to represent the visual context of the location, followed by a title and supporting elements. A larger text area is provided to display descriptive information related to the POI. Additionally, a button is placed at the bottom to allow users to perform further actions, such as accessing Map View, ensuring a clear continuation of user interaction.

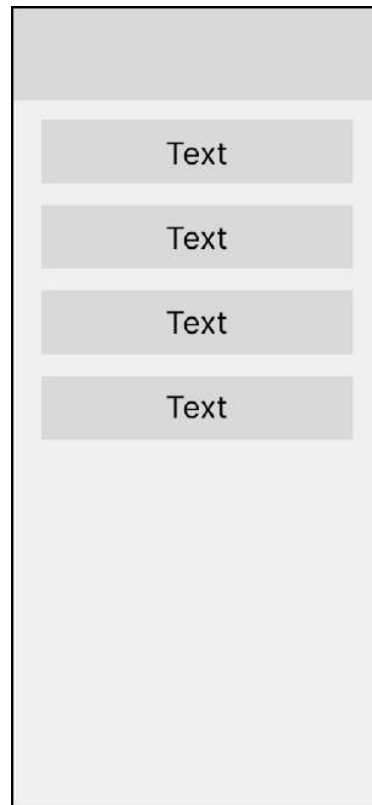


Figure 4.11 How To Use View

The How To Use View is designed to provide guidance to users regarding how to operate the application and its features. This interface is structured as a vertical list of text blocks, each representing a step or instruction. The layout emphasizes clarity and sequential understanding, allowing users to follow instruction easily. This feature is important to support first-time users in understanding how to interact with the AR system and other functionalities.



Figure 4.12 Overview View

The Overview View is designed to provide users with a general understanding of the Ratu Boko heritage site as a whole before exploring specific points of interest. This view functions as an entry point for users to grasp the broader significance of Ratu Boko, helping them build contextual awareness before interacting with more detailed features such as POI exploration.

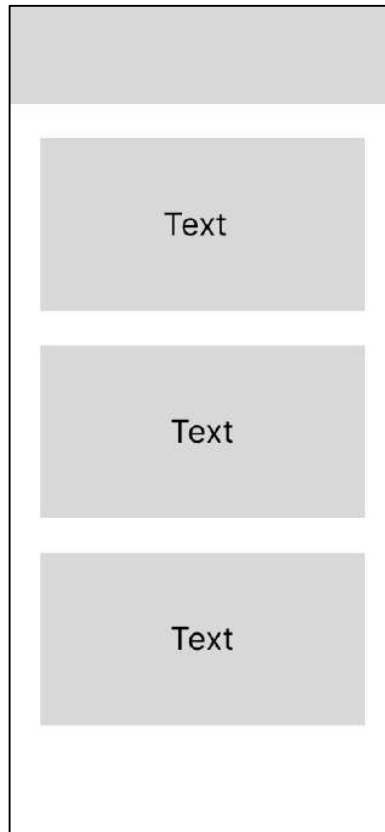


Figure 4.13 Profile View

The Profile View is designed to display application-related information within the application. All references and sources are displayed in this UI view.

The AR views in the low-fidelity design represent the core interactive feature of the application, where users engage directly with marker-based AR technology. These views are designed to illustrate the step-by-step-interaction process.

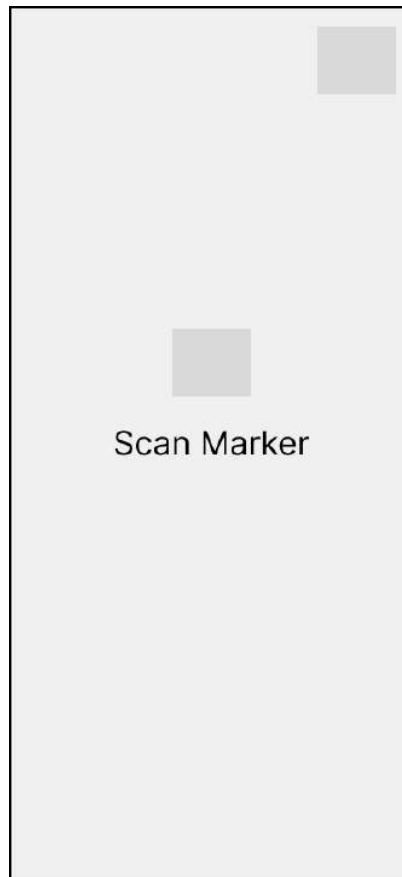


Figure 4.14 Standby Mode

The Standby Mode represents the initial state of the AR view feature before any marker is detected. In this view, the interface is kept minimal, with a central instruction prompting users to scan a marker object. The layout avoids unnecessary elements to ensure that the users focus on positioning their camera correctly.

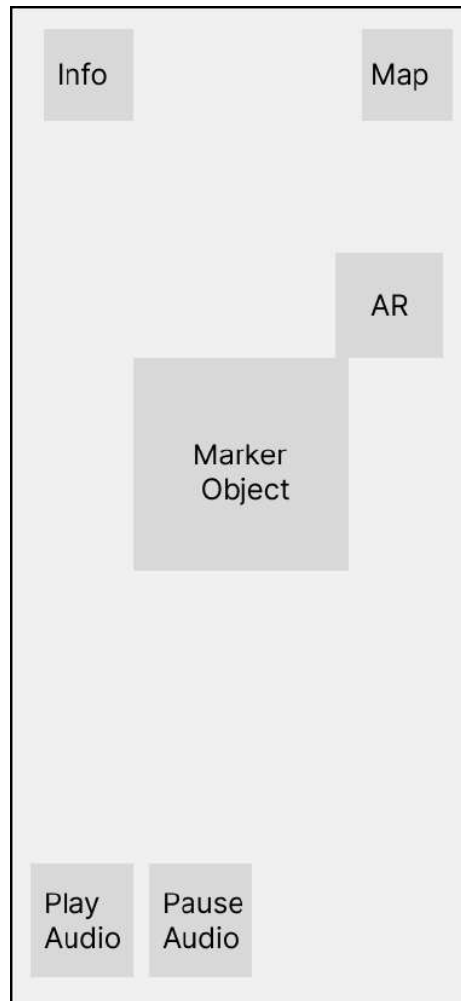


Figure 4.15 Marker Detected View

The Marker Detected View is activated when the system successfully recognizes a predefined marker. In this state, a virtual AR Object appears aligned with the marker, representing the corresponding real-world element. Additional interface elements such as “Information” and “Map” buttons are introduced to allow users to access further details or navigation features. Audio controls are also provided to support audio explanations, enhancing accessibility and allowing users to consume information without relying solely in visual interaction.

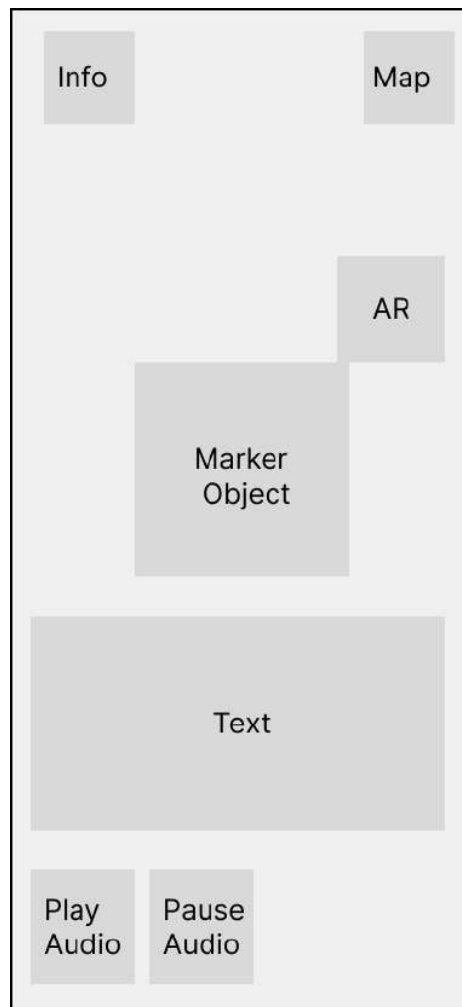


Figure 4.16 Information Panel Opened View

The Information Panel Opened View extends the AR interaction by displaying contextual information related to the detected object. In this interface, a text container appears below the AR object, providing a description of the selected points of interest. The layout is designed to balance AR visualization and textual information without overwhelming the user. Audio controls remain available, enabling users to listen to the explanation, which supports different user preferences and improves overall usability.



Figure 4.17 Map Detail Opened View

The Map Detail Opened View provides the information associated with the marker position in the Pendapa area, allowing users to understand the spatial context of the location. This addition supports the application to help the user find the approximate location of each marker-based object.

4.2.6 High-Fidelity Interface Design

The high-fidelity designs represent the visual implementation of the interface, including color schemes, typography, icons, and interactive elements. The design aims to create a visually appealing and consistent interface while maintaining clarity and usability across all views.

The interface is designed to ensure consistency across different features, including the onboarding page, main menu, POI list, map view, Overview page, POI details, and AR interface. Each view follows a unified design language to maintain coherence throughout the

application. Visual elements are carefully arranged to support intuitive interaction and to guide users in accessing information efficiently.

In addition, the AR interface is designed to integrate visual overlays seamlessly with the real-world environment. Elements such as text, buttons, and indicators are positioned to ensure readability in outdoor conditions, where lighting could vary. This approach enhances the immersive experience while maintaining functional accessibility.

To illustrate the final interface design, examples of the high-fidelity interface for non-AR features are presented in the figures below.

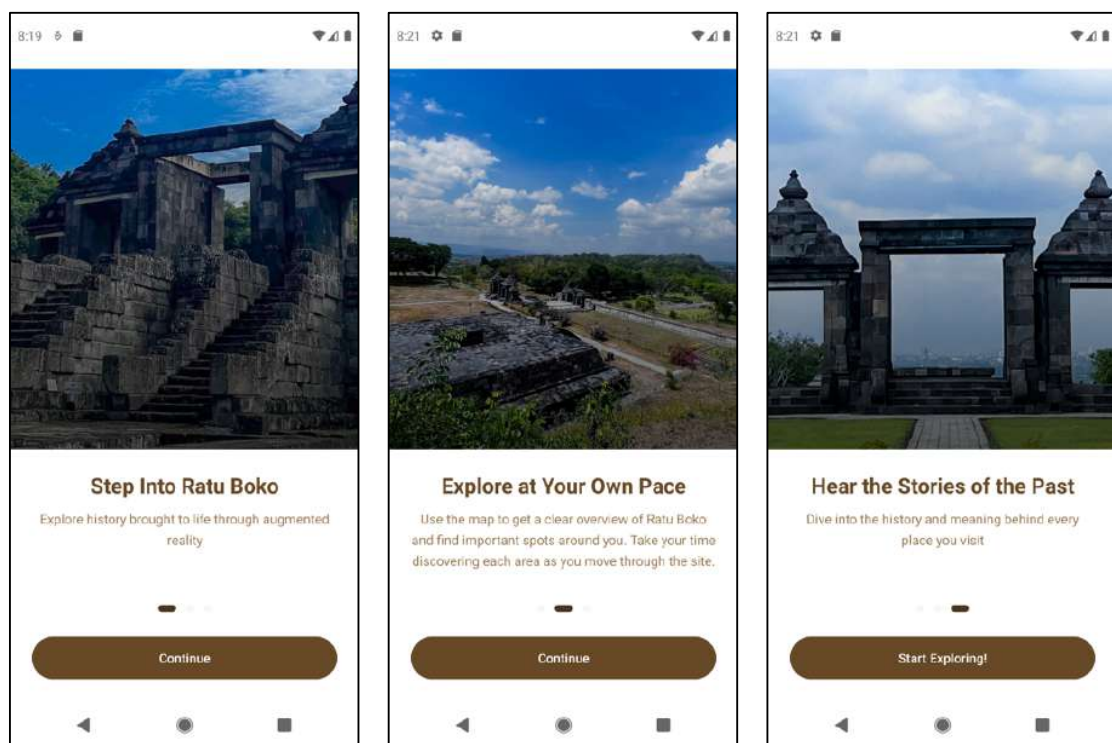


Figure 4.18 Onboarding View

The Onboarding View allows users to obtain an initial understanding of the application's purpose and core features before entering the system. Through a combination of visual imagery and concise descriptions, users learn that the application provides AR-based exploration, self-guided navigation, and historical storytelling.

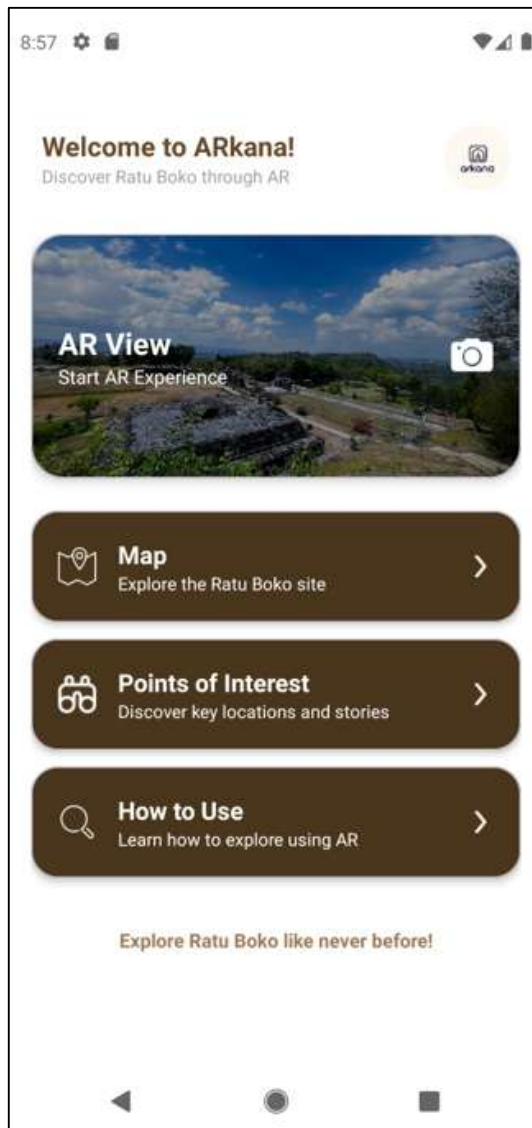


Figure 4.19 Main Menu View

The Main Menu View serves as the central navigation hub, presenting key features such as AR view, Map, Points of Interest, and How To Use. Each feature is represented using visually distinct cards with icons and short descriptions. The layout is designed to be clean and intuitive, allowing users to quickly identify and access the desired feature.

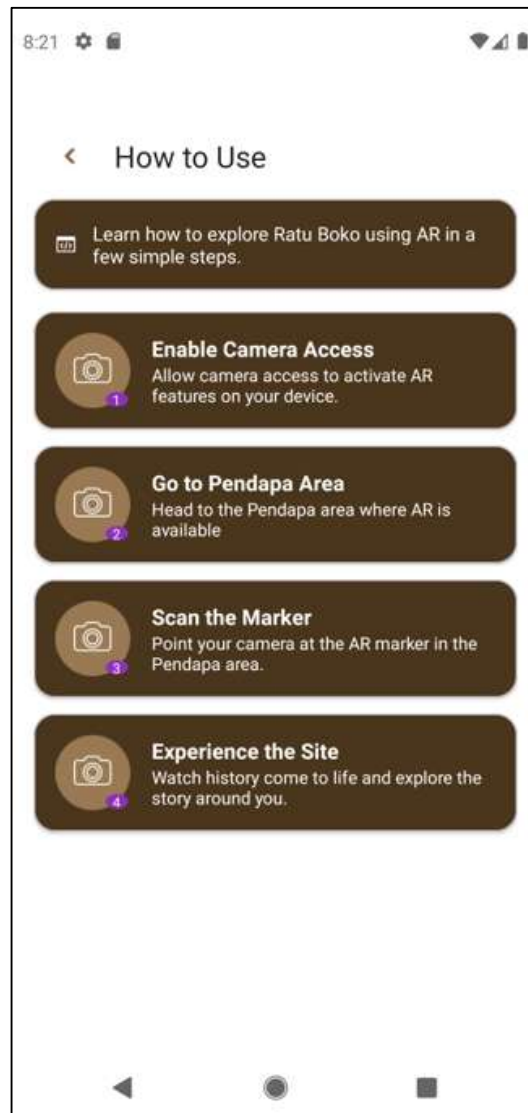


Figure 4.20 How To Use View

The How To Use View presents step-by-step instructions enabling users to obtain clear procedural knowledge on how to operate the application features, particularly the AR functionality. By presenting step-by-step instructions, users can understand how to activate the camera, scan markers, and access information. This reduces potential confusion and ensures that users can independently navigate the application.



Figure 4.21 Overview View

The Overview View provides a comprehensive introduction to the Ratu Boko site by combining visual and textual information. This layout helps users build a general understanding of the site before exploring specific points of interest. The content itself explains the historical and cultural significance of Ratu Boko site.

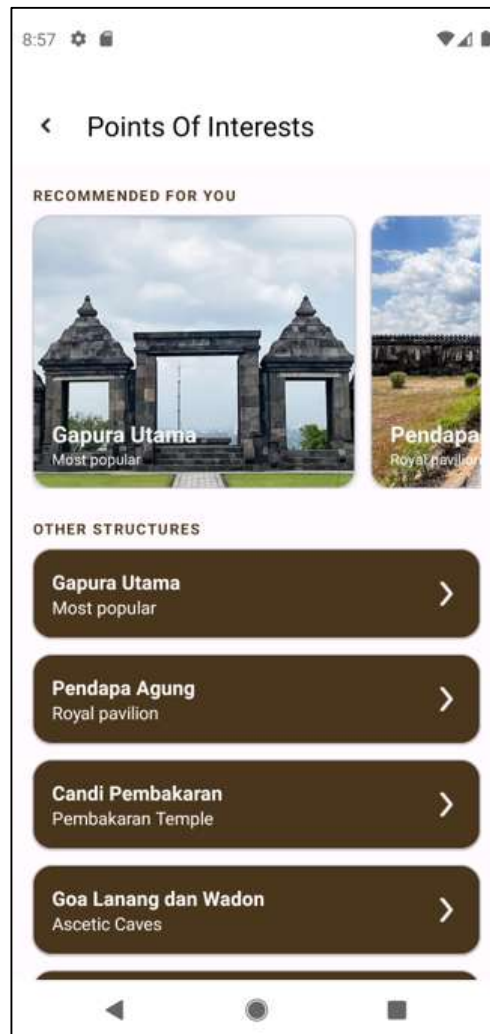


Figure 4.22 POI List View

The POI List View allows users to obtain a structured list of available points of interest that can be explored within the site. By organizing location into highlighted and categorized sections, users can easily discover places that match their interests.



Figure 4.23 POI Detail View

The POI Detail View enables users to obtain in-depth information about a specific location within the Ratu Boko site. Through detailed descriptions and supporting visuals, users can understand the historical function and significance of the selected object. The inclusion of navigation option further allows users to connect this knowledge with its physical location.



Figure 4.24 Map View

The Map View allows users to obtain spatial awareness of the Ratu Boko site and understand the relative positions of various points of interest. By displaying location markers on a real map interface, users can identify where they are and where they can go next. This supports navigation and exploration within the physical environment.

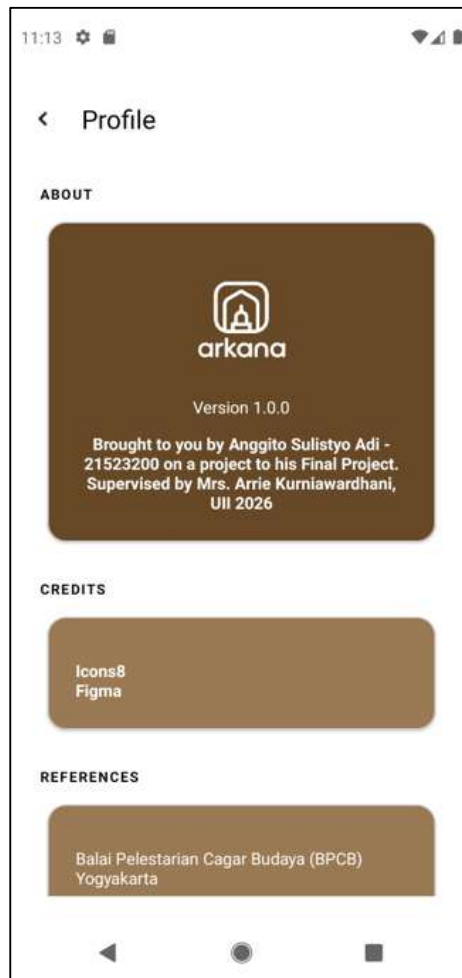


Figure 4.25 Profile View

The Profile View allows users to obtain information related to the application and its development context. By presenting details such as application version, credits and references, users can understand the background and credibility of the system.

These designs include fully styled interfaces of the AR features on the application that is presented in the figures below.



Figure 4.26 Standby Mode View

The Standby Mode allows users to obtain clear guidance on how to initiate interaction with the AR system. In this state, a visual marker guide and instruction text such as “Scan Marker” are displayed at the center of the screen. This helps users understand that the system requires a physical marker to activate AR content.



Figure 4.27 Marker Detected View

The Marker Detected View enables users to obtain a direct visual connection between the physical marker and its corresponding digital content. When the marker is successfully recognized, AR elements such as directional arrows, labels are overlaid onto the real-world view. These visual cues help users identify specific parts of the structure and understand their orientation.



Figure 4.28 Information Panel Opened View

The Information Panel Opened View allows users to obtain a detailed contextual knowledge about the detected object. A structured panel appears containing the title and descriptive text explaining the historical function or meaning of the object. This panel is designed to be readable while still maintaining visibility of the AR environment in the background. Additionally, audio controls are provided to support audio guides, enabling users to access the information in both visual and auditory formats.

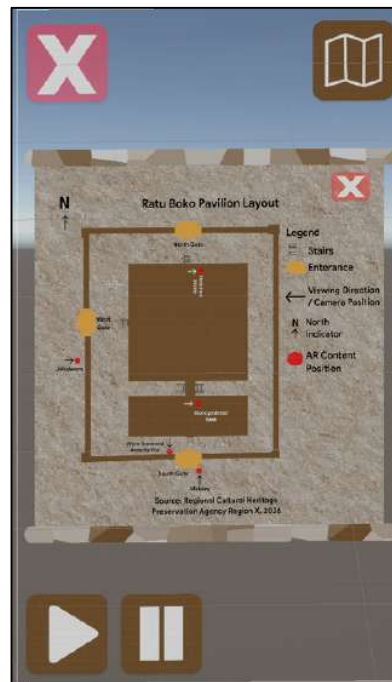


Figure 4.29 Map Detail Opened View

The Map Detail Opened View enables users to obtain spatial context related to the AR object they are observing. In this view, a detailed layout map of the Pendapa is presented, including markers that indicate important locations and AR content positions. Supporting elements such as legends and directional indicators help users interpret the map effectively.

4.3 Development

This phase focuses on the implementation of the designed system into a functional mobile application. The development process integrates AR features with supporting components such as POI data and map features within a unified Android application. The system is developed using Unity and Vuforia for AR functionality, and Kotlin within Android Studio for the mobile application framework.

The development process is carried out in several stages, including AR environment setup, marker database configuration, AR content implementation, Android application development and system integration. Each stage is implemented iteratively to ensure that all system components function cohesively and meet the defined requirements. This approach also allows early detection of technical issues, particularly those related to AR tracking stability and mobile compatibility.

4.3.1 AR Development using Unity and Vuforia

The AR functionality in this application is developed using the Unity game engine integrated with Vuforia Software Development Kit (SDK). Unity serves as the primary development environment for managing AR scenes, 3D content, and user interaction, while Vuforia provides image-based tracking capabilities that enable the system to detect and recognize predefined markers in real-world environments.

The development process begins by creating a new Unity project using the Universal Render Pipeline (URP) 3D template. This template is selected to ensure optimized rendering performance and compatibility across various Android devices. After initializing the project, the next step involves enabling Vuforia Engine support by obtaining a license key from the Vuforia developer portal. This license key is required to activate AR functionalities within the Unity environment. Figure 4.30 illustrates the Vuforia License Manager interface, where the license key required to activate AR functionality in Unity is generated and managed.

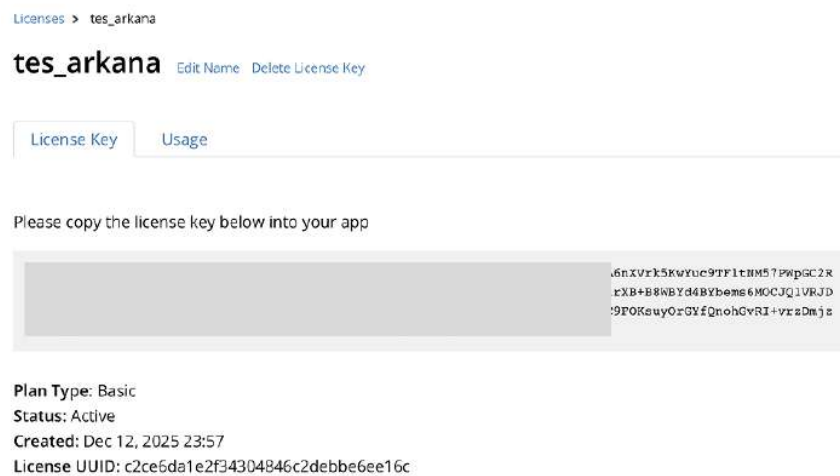
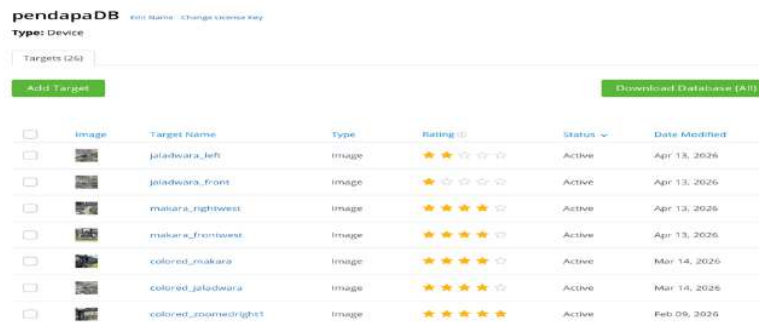


Figure 4.30 Vuforia's Licence Key

Once obtained, the license key is configured within the Unity Editor to enable access to Vuforia services. This configuration allows the application to connect with the image target database that has been previously prepared through the Vuforia web platform. The database contains a collection of image markers that will be used for object recognition during AR interaction.

Following this, image targets are created by uploading marker images into the Vuforia Target Manager database. Each image is processed by Vuforia to generate feature points, which

are used to determine how well the image can be detected and tracked in real-time. To ensure compatibility, each image must not exceed the maximum file size of 2 MB, requiring optimization or compression of image assets before uploading. Figure 4.31 shows the Vuforia Target Manager interface containing the uploaded image targets along with their feature ratings, which indicate the quality and detectability of each marker.



The screenshot shows the Vuforia Target Manager interface. At the top, it says 'pendapaDB' and 'type: Device'. Below that, there's a search bar and a 'Targets (2/6)' indicator. There are two buttons: 'Add Target' and 'Download Database (All)'. The main part of the interface is a table with the following columns: 'Image' (with a checkbox), 'Target Name', 'Type', 'Rating' (with a star icon), 'Status' (with a dropdown arrow), and 'Date Modified'.

Image	Target Name	Type	Rating	Status	Date Modified
☐	jaladwara_left	Image	★☆☆☆☆	Active	Apr 13, 2026
☐	jaladwara_front	Image	★☆☆☆☆	Active	Apr 13, 2026
☐	makara_rightwest	Image	★☆☆☆☆	Active	Apr 13, 2026
☐	makara_frontwest	Image	★☆☆☆☆	Active	Apr 13, 2026
☐	colored_makara	Image	★☆☆☆☆	Active	Mar 14, 2026
☐	colored_jaladwara	Image	★☆☆☆☆	Active	Mar 14, 2026
☐	colored_corneredright	Image	★☆☆☆☆	Active	Feb 09, 2026

Figure 4.31 Vuforia's Database for Image-targets.

Each marker corresponds to a specific object within the Pendapa area, including Notched Stone, Batu Umpak, Jaladwara, Stone Material, and Makara. The quality of each image target is evaluated based on its feature richness, as images with higher feature points provide more stable and reliable detection. Once the database is finalized, it is imported into the Unity project, allowing the system to recognize markers during runtime.

After integrating the image target database, AR content is implemented by associating virtual elements with each marker inside the Unity scene. These elements include informational overlays, object highlights, and audio-visual components that enhance user understanding of each point of interest. The relationship between detected markers and displayed information is managed through scripted logic that dynamically updates content based on the active target.

This behavior is handled programmatically using scripts such as ImageTargetHandler, which listens to Vuforia's tracking status and assigns the currently detected marker to the system. When a marker is recognized, the system retrieves the corresponding data (title and description) and prepares it for display through the user interface, as structured in ARManager and POIData. Figure 4.32 presents the configuration of an Image Target in Unity, including attached scripts and linked POI data used to control content display when a marker is detected.

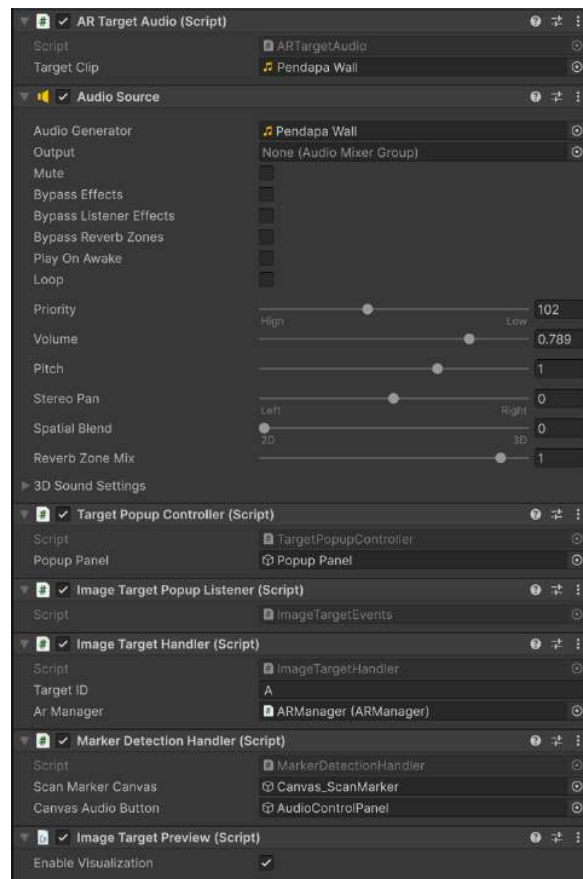


Figure 4.32 Unity Inspector with Attached Scripts

In addition to visual information, the system also integrates audio feedback that is triggered based on marker detection. This is achieved through scripts such as ARTargetAudio and ARAudioController, which manage audio playback dynamically depending on whether a target is currently being tracked. When a marker is detected, the corresponding audio narration is activated, and when the marker is lost, the audio is paused automatically. Figure 4.33 demonstrates the AR scene during runtime, where a marker is successfully detected and the corresponding audio control interface becomes available to the user.



Figure 4.33 AR Scene Displaying Marker Detection with Active Audio Control

The placement of virtual content is carefully adjusted within the Unity scene to ensure proper alignment with the detected marker. This alignment allows digital elements to appear anchored to the physical environment, enhancing realism and immersion. The system uses Vuforia's tracking status (e.g., TRACKED and EXTENDED_TRACKED) to maintain stability of virtual objects even when partial occlusion occurs.

Furthermore, user interaction is designed to be simple and intuitive. When a marker is detected, interface elements such as information buttons and panels are dynamically displayed, allowing users to access additional details only when needed. This interaction flow is controlled through UI management scripts, ensuring that information is presented contextually without overwhelming the user. Figure 4.34 displays the information panel that appears after a marker is detected, providing contextual details related to the recognized object.

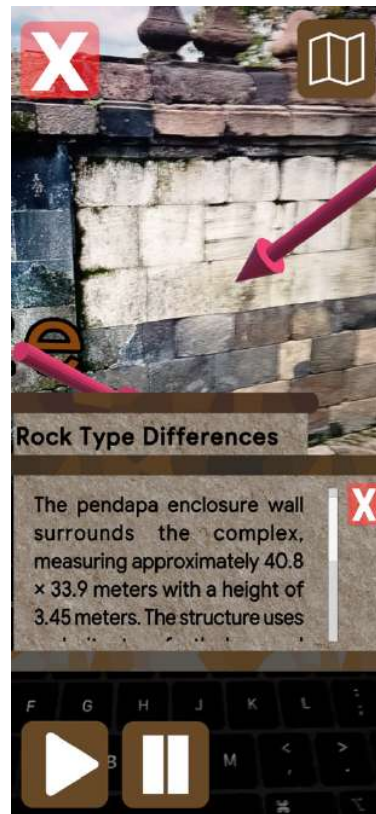


Figure 4.34 Information Panel Displayed After Marker Detection

Overall, the AR interaction is designed to be passive, where users only need to point the device camera toward a marker to trigger the corresponding content. This approach minimizes user effort while maintaining effective information delivery. By combining image recognition, dynamic content mapping, and responsive interaction design, the system provides an engaging and informative AR experience within the heritage tourism context.

4.3.2 Android Application Development (Kotlin)

The mobile application is developed using Kotlin within the Android Studio environment. The application serves as the main platform that integrates AR functionality with additional features such as maps and informational access. The system is designed as a multi-activity Android application, where each feature is encapsulated within a dedicated interface to ensure modularity and maintainability.

The application flow begins with an onboarding interface that introduces users to the main features and usage instructions. This onboarding process is implemented using a ViewPager-based layout, allowing users to navigate through multiple instructional screens

before entering the main application. Figure 4.35 illustrates the onboarding interface that presents introductory information and guides users before accessing the main application features.

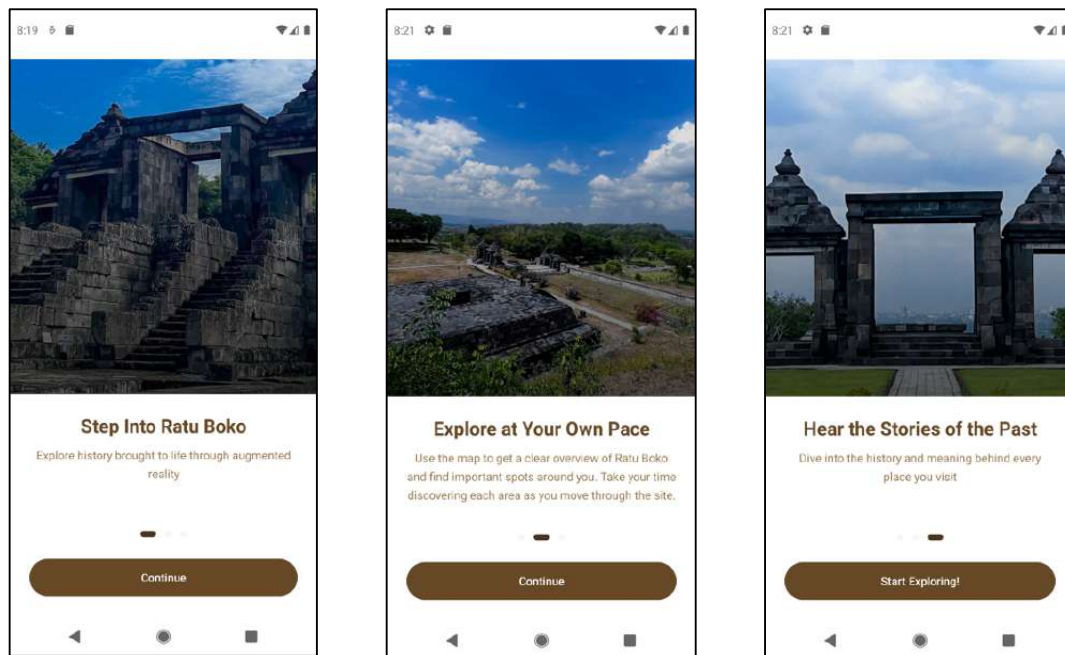


Figure 4.35 Onboarding Interface

Following the onboarding process, users are directed to the main menu interface, which acts as the central navigation hub of the application. This interface provides access to key features, including AR interaction, map exploration, POI browsing, and usage instructions. Navigation between these features is implemented using intent-based transitions, enabling seamless movement across different application modules. For example, the AR feature is triggered by launching the Unity activity directly from the Android application, as implemented in HomeActivity. Figure 4.36 shows the main menu interface, which provides access to AR features, maps, POI information and application profile.

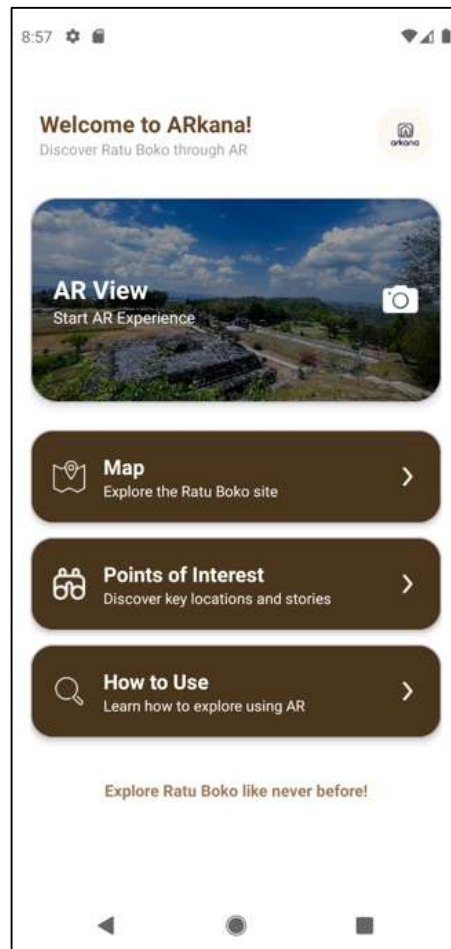


Figure 4.36 Main Menu Interface

To support structured information access, a Point of Interest (POI) system is implemented within the application. Each POI represents a specific site within the Ratu Boko Site area and contains associated descriptive data, including title, description, images, and categorization. The POI data is managed through a repository-based approach, where content is loaded from local JSON files and accessed dynamically within the application, as shown in PoiRepository. Figure 4.37 presents the POI list interface, displaying categorized objects that users can browse and select for more detailed information.

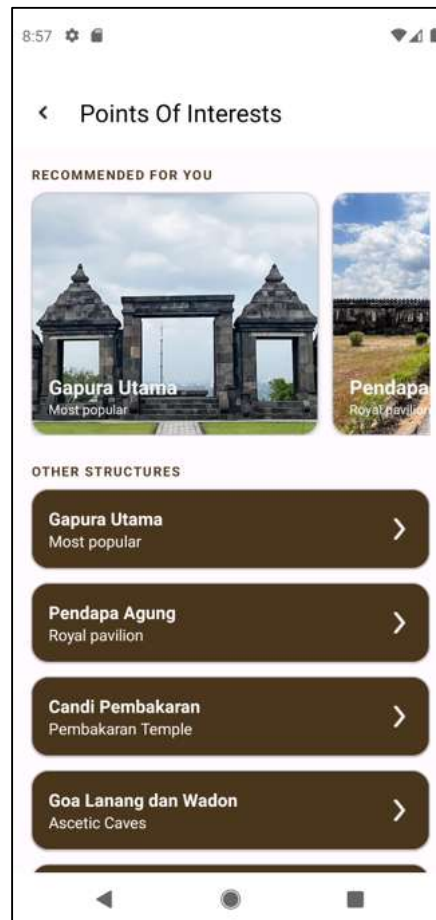


Figure 4.37 POI List Interface

When a POI is selected, the application navigates to a detailed view that displays comprehensive information about the selected object. This includes textual descriptions, image galleries, and additional contextual elements. The detail interface is dynamically populated based on the selected POI ID, ensuring that content remains consistent and scalable across different objects, as implemented in `PoiDetailActivity`. Figure 4.38 illustrates the POI detail interface, which presents descriptive content, images, and additional contextual information for each object.



Figure 4.38 POI Detail Interface

In addition to textual information, the application also supports spatial exploration through an interactive map feature. The map is implemented using the Mapbox SDK, allowing users to visualize the layout of the Ratu Boko site and identify the location of each POI. Markers are dynamically placed on the map using coordinate data, and users can interact with these markers to access detailed information about specific objects. Figure 4.39 shows the map interface with POI markers, enabling users to explore the objects within the site.

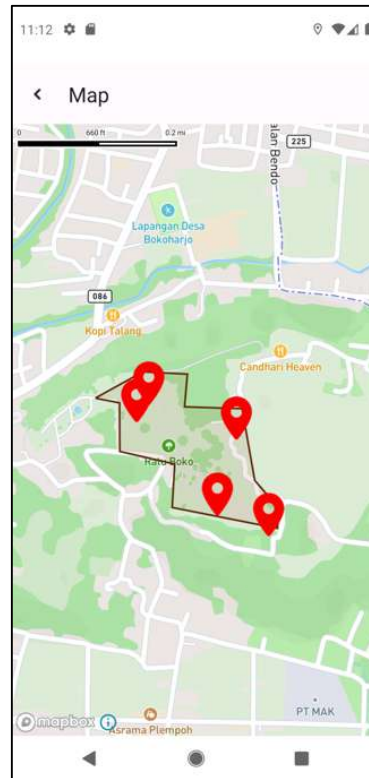


Figure 4.39 Map Interface

The map feature also includes additional functionalities such as location detection and polygon-based boundary visualization, which helps users understand the site area more clearly. When a marker is selected, the application transitions to the corresponding POI detail view, creating a seamless connection between spatial exploration and informational content, as implemented in MapActivity.

4.3.3 Integration between Unity and Android Project

The integration between the AR module and the Android application is implemented using the Unity as a Library (UaaL) approach, where the Unity project is exported as an Android-compatible module. In this method, Unity does not function as a standalone application but instead becomes a library module (UnityLibrary) that can be embedded into an existing Android project developed in Android Studio. This approach is supported by Unity's official documentation, which enables developers to integrate real-time 3D and AR content into native mobile applications.

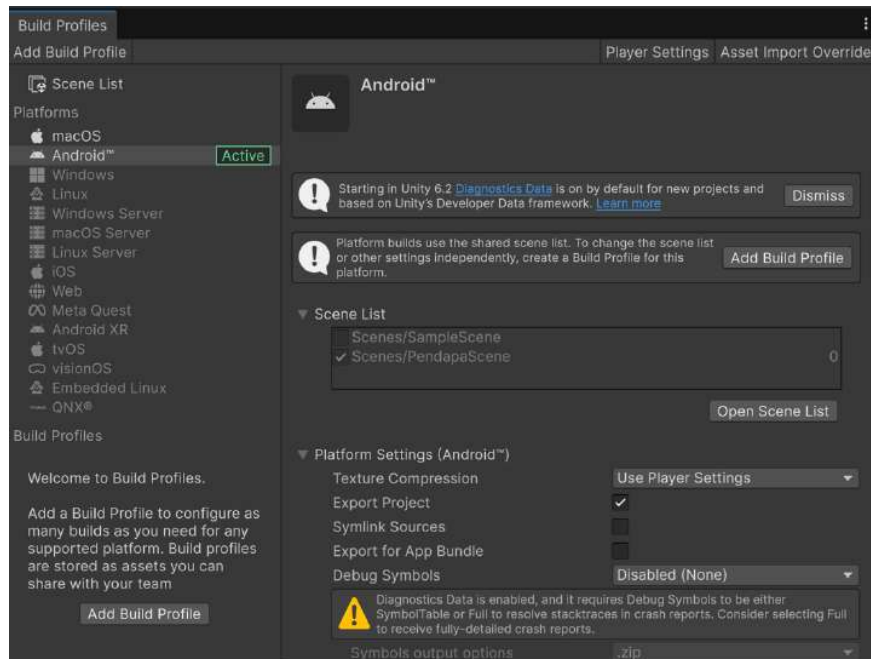


Figure 4.40 Unity Build Settings configured for “Export Project” with Android

The process begins by configuring the Unity project build settings to enable the Export Project option. Once exported, the Unity project generates a structured Android project consisting of two main modules: the UnityLibrary module, which contains all AR-related assets, scenes, and dependencies, and the launcher module, which serves as a sample entry point. In this implementation, only the UnityLibrary module is utilized and imported into the main Android Studio project.

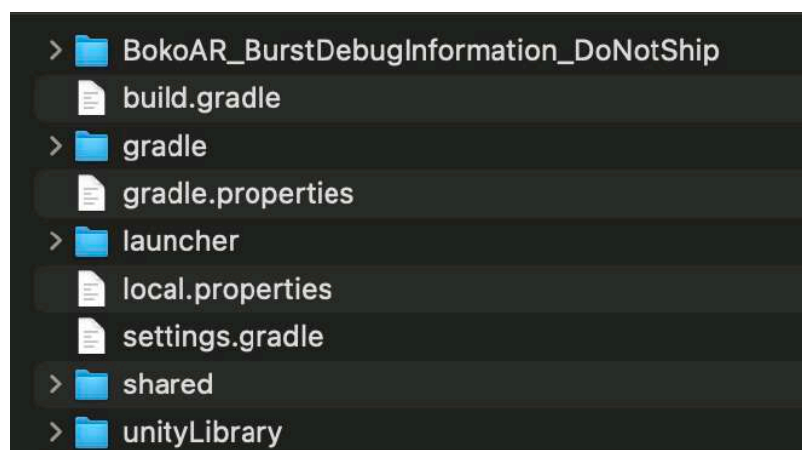


Figure 4.41 Exported Unity Project Structure UnityLibrary and Launcher Modules

After the export process, the UnityLibrary module is integrated into Android Studio by adding it as a module dependency within the main application project. Gradle configuration is then adjusted to ensure proper linking between the main application module and the UnityLibrary. This includes synchronizing dependencies, resolving compatibility between SDK versions, and ensuring that required permissions and configurations are properly defined.

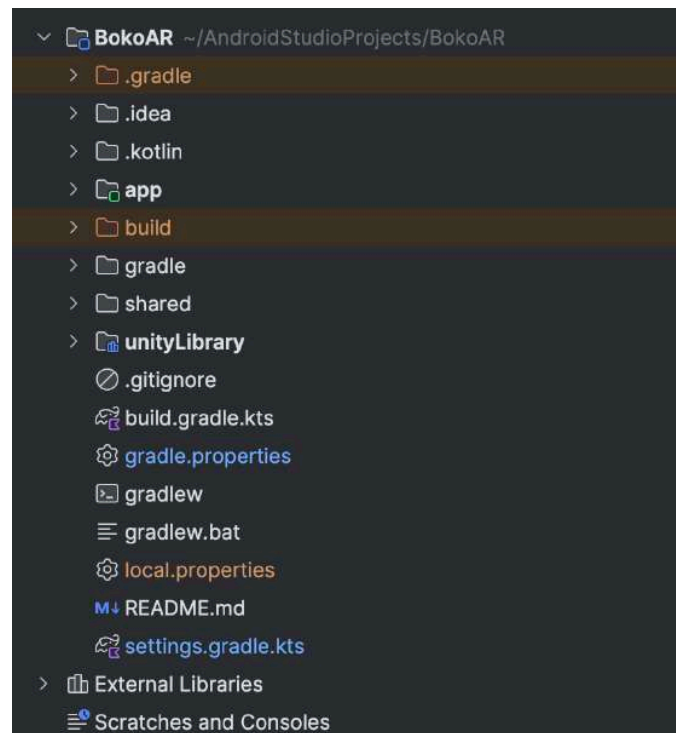


Figure 4.42 Android Studio Project Structure with UnityLibrary Imported

To enable communication between the Android application and the Unity module, activity control and lifecycle management are implemented. The application triggers Unity when AR features are accessed, allowing users to transition from the native interface to AR environment seamlessly. When the AR session is complete, control is returned to the main Android application without restraining the system. This mechanism ensures smooth navigation and maintains application state across different modules.

Additionally, the integration incorporates the Vuforia Engine within Unity as part of the UaaL workflow, allowing AR functionalities such as marker detection and tracking to operate within the embedded Unity module. This approach enables AR capabilities to run inside a native Android application while maintaining performance and tracking stability. As a result, AR can be accessed dynamically without requiring a separate application.



Figure 4.43 AR Marker Detection as Integrated Application View

Through this integration approach, AR functionality becomes an integral part of the overall application flow. Users can seamlessly access AR features alongside other functionalities such as POI information and map-based navigation. This ensures that all system components operate cohesively within a single application environment, ultimately providing a unified and interactive user experience.

4.4 Implementation

This phase focuses on deploying application and evaluating its use in a real-world context. The implementation was conducted directly at the Ratu Boko heritage site to simulate actual usage conditions. Since the application operates in an outdoor environment, factors such as lighting conditions, camera positioning, and user movement were taken into consideration, as they may influence the performance of marker-based AR detection.

The application was installed on several Android devices prior to testing to ensure that all required features, including cameras access and sensor functionality, operated properly. This preparation ensured that the system could run smoothly during the user interaction session.

The implementation involved 12 respondents who participated in the testing session. The respondents consisted of individuals within the age range of approximately 20-28 years, representing potential users of the application targeting a younger tourists with basic English skills. Experts such as Mrs. Septi Indrawati Kusumaningsih, S.S., M.A., Ratu Boko's archaeologist and Mr. Yulianto, the tour guide in Ratu Boko also experienced the application with the help of the application contents translated into Bahasa Indonesia.

It is important to note that the application is fully presented in English, which influenced user experience to some extent. While most respondents were able to understand the content,

several users required additional effort to interpret certain terms and descriptions. This indicates that language may act as a minor barrier for some users, particularly those who are not fully comfortable with English. While all respondents were familiar with smartphone usage, their experience with Augmented Reality applications varied and is considered a new technology for them to use. Figures below show the respondent in testing out the AR feature in the Pendapa area.



Figure 4.44 Respondent Scanning the Batu Umpak



Figure 4.45 Respondent Scanning the Jaladwara



Figure 4.46 Respondent Scanning the Notched Stone

During the session, each respondent was asked to perform a series of predefined tasks. These tasks included launching the application, navigating the main menu, accessing the AR feature, scanning markers, and exploring additional features such as the POI list and map interface. This process was designed to simulate the user scenario within the application. The session was conducted two times to simulate different lighting conditions, one session is conducted at 08.00 am, with cloudy weather. Another session is conducted at 10.00 am, simulating a midday scenario. During the first session conducted at 08.00 AM under cloudy conditions, respondents were asked to perform a series of predefined tasks, including launching the application, navigating the main menu, accessing the AR feature, scanning markers, and exploring additional features such as the POI list and map interface. This session aimed to simulate a real user scenario in relatively stable lighting conditions.

The results show that only some markers were successfully detected by the camera, while others were not fully recognized. During the first session conducted at 08.00 AM under cloudy weather conditions, the moderate lighting generally supported marker detection; however, inconsistencies still occurred. Specifically, the markers that were successfully recognized include Notched Stone, Batu Umpak, Stone Material, and Jaladwara, although the detection of Jaladwara was only temporary and exhibited unstable tracking. Some markers placed on stone surfaces were difficult to detect due to the similarity in texture and color between the marker and the surrounding environment.

Additionally, markers located on the ground or at the base level experienced lower detection rates. This was influenced by the presence of wild vegetation covering parts of the stone surfaces, which obstructed the visibility of the markers. Despite these limitations, the AR content, particularly the displayed text, remained readable and functioned as intended under these lighting conditions.

The second session was conducted at 10.00 AM to simulate brighter daylight conditions. The same set of tasks was performed by respondents to maintain consistency in testing scenarios. In this session, marker detection performance was more significantly affected by environmental factors. The intensity of sunlight caused strong reflections on the stone surfaces in the Pendapa area, reducing the contrast between the markers and their background. As a result, the camera had greater difficulty detecting the markers.

Compared to the first session, detection performance decreased, where the Stone Material wall marker was no longer detected. Similar to the earlier findings, markers placed on the ground remained challenging to detect due to both surface similarity and partial obstruction by

vegetation. Furthermore, the Kala Makara marker was not successfully detected in both testing sessions, indicating a consistent limitation in recognizing this particular object.

In addition, the visibility of AR content was influenced by screen brightness variations across different devices. Under direct sunlight, some devices required higher brightness levels to maintain clear visibility of the displayed text. These findings highlight that environmental conditions, surface characteristics, and device variability play significant roles in the effectiveness of marker-based AR systems in outdoor heritage environments.

Overall, this session highlights that high-intensity lighting conditions can negatively impact marker-based AR performance, particularly in outdoor heritage environments with reflective and textured surfaces.

Based on observation during the implementation, most respondents were able to operate the application without significant difficulty, the only noticeable difficulty the respondent experienced were positioning the camera to the marker object, as there were no physical marker present and the only guide is the marker-used sheet to help guide the users to the position the camera view is to the image target, without it, first-time users could possibly not know how the target is and have difficulties in locating one marker.

Overall, the implementation phase demonstrates that the application can function effectively in real-world conditions while supporting user interaction as intended. The findings from this phase serve as a foundation for further evaluation, where system usability, functionality and compatibility are assessed using structured testing methods.

4.5 Evaluation

Evaluation of the developed application is a way to ensure that it meets the functional and non-functional requirements. The testing process is conducted using four approaches: Content validation to validate the correctness of information presented in the application. Black-box testing to evaluate the system's functionality, content validation, to verify the accuracy and appropriateness of the information presented in the application based on expert evaluation, compatibility testing to assess performance across different devices and usability evaluation using the System Usability Scale (SUS).

4.5.1 Black-box Testing

In this testing process, a set of test scenarios is designed based on the core features of the application, including AR marker detection, POI access, map interaction, and navigation

between interfaces. Each scenario involves providing specific user inputs and observing the resulting system behavior. The outputs produced by the system are then compared with the expected results to determine whether the functionality is valid or requires improvement.

The results of the black-box testing are summarized in Table 4.10. Based on the evaluation, each feature is assessed in terms of its ability to correctly process input and generate appropriate output. This ensures that the system meets its functional requirements and can be reliably used in real-world scenarios.

Table 4.6 Black-box Testing

No	Feature	Test Scenario	Expected Result	Actual Result	Status
1	AR Marker Detection	User selects AR feature from main menu	AR view with camera is activated successfully	The AR view is activated successfully	Passed
2	AR Marker Detection	User scans a valid marker	Corresponding AR content (3D Text, audio, Info panel) is displayed correctly	The marker is detected and displayed according to the detected marker.	Passed
3	AR Marker Detection	User opens AR map (marker position guide)	Map displays positions of available markers in the Pendopo area	Map is displayed	Passed
4	AR Marker Detection	User taps information panel in AR view	Information panel appears with correct object description	Information panel appears with the correct object description.	Passed
5	AR Marker Detection	User plays audio narration	Audio plays clearly and matches the	Audio plays clearly	Passed

			detected object		
6	AR Marker Detection	User pauses audio narration	Audio pauses	Audio paused	Passed
7	POI Access	User navigates from Overview to POI list	POI list is displayed correctly	POI list is displayed	Passed
8	POI Access	User selects a POI from the list	POI detail page (image, description, coordinate in map) is displayed	The POI detail is presented	Passed
9	How to Use	User opens “How to Use” page	Instructional content is displayed clearly	How to use page is displayed	Passed
10	Onboarding	User launches app for the first time	Onboarding screens are displayed sequentially	Onboarding pages are displayed	Passed
11	Navigation	User navigates between pages (Back/Home)	Application transitions between pages without errors	Application transitions between pages without any errors	Passed

Based on the testing results, all implemented features function according to their intended behavior. The system is able to process user inputs and generate appropriate outputs without encountering functional errors. This indicates that the application meets its functional requirements and is ready for use in real-world scenarios, particularly in supporting interactive tourism experiences at the Ratu Boko site.

4.5.2 Content Validation

To ensure the accuracy and reliability of the historical information presented in the application, content validation was conducted involving a domain expert in cultural heritage and archaeology from Institute for Preservation of Cultural Heritage, Mrs. Septi Indrawati Kusumaningsih, S.S., M.A.. The evaluation aims to assess the correctness, clarity, and relevance of the narrative content embedded in both the augmented reality (AR) features and points of interest (POI) descriptions. This validation process is essential to ensure that the developed application aligns with established historical knowledge and maintain academic credibility.

The results of the content validation are presented in Table 4.6, which summarizes the expert's assessment across multiple aspects, including historical accuracy, clarity of information, narrative flow, and suitability for the target audience.

Table 4.7 Content Validation with Archaeologist Score

No	Aspect	Score
1	Historical Accuracy	4
2	Clarity of Information	4
3	Audience Suitability	5
4	Narrative Flow	4
5	Context Relevance	4
6	Language Style (Audio Guide)	3
7	Engagement	4
8	Narrative Length	4
9	Information Clarity	4
Total		36
Average		4.0

The validity category is determined based on a 5-point Likert scale, where the scoring system is explained in Table 4.7.

Table 4.8 Likert Scale Validity Criteria

Score Range	Category	Interpretation
4.21 – 5.00	Very Valid	No revision needed
3.41 – 4.20	Valid	Minor revision
2.61 – 3.40	Fairly Valid	Some revision needed

1.81 – 2.60	Less Valid	Major revision
1.00 – 1.80	Not Valid	Not suitable

The average score is calculated using the formula:

$$\text{Mean Score} = \frac{\text{Total Score}}{\text{Number Of Items}} = \frac{36}{9} = 4.0$$

Which indicates that the content is categorized as **Valid**.

Based on the evaluation shown in Table 4.x, most aspects received scores of 4 (appropriate) and 5 (very appropriate), indicating that the content is generally well-aligned with historical facts and suitable for public understanding. The overall mean score obtained is 4.0 on a 5-point Likert scale, which falls into the “Valid” category. This suggests that the developed content is suitable for use with only minor revisions required.

However, one aspect, particularly the suitability of language style in the audio guide, received a score of 3, suggesting that improvements are needed to better reflect a more natural and engaging delivery style. The feedback also highlights several important areas for improvement. Certain parts of the narrative require additional detailing and strengthening, especially in explaining specific structures such as Pendopo and Water pools to enhance both historical depth and aesthetic appreciation. Additionally, Mrs. Septi emphasized the need to simplify technical terms and provide clearer explanations for less familiar terminology to ensure accessibility for general audiences.



Figure 4.47 Expert Validation with Mrs. Septi Indrawati Kusumaningsih, S.S, M.A

Moreover, based on the feedback, Mrs. Septi recommended simplifying sentence structures and using more effective wording to improve readability and comprehension. The inclusion of supporting visual elements, such as annotated images or labeled object components, was also suggested to enhance user understanding of architectural details. In addition, she emphasized the importance of providing Bahasa Indonesia as an alternative language option to accommodate a wider range of users, particularly local visitors who may not be fully comfortable with English. These findings indicate that although the content is already accurate and relevant, further refinement is required to optimize clarity and user engagement.

In addition to expert validation, practical validation was also conducted through evaluation by a tour guide, Mr. Yulianto, with field experience in heritage tourism at Ratu Boko.

Table 4.9 Evaluation Aspects of Tour

No	Aspect	Result
1	Content matches explanation	Yes
2	Covers important points	Yes
3	No contradictions with field practice	Yes
4	Matches tour flow	No
5	Easy to understand	Yes
6	Interesting delivery	Yes
7	Not too long/confusing	Yes
8	Helps independent understanding	Yes
9	Supports guiding acitivity	Yes
10	AR adds value	Yes
Total Yes		9
Percentage		90%

The results show that 9 out of 10 evaluation aspects were marked as “Yes”, resulting in a suitability level of 90%, which indicates that the application is highly aligned with real-world guiding practices. The percentage of suitability is calculated using the formula:

$$Percentage = \frac{Total\ Yes}{Number\ Of\ Items} \times 100\% = \frac{9}{10} \times 100\% = 90\%$$

To provide a clearer interpretation, the suitability is categorized based on the following scale as explained in Table 4.9.

Table 4.10 Suitability Categorization

Percentage Range	Category	Interpretation
81% - 100%	Very Suitable	Highly aligned with real-world practice, only minor improvements needed
61% - 80%	Suitable	Generally appropriate, but requires some improvements
41% - 60%	Fairly Suitable	Moderately aligned, needs significant revision
$\leq 40\%$	Not Suitable	Does not meet practical requirements

Based on this categorization, the obtained results of 90% falls into the “Very Suitable” category, with only minor improvements needed. Mr. Yulianto confirmed that the application content is consistent with the information typically delivered during guided tours and supports visitors in understanding the site independently.

Although the application was considered easy to use and helpful in providing both information and navigation during visits, indicating that the intergration of feature such as AR visualization is functionality relevant in the field. However, Mr. Yulianto also highlighted that the sequence of information delivery does not fully match the actual tour flow, and suggested improvements such as enabling offline access due to network limitations at the site. In addition, from a practical guiding perspective, he emphasized the importance of providing Bahasa Indonesia as an alternative language option to better accommodate local visitors. This would ensure that the application can be more effectively used across a broader audience with varying levels of English proficiency.



Figure 4.48 Documentation with Tour Guide, Mr Yulianto

Overall, the combination of expert validation and practitioner evaluation demonstrates that the developed application meets both academic and practical requirements. The expert assessment confirms the accuracy and credibility of the content, while the tour guide validation ensures its applicability in real tourism scenarios. Nevertheless, several improvements have been identified, particularly in refining narrative structure, simplifying and having language accessibility, aligning information flow with real tour sequences, and enhancing technical accessibility which will be considered for future development.

4.5.3 Compatibility Testing

This evaluation focuses on several key aspects, including application performance, responsiveness, and AR tracking stability. Each device is tested by executing core features of the application, such as AR marker detection, POI access, and map interaction. The system behavior is then observed to determine whether it performs as expected on each device configuration.

To ensure a structured evaluation, each device is assessed using a four-point rating scale ranging from Poor (1) to Excellent (4). The evaluation focuses on two main aspects: AR Performance and Tracking Stability. AR performance refers to the smoothness of rendering 3D objects and the responsiveness of user interactions, while Tracking Stability measures the consistency and accuracy of marker detection and object placement in real-time conditions. A device is categorized as “Pass” if all core feature function without critical errors and achieve a minimum rating of “Good” (score ≥ 3) in all evaluated aspects. The OS Version column indicates the Android version used during testing, which may influence system compatibility

and API support. The RAM column represents the memory capacity of each device, which affects application performance, particularly in AR processing. The AR Performance and Tracking Stability columns present the evaluation results based on direct observation during testing. The results of the compatibility testing are summarized in Table 4.5. Each device is evaluated based on whether the application functions properly without critical errors. To provide a clearer overview of system compatibility, the results are quantified using the following formula:

$$\text{Compatibility Rate} = \frac{\text{Number of Compatible Devices}}{\text{Total Tested Devices}} \times 100\%$$

Table 4.11 Compatibility Testing

No	Device	OS Version	RAM	AR Performance	Tracking Stability	Result
1	Samsung A15	16	8 GB	Excellent	Good	Pass
2	Samsung A24	13	4 GB	Good	Good	Pass
3	Vivo V2352	14	8 GB	Excellent	Good	Pass
4	Xiaomi 14 T	14	8 GB	Excellent	Excellent	Pass
5	Samsung A56	14	8 GB	Excellent	Excellent	Pass

Based on the testing results, the application successfully runs on 5 out of 5 tested devices, resulting in a compatibility rate of:

$$\text{Compatibility Rate} = \frac{5}{5} \times 100\% = 100\%$$

The results indicate that the application is compatible with a wide range of Android devices with varying specifications. However, performance differences are observed in lower-specification devices

Although all devices achieved a “Pass” classification, slight differences in performance were observed. Devices with higher RAM capacity (8GB) demonstrated smoother rendering and faster response times during AR interactions. In contrast, the device with lower RAM (4GB) exhibited minor delays in rendering, resulting in a “Good” rating for AR Performance. However, these differences did not significantly impact the overall usability of the application.

Overall, the results demonstrate that the application maintains stable performance and functional reliability across different device configurations. This confirms that the system is suitable for real-world implementation.

4.5.4 SUS Evaluation

The usability evaluation was conducted using the System Usability Scale (SUS) to assess users' perceptions regarding the ease of use, learnability, and overall usability of the developed application. Prior to completing the SUS questionnaire, respondents followed a structured evaluation procedure to ensure that they experienced the application's features within its intended usage context. The evaluation procedure is illustrated in Figure 4.49.

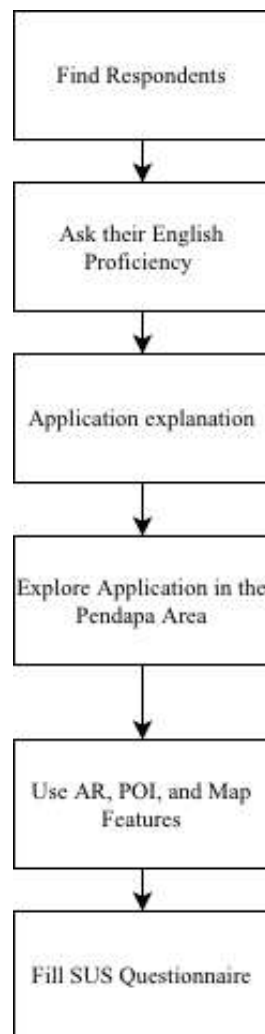


Figure 4.49 SUS Evaluation Procedure

The evaluation began by recruiting visitors at the Ratu Boko Heritage Site who were willing to participate in the study. Since the application was developed in English, respondents were first asked about their English language proficiency to ensure that they could understand

the content presented within the application and the SUS questionnaire statements. Only respondents who indicated that they could understand basic English instructions and informational content were included in the usability testing. After the screening process, respondents received a brief introduction regarding the purpose of the application, its main features, and the procedure for using the marker-based AR functionality. This briefing was intended to ensure that all respondents understood how to operate the application before the evaluation session began.

Following the briefing, respondents were invited to explore the application within the Pendapa Area of the Ratu Boko Heritage Site. During this session, respondents were allowed to interact freely with the application's features, including marker scanning, AR content viewing, point-of-interest (POI) exploration, and map navigation. Conducting the evaluation in the actual heritage environment allowed respondents to experience the application under its intended conditions of use. After completing the exploration session, respondents were asked to fill out the System Usability Scale (SUS) questionnaire consisting of ten statements evaluated using a five-point Likert scale. The collected responses were then processed using the SUS scoring method to determine the overall usability score of the application.

Table 4.12 System Usability Scale (SUS) Statements

No	Statement
1	I think I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to use this system.
5	I found the various function in this system were well integrated.
6	I thought there were too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very cumbersome to use
9	I felt very confident using the system
10	I needed to learn a lot of things before I could get going with this system.

The scoring of the SUS questionnaire is carried out using standard procedures. Each response contributes to the final score based on the following rules:

- For odd-numbered statements (1, 3, 5, 7, 9):

$$\text{Score Contribution} = \text{Response} - 1$$

- For even-numbered statements (2, 4, 6, 8, 10):

$$\text{Score Contribution} = 5 - \text{Response}$$

The total score for each respondent is then calculated using the following formula:

$$\text{SUS Score} = \left(\sum \text{Score Contribution} \right) \times 2.5$$

Table 4.13 SUS Score of Respondents

R	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	TOTAL	SCORE
R1	3	2	3	1	4	3	3	4	3	2	28	70
R2	3	4	4	3	4	4	4	4	4	3	37	92.5
R3	3	4	4	3	4	4	4	3	4	3	36	90
R4	2	2	2	3	2	3	3	2	3	3	25	62.5
R5	4	4	4	3	4	3	4	4	4	4	38	95
R6	4	4	4	4	4	2	3	3	4	3	35	87.5
R7	3	3	4	2	3	2	3	3	3	3	29	72.5
R8	2	4	3	4	3	3	4	3	2	2	30	75
R9	3	4	4	2	3	3	4	4	3	1	31	77.5
R10	2	4	4	4	4	3	4	4	4	4	37	92.5
R11	2	4	4	4	4	4	3	4	3	3	35	87.5
R12	4	4	4	2	3	4	4	4	4	4	37	92.5

The final SUS score of the application is calculated by averaging the SUS scores obtained from all respondents using the following formula:

$$\text{Final SUS Score} = \frac{\sum \text{SUS Score of All Respondents}}{\text{Number of Respondents}}$$

$$\text{Final SUS Score} = \frac{995}{12} = 82.91666667$$

The final System Usability Scale (SUS) score is calculated by averaging the individual SUS scores obtained from all respondents. As shown in the formula, the total SUS score of all

respondents is summed and then divided by the number of respondents. In this study, the total score of 995 from 12 respondents results in a final SUS score of 82.916.

A more detailed analysis of individual responses reveals several minor variations across specific items. Notably, lower scores are observed in Question 6, which relates to system consistency. Several respondents provided moderate ratings for this item, indicating that certain aspects of the system, such as transitions between features or differences in interaction between AR and non-AR components, may not be fully consistent.

In addition, Question 8, which reflects perceived complexity, also shows occasional lower scores. This suggests that some users experienced minor difficulties when interacting with the system. These challenges are likely associated with the AR interaction process, particularly marker detection, which requires proper camera positioning and is influenced by environmental conditions such as lighting and surface characteristics.

Furthermore, slight variations in responses to Questions 1 and 3 indicate that while the system is generally easy to use and well-received, it may not provide a completely effortless experience for all users. This observation aligns with the technical limitations identified during testing, where marker detection was not always stable.

Additionally, a notable variation is observed in Question 10, where Respondent R9 provided a significantly lower score compared to other participants. This response indicates that the respondent strongly disagreed with the need for prior learning before using the system, suggesting that the application was perceived as highly intuitive. While this reflects a positive usability perception, the contrast with other respondents highlights differences in user experience and familiarity with the system.

An outlier can be observed in Respondent R4, who provided consistently lower scores compared to other participants. This may reflect individual differences in user experience, familiarity with AR technology, or specific difficulties encountered during testing. However, this variation does not significantly affect the overall result.

Overall, while minor inconsistencies exist at the item level, these do not contradict the overall SUS score. Instead, they provide valuable insight into aspects of the system that can be further improved, particularly in terms of interaction consistency and the robustness of AR detection.

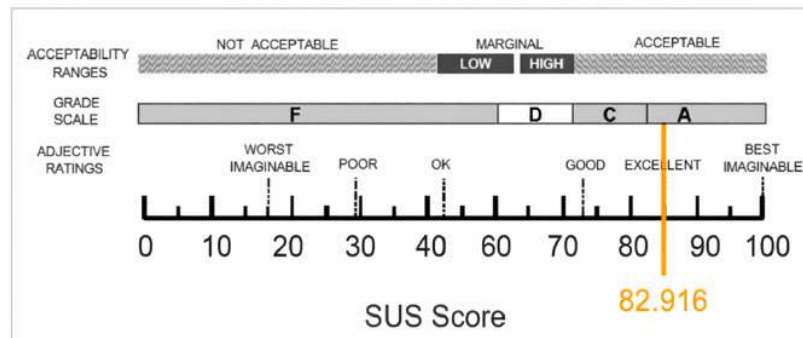


Figure 4.50 Final SUS Score of the Application

Based on the SUS interpretation scale illustrated in Figure 4.49, a score of 82.916 falls within the “Excellent” category in the adjective rating and is included in the acceptable range with a grade A classification. This indicates that the application demonstrates a high level of usability and is well accepted by users.

The visualization in the figure further emphasizes that the obtained score is positioned above the average usability threshold, confirming that the system performs significantly better than standard usability benchmarks. Overall, both the numerical calculation and its graphical interpretation consistently indicate that the developed application provides a positive and effective user experience.

CHAPTER V

CONCLUSION AND SUGGESTIONS

5.1 Conclusion

First, the development of a marker-based Augmented Reality (AR) application for the Ratu Boko heritage site has been successfully implemented. The application was developed using the ADDIE model and integrates AR functionality through Unity and Vuforia with an Android-based system. The developed application includes features such as marker detection, AR visualization, point-of-interest (POI) information, and map integration, all of which function according to their intended design.

Second, the developed AR application is able to present information at the Ratu Boko site through object-based visualization. Information is delivered using a combination of visual overlays, textual descriptions, and audio narration, allowing users to understand the function of selected objects within the Pendapa area. The use of marker-based tracking enables the application to display contextual information directly on physical objects, supporting a more interactive and engaging information delivery compared to conventional media.

Third, based on user evaluation, the developed application demonstrates a high level of usability. The System Usability Scale (SUS) evaluation resulted in a score of 82.916, which falls into the “Excellent” category. In terms of interaction behavior, respondents showed a strong preference for engaging with audio elements and the AR’s digital content rather than just reading textual descriptions. The AR feature attracted most attention, as they mostly are having their first try with the AR technology. This indicates that the application is easy to use, well-received by users, and capable of providing a positive user experience in real-world usage.

Overall, the developed AR application shows its potential as an interactive tourism medium that supports users in accessing and understanding information at the Ratu Boko heritage site.

5.2 Suggestion

Future development may focus on implementing markerless AR technologies, such as Simultaneous Localization and Mapping (SLAM), to reduce dependency on predefined image targets and provide a more flexible user experience. Such an approach would allow digital content to be anchored directly to environmental features, potential improving scalability and

usability in outdoor heritage environments. Building upon the current implementation, future research may expand the application to cover additional areas within the Ratu Boko Heritage Site and include a broader range of architectural elements. Expanding the coverage of the application would enable visitors to access more comprehensive information regarding the site's historical and cultural significance. Beyond expanding the application scope, future versions may incorporate richer AR content, such as three-dimensional reconstructions, interactive animations, and contextual storytelling features. These additions may further enhance visitor engagement and support a deeper understanding of the historical functions and meanings of heritage structures.

From a user experience perspective, future development may also focus on improving the user interface to strengthen both usability and cultural identity. A heritage-oriented design system could be implemented by incorporating visual elements inspired by the Ratu Boko Heritage Site and Javanese cultural aesthetics, including color palettes derived from local architectural materials, decorative motifs adapted from historical ornaments, and site-specific visual branding. From a technical perspective, this improvement may be implemented through a centralized design system that standardizes typography, spacing, color tokens, icons, and interface components throughout the application. Furthermore, responsive layouts, improved visual hierarchy, accessibility-oriented design, and enhanced outdoor readability may be incorporated to support a wider range of Android devices and usage conditions. These enhancements are expected not only to improve usability but also to create a stronger sense of place and cultural identity, making the application more representative of the Ratu Boko Heritage Site as a cultural tourism destination.

Considering that the current implementation is limited to the English language, future development may also incorporate multilingual support, particularly bahasa Indonesia and English language options. Such an enhancement would improve accessibility for a broader range of visitors while accommodating both domestic and international tourists. Furthermore, multilingual support would allow future studies to investigate how language selection influences user comprehension, engagement, and overall usability when interacting with cultural heritage content.

To further strengthen the evaluation process, future studies may involve larger and more diverse participant groups while incorporating additional evaluation methods, such as the User Experience Questionnaire (UEQ), to obtain a more comprehensive assessment of user

experience. Such evaluations may provide deeper insights into user perceptions and support the continued refinement of AR applications for cultural heritage tourism.

REFERENCES

- Adhitama, M. S., Putri, D. H., & Ramdlani, S. (2025). Mobile-Based Augmented Reality for Digital Heritage: 3D Documentation of Sumenep Palace Architecture. *Review of Urbanism and Architectural Studies*, 23(1), 128–139. <https://doi.org/10.21776/ub.ruas.2025.023.01.12>
- Adi, N., Sudana, O., & Cahyawan, A. (2024). Developing a Marker-Based AR Application to Introduce Temples and Cultural Heritage to Younger Generations. *Jurnal Nasional Pendidikan Teknik Informatika (JANAPATI)*, 13(3). <https://doi.org/10.23887/janapati.v13i3.76126>
- Arena, F., Collotta, M., Pau, G., & Termine, F. (2022). An Overview of Augmented Reality. *Computers 2022, Vol. 11, 11(2)*. <https://doi.org/10.3390/COMPUTERS11020028>
- Awan, A. B., Sabahat, N., & Mahmood, A. W. (2024). Enhancing User Experience: Exploring Mobile Augmented Reality Experiences. *VFAST Transactions on Software Engineering*, 12(1), 121–132. <https://doi.org/10.21015/VTSE.V12I1.1741>
- Bachiller, C., Monzo, J. M., & Rey, B. (2023). Augmented and Virtual Reality to Enhance the Didactical Experience of Technological Heritage Museums. *Applied Sciences 2023, Vol. 13, 13(6)*. <https://doi.org/10.3390/APP13063539>
- Boboc, R. G., Băutu, E., Gîrbacia, F., Popovici, N., & Popovici, D. M. (2022). Augmented Reality in Cultural Heritage: An Overview of the Last Decade of Applications. *Applied Sciences (Switzerland)*, 12(19). <https://doi.org/10.3390/APP12199859>
- Branch, R. M. (2009). *Instructional Design: The ADDIE Approach - Robert Maribe Branch - Google*. *Buku*. <https://books.google.co.id/books?id=mHSwJPE099EC&printsec=copyright&hl=id#v=onepage&q&f=false>
- Brooke, J. (1986). *SUS - A quick and dirty usability scale*.
- Cao, J., Lam, K. Y., Lee, L. H., Liu, X., Hui, P., & Su, X. (2023). Mobile Augmented Reality: User Interfaces, Frameworks, and Intelligence. *ACM Computing Surveys*, 55(9). <https://doi.org/10.1145/3557999>
- Cho, H. (2025). Augmenting Heritage: Youth-Driven AR Innovation in Museum Spaces. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-M-9–2025(M-9–2025), 293–298. <https://doi.org/10.5194/ISPRS-ARCHIVES-XLVIII-M-9-2025-293-2025>

- Dolnicar, S., Grün, B., & Leisch, F. (2011). Quick, Simple and Reliable: Forced Binary Survey Questions. *International Journal of Market Research*, 53(2), 7. <https://doi.org/10.2501/IJMR-53-2-231-252>
- Ghaemi, Z., Satriadi, K. A., Engelke, U., Ens, B., & Jenny, B. (2023). Visualization Placement for Outdoor Augmented Data Tours. *Proceedings - SUI 2023: ACM Symposium on Spatial User Interaction*, (23), 14. <https://doi.org/10.1145/3607822.3614518>
- Ham, & Park, Y. (2011). CCIS 257 - Mobile Application Compatibility Test System Design for Android Fragmentation. In *CCIS* (Vol. 257).
- Hirsch, L., Welsch, R., Rossmly, B., & Butz, A. (2022). Embedded AR Storytelling Supports Active Indexing at Historical Places. *ACM International Conference Proceeding Series*, 12. <https://doi.org/10.1145/3490149.3501328>
- International Organization for Standardization & International Electrotechnical Commission. (2023). *International Organization for Standardization & International Electrotechnical Commission*. <https://www.iso.org/standard/78176.html>
- Izzat, & Saleem. (2023). Software Testing Techniques and Tools: A Review. *Journal of Education and Science*, 32(2), 30–44. <https://doi.org/10.33899/edusj.2023.137480.1305>
- Khan, Mohd. E. (2021). *Different Approaches to Black Box Testing Technique for Finding Errors*. <https://papers.ssrn.com/abstract=3890672>
- Khor, C. Y., & Mubin, S. A. (2024). AR MOBILE APPLICATION FOR ENHANCING NATIONAL MUSEUM HERITAGE VISUALIZATION. *International Journal of Software Engineering and Computer Systems*, 10(1), 1–19. <https://doi.org/10.15282/IJSECS.10.1.2024.1.0119>
- Kleftodimos, A., Evagelou, A., Triantafyllidou, A., Grigoriou, M., & Lappas, G. (2023). Location-Based Augmented Reality for Cultural Heritage Communication and Education: The Doltso District Application. *Sensors*, 23(10). <https://doi.org/10.3390/s23104963>
- Lin, H. C. K., Lu, L. W., & Lu, R. S. (2024). Integrating Digital Technologies and Alternate Reality Games for Sustainable Education: Enhancing Cultural Heritage Awareness and Learning Engagement. *Sustainability* 2024, Vol. 16, 16(21). <https://doi.org/10.3390/SU16219451>
- Magrini, M., Matarese, F., & Moroni, D. (2022). Test and Validation of a Multi-Block Solution for Improved Tracking in Outdoor Scenarios: A Case Study in the Pinocchio Park. *Information (Switzerland)*, 13(10). <https://doi.org/10.3390/info13100449>

- Md Nor, R., Hafizuddin, M., & Razak, A. (2021). Interactive Design in Enhancing User Experience in Museum. *Journal of Computing Research and Innovation*, 6(3), 86–91. <https://doi.org/10.24191/JCRINN.V6I3.249>
- Mendoza-Ramírez, C. E., Tudon-Martinez, J. C., Félix-Herrán, L. C., Lozoya-Santos, J. de J., & Vargas-Martínez, A. (2023). Augmented Reality: Survey. *Applied Sciences* 2023, Vol. 13, 13(18). <https://doi.org/10.3390/AP131810491>
- Mobile Android version share worldwide 2025| Statista. (n.d.). Retrieved March 30, 2026, from <https://www.statista.com/statistics/921152/mobile-android-version-share-worldwide/>
- Mohammadhossein, N., Richter, A., Richter, S., & Thatcher, J. (2025). Navigating augmented reality: A practice-oriented guide to identifying and overcoming implementation obstacles. *Business Horizons*. <https://doi.org/10.1016/j.bushor.2025.03.003>
- Moses Adeleke Adeoye, Kadek Adrian Surya Indra Wirawan, Made Shania Satya Pradnyani, & Nyoman Intan Septiarini. (2024). Revolutionizing Education: Unleashing the Power of the ADDIE Model for Effective Teaching and Learning. *JPI (Jurnal Pendidikan Indonesia)*, 13(1), 202–209. <https://doi.org/10.23887/jpiundiksha.v13i1.68624>
- Nielsen, J. (1994). *Usability Engineering - Jakob Nielsen - Google Books*. https://books.google.co.id/books?hl=en&lr=&id=95As2OF67f0C&oi=fnd&pg=PR9&dq=jakob+nielsen+usability&ots=3dFDCqcpUv&sig=8CIXhEBoxuUu-5eQxsdo1_RR0qY&redir_esc=y#v=onepage&q=jakob%20nielsen%20usability&f=false
- Paranagama, H., Ranwalage, A., Athukorala, K., De Silva, D., & Pradeep, R. (2016). *Kryptext- A secure communication tool for intelligence operations*.
- Pargaonkar, S. (2023). A Comprehensive Review of Performance Testing Methodologies and Best Practices: Software Quality Engineering. *International Journal of Science and Research (IJSR)*, 12(8), 2008–2014. <https://doi.org/10.21275/sr23822111402>
- Sauro, J. (2016). Quantifying the user experience : practical statistics for user research / Jeff Sauro, James R. Lewis. *Quantifying the User Experience : Practical Statistics for User Research*. https://books.google.com/books/about/Quantifying_the_User_Experience.html?hl=id&id=USPfcQAAQBAJ
- Simon, J. (2023). AUGMENTED REALITY APPLICATION DEVELOPMENT USING UNITY AND VUFORIA. *Interdisciplinary Description of Complex Systems*, 21(1), 69–77. <https://doi.org/10.7906/indecs.21.1.6>

- Soenarto, A., Subroto, S., & Santoso, D. (1993). *Ratu Boko yang terlupakan*. http://pustaka.kebudayaan.kemdikbud.go.id/index.php?p=show_detail&id=5639&keywords=Ratu+Boko
- Soraya, S. (2022). *Implementation of Augmented Reality (AR) using Assembler in High School Applied Physics Education with the ADDIE Model Approach*. 12072. <https://doi.org/10.1088/1742-6596/2377/1/012072>
- Suhaizal, H., Rahman, K. A. A., Khamis, N., Shukor, U. H., Lah, N. H. C., & Zulkifli, N. N. (2023). The Design and Development of Augmented Reality (AR) Application for Internet Evolution Learning Topics. *International Journal of Interactive Mobile Technologies*, 17(5), 162–181. <https://doi.org/10.3991/ijim.v17i05.36483>
- Suter, D., Hodel, S., Liebmann, F., Fürnstahl, P., & Farshad, M. (2023). Factors affecting augmented reality head-mounted device performance in real OR. *European Spine Journal*, 32(10), 3425–3433. <https://doi.org/10.1007/s00586-023-07826-x>
- Suyuti, H., & Setyanto, A. (2023). The Use of Augmented Reality Technology in Preserving Cultural Heritage: A Case Study of Old Jami Mosque of Palopo. *Ceddi Journal of Information System and Technology (JST)*, 2(1), 28–37. <https://doi.org/10.56134/jst.v2i1.35>
- Syed, T. A., Siddiqui, M. S., Abdullah, H. B., Jan, S., Namoun, A., Alzahrani, A., Nadeem, A., & Alkhodre, A. B. (2022). In-Depth Review of Augmented Reality: Tracking Technologies, Development Tools, AR Displays, Collaborative AR, and Security Concerns. *Sensors 2023, Vol. 23*, 23(1). <https://doi.org/10.3390/S23010146>
- Taman Wisata Candi. (2024). *ARA-2024-PT-TAMAN-WISATA-CANDI-BOROBUDUR-PRAMBANAN-DAN-RATU-BOKO_compressed*.
- Tri Worosetyaningsih. (2019). *Candi Ratu Boko: antara mitos dan perkembangan zaman - Bintangpusnas Edu*. <https://bintangpusnas.perpusnas.go.id/konten/BK18896/candi-ratu-boko-antara-mitos-dan-perkembangan-zaman>
- Tsabita, K., & Nurrizqa, N. (2025). Perancangan Augmented Reality Book Sebagai Media Pembelajaran Monumen Bersejarah Menggunakan Metode Marker Based Tracking. *JTIM: Jurnal Teknologi Informasi Dan Multimedia*, 7(4), 881–897. <https://doi.org/10.35746/jtim.v7i4.819>
- Vlachogianni, P., & Tselios, N. (2022). Perceived usability evaluation of educational technology using the System Usability Scale (SUS): A systematic review. *Journal of*

- Research on Technology in Education*, 54(3), 392–409.
<https://doi.org/10.1080/15391523.2020.1867938>
- Wan Ali, W. N. A., & Wan Yahaya, W. A. J. (2023). WATERFALL-ADDIE MODEL: AN INTEGRATION OF SOFTWARE DEVELOPMENT MODEL AND INSTRUCTIONAL SYSTEMS DESIGN IN DEVELOPING A DIGITAL VIDEO LEARNING APPLICATION. *Asean Journal of Teaching and Learning in Higher Education*, 15(1), 1–28. <https://doi.org/10.17576/ajtlhe.1501.2023.01>
- Wang, C. H., Hsiao, C. Y., Tai, A. T., & Wang, M. J. J. (2023). Usability evaluation of augmented reality visualizations on an optical see-through head-mounted display for assisting machine operations. *Applied Ergonomics*, 113, 104112. <https://doi.org/10.1016/J.APERGO.2023.104112>
- Washizaki. (2025). *swebok-v4*.
- Wen, X., Sotiriadis, M., & Shen, S. (2023). Determining the Key Drivers for the Acceptance and Usage of AR and VR in Cultural Heritage Monuments. *Sustainability (Switzerland)*, 15(5). <https://doi.org/10.3390/su15054146>
- Yoon, I. C., Sussman, A., Memon, A., & Porter, A. (2008). Effective and scalable software compatibility testing. *ISSTA'08: Proceedings of the 2008 International Symposium on Software Testing and Analysis 2008*, 63–73. <https://doi.org/10.1145/1390630.1390640>
- Zhang, G., Sun, J., Gong, J., Zhang, D., Li, S., Hu, W., & Li, Y. (2023). Exploration of visual variable guidance in outdoor augmented reality geovisualization. *International Journal of Digital Earth*, 16(2), 4095–4112. <https://doi.org/10.1080/17538947.2023.2259874>

APPENDIX

LEMBAR VALIDASI KONTEN (EXPERT JUDGMENT)

Judul Penelitian:

Pengembangan Aplikasi Augmented Reality Berbasis Penanda untuk Mendukung Wisata Sejarah di Ratu Boko / Development of a Marker-Based Augmented Reality Application as an Interactive Learning Media for the Ratu Boko Heritage Site

Nama Expert: Septi Indrawati Kusumaningsih

Bidang Keahlian: Cagar Budaya

Institusi: Balai Pelestarian Kebudayaan D.I. Yogyakarta

Petunjuk Pengisian

Mohon memberikan skor pada setiap aspek sesuai dengan penilaian Bapak/Ibu, serta mengisi bagian saran jika terdapat masukan.

Berikan penilaian terhadap konten narasi aplikasi berdasarkan skala berikut:

- 1 = Sangat tidak sesuai
- 2 = Tidak sesuai
- 3 = Cukup sesuai
- 4 = Sesuai
- 5 = Sangat sesuai

BAGIAN A — PENILAIAN KONTEN

Penilaian dilakukan terhadap keseluruhan konten narasi dalam aplikasi (AR dan POI).

No	Aspek yang Dinilai	Deskripsi	Skor (1-5)
1	Akurasi konten sejarah	Informasi sesuai dengan fakta sejarah/arkologi	4.
2	Kejelasan informasi	Narasi mudah dipahami oleh pengguna umum	4.
3	Kesesuaian dengan audiens	Bahasa dan gaya sesuai untuk wisatawan	5.

4	Alur narasi	Penyampaian runtut dan enak diikuti	4
5	Kesesuaian dengan konteks lokasi	Narasi relevan dengan objek fisik di lapangan	4

BAGIAN B — PENILAIAN KHUSUS AUDIO GUIDE

No	Aspek yang Dinilai	Deskripsi	Skor (1-5)
6	Kesesuaian gaya bahasa	Bahasa terasa natural seperti pemandu wisata	3.
7	Tingkat engagement	Narasi menarik dan tidak membosankan	4
8	Panjang narasi	Durasi tidak terlalu panjang/pendek	4
9	Kejelasan penyampaian informasi	Informasi tidak bertele-tele	4

BAGIAN C — SARAN DAN MASUKAN

1. Apakah terdapat bagian yang kurang akurat atau perlu revisi?

Beberapa bagian perlu ditambahkan dan didetailkan / diperjelas. Misal di informasi tentang Jaladwara perlu ditambahkan nilai estetika, penjelasan tentang pendopo dan kolam ada yang perlu diperbaiki.

2. Apakah ada istilah yang terlalu teknis atau sulit dipahami?

Secara umum sudah lebih sederhana dan mudah diterima oleh pembaca yang awam tentang candi, perlu ditambahkan kata-kata penjelasan untuk istilah-istilah yang tidak umum.

3. Saran untuk meningkatkan kualitas narasi:

Jika bisa diangkat atau disederhanakan istilah dan kalimat yang lebih efektif akan lebih mudah dipahami. Beberapa objek perlu didetailkan, misal foto kala dan bagian-bagiannya, makara dan bagian-bagiannya.

Sleman, 14 April 2026



(Septi Indrawati K.)

Hasil penilaian ini akan digunakan sebagai dasar perbaikan dan validasi konten dalam penelitian.

Validasi Tour Ratu Boko

LEMBAR EVALUASI TOUR GUIDE (PRAKTIKI WISATA)

Judul Penelitian:

Pengembangan Aplikasi Augmented Reality Berbasis Penanda untuk Mendukung Wisata Sejarah di Ratu Boko / Development of a Marker-Based Augmented Reality Application as an Interactive Learning Media for the Ratu Boko Heritage Site

Identitas Responden

Nama: *Yuliana R*
Profesi: Tour Guide di Ratu Boko
Pengalaman (tahun): *8 tahun*

Petunjuk Pengisian

Berikan penilaian terhadap aplikasi berdasarkan pengalaman Anda sebagai pemandu wisata.
Beri tanda Silang (x) pada kolom yang sesuai dan tambahkan komentar jika diperlukan.

A. Kesesuaian Konten dengan Praktik Pemanduan

No	Pernyataan	Ya	Tidak
1	Informasi dalam aplikasi sesuai dengan penjelasan yang biasa disampaikan kepada wisatawan	X	
2	Konten mencakup poin-poin penting yang biasanya dijelaskan saat tur	X	
3	Tidak terdapat informasi yang bertentangan dengan praktik pemanduan di lapangan	X	
4	Urutan penyampaian informasi sudah sesuai dengan alur kunjungan wisata		X

B. Keterpahaman & Penyampaian Informasi

No	Pernyataan	Ya	Tidak
5	Bahasa yang digunakan mudah dipahami oleh wisatawan umum	X	
6	Penyampaian informasi cukup menarik untuk didengarkan/dibaca	X	
7	Informasi tidak terlalu panjang atau membingungkan	X	

C. Kegunaan dalam Kegiatan Wisata

No	Pernyataan	Ya	Tidak
8	Aplikasi ini dapat membantu wisatawan memahami lokasi secara mandiri	X	
9	Aplikasi ini dapat menjadi pelengkap bagi kegiatan pemanduan wisata	X	
10	Fitur Augmented Reality memberikan nilai tambah dalam pengalaman wisata	X	

D. Saran dan Masukan

1. Apa kelebihan utama dari aplikasi ini menurut Anda?

Mudah dioperasikan, cukup membantu mendapat informasi dan rute saat berkunjung di Ratu Boko.

2. Apa kekurangan atau hal yang perlu diperbaiki?

Jalur / urutan informasi, belum optimal ditundak di lokasi, usul bisa digunakan saat off line.

3. Apakah ada informasi yang sebaiknya ditambahkan?

persiapan saat berkunjung, informasi pendahuluan, saran waktu kunjungan

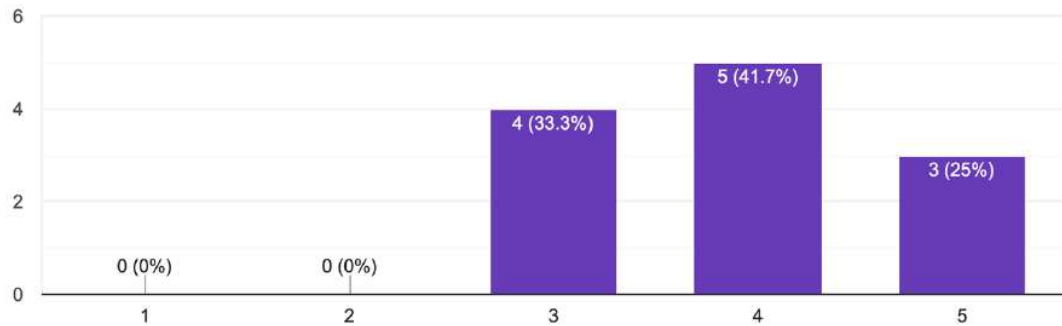
[Empty rectangular box for stamp or signature]

Sleman, 14 April 2026

AM
Julian to

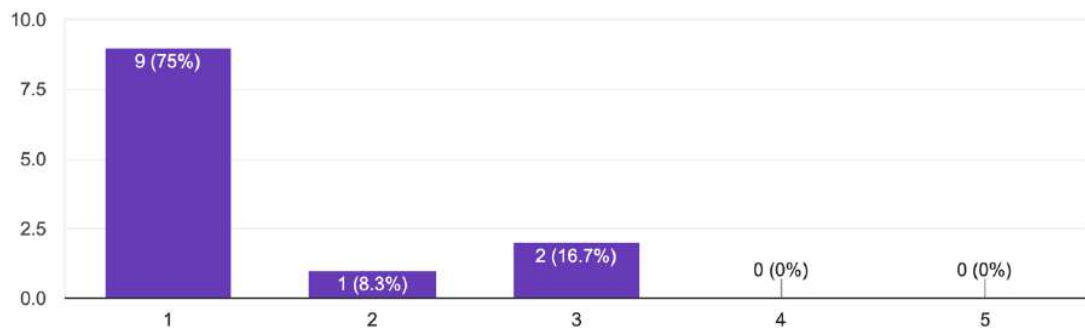
1. Saya merasa ingin menggunakan aplikasi ini secara sering. 1. I feel like using this app frequently.

12 responses



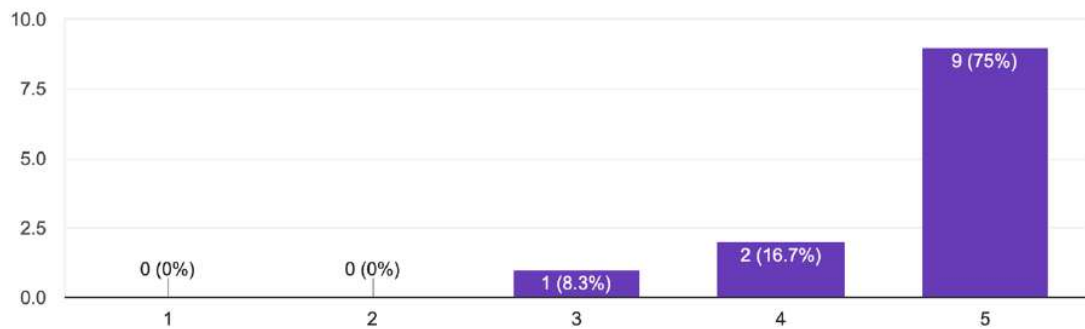
2. Saya merasa aplikasi ini terlalu rumit untuk digunakan. 2. I find this app too complicated to use.

12 responses



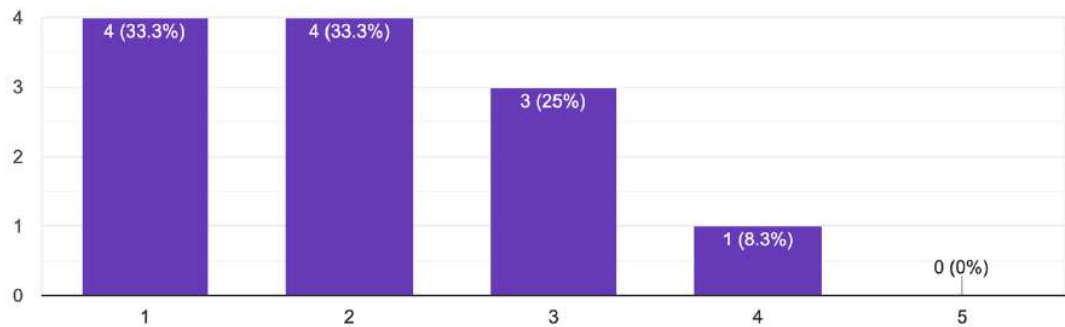
3. Saya merasa aplikasi ini mudah digunakan. 3. I find this app easy to use.

12 responses



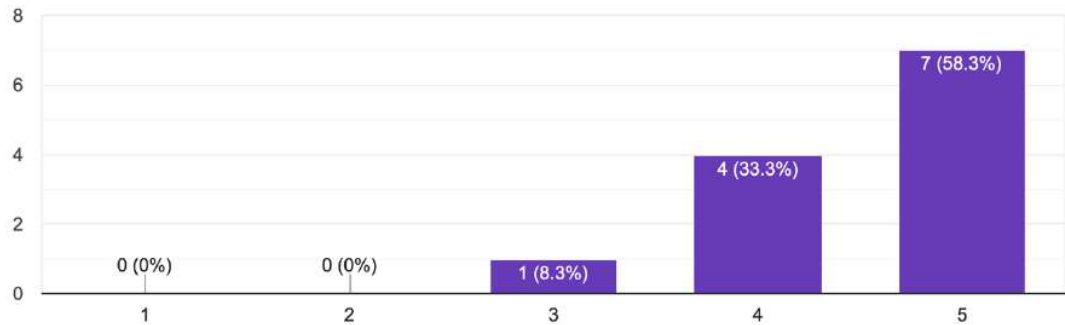
4. Saya membutuhkan bantuan dari orang lain atau teknisi untuk menggunakan aplikasi ini. 4. I need help from another person or technician to use this application.

12 responses



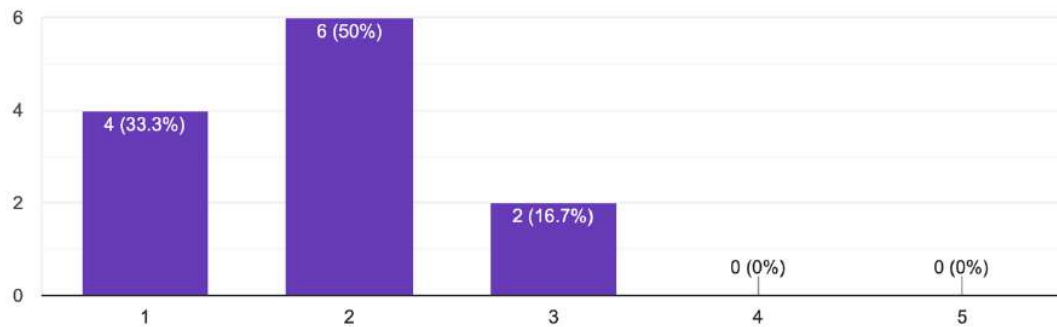
5. Saya merasa fitur-fitur dalam aplikasi ini berjalan dengan baik. 5. I feel the features in this application work well.

12 responses



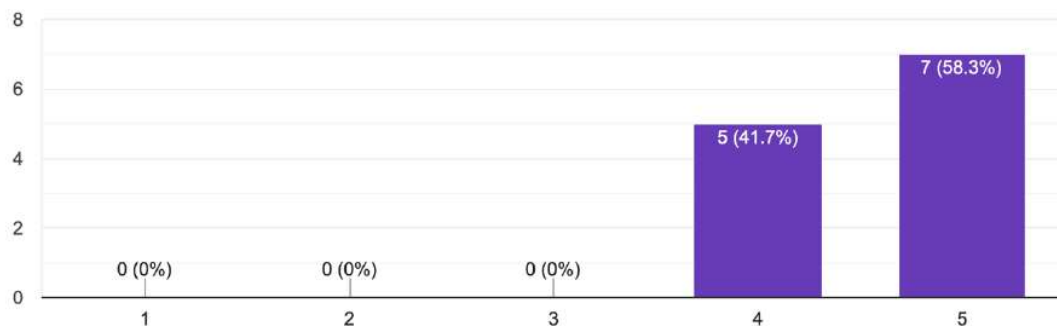
6. Saya merasa terdapat banyak ketidakkonsistenan dalam aplikasi ini. 6. I feel there are a lot of inconsistencies in this application.

12 responses



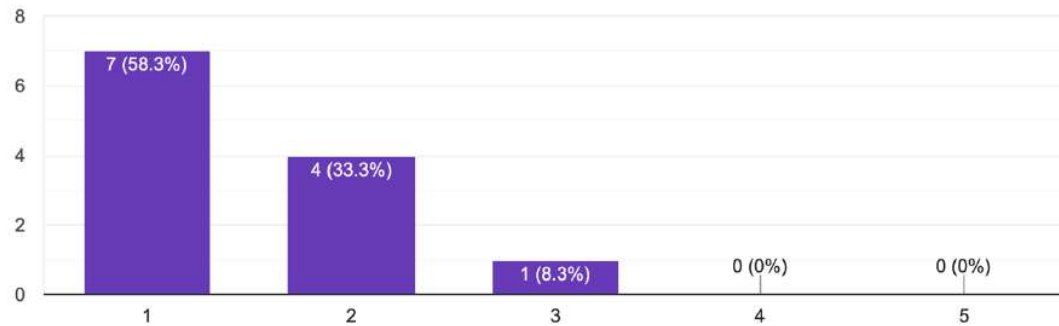
7. Saya merasa kebanyakan orang akan dapat menggunakan aplikasi ini dengan cepat. 7. I feel most people will be able to use this app quickly.

12 responses



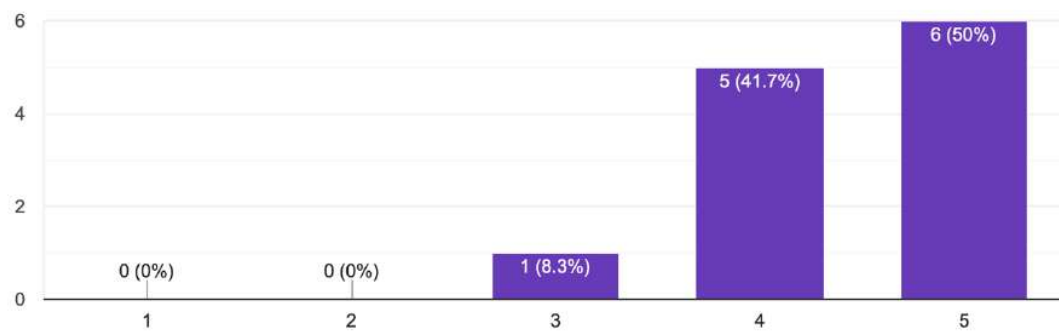
8. Saya merasa aplikasi ini membingungkan untuk digunakan. 8. I find this app confusing to use.

12 responses



9. Saya merasa percaya diri saat menggunakan aplikasi ini. 9. I feel confident when using this application.

12 responses



10. Saya perlu belajar banyak hal sebelum bisa menggunakan aplikasi ini dengan baik. 10. I need to learn a lot of things before I can use this application well.

12 responses

