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RESEARCH ARTICLE

Enhancing Museum Experience through Augmented Reality: The Case of the Indonesian Postal Museum

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Abstract: The Indonesian Postal Museum, in response to the challenges of digital adaptation and engagement, embarked on an innovative journey to integrate augmented reality technology into its exhibits amidst a global trend toward virtual tours and online exhibitions. This initiative represents a significant stride in digitizing the museum's rich historical collections dating back to 1931. The introduction of Mussia AR, developed specifically for the museum, not only addresses the need to transition to digital platforms but also enhances visitor engagement and educational outcomes. This application effectively bridges the gap between traditional exhibits and the expectations of a modern, technologically-savvy audience, enriching the learning experience with interactive multimedia content. Our research focuses on user-centric design and iterative development, covering a comprehensive methodology from preliminary analysis to application development and rigorous testing & evaluation. This project is a proactive response to the two-fold challenge faced by museums globally: adapting to digital engagement preferences and the urgent need for digitization in the wake of the pandemic. The paper presents the development process of Mussia AR, its implementation, and its impact on the visitor experience at the Indonesian Postal Museum. User testing, employing the usability test method and quantitatively analyzed using the Likert scale, revealed significant improvements in functionality (87.60%), user experience (84.64%), and user interface (85.00%). A comparative analysis with other AR museum applications also setting a new standard in museum AR experiences.

Keywords: augmented reality, Indonesian Postal Museum, indoor navigation, mobile application

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1 Introduction

In the current landscape of rapid digital evolution, museums globally face the pressing challenge of adapting to the digital preferences of a diverse, technologically-savvy audience. This shift towards digital engagement necessitates innovative methods beyond traditional passive exhibit observation to captivate and educate visitors effectively [1,2]. This challenge is acutely felt in historical and cultural museums where the dynamic presentation of information is critical for educational impact and cultural preservation [3,4]. In this context, the museum must reimagine visitor engagement and learning experiences to stay relevant and appealing in the digital age. The Indonesian Postal Museum, a repository of rich historical collections, faces a similar challenge, seeking to revitalize visitor engagement and education about postal history and its relevance in today's digital age [5].

Furthermore, the onset of the COVID-19 pandemic presented an unprecedented challenge for museums globally, including the Indonesian Postal Museum. The enforced lockdowns and social distancing measures drastically decreased physical visitors, significantly impacting museums that traditionally relied on in-person experiences [6,7]. This situation necessitated a swift adaptation to digital platforms to maintain engagement with existing audiences and reach new visitors in a rapidly changing digital landscape [8]. Figure 1 shows the decline of Postal Museum visitors during the pandemic.

The Indonesian Postal Museum, like many others, faced the urgent task of digitizing its collections and experiences, a move that aligned with global trends in the museum sector towards virtual tours, online exhibitions, and digital learning initiatives [9,10]. This transition posed technological and strategic challenges, requiring museums to rethink their approach to visitor engagement and educational dissemination in the context of limited physical interactions [11].

Established in 1931 as Museum PTT in Bandung, the Indonesian Postal Museum initially displayed a collection of domestic and foreign stamps. World War II impacted its maintenance, leading to a shift towards a more diverse collection. In 1980, the Directorate of Perum Pos and Giro expanded the museum's collection to include photographs, postal equipment, and other historical objects, marking a significant evolution in its offerings [5].

For several compelling reasons, augmented reality (AR) technology was chosen over other immersive technologies like virtual reality (VR) or the metaverse. Firstly, AR's ability to overlay digital information onto the physical world offers a unique blend of real and virtual experiences, making it particularly suitable for museums where interaction with real objects is essential [12,13]. Unlike VR, which creates a completely virtual environment, AR enhances the real world, thus preserving the authenticity and physicality of museum exhibits and improving learning [14,15].

Furthermore, AR does not require the extensive infrastructure or user isolation typical of VR, making it more accessible and less disruptive in museums [16]. Studies have shown that AR, with its immersive and interactive capabilities, significantly increases museum visits by offering an enriched, engaging experience that appeals to a contemporary audience. For instance, Kennedy *et al.* (2021) and Bird *et al.* (2023) have documented the success of AR in promoting interest, positive emotions, and knowledge among museum visitors, thereby contributing to an increase in museum attendance [17,18]. This evidence underscores AR's effectiveness in bridging the gap between traditional museum experiences and the expectations of today's technologically adept visitors, making it an optimal choice for enhancing learning and retention in educational settings [14,15].

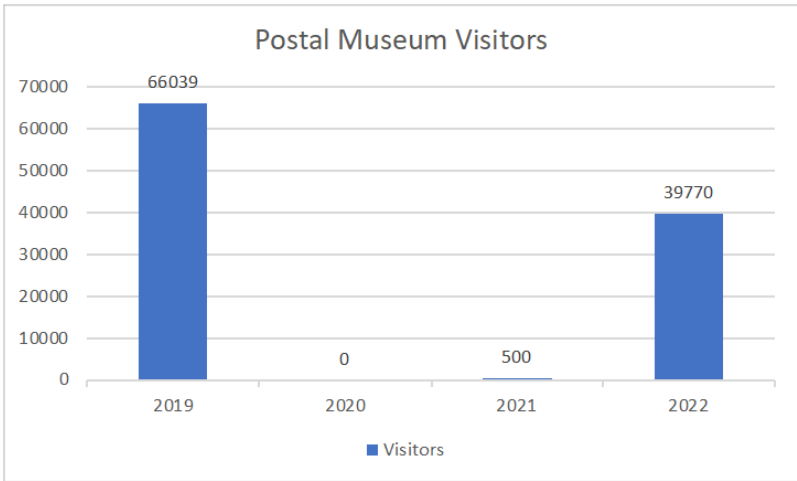

Figure 1: Postal museum visitor 2019-2022.

Recognizing this potential, our research focuses on developing Mussia AR, an AR application tailored for the Indonesian Postal Museum [16–18]. The application aims to transform the visitor experience by making museum exhibits more interactive and informative, increasing visitor engagement and enhancing educational outcomes. Our project leverages the capabilities of the Immersal SDK, a platform that utilizes spatial mapping technology to create realistic and interactive AR environments [19]. This approach is expected to offer a novel way for visitors to engage with the museum's collections, providing a richer understanding of postal history through interactive multimedia content, including text, audio, and video [20–23].

This paper details the development, implementation, and evaluation of Mussia AR, an AR application designed for the Indonesian Postal Museum. It focuses on assessing the application's impact on enhancing museum experiences and its viability as a prototype for integrating AR in museums. The research is structured into several sections, including a literature review, methodology explanation, presentation of results, discussion, and conclusion. The core objective is to explore the efficacy of AR technology in improving visitor engagement and learning in a museum setting. The paper analyzes the benefits and challenges of AR in this context. It concludes by summarizing key insights and proposing directions for future research in AR applications for cultural and educational purposes.

2 Research Method

Our research adopted a systematic approach to developing the Mussia AR application, focusing on user-centric design and iterative development. The methodology can be broadly categorized into three phases: Preliminary Analysis, Application Development, and Testing & Evaluation. Figure 2 shows the research method conducted in this research.

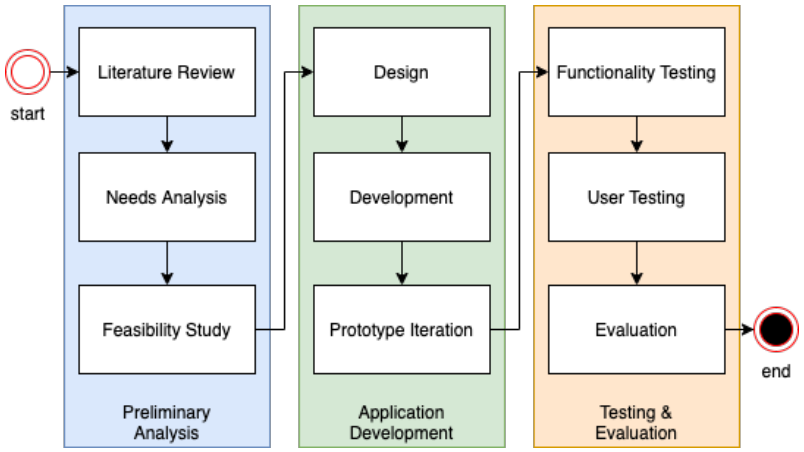

Figure 2: Research method.

2.1 Preliminary Analysis

2.1.1 Literature review

We extensively reviewed existing literature on AR technologies, focusing on their application in museum settings. This review helped identify best practices and effective AR frameworks.

2.1.2 Needs analysis

We gathered insights into user needs and preferences through surveys and interviews with museum visitors and staff. This step was crucial in determining the features and content of the Mussia AR application. Figure 3 illustrates the needs of the systems in the form of use case. There are four main functionalities: target object view and navigation, show help page, show about museum page, and show about application page.

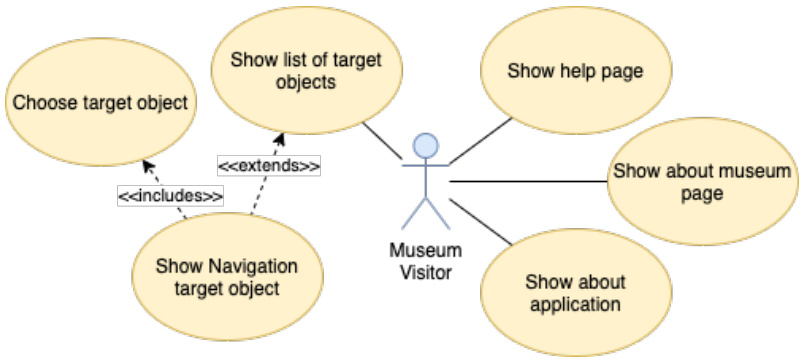

Figure 3: Use case of the Mussia AR.

2.1.3 Feasibility study

Our evaluation focused on the technical viability and practicality of applying AR technology at the Indonesian Postal Museum. This initial assessment occurred on January 17, 2023, within the museum's premises. For this study, we interviewed museum managers and visitors. The specific questions posed during these interviews are detailed in Table 1.

2.2 Application Development

2.2.1 Design

Based on the insights from our preliminary analysis, we designed the Mussia AR application. This included creating user interface (UI) designs, content layouts, and interaction models, as shown in Figure 4.

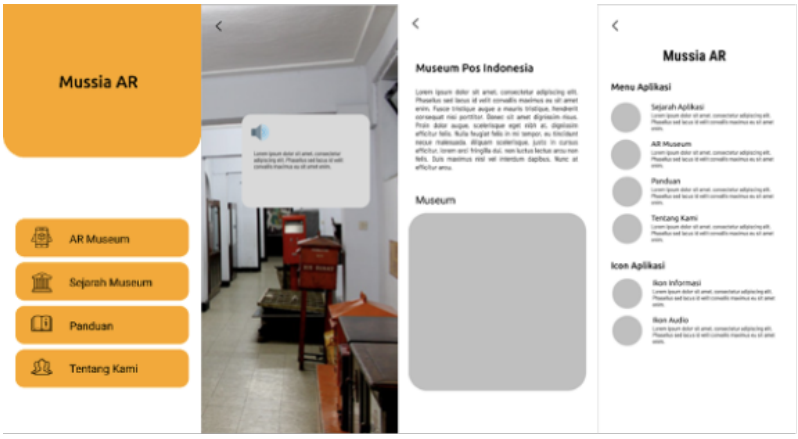

Figure 4: UI of Mussia AR.

Table 1: Preliminary study questions

No.	Asked Questions	Respondents
1	Do you know about Augmented Reality?	Visitors
2	Have you ever used an Augmented Reality based application?	Visitors
3	Do you like getting information through a smartphone media?	Visitors
4	What obstacles do you feel when getting information from a smartphone media?	Visitors
5	Can you identify museum objects without navigational assistance?	Visitors
6	Do you think an interactive application is needed for museums?	Visitors & Managers
7	In your opinion, what features are needed to explain museum object information?	Visitors & Managers
8	Is the navigation feature needed in this application?	Visitors & Managers
9	Is the room scan feature needed in this application?	Visitors & Managers
10	Are audio and video features of object information needed in this application?	Visitors & Managers

Mussia AR uses real museum objects as target objects. Figure 5 illustrates samples of the objects we used as the targets.

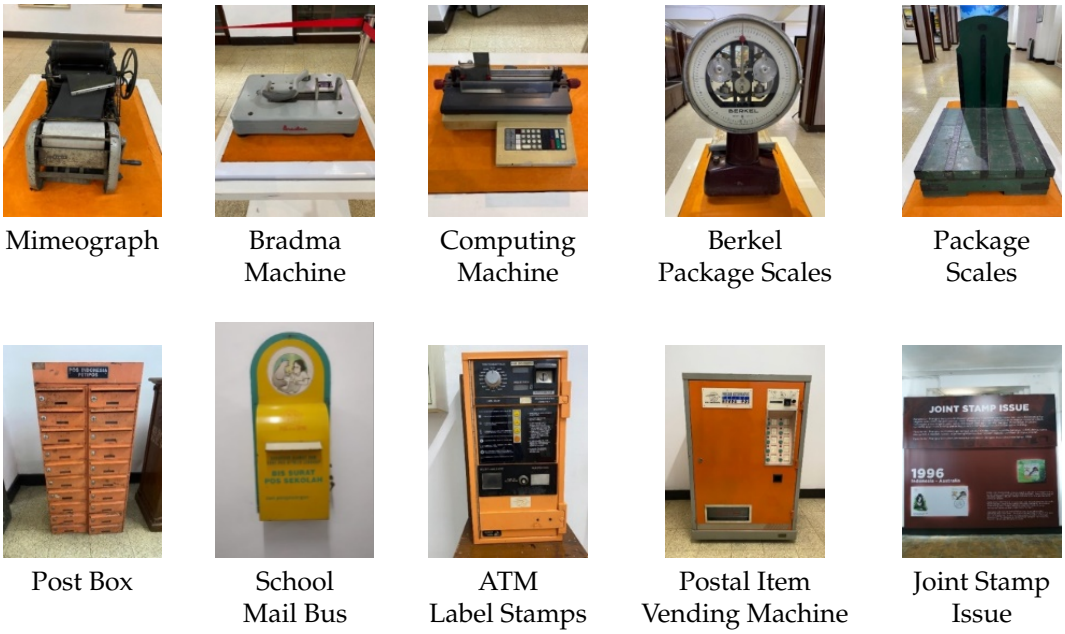

Figure 5: Target object in the Postal Museum.

2.2.2 Development

We chose the Immersal SDK for AR development due to its spatial mapping capabilities. The development process involved programming the AR experience, integrating multimedia content, and ensuring compatibility with various devices. We used software specifications:

- Unity 2021.3.17f1
- Immersal SDK v1.18.0
- Figma 116.5.18
- Unity Assets: 3D WebView for Android with Gecko Engine Web Browser

2.2.3 Prototype iteration

The application underwent several iterations, with each version tested for UI and interaction design. Feedback from these tests was used to refine the application.

2.3 Testing & Evaluation

2.3.1 Functionality testing

We conducted thorough testing to ensure the technical robustness of the application, including load testing, compatibility testing, and bug fixing.

2.3.2 User testing

A sample group of museum visitors used the application, providing feedback on usability, engagement, and educational value. This phase was crucial in understanding the real-world application of Mussia AR.

2.3.3 Evaluation

We evaluated the application based on predefined criteria such as user engagement, ease of use, information retention, and overall visitor experience improvement. Testing is conducted in three phases: code quality assessment, functionality testing, and user testing to guarantee the application's quality.

3 Results

The development and implementation of the AR navigation system in the Geological Museum, Indonesia, yielded significant results, reflecting the potential of AR in enhancing museum experiences. Figure 6 explains the workflow of the Mussia AR application. It starts with opening the Mussia AR application on a smartphone, and the user selects the museum's AR feature, scans the room, and then selects objects with a target. The target will display text, audio, and video output for more detailed information.

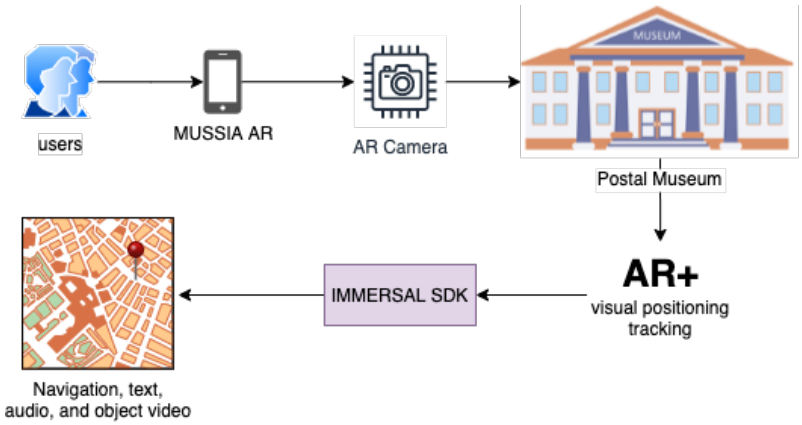

Figure 6: Mussia AR workflow.

3.1 Implementation Result

The design process incorporated inputs from multiple stakeholders, including supervisors, museum staff, and visitors. While the overall features and functionality align with the initial design, there are minor modifications in the UI.

In the development of the Mussia AR application for the museum, a significant enhancement was made to the audio feature of the AR Museum display. Initially, the design required users to click an audio icon to actively initiate an explanatory narration. However, this approach was refined during the implementation phase to allow for automatic triggering of the audio when a point of interest (POI) is selected, enhancing user intuitiveness and engagement (see Figure 7).

Points of Interest, or POIs, are critical reference points used by the visual positioning system (VPS) to determine a device or vehicle's real-world location and orientation. These POIs can be buildings, signs, statues, or other easily recognizable objects captured by the device's camera.

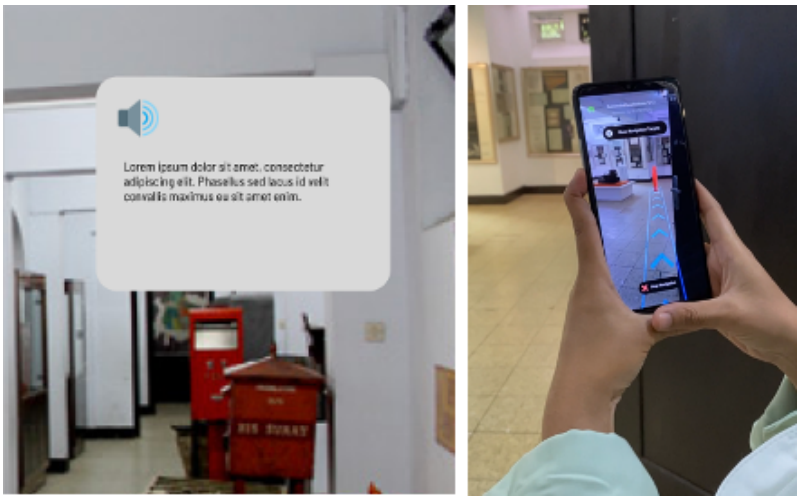

Figure 7: UI design and implementation difference.

The application utilizes natural features tracking connected to these POIs. The workflow for integrating these features in the museum environment is as follows:

1. Developers first scan the museum space, capturing data as point clouds. These serve as reference points for the VPS.
2. This data is then processed using Immersal Cloud and Unity to overlay additional 3D information, such as navigational arrows or supplementary content.
3. The resulting Android application, developed through Unity, is then utilized by users.
4. Upon opening the app, users direct their camera in various directions to localize their position relative to the environment.
5. Once the position is determined, 3D objects are displayed, enhancing the user's interaction with the museum space.

This adaptive approach to the audio feature, coupled with the sophisticated use of POIs and natural features tracking, significantly enriches the visitor experience by seamlessly integrating digital enhancements into the physical environment of the museum.

3.2 Code Quality Testing

The testing of the project's code quality is executed through the console within the Unity application. This involves utilizing Unity's built-in console feature, which monitors and examines the code's performance and behavior in real-time. The console provides a platform to identify and debug any issues, ensuring that the code adheres to the desired quality standards and functions as intended within the Unity environment.

3.3 Functionality Testing

Functionality testing for the application is conducted using the black box testing method. This approach emphasizes examining the application's functionality, particularly focusing on its inputs and outputs, to determine if they align with the expected results.

The key aspect of black box testing is that it does not involve delving into the internal code structure; instead, it assesses the software's functional performance. The entirety of this testing process for the application is performed using a Samsung A20s smartphone, ensuring compatibility and effectiveness on this specific device. An example of a functionality testing scenario and result are shown in Table 2 and Figure 8.

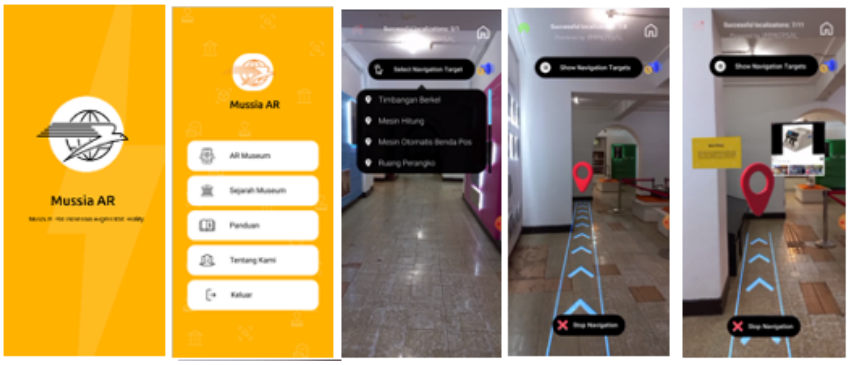

Figure 8: Result of target object in the Postal Museum.

3.4 User Testing

User testing is conducted employing the usability test method. This process begins with creating a paper-based questionnaire, which is distributed to the participants. The responses are then quantitatively analyzed using the Likert scale, a popular method for measuring attitudes and opinions.

The study engaged 35 respondents consisting of 4 museum managers, 3 staff members, and 28 visitors, each of whom had installed and used the Mussia AR application on their

Table 2: Target object in the Postal Museum

Test Scenario	Success Criteria	Expected Results (Interaction)	Technique	Performance
Testing the AR Museum page	The camera turns on and displays a list of objects that can be scanned and displays a brief description, audio, and video of the object.	Successfully displays the navigation to the destination	Open the Mussia AR application.	1.70 s
			Show splash screen.	0.10 s
			Show dashboard page.	0.10 s
			Displays navigation to the selected object.	0.50 s
			Displays a short description of the object.	1.00 s
			Displays a short explanatory audio.	0.80 s
			Displays a video object museum.	19.69 s

smartphones before participating in the questionnaire. This approach ensured that the feedback collected was based on firsthand experience with the application.

The reason for choosing 35 respondents for the study was to obtain a diverse and comprehensive set of feedback on the Mussia AR application. The criteria for selecting these respondents were:

1. **Representation of Different Perspectives**: The mix of 4 museum managers, 3 staff members, and 28 visitors provided a well-rounded view of the application's usability and effectiveness. Museum managers and staff could offer insights into the application's integration and operational aspects, while visitors could provide user experience feedback.
2. **Firsthand Experience with the Application**: Each respondent had personally installed and used the Mussia AR application on their smartphones. This criterion was essential to ensure that the feedback was based on actual usage and interaction with the application, leading to more accurate and reliable data.

By conducting the test on-site at the museum, the study further ensured that all participants had genuinely interacted with the application in its intended environment, thereby enhancing the validity of their responses.

3.4.1 Functionality test

The functionality test for the Mussia AR application includes a set of questions designed to assess various aspects of the app's impact and usability. These questions are:

1. Does the Mussia AR application enhance the public's interest in visiting the Indonesian Postal Museum?
2. Is the Mussia AR application challenging for visitors to use?
3. Does the Mussia AR application facilitate easy access to information about museum objects for visitors?
4. Is the Mussia AR application less informative regarding museum objects?
5. Does the Mussia AR application assist visitors in locating museum objects?
6. Are any errors encountered in the navigation feature of the Mussia AR application?

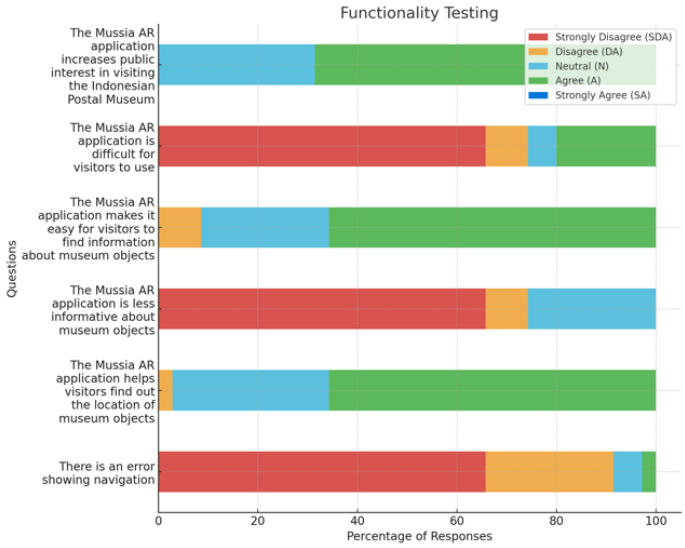

Figure 9: Functionality test result.

These questions aim to gather insights on user experience, usability, informational content, and technical performance of the application. The survey result is shown in Figure 9.

3.4.2 User experience test

The user experience test for the Mussia AR application comprises several questions focusing on the effectiveness and usability of its features. These questions are:

1. Is the navigation feature extremely helpful in the application?
2. Is it challenging to display a brief description, audio, and video of the object at the point of interest?
3. Does the audio feature contribute significantly to understanding the complete information about an object?

4. Is there a discrepancy between the placement of the point of interest and the object's actual location?
5. Is the video feature particularly useful in identifying objects with similar appearances?
6. Would you not recommend the Mussia AR app to others?

These questions are designed to evaluate the app's navigational aids, the ease of accessing multimedia information, and overall user satisfaction with the application. The survey result is shown in Figure 10.

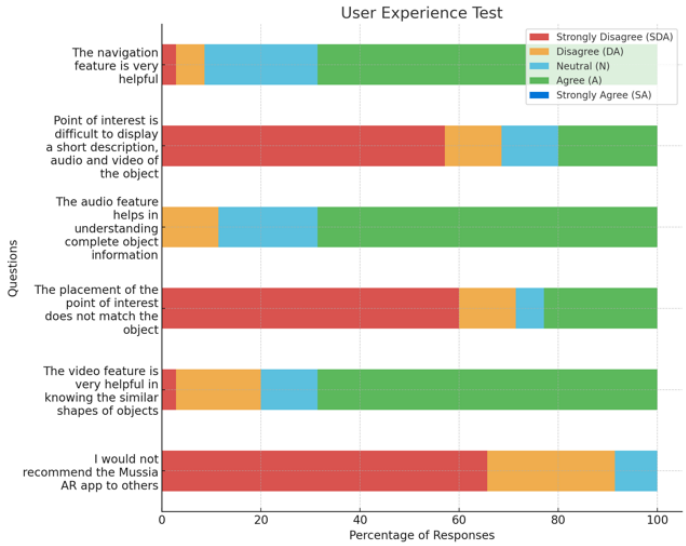

Figure 10: User experience test result.

3.4.3 User interface test

The UI test for the Mussia AR application includes questions to assess the app's visual and interactive elements. These questions are:

1. Is the color usage in the Mussia AR application appropriate and visually appealing?
2. Do the button layouts on each feature align well with user expectations and usability standards?
3. Is the overall interface design of the Mussia AR application suitable and user-friendly?
4. Is the video display size in the application too small for effective viewing?
5. Is the information layout within the Mussia AR application well-organized and easy to navigate?
6. Is the font used in the application legible and easy to read?

These questions are crafted to evaluate the app's aesthetic appeal, functional layout, and ease of use, focusing particularly on the effectiveness of design elements. The survey result is shown in Figure 11.

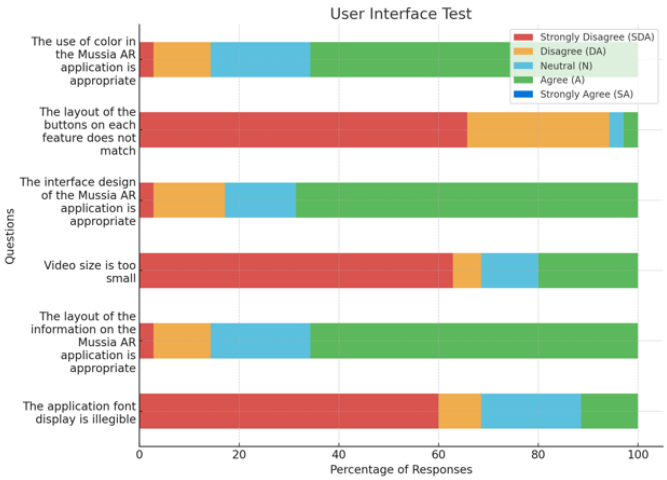

Figure 11: UI test.

3.5 Survey Likert Data Analysis

We computed the Likert scores from previous user testing to better understand our application's performance. Table 3 presents the Likert scores for three questionnaires assessing different aspects of the Mussia AR application.

Table 3: Likert scores of the three questionnaires

Aspect Parameters	**Percentage**
Functionality test	87.60%
User experience test	84.64%
UI test	85.00%

The functionality test, which evaluated the application's performance and features, received a high approval rating of 87.60%. This suggests that the application effectively met its intended functional objectives. The user experience test, focusing on the overall experience of interacting with the application, scored 84.64%. This indicates a positive reception from users, with slight room for improvement in user experience.

Lastly, the UI test, assessing the design and ease of navigation, scored 85.00%. This reflects a strong user approval for the interface design, signifying that the application was user-friendly and visually appealing. These scores demonstrate that the Mussia AR application was well-received across key parameters, indicating its success in enhancing the museum experience through AR technology.

4 Discussion

The development and implementation of Mussia AR, an AR navigation system at the Geological Museum, Indonesia, represents a significant stride in museum digitization efforts.

As outlined in Figure 5, the workflow illustrates a seamless integration of AR technology in enhancing visitor interactions with museum exhibits.

4.1 Comparison with Existing Solutions

4.1.1 Ranggawarsita AR Museum [24]

Application description: Information Media Exhibition Objects Ranggawarsita Museum. Augmented Reality Museum Ranggawarsita is a supporting medium for visitors to obtain information on exhibition objects and provide information beyond the existing information on exhibition objects if there is no direct visual communication by the museum companion or guide.

The advantages of the application: There are two languages in the application: Indonesian and English. There is a list of objects that can be scanned. Disadvantages of the application: Sometimes, the audio volume control feature must be fixed.

4.1.2 Banten Archaeological Museum AR [25]

App description: Banten Archaeological Site Museum augmented reality application. This application provides information about the Banten Archaeological Site Museum and information on the collection of museum objects in 3 dimensions so that users can get information in an interesting way and enjoy it.

The advantages of the application: The application can be used without an internet network. Object explanation audio is clear. Disadvantages of the application: There is a truncated display on the screen. The audio in the application cannot be turned off.

4.1.3 Feature comparison

After a review, the features of the Ranggawarsita AR Museum [24] and Banten Archaeological Museum AR [25] applications can be presented in Table 4. This table also contains the feature plans developed in this final project application.

Table 4 summarizes a comparison of AR features across three different entities: Ranggawarsita AR Museum [24], Banten Archaeological Museum AR [25], and Mussia AR. In summary, while all three AR experiences share common features like application guides and museum history information, Mussia AR stands out with exclusive features like room scanning and object videos.

Table 4: Likert scores of the three questionnaires

No.	Features	Ranggawarsita Museum AR	Banten Museum AR	Mussia AR
1	Room scanning			✓
2	Application guide	✓	✓	✓
3	Museum history info	✓	✓	✓
4	Info on the number of objects that can be scanned	✓		✓
5	Object explanation audio		✓	✓
6	Object videos			✓

4.2 Implementation and Adaptation

The design process, informed by inputs from supervisors, museum staff, and visitors, highlights the importance of a collaborative approach in developing visitor-centric applications. The minor modifications in the UI, especially the intuitive auto-play audio feature at Points of Interest (POIs), as shown in Figure 6, demonstrate the application's adaptability and responsiveness to user preferences. This change is an excellent example of iterative design, reflecting a keen understanding of visitor behavior and preferences in museum settings.

4.3 Code Quality and Functionality Testing

Unity's console feature for code quality testing underscores the project's commitment to technical excellence. The project team has laid a strong foundation for a reliable and effective AR experience by ensuring the code adheres to quality standards and functions as intended.

Functionality testing, particularly the black box method, was crucial in assessing the application's performance from an end-user perspective. As detailed in Table 2, the testing scenarios confirm the application's compatibility and effectiveness on devices like the Samsung A20s, which is vital for widespread visitor accessibility.

4.4 User Testing and Feedback

The user testing phase, incorporating functionality, user experience, and UI tests, offers valuable insights into the application's real-world impact. The Likert scale analysis, summarizing the results in Table 3, shows high satisfaction percentages across all test parameters, indicating the application's success in enhancing the visitor experience.

Functionality tests reveal that Mussia AR significantly increases visitor interest in the museum and facilitates easy access to information, addressing two critical goals of the project. The user experience and UI tests, as detailed in Figure 9 and Figure 10, further affirm the application's effectiveness in navigation aid and information dissemination, alongside its aesthetic and functional appeal.

4.5 Implications and Future Directions

This project exemplifies the transformative potential of AR in cultural and educational settings. By offering an interactive and immersive way to explore museum collections, Mussia AR enhances the visitor experience and serves as a model for future AR implementations in museums. The application's success in improving visitor engagement and providing easy access to information aligns with the growing trend of integrating digital technologies in educational and cultural institutions.

Future developments could focus on expanding the application's device compatibility and exploring multilingual support, thereby broadening its accessibility. Additionally, integrating user feedback into continuous updates will ensure the application remains responsive to visitor needs and technological advancements.

5 Conclusion

The Mussia AR application at the Geological Museum in Indonesia has marked a significant milestone in using AR technology in museum environments. This project has effectively utilized AR to create more interactive, informative, and engaging museum experiences. Notably, the application's functionality test received an impressive 87.60% approval rating, indicating its successful alignment with functional objectives. User experience, evaluated at 84.64%, suggests an overall positive reception with some opportunities for further enhancement. Additionally, the UI was well-received, scoring 85.00%, highlighting its user-friendliness and appealing design. These results affirm the application's effectiveness in meeting its goals and enhancing the museum experience.

Future developments should focus on increasing device compatibility and adding multilingual support to enhance accessibility. Regularly incorporating user feedback for continuous improvements will also be essential. This project serves as a model for integrating innovative AR technologies in cultural institutions, underscoring its potential to enrich educational experiences in museum settings.

References

[1] N. Simon, "The participatory museum. museum 2.0," tech. rep., 2010.

[2] L. Smith, "Emotional heritage: Visitor engagement at museums and heritage sites," tech. rep., Routledge, 2020.

[3] J. H. Falk, "An identity-centered approach to understanding museum learning," tech. rep., Curator: The museum journal, 2006.

[4] E. Hooper-Greenhill, "Museums and the interpretation of visual culture," tech. rep., Routledge, 2020.

[5] Pos Indonesia, "Museum pos indonesia," museum pos indonesia," 2023.

[6] International Council of Museums, "The impact of covid-19 on the museum sector," tech. rep., International Council of Museums, 2020.

[7] G. Resta, F. Dicuonzo, E. Karacan, and D. Pastore, "The impact of virtual tours on museum exhibitions after the onset of covid-19 restrictions: visitor engagement and long-term perspectives," *SCIRES-IT - SCIentific RESearch and Information Technology*, vol. 11, pp. 151–166, July 2021.

[8] J. Cuno, "Museums and digital engagement in the era of covid-19," *Journal of Museum Education*, vol. 45, no. 3, p. 259–265, 2020.

[9] C. Devine and M. Tarr, "The Digital Layer in the Museum Experience."

[10] D. Pesce, P. Neirotti, and E. Paolucci, "When culture meets digital platforms: value creation and stakeholders' alignment in big data use," *Current Issues in Tourism*, vol. 22, pp. 1883–1903, Sept. 2019.

[11] A. M. Jones, "Challenges and Opportunities for Museums During," *Museum Management and Curatorship*, vol. 35, no. 4, pp. 337–354, 2020.

[12] M. Lopez and A. Garcia, "Augmented Reality in Museums: Exploring New Ways to Engage with Audiences," *Museum Management and Curatorship*, vol. 34, no. 5, pp. 492–509, 2019.

[13] J. Xiong, E.-L. Hsiang, Z. He, T. Zhan, and S.-T. Wu, "Augmented reality and virtual reality displays: emerging technologies and future perspectives," *Light: Science & Applications*, vol. 10, p. 216, Oct. 2021.

[14] D. Johnson and E. Smith, "Augmented Reality in Education: A Study on Its Effectiveness in Enhancing Learning Outcomes," in *Proceedings of the International Conference on Educational Technology*, pp. 101–110, 2020.

[15] F. Amenduni, C. De Medio, M. Valente, and M. R. Re, "Adopting Augmented Reality to Engage Higher Education Students in a Museum University Collection: the Experience at Roma Tre University," 2019.

[16] M. Fernandes and P. Santos, "Augmented Reality in Cultural Heritage: Enhancing Visitor Experiences," *J. Cult. Herit.*, vol. 48, pp. 121–130, 2021.

[17] A. A. U. Kennedy, I. Thacker, B. D. Nye, G. M. Sinatra, W. Swartout, and E. Lindsey, "Promoting interest, positive emotions, and knowledge using augmented reality in a museum setting," *International Journal of Science Education, Part B*, vol. 11, pp. 242–258, July 2021.

[18] J. M. Bird, P. A. Smart, D. J. Harris, L. A. Phillips, G. Giannachi, and S. J. Vine, "A Magic Leap in Tourism: Intended and Realized Experience of Head-Mounted Augmented Reality in a Museum Context," *Journal of Travel Research*, vol. 62, pp. 1427–1447, Sept. 2023.

[19] T. Richardson and L. Wong, "Utilizing Immersal SDK for Creating Immersive AR Experiences," in *Proceedings of the International Conference on Augmented Reality*, pp. 75–82, 2020.

[20] K. Lee and R. Green, "Integrating Multimedia Content in AR for Enhancing Museum Experiences," *Journal of Multimedia Tools and Applications*, vol. 81, no. 9, pp. 12345–12360, 2022.

[21] F. Z. Kaghat, A. Azough, M. Fakhour, and M. Meknassi, "A new audio augmented reality interaction and adaptation model for museum visits," *Computers & Electrical Engineering*, vol. 84, p. 106606, June 2020.

[22] I. Ahmad, Y. Rahmanto, D. Pratama, and R. I. Borman, "Development of augmented reality application for introducing tangible cultural heritages at the lampung museum using the multimedia development life cycle," *ILKOM Jurnal Ilmiah*, vol. 13, pp. 187–194, Aug. 2021.

[23] Z. Gong, R. Wang, and G. Xia, "Augmented Reality (AR) as a Tool for Engaging Museum Experience: A Case Study on Chinese Art Pieces," *Digital*, vol. 2, pp. 33–45, Mar. 2022.

[24] Pemerintah Kota Semarang, "Museum Jawa Tengah Ranggawarsita," 2024.

[25] W. Sulistiyono, "AR Museum Purbakala Banten," 2023.