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Revitalization of museum collections through augmented reality to improve interactive educational services

Fortia Magfira[1], Marisha Pertiwi[1], Nolan Efranda[1], Feri Irawan[1], Rifaldi Herikson[1], Berta Erwin Slam[1], Sepli Yandri[2], Euis Ammelia[3], Basyaruddin Ismail Harahap[4]

[1]Department of Informatics Engineering, Faculty of Maritime Engineering and Technology, [2]Department of Architecture, Faculty of Maritime Engineering and Technology, [3]Department of International Relations, Faculty of Social and Political Sciences, [4]Department of Electrical Engineering, Faculty of Maritime Engineering and Technology, Universitas Maritim Raja Ali Haji Jl. Raya Dompak, Tanjungpinang, Kepulauan Riau, 29115, Indonesia

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ABSTRACT

Museums play an important role in preserving cultural heritage; however, limited interactive media can reduce visitor engagement and understanding. The Sultan Sulaiman Badrul Alamsyah Museum faces a similar challenge, particularly the absence of digital visualization for exclusive collections that are rarely exhibited. This community service activity aims to revitalize museum collections through the use of digital technology and Augmented Reality (AR), while also strengthening the capacity of museum staff in delivering technology-based educational services. The implementation method included socialization, training, and mentoring on the use of an AR application for museum staff and students of SMAN 1 Tanjungpinang as educational users, involving a total of 25 participants. The evaluation was conducted descriptively through direct observation and simple questionnaires to assess user understanding, operational skills, and responses to the use of AR technology. The results show that eight exclusive museum collections were successfully digitized into 3D models and integrated into an Android-based AR application. After the intervention, museum staff demonstrated improved capability in operating and utilizing the AR application as an interactive educational medium. The application shows strong potential for sustainable use as part of museum services and for supporting educational activities and school visits.

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1. INTRODUCTION

The development of digital and interactive technologies has brought significant changes in the way people access information, learn, and interact with cultural environments (Putra & Pratama, 2023). This transformation has encouraged the education and tourism sectors to adopt technologies that provide more immersive, contextual, and engaging learning experiences. Museums, as institutions of education and cultural preservation, are also required to adapt to these developments in order to remain relevant, particularly for younger generations who are familiar with digital technology.

✉ Corresponding Author: **Fortia Magfira**: Tel. +62 771 4500089 | E-mail: fortiamagfira@umrah.ac.id

The use of immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) has been shown to enhance learning effectiveness, enrich information delivery, and increase user engagement in various educational and cultural contexts (Shonima & Sowmya, 2024; Xiang, 2024). AR enables the integration of three-dimensional virtual objects into the real environment in real time through digital devices, while VR provides a simulated digital environment that allows users to interact immersively (Ahmad & Ghozali, 2024; Sari et al., 2023). In the context of learning and cultural literacy, AR has also been proven effective as a mobile-based interactive educational medium that can enhance users' understanding of and interest in cultural content (Pradana et al., 2022; Utami et al., 2023).

The problems faced by the Sultan Sulaiman Badrul Alamsyah Museum were identified based on field observations, direct interviews with museum management, and partner requests submitted at the initial stage of the community service program. The observation results indicate that the presentation of collection information remains conventional, limited to static information boards and verbal explanations from museum guides. Interviews with the museum management revealed limitations in interactive educational media capable of optimally engaging young visitors. In addition, the museum explicitly expressed the need for digital media that could enhance the attractiveness of the collections while strengthening the museum's educational function. This condition has resulted in a low level of visitor interaction with the collections and the suboptimal role of the museum as a space for learning history and culture.

Recent studies demonstrate that the implementation of AR and VR in museums and the cultural sector has significant positive impacts. Immersive technologies have been proven to enhance presence, engagement, and visitor motivation in museums (Ariya et al., 2025). AR and VR also improve the quality of didactic experiences in technology and cultural heritage museums without disrupting the existence of physical collections (Bachiller et al., 2023). Bibliometric studies indicate a growing global trend in the use of immersive technologies for cultural heritage preservation and education (Zhang et al., 2024). Other research confirms that AR is effective as a medium for interpreting museum collections, enhancing visitors' understanding of historical contexts and cultural values (Firdausy et al., 2025; Mewengkang et al., 2025; Rahmawati et al., 2024).

The need for museum digitalization is also aligned with national and regional policies aimed at strengthening the cultural and tourism sectors. Regional government strategies to enhance the attractiveness of historical tourism emphasize the importance of innovation based on digital technology (Rizkan et al., 2023). At the national level, the Cultural Advancement Master Plan 2018–2040 underscores digitalization as a primary strategy for cultural preservation and development (Kementerian Pendidikan dan Kebudayaan Republik Indonesia, 2018). Furthermore, the cultural digital transformation program encourages the utilization of interactive technologies as media for education and the dissemination of cultural information (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi, 2021).

Based on these conditions, this community service activity was designed by positioning the partner as a co-creator and empowerment subject. The museum management does not merely act as a recipient of technology but is actively involved in the process of needs identification, determination of priority collections, digital content design, and system evaluation. This participatory approach aims to ensure that the developed solution aligns with the museum's actual needs, is easy to operate, and remains sustainable after the completion of the program.

The proposed solution involves the development of a mobile application based on Augmented Reality that presents museum collections as interactive 3D objects, complemented by educational information accessible to visitors. Through this approach, the museum is expected to enhance the quality of its educational services, broaden access to collection information, and strengthen its role as a technology-based center for learning history and culture.

Therefore, the objective of this community service program is to support the transformation of the Sultan Sulaiman Badrul Alamsyah Museum into an interactive digital museum through the integration of Augmented Reality technology tailored to the partner's needs. This program is expected to increase the museum's attractiveness, reinforce its educational function, and promote the innovative and sustainable preservation of cultural heritage.

2. METHODS

This community service program was conducted over a three-month period (September–November 2025) and involved a service team from Universitas Maritim Raja Ali Haji consisting of nine lecturers from various disciplines and six students serving as technical assistants and facilitators. The Sultan Sulaiman Badrul Alamsyah Museum in Tanjungpinang served as the main partner, acting as both the subject of empowerment and co-creator in the development and utilization of Augmented Reality (AR) technology. The partner participants included museum managers and staff, with the involvement of 20 students from SMAN 1 Tanjungpinang as educational users. The implementation of the program was divided into three main stages: pre-activity preparation, AR system development and implementation, and training, mentoring, and evaluation.

Pre-Activity

The pre-activity stage aimed to identify the partner's needs and ensure program readiness through a literature review, field survey, and internal and external coordination, as shown in Figure 1. The literature review was conducted to strengthen the conceptual foundation for the use of AR in museums, while the field survey aimed to observe the museum's condition, collection characteristics, and the potential for technology implementation. Coordination activities were carried out to develop a work plan, assign team roles, and agree upon the scope and form of the partner's active involvement. This stage concluded with an initial evaluation to ensure both technical and non-technical readiness.

Figure 1. Pre-activity stages

Based on Figure 1, the pre-activity stages show a systematic program preparation flow, starting from strengthening the concept, mapping partner needs, to initial coordination and evaluation as the basis for implementing AR system development.

AR System Development and Implementation Stage

This stage constituted the core activity, focusing on the development of a technology-based solution tailored to the partner's needs, as illustrated in Figure 2. The activities began with a needs analysis using a SWOT approach, followed by the digitalization of museum collections through 3D object modeling and integration into a mobile-based AR application. The museum management was involved in the selection of collections and the validation of educational content. Subsequently, AR markers were designed and printed, the system was integrated into the museum environment, and functional testing was conducted to ensure the accuracy, stability, and usability of the application.

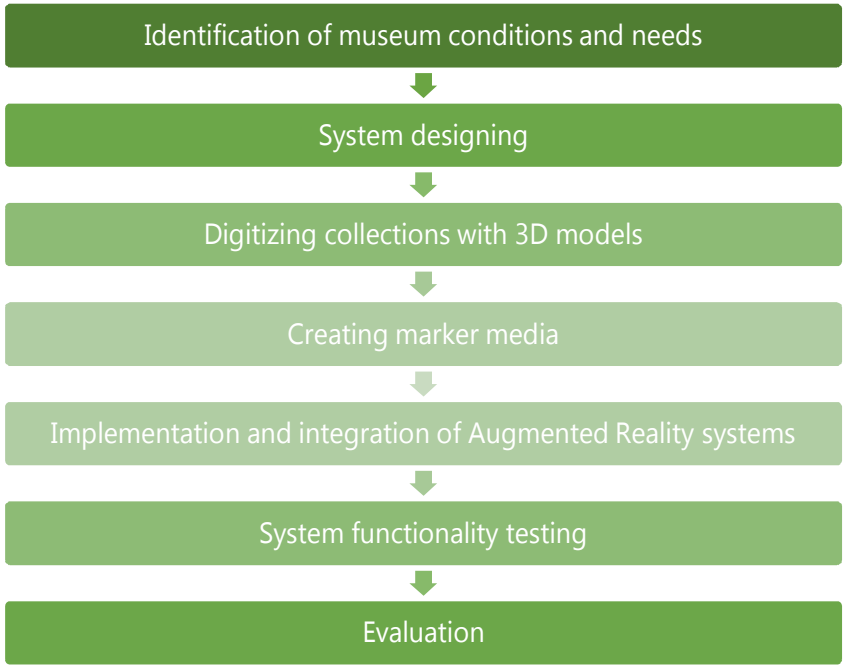

Figure 2. Stages of the implementation process

Based on Figure 2, the stages of AR system development and implementation illustrate a participatory and partner needs-based technology development process, starting from analysis and digital content development to system testing prior to its direct use in the museum environment.

Training, Mentoring, and Evaluation Stages

The final stage aimed to ensure that the system could be utilized optimally and sustainably. The activities included socialization and training on the use of the AR application for museum managers and students of SMAN 1 Tanjungpinang, followed by the handover of the system and technical documentation in the form of installation guidelines, user manuals, and standard operating procedures (SOPs). The service team conducted monitoring and mentoring to assist the partner in addressing technical issues. The final evaluation was carried out descriptively through observation and user feedback to assess the effectiveness of AR implementation in supporting educational services and the revitalization of museum collections.

3. RESULTS AND DISCUSSION

Results

Pre-activity stages

The activity began with a literature review on museum digitalization, 3D modeling, and Augmented Reality technology. Subsequently, the team identified the museum's needs regarding the types of collections with potential for digitalization and the available digital infrastructure. This step indicated that the museum required a more interactive visual interpretation medium to help visitors understand the historical value of the collections.

The activity continued with a survey conducted to examine the physical condition of the collections, lighting, exhibition spaces, and potential locations for the installation of AR markers.

Figure 3. Team survey to partners

Based on Figure 3, the field survey was conducted directly to identify the condition of the collections, the exhibition layout, and environmental factors influencing the implementation of AR technology in the museum. The survey results indicated that some collections were not supported by adequate narrative information. This condition reinforced the need to utilize AR as a medium for digital narrative presentation and 3D visualization. Coordination with the museum management resulted in the determination of eight exclusive priority collections to be digitalized and presented through AR.

AR system development and implementation stages

The implementation of the museum collection revitalization program through digital technology and Augmented Reality resulted in several significant outcomes obtained from each stage of the activity. The stage of identifying the museum's condition and needs provided a clear understanding of the actual state of the Sultan Sulaiman Badrul Alamsyah Museum. The analysis indicated that the museum possesses a number of historically valuable collections; however, these have not yet been digitalized, resulting in limited access to information for visitors. The priority collections to be transformed into AR format consist of eight exclusive museum items that are only displayed during specific events, namely the silver caping, gold bowl, silver bowl, gold plate, silver plate, gold spoon, gold pending, and silver pending. In addition, several obstacles were identified, such as limited educational media and minimal visual interaction. This information served as the basis for determining the features and direction of the AR system development.

Based on Figure 4, collection observation was conducted to assess visual details, physical condition, and the suitability of objects for the 3D modeling process and AR-based presentation. The system design stage resulted in an Android-based mobile AR application that enables users to display 3D objects through marker scanning.

Based on Figure 5, the system flow illustrates the process of using the AR application, starting from menu selection and marker scanning to the visualization of 3D objects and collection information. The collection digitalization stage through 3D modeling resulted in digital representations of museum collections that are more interactive and engaging. Certain collections were scanned or remodeled into

three-dimensional formats so that they could be visualized realistically through the AR application. These 3D models enable visitors to observe details that may be difficult to see in the physical collections, thereby enhancing educational value and the overall visitor experience.

Figure 4. Observation of museum collections by the team

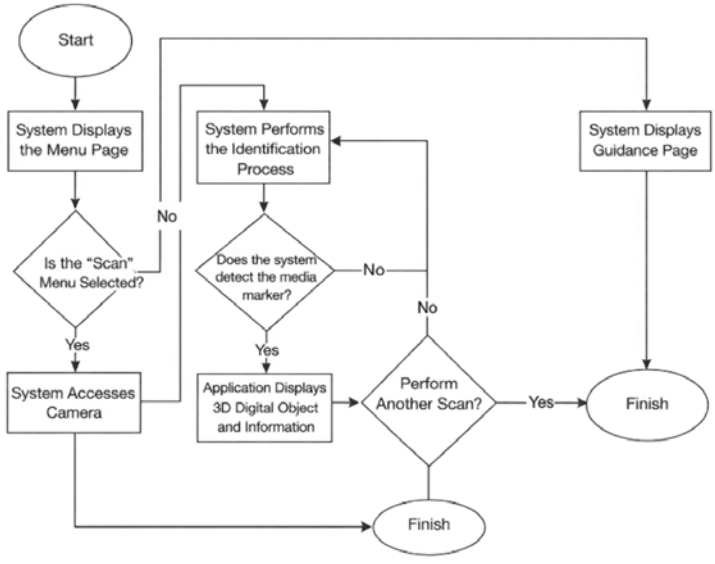

Figure 5. System flow diagram

Figure 6. 3D models of the museum collection
Figure 7. AR marker media museum collection

Based on Figure 6, the 3D models enable a more realistic visualization of collection details and support the enhancement of visitors' educational experiences. The marker development process produced a number of visual markers printed in the form of posters or information cards. These markers function as triggers for the AR application to display 3D objects and related collection information. The markers were tested in terms of design, size, and scanning accuracy to ensure compatibility with the application.

Based on Figure 7, the markers function as a bridge between the physical collections and the digital AR content through the scanning process. In the implementation and integration stage of the AR system, the developed application was connected with the markers and 3D models. The result was an AR system ready for use in the museum environment. This integration enables each marker scanned via a mobile device to display the corresponding 3D object.

Figure 8. AR app displays 3D objects when scanning markers
Figure 9. Trial by the museum

Based on Figure 8, the AR system successfully displayed 3D objects according to the scanned markers. The functionality testing stage indicated that most markers could be scanned accurately, and the 3D objects appeared stably. The testing also involved users to assess comfort, ease of navigation, and clarity of information. The findings at this stage were highly useful for improving technical aspects such as lighting conditions, marker size, and application responsiveness.

Based on Figure 9, the trial conducted with the museum management demonstrated the accuracy of marker scanning and the ease of application use. The evaluation stage was carried out through direct review after the system had been installed in the museum. Several inputs from the museum management were utilized to refine the features, such as adding narrative information and improving the quality of the 3D models. Overall, the implementation of AR was considered successful in supporting the revitalization of museum collections and providing added value in the presentation of historical information.

Training, mentoring, and evaluation stages

This stage aimed to ensure that the Augmented Reality (AR) system that had been developed could be utilized optimally and sustainably by the museum. The results of the socialization and training activities indicated that the museum management and 20 students from SMAN 1 Tanjungpinang were able to understand and operate the developed AR application. Participants were able to scan markers, display 3D objects of museum collections, and access the available digital information through mobile devices. This activity enhanced participants' understanding and skills in utilizing AR technology as a medium for education and promotion of museum collections. Based on Figure 10, the socialization activity introduced the functions and benefits of the AR application to users.

Figure 10. AR application socialization (ARSULA)

Figure 11. Photo of socialization participants trying out AR at the collection location

Based on Figure 11, users were able to directly practice marker scanning and 3D collection visualization. The system handover and technical documentation process resulted in the partner's readiness to manage and operate the application independently. The submitted documents, including installation guidelines, user manuals, and operational SOPs, serve as essential references for museum management in maintaining the sustainability of system utilization. With this documentation in place, the partner's dependence on the development team can be minimized.

Figure 12. The application handover process by the PKM chairman to the museum

Based on Figure 12, the handover of the ARSULA application was formally conducted by the head of the community service team to the Sultan Sulaiman Badrul Alamsyah Museum as a sign of the completion of the implementation stage and the partner's readiness to manage the system independently. This activity was accompanied by the submission of technical documentation, including installation guidelines, user manuals, and operational SOPs, to support the sustainability of the application's utilization.

Post-socialization monitoring and mentoring activities indicated that the AR system operated stably within the museum environment. Minor technical issues, such as lighting conditions and marker positioning, were resolved through direct assistance, demonstrating that the system is adaptive and easily adjustable to field conditions.

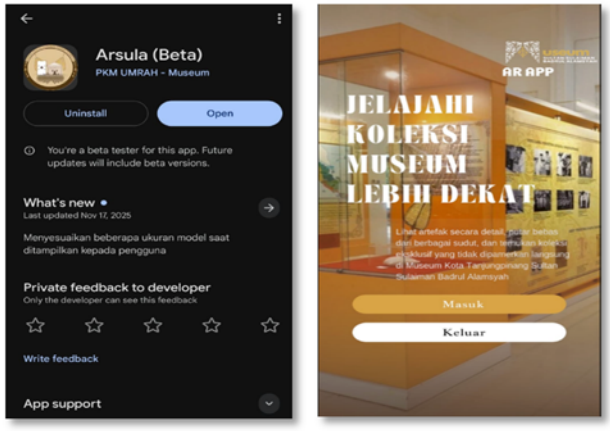

Figure 13. Arsula Application

Based on Figure 13, the ARSULA application is capable of displaying museum collection objects in the form of 3D visualizations through marker scanning, featuring a user-friendly interface and clear information, thereby supporting users' understanding of the educational content.

The program evaluation was conducted descriptively using observation sheets and simple questionnaires. The evaluation results indicate that 23 out of 25 participants (±92 percent) were able to operate the AR application independently, 22 participants (±88 percent) experienced an improvement in their understanding of collection information, and 23 participants (±92 percent) stated that AR technology increased the attractiveness of the museum collections. These results were used as indicators of program success without inferential statistical testing.

To present the program outcomes in a measurable manner, the evaluation results are displayed in a tabulated pre- and post-intervention format as shown in Table 1.

Table 1. Evaluation results before and after AR intervention

Evaluation Indicators	Before Intervention	After Intervention
Ability to operate digital media	Low	92% are self-sufficient
Understanding collection information	Limited	88% increase
Attractiveness of museum collections	Low-Mid	92% increase
User interaction with collections	Passive	Interactive

Discussion

The implementation of the Community Service Program (PKM), which focused on revitalizing the collections of the Sultan Sulaiman Badrul Alamsyah Museum through the utilization of digital technology and Augmented Reality (AR), demonstrates that the integration of information technology in museum management can generate significant positive impacts on the improvement of educational services and visitor experience. The program was designed and implemented in a structured, phased, and sustainable manner, involving both the implementation team and the museum management as the primary partner. The partner's involvement from the planning stage through evaluation ensured that each phase of the program was aligned with actual conditions, operational needs, and the specific characteristics of the museum's collections.

The digitalization of collections and the application of AR technology served as a solution to the limitations of conventional information media previously used by the museum, such as static text labels and limited information boards. Through the visualization of collections in three-dimensional (3D) models and the presentation of interactive digital information, museum collections are no longer positioned as passive artifacts but rather as communicative, contextual, and accessible learning media for visitors from diverse age groups and educational backgrounds. This approach aligns with the objectives of museum revitalization, namely enhancing information accessibility, strengthening the museum's educational function, and utilizing digital technology as a supporting tool for cultural preservation.

Based on the evaluation results, the level of program achievement was categorized as high. A total of 23 out of 25 participants (±92 percent) were able to operate the Augmented Reality application independently after attending the socialization and training sessions. This outcome indicates that the developed system possesses good usability, an intuitive interface, and a user flow that is easily understood by general users. In addition, the effectiveness of the training materials and mentoring methods contributed to participants' success in mastering the application. The participants' ability to operate the application independently serves as a key indicator that the implemented AR technology has strong potential for sustainable use by museum management and the broader community without full dependence on the development team.

In addition to improving technical skills, this Community Service Program (PKM) also had a positive impact on enhancing participants' understanding of the information and historical value of the museum collections. The evaluation results indicate that 22 participants (±88 percent) experienced an improvement in their understanding of the meaning, function, and historical context of the museum collections after using the AR media. This finding confirms that visually based, interactive, and multimodal information delivery is more effective than conventional methods in conveying historical and cultural narratives. AR media enables users to observe collection details more comprehensively while simultaneously accessing integrated supporting information.

From the perspective of attractiveness and user experience, 23 participants (±92 percent) stated that the implementation of AR technology increased their interest in the museum collections. This finding suggests that the utilization of digital technology can strengthen the museum's image as a modern, innovative, and technologically relevant educational space. The increased attractiveness has the potential to encourage repeat visits and attract new visitor segments, particularly students and younger generations, thereby supporting the development of the museum as a culture- and technology-based educational tourism destination.

The program's effectiveness was measured using observation sheets and simple questionnaires without inferential statistical analysis. Nevertheless, the data obtained provide sufficiently strong preliminary evidence of the program's success in achieving its intended objectives. Overall, the discussion indicates that this PKM activity not only succeeded in enhancing users' ability to utilize Augmented Reality

technology but also made a tangible contribution to the preservation, revitalization, and utilization of museum collections through an innovative and sustainable digital approach.

4. CONCLUSION AND RECOMMENDATIONS

Based on the results of the community service implementation, it can be concluded that the application of Augmented Reality technology successfully supported the revitalization of the Sultan Sulaiman Badrul Alamsyah Museum collections. The digitalization of eight exclusive collections in the form of 3D models and their integration into the AR application provided a more interactive and informative interpretative medium. The evaluation indicated the achievement of the AR application operational hard-skill indicator at approximately ±92 percent, as well as an increase of ±88 percent in users' understanding of collection information. In addition, AR technology had a positive impact on the attractiveness of the museum collections. Therefore, this program has made a tangible contribution to improving the quality of museum educational services and supporting the museum's digital transformation. Overall, the activity demonstrates that the utilization of digital technology developed based on partner needs can serve as an effective approach to enhancing the museum's educational function while supporting sustainable cultural heritage preservation efforts.

For future development, it is recommended that the number of digitalized collections be expanded to further optimize the benefits of the AR application. The addition of supporting features, such as multilingual support, may also enhance user experience. The museum is expected to utilize the AR application sustainably as a medium for education and promotion, as well as to update the content periodically. The integration of AR technology with other digital platforms, such as virtual tours, also represents a potential direction for future development.

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