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Integration of 360-Degree Panorama and Interactive Multimedia in the Development of the Cotta Cinna Museum Virtual Tour Information System

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ABSTRACT

This study aims to develop an interactive virtual tour information system for the Cotta Cinna Museum by integrating 360-degree panoramic technology and interactive multimedia to provide digital access to the museum environment and its information. The system was developed using the Multimedia Development Life Cycle (MDLC) method, involving requirements identification, observation, interviews, documentation, system development, functional testing, and user evaluation. Data collection involved five purposively selected informants, while product evaluation involved 30 users, resulting in 35 research participants. The developed system consists of eight virtual scenes representing different museum areas and incorporates eight main features, including 360-degree panoramic visualization, inter-scene navigation, interactive hotspots, location information, panorama menus, and viewing controls. Functional testing using black-box testing covered 12 test scenarios, all of which were successfully executed, resulting in a 100% functional success rate. Furthermore, user evaluation revealed positive responses across four assessment dimensions: ease of use, navigation, interaction, and system acceptance. Very good ratings were recorded from 18 users for ease of use, 17 for navigation, 19 for interaction, and 20 for system acceptance. No poor or very poor ratings were reported across the four dimensions. These findings demonstrate the successful development of an interactive museum virtual tour system integrating panoramic visualization and multimedia navigation. The resulting system provides a digital platform for accessing and exploring the Cotta Cinna Museum environment.

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1. INTRODUCTION

Museums are institutions that play a strategic role in preserving, maintaining, documenting, and disseminating knowledge about history, culture, and the heritage of civilization to the public. The existence of museums not only serves as a place for storing historical artifacts but also as a learning space, information

center, public education medium, and a means of fostering collective awareness of a society's historical values. In the development of information technology, the function of museums has expanded because the dissemination of information about collections, exhibition spaces, and the historical value of an object no longer has to rely entirely on physical visits. Digital transformation provides opportunities for museum institutions to develop more flexible, interactive, and accessible information media for the public through various technological devices. The digitization becomes increasingly relevant when society needs information that is not only textual but also capable of providing visual representations and exploration experiences that closely resemble the actual condition of the objects. Research on the implementation of virtual tour technology in museums shows that digital technology can be utilized as a medium for information and promotion, expanding the ways in which the public recognizes the environment and museum collections (Jubaedi et al., 2020). The use of virtual tours is also relevant to efforts to introduce historical sites through a digital approach that allows the public to gain an understanding of the objects without always having to be physically present at the location (Wikanningrum, 2016). In the perspective of strengthening the educational function, museums require communication strategies that can connect historical information with the needs and characteristics of visitors who are increasingly accustomed to using digital technology. Sutarsyah et al. (2022) demonstrate the importance of strengthening museums as centers of information and education through promotional strategies that support the dissemination of knowledge to the public. Meanwhile, Hidayat et al. (2024) place the museum's appeal as an important aspect in understanding the potential of museums as destinations with tourism and educational value. This condition shows that the development of digital information media is not merely an adaptation to technological advancements, but rather part of an effort to strengthen the museum's function as an institution of information, education, and cultural preservation. In the context of this research, the Cotta Cinna Museum becomes a relevant location for developing a virtual tour information system because the need to convey information about the museum's environment and objects requires a medium that can integrate visual representations of space, contextual information, and user interaction mechanisms into a single, cohesive digital system.

The fundamental problem in conveying information about museums and historical objects is the gap between the public's need to understand the condition of a location comprehensively and the limitations of the available information media. Based on the initial research identification at the Cotta Cinna Museum, information about the location is still conveyed through conventional media, such as brochures, photos, information boards, and social media, while the use of interactive digital technology based on 360-degree panoramas is still limited. Two-dimensional visual media can indeed provide an overview of certain objects, but they do not yet fully allow users to observe the space from various angles, determine the direction of exploration, and move interactively from one location point to another. These limitations imply that the presentation of spatial information needed by potential visitors to gain an initial understanding of the museum's conditions before making an actual visit is not yet optimal. This issue becomes even more important because museums not only need to show the existence of an object but also need to convey the spatial context, inter-location relationships, and information that explains the meaning and characteristics of the displayed objects. Budi and Wenas's (2018) research on campus virtual tours demonstrates the relevance of 360-degree panoramas as an information medium that allows users to recognize the environment through digital spatial representation. Amali et al. (2024) also demonstrate the application of 360-degree panorama images combined with web technology to build a virtual exploration experience based on location visualization. In the context of tourist destinations, Satya et al. (2024) developed a 360-degree virtual tour as a digital approach to introduce tourist attractions, while Nur et al. (2024) highlighted the use of similar technology in the development of tourist attraction exploration media. The findings of the research indicate that 360-degree panoramas have the potential to bridge the limitations of spatial representation that rely solely on conventional photos. However, the provision of a 360-degree panorama alone does not necessarily guaranty that users will gain an adequate understanding of the observed object, as spatial visualization and information delivery are two complementary needs. Therefore, the research problem does not only lie in how to document the environment of the Cotta Cinna Museum into a 360-degree panorama image, but also in how to develop a system that can connect that visualization with location information, navigation, and interactive multimedia elements. This need serves as the basis for developing a virtual tour information system that not only displays the physical condition of the museum but also provides integrated exploration mechanisms and access to information.

One of the technological approaches that can be used to address this issue is a virtual tour based on a 360-degree panorama. A virtual tour is a digital representation of a real environment that allows users to explore the space through electronic devices by controlling the direction of view and moving between location points. In its implementation, a 360-degree panorama can be created through the processing of several images using the image stitching process, or by using images captured from a 360-degree camera device. This representation allows users to observe the environment both horizontally and vertically, and to adjust their viewpoint according to their exploration needs. Wikanningrum (2016) demonstrates the use of digital photos in the development of virtual tours to promote historical sites in Indonesia, making this technology relevant in expanding the reach of information about historical heritage. Jubaedi et al. (2020) also

demonstrate that the application of virtual tours in museums can serve as an alternative information medium that combines environmental visualization with the delivery of information to the public. The development of a 360-degree panoramic virtual tour in the campus environment by Dewi et al. (2022) shows that spatial representation can be combined with navigation and interface design to produce more informative promotional media. Meanwhile, the research by Amali et al. (2024) shows that 360-degree panorama images can be integrated with Leaflet JavaScript technology in the development of web-based virtual tour systems. In the context of tourism environment development, Sumarmi et al. (2023) highlight web-based virtual tours as a means of destination branding, while Rachmadian et al. (2023) demonstrate the use of web-based virtual tour systems for optimizing digital tourism branding. The implementation shows that virtual tour technology has flexible applications across various objects, including museums, historical sites, campuses, and tourist destinations. However, the characteristics of a museum demand a more substantive presentation of information because the objects being explored are not only physical environments but can also relate to collections, artifacts, historical narratives, and knowledge that have educational value. Therefore, the integration of 360-degree panoramas in this research is aimed at building a spatial representation of the Cotta Cinna Museum that allows users to explore independently, while the integration of multimedia information is intended to enrich the context of each location visited virtually. Thus, the 360-degree panorama is positioned as the foundation of spatial representation, while multimedia interactivity becomes the component that connects the visual experience with the user's need for information and understanding.

The need to provide a more meaningful exploration experience requires the virtual tour system to integrate interactive multimedia elements in a planned manner. Multimedia allows the presentation of information through a combination of text, images, audio, video, and various other visual components that can be accessed according to user needs. In a virtual tour system, these elements can be integrated through information hotspots, navigation buttons, object description panels, audio narration, documentation videos, and supporting features that provide explanations about specific locations. The integration is important because users do not only need to experience seeing a space, but also require information that explains the characteristics, functions, history, and the relationship of the objects with the museum context. Jubaedi et al. (2020) demonstrate the relevance of integrating virtual tour technology with the presentation of museum information, while Thomas et al. (2018) show the use of virtual tours as an interactive promotional medium through the integration of visual elements and supporting information. In the context of developing a virtual tour application, Ananraytama et al. (2018) highlighted the application of a three-dimensional map feature to enhance spatial representation and orientation in the tourism promotion system. On the other hand, Dianta et al. (2021) demonstrated the development of a website-based virtual tour application as a medium for environmental introduction that integrates panoramas and navigation mechanisms. The development of an H5P-based virtual tour by Negara et al. (2024) also demonstrates the relevance of utilizing digital platforms in creating virtual learning and exploration experiences. Meanwhile, research on the development of virtual reality-based history learning media at the Museum of National Awakening by Suryani et al. (2022) shows that immersive visual technology can be utilized to support the delivery of historical material in the museum context. The integration of multimedia in this research is therefore not intended merely as an addition of decorative components to the interface, but rather as a mechanism for delivering information connected to spatial points and objects explored by the user. Each hotspot can be designed to perform a specific function, such as linking one panorama to another, displaying a description of an object, opening photo documentation, or presenting relevant audiovisual material. Users thus have control over the information they wish to access, while the navigation structure provides a more systematic exploration direction. This principle is also in line with the use of digital technology to enhance the quality of information communication and expand public access to museum knowledge. By combining 360-degree panoramas and interactive multimedia, the developed system is expected to create a stronger connection between the visual representation of space, the delivery of historical information, and user exploration activities.

The development of a virtual tour information system that integrates 360-degree panoramas and interactive multimedia requires a development methodology capable of systematically managing the entire production process. In this research, the Multimedia Development Life Cycle (MDLC) approach was chosen because it has stages that specifically support the development of multimedia applications, from concept formulation to product distribution. MDLC consists of six main stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution. These stages provide a framework to ensure that user needs, interface design, multimedia asset collection, integration processes, testing, and system publication can be managed in a structured manner. Maulana et al. (2023) demonstrate the application of MDLC in the development of an interactive virtual tour at Asriloka Wonosalam, which shows the relevance of this approach in producing a multimedia-based virtual exploration system. Thomas et al. (2018) also demonstrated that the development of virtual tours as interactive promotional media requires the integration of visual components and interaction mechanisms designed according to the system's needs. Suhud et al. (2022) developed a virtual tour application for Kebun Raya Bogor–LIPI as a medium for dissemination and literacy of biological sciences, involving various multimedia assets in its development process. Negara et al. (2024) also demonstrate the application of a web-based virtual tourism development approach through H5P, which illustrates the

importance of managing digital components in the system production process. Operationally, the Concept stage in this research is directed toward identifying the needs of museum managers and potential users, determining the system's objectives, and establishing the scope of the locations to be visualized. The Design stage is used to design the navigation structure, user interface, storyboard, inter-panorama relationships, and hotspot functions that will be provided. The Material Collecting stage is carried out through the collection of 360-degree panorama photos, documentation photos, videos, informational texts, and other supporting materials relevant to the characteristics of the Cotta Cinna Museum. The Assembly stage is the process of integrating all those assets into the virtual tour system, resulting in a digital environment that can be explored interactively. Next, the Testing phase is aimed at examining the system's functional compatibility, navigation accuracy, information accessibility, and ease of use, while the Distribution phase involves preparing the system for publication and access by users through the designated platform. Although MDLC has six stages, its implementation does not always have to be strictly linear because asset collection and application assembly can occur iteratively according to development needs (Maulana et al., 2023; Aman et al., 2023). Thus, the application of MDLC in this research not only serves as a technical procedure for application development but also as a methodological framework to integrate museum information needs, visual representation quality, and multimedia interactivity into a structured system.

Another aspect that determines the success of virtual tour development is the quality of user experience and usability. A system with high-quality panoramic visualization does not necessarily provide an optimal experience if its navigation is confusing, information is difficult to find, or interactions between components do not meet user expectations. Therefore, the development of a virtual tour needs to consider the relationship between visual quality, information structure, interface design, navigation control, and user ease in operating each feature. Subekti et al. (2021) developed a virtual tour of the National University environment based on Android with a virtual reality approach, which demonstrates the application of digital exploration technology in the institutional environment. Othman et al. (2021) specifically highlighted the evaluation of usability in smartphone-based virtual reality applications for living museums, thereby providing empirical evidence that ease of use is an important aspect in the application of virtual technology in museum environments. The research also highlights the importance of considering user acceptance, usability, and learnability in evaluating the user experience of the system. In the development of a virtual tour, functionality testing can be conducted using the black-box testing method to ensure that menus, navigation buttons, hotspots, and information features operate according to the specified requirements. Meanwhile, usability evaluation can use instruments such as the System Usability Scale (SUS) to obtain an overview of users' perceptions regarding the ease of system operation. The 360-degree panorama virtual tour research by Budi and Wenas (2018) is relevant in demonstrating the importance of information system design that facilitates users in recognizing the environment through virtual media. The research by Dewi et al. (2022) also shows that virtual tour design needs to consider the panorama structure and visual communication needs so that the developed media can function as a means of information and promotion. In the context of exploration experience, clear navigation allows users to determine their viewing direction, move from one point to another, and access additional information without losing orientation to the spatial structure. Features such as hotspots, location lists, back buttons, information panels, sound settings, and zoom mechanisms can be part of the interaction design that supports these activities. However, the addition of features must consider their alignment with user needs to avoid creating an overly complex interface. On that basis, the development of the virtual tour system for the Cotta Cinna Museum needs to place visual quality, information clarity, and ease of interaction as interconnected components. Further system testing is necessary to determine whether the developed product meets functional requirements and provides a user experience that aligns with the research objectives. Thus, the quality of the system is not only assessed based on the success of displaying a 360-degree panorama but also on the system's ability to provide information that can be accessed, understood, and explored by users independently.

Previous research has made significant contributions to the development of virtual tours as media for information, promotion, education, and digital documentation on various objects. Jubaedi et al. (2020) examined the implementation of virtual tour technology in museums, thereby providing a foundation for the application of this technology in the context of museum institutions. Wikanningrum (2016) developed a virtual tour of historical sites in Indonesia by utilizing crowdsourced digital photos as an effort to promote the historical sites of the archipelago. Budi and Wenas (2018) developed a virtual tour of UKSW Campus I as an information medium for new students, while Dianta et al. (2021) developed a website-based virtual tour application to introduce the PENS campus environment. In the context of tourist attractions, Thomas et al. (2018) developed a virtual tour as an interactive promotional medium for accommodations in the Bunaken Islands, while Ananraytama et al. (2018) integrated 3D Maps features into the virtual tour application for promoting Qubu Resort. The development of the virtual tour of Kebun Raya Bogor–LIPI by Suhud et al. (2022) demonstrated the use of virtual applications as a medium for the dissemination and literacy of biological sciences. Aman et al. (2023) developed a panorama virtual tour as a guide and educational medium for historical objects at Datu Luwu Palace, thereby providing direct relevance to the use of 360-degree panoramas in introducing historical objects. In the context of museums, Suryani et al. (2022) developed a

virtual reality-based history learning media at the National Awakening Museum, while Othman et al. (2021) studied the usability aspects of smartphone virtual reality applications in living museums. Sutarsyah et al. (2022) also emphasize the strengthening of museums as centers of information and education, while Af'idah et al. (2024) highlight the support for the implementation of virtual tours as an innovative promotion of tourism and historical learning at the Semedo Museum. Haryadi and Saputro (2022) examined the revitalization of the Ronggowarsito Museum based on an interactive approach through the adaptation of design thinking, which shows that the renewal of museum media is also related to design approaches and visitor experiences. Outside the context of museums, Sumarmi et al. (2023), Rachmadian et al. (2023), and Satya et al. (2024) demonstrate the development of virtual tour applications for strengthening branding and promoting tourist destinations. Amali et al. (2024) contribute from a technical aspect through the development of a virtual tour based on 360-degree panorama images and Leaflet JavaScript. Overall, these studies show that virtual tours have been applied in various contexts and have the potential to serve as digital information media. However, the diversity of contexts, objectives, technologies, and development methods also indicates the need for research that more specifically examines the integration of panoramic representation, multimedia information, interactive navigation, and the specific needs of museums within a directed system development framework.

Although previous research has shown various successes in the application of virtual tours, there is still room for development in the aspect of integrating space visualization and information presentation oriented toward the needs of museum exploration. Some studies place more emphasis on the use of virtual tours as a medium for location promotion, environmental introduction, or digital documentation, while other research focuses on the application of virtual reality technology and usability evaluation. The development of virtual tours for historical sites by Wikanningrum (2016), for example, focuses on the use of digital photos to introduce historical sites, while the research by Budi and Wenas (2018) is oriented toward providing information about the campus environment. On the other hand, Amali et al. (2024) focus on the development of virtual tours based on 360-degree panorama images with web technology, while Maulana et al. (2023) emphasize the application of MDLC in the development of interactive virtual tours. Aman et al. (2023) contribute to the use of virtual panoramas as a media guide and education for historical objects, while Othman et al. (2021) highlight the importance of usability evaluation in virtual reality applications for museum environments. However, based on the synthesis of the available literature, there is still a need for a study that integratively connects the four main dimensions, namely spatial representation through 360-degree panoramas, information presentation through multimedia elements, user interaction through navigation and hotspots, and system development through the MDLC stages. The gap does not mean that previous research did not integrate these components at all, but rather indicates that the combination and emphasis still differ according to the context of the object and the development goals of each study. Research on virtual tours in museums, historical sites, campus environments, and tourist destinations has information needs that are not entirely the same. Museums require presentations that not only show the condition of the space but also connect the space with objects, documentation, and historical information that are part of their educational function. This issue is relevant to research findings on museum interactivity, which show that users may only navigate the virtual space without paying adequate attention to artifacts or exhibition materials. Therefore, interactivity needs to be designed so that users can access information attached to the objects and locations being explored. The literature on virtual tour development also shows that hotspots can function not only as tools for scene transitions but also as mechanisms for displaying videos, photo albums, and supporting information (Dianta et al., 2021; Suhud et al., 2022). Thus, the research gap in this study lies in the need to design a systematic integration between 360-degree panoramas, contextual multimedia information, and interactive navigation in the virtual tour information system specifically developed based on the needs of the Cotta Cinna Museum.

2. LITERATURE REVIEW

A 360° panorama-based virtual tour (VT) is essentially understood as a simulation of a real location constructed from a series of images that are then stitched together to produce a 360° panorama, allowing users to gain a visual experience as if they have "been" at that location through their device's screen (A. D. Jubaedi et al., 2020; A. Wikanningrum, 2016; R. B. N. Budi et al., 2018). In the context of implementation in museums, VT is positioned as both an information medium and a promotional medium to overcome the limitations of conventional promotion and to enrich the visit experience with the sensation of visually exploring the museum space (A. D. Jubaedi et al., 2020; S. Sutarsyah et al., 2022, T. Hidayat et al., 2024).

Technically and conceptually, 360° VT is often described as the result of processing several photos digitally into a panorama, then developed into an application/website that allows users to rotate 360°, look in various directions (up/down), and zoom in to observe details (D.I. Afidah et al., 2024; D.G. Thomas et al., 2018). Thus, VT 360° bridges the need for spatial representation, navigation, and the presentation of contextual information (text, audio, music, or other elements) in a single integrated experience (A. D. Jubaedi et al., 2020; D.I. Afidah et al., 2024; T. Haryadi et al., 2022).

MDLC consists of six main stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution. These stages provide a framework to ensure that user needs, interface design, multimedia asset collection, integration processes, testing, and system publication can be managed in a structured manner. Maulana et al. (2023) demonstrate the application of MDLC in the development of an interactive virtual tour at Asriloka Wonosalam, which shows the relevance of this approach in producing a multimedia-based virtual exploration system. Thomas et al. (2018) also demonstrated that the development of virtual tours as interactive promotional media requires the integration of visual components and interaction mechanisms designed according to the system's needs. Suhud et al. (2022) developed a virtual tour application for Kebun Raya Bogor–LIPI as a medium for dissemination and literacy of biological sciences, involving various multimedia assets in its development process. Negara et al. (2024) also demonstrate the application of a web-based virtual tourism development approach through H5P, which illustrates the importance of managing digital components in the system production process. Operationally, the Concept stage in this research is directed toward identifying the needs of museum managers and potential users, determining the system's objectives, and establishing the scope of the locations to be visualized. The Design stage is used to design the navigation structure, user interface, storyboard, inter-panorama relationships, and hotspot functions that will be provided. The Material Collecting stage is carried out through the collection of 360-degree panorama photos, documentation photos, videos, informational texts, and other supporting materials relevant to the characteristics of the Cotta Cinna Museum. The Assembly stage is the process of integrating all those assets into the virtual tour system, resulting in a digital environment that can be explored interactively. Next, the Testing phase is aimed at examining the system's functional compatibility, navigation accuracy, information accessibility, and ease of use, while the Distribution phase involves preparing the system for publication and access by users through the designated platform. Although MDLC has six stages, its implementation does not always have to be strictly linear because asset collection and application assembly can occur iteratively according to development needs (Maulana et al., 2023; Aman et al., 2023). Thus, the application of MDLC in this research not only serves as a technical procedure for application development but also as a methodological framework to integrate museum information needs, visual representation quality, and multimedia interactivity into a structured system.

The quality of a virtual tour (VT) system based on a 360° panorama is primarily determined by its ability to visually represent a location, allowing users to obtain a relatively complete spatial image and feel as if they are "present" at that location (S. Sumarni et al., 2023; W.W. Satya et al., 2024). Literature on virtual museum tours emphasizes that 360° panoramas allow all sides of a space to be depicted, and users can navigate their view through the screen (for example, with a mouse or VR device), creating the sensation of walking through a physical building transferred to digital media (S. Sumarni et al., 2023). In the context of museums, VT is also positioned as a relevant means of remote visitation when physical visits are limited, but it still emphasizes that VT does not fully replace the experience of an in-person visit (A. Wikanningrum, 2016).

Visual quality is also explicitly reviewed in the development of web-based virtual tours for tourism that use high-resolution 360° images to enhance the immersive experience, and it states that good visual quality affects the clarity of tourism information delivery (H. Saputra et al., 2024). In line with that, the campus VT study based on 360° panorama emphasizes the improvement of accessibility as well as the quality and access of tours through the integration of navigation elements (such as maps/plans) as part of enhancing the user's immersive experience (R. B. N. Budi et al., 2018). Thus, "quality" in VT needs to be understood as a combination of the quality of visual representation of the space and the quality of digital information presentation accompanying that space (R. B. N. Budi et al., 2018; H. Saputra et al., 2024; S. Sumarni et al., 2023).

3. RESEARCH METHOD

This research uses a research and development (R&D) approach with the Multimedia Development Life Cycle (MDLC) model as the main framework for developing the virtual tour information system for the Cotta Cinna Museum. This approach was chosen because the focus of the research is not only to identify the museum's information needs but also to produce an interactive multimedia product based on a 360-degree panorama that can be used as a virtual exploration medium. The MDLC model includes six stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution. The use of MDLC is relevant for the development of multimedia applications because these stages accommodate the processes of needs formulation, design, asset collection, component integration, testing, and product dissemination (Maulana et al., 2023; Jubaedi et al., 2020). The research was conducted at the Cotta Cinna Museum with the museum environment as the main context for observation and system development. The research subjects include museum managers, visitors or potential users, as well as individuals with knowledge of the location who can support the provision of information and documentation of the objects. The selection of the participant group is based on the need to obtain information from the management side and the needs of the end users. However, the available research documents do not yet include the number of participants, detailed

demographic characteristics, or specific sampling techniques, so this information needs to be supplemented based on the actual implementation of the research.

Data collection was conducted through field observations, interviews, user needs questionnaires, and documentation. Observation is directed to identify the physical condition of the museum, locations with informative and visual value, as well as the spatial representation needs in the virtual tour system. Interviews were conducted with managers and users or potential users to obtain information regarding the needs for digital media, the types of information that need to be presented, and expectations for the system's navigation and interactivity functions. Questionnaires are used to gather user needs and responses related to information presentation, ease of use, and the experience of virtually exploring the location. Documentation includes object photos, 360-degree panorama photos, environmental videos, location maps, interview recordings, and information documents relevant to the research object. The research instruments consist of observation guidelines, interview guidelines, user needs questionnaires, multimedia asset collection checklists, and system testing instruments. All of these instruments are aimed at obtaining data that supports product development while also evaluating the suitability of function and information presentation. The use of observation, interviews, and documentation also allows the system's needs to be reviewed based on the location conditions and the statements of the involved parties, similar to the approach of developing virtual tours in the context of museums and other information objects (Jubaedi et al., 2020; Budi & Wenas, 2018).

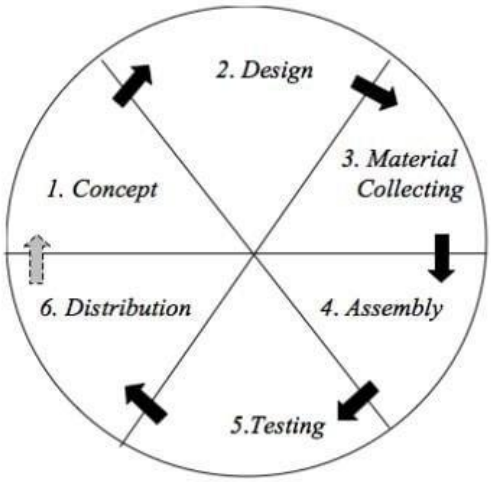


Fig 1. Multimedia Development Life Cycle (MDLC)

The development procedure is carried out through six stages of the MDLC. First, the Concept stage is conducted by setting development goals, target user groups, the scope of locations to be visualized, and the information needs to be included in the virtual tour. At this stage, the results of initial observations and interviews with the managers are used as the basis for formulating the features and system requirements. Second, the Design phase is carried out by creating the interface design, navigation structure, storyboard, and relationships between panorama points. The design also includes the placement of hotspots and information presentation mechanisms so that users can move from one point to another and access object descriptions in a structured manner. Third, the Material Collecting stage is carried out by gathering and preparing multimedia materials, including 360-degree panoramas, photos, videos, audio, informational text, and location maps. Documentation collection pays attention to the points determined in the concept stage to ensure that the visual representation meets the tour's needs. Fourth, the Assembly stage is the process of processing and integrating all multimedia assets into the system, including arranging panorama scenes, setting up navigation, and installing interactive information elements. Fifth, the Testing stage is conducted to check whether the system functions according to the design and established requirements. Sixth, the Distribution stage is carried out by publishing or handing over the system to users so that the virtual tour can be utilized as a medium for information and exploration of the Cotta Cinna Museum. This sequence aligns with the application of MDLC in the development of the virtual tour, which integrates panorama processing, scene assembly, function testing, and system publication (Maulana et al., 2023; Sumarmi et al., 2023; Satya et al., 2024).

4. RESULTS AND DISCUSSION (10 PT)

4.1. General Description of Research Subjects

The research on the development of the virtual tour information system for the Museum Cotta Cinna involves research subjects consisting of system requirement informants and users who participate in product evaluation. Overall, there are 35 people involved in the research series, consisting of five system requirement informants and 30 users who are the subjects of product testing. The five informants were selected using purposive sampling techniques, based on their roles, experience, and knowledge of the Cotta Cinna Museum

as well as the needs for virtual information system development. Meanwhile, 30 users were involved to provide feedback after using the developed virtual tour system. The two groups have different functions in the data collection for the research. System requirement informants provide information regarding the condition of the museum, spatial representation, object information needs, and necessary navigation characteristics. The test users provide feedback on aspects of usability, navigation, interaction, and system acceptance. Thus, the research data includes qualitative information from interviews and observations as well as user evaluation data and system functional testing.

Table 1. Characteristics of System Requirement Informants

Code	Position/Role	Information Focus
I1	Museum Manager	Museum conditions and information requirements
I2	Museum Staff	Spaces and objects that need to be represented
I3	Museum Guide/Museum Informant	Visitor flow and information about museum objects
I4	Museum Visitor	Information access and navigation needs
I5	Digital Media User	Virtual tour usage requirements

Based on Table 1, the five informants represent five different positions in the context of management, introduction, visits, and utilization of the museum's digital media. Informant I1 provided information about the condition of the museum and the need to convey information to the public. Informant I2 provided details about the spaces and objects that need to be represented in the system. Informant I3 provided information about the flow of visits and the relationship between the locations and the displayed objects. Informant I4 provided the visitors' perspective on the ease of accessing information and navigation. Meanwhile, I5 provides information regarding the need for system usage through digital devices. The informants' identities are presented in coded form to maintain the confidentiality of their personal identities.

Table 2. Composition of Research Subjects

Subject Group	Number	Technique/Activity
System Requirements Informants	5 participants	Interviews
User Evaluators	30 participants	User evaluation
Total	35 participants	Data collection and evaluation

4.2. Results of System Needs Identification Based on Interviews

The results of interviews with five informants indicate a need for digital information media that can visually present the condition of the Cotta Cinna Museum and allow the public to gain an overview of the museum without having to make a physical visit first. All informants expressed needs related to digital information media, representation of museum space, use of 360-degree panoramas, information on objects or locations, simple navigation, and access through digital devices. These needs were recorded in six aspects used as the basis for system requirement identification.

Informant I1 conveyed the need for virtual media to provide an overview of the museum to the public who have not yet been able to visit in person. This statement was recorded in the following interview: “Visitors can see an overview of the museum first through digital media before coming in person” (I1, interview). Informant I2 conveyed that certain parts of the museum need to be visually represented so that users can understand the spatial conditions from various angles. Informant I2 stated, "important parts of the museum should be viewable from several angles" (I2, interview). Next, I3 expressed the need for connectivity between the location and object information through interactive points. The informant stated, "if there is an information point, visitors can more easily understand the object they are looking at" (I3, interview).

Informant I4 expressed the need for simple navigation so that new users can operate the system without difficulty. Meanwhile, I5 conveyed the need for the system to be usable through digital devices without a complex usage process. The results of the interviews were subsequently summarized based on six aspects of system requirements as shown in Table 3.

Table 3. Distribution of System Requirements Based on Informants

System Requirements	I1	I2	I3	I4	I5	Total Informants
Digital information media	✓	✓	✓	✓	✓	5
Museum space representation	✓	✓	✓	✓	✓	5

System Requirements	I1	I2	I3	I4	I5	Total Informants
360-degree panorama	✓	✓	✓	✓	✓	5
Object/location information	✓	✓	✓	✓	✓	5
Simple navigation	✓	✓	✓	✓	✓	5
Access through digital devices	✓	✓	✓	✓	✓	5

Table 3 shows that all six aspects of system needs were recorded from all informants, with five informants for each aspect. This data is part of the needs identification results in the development of the virtual tour system

4.3. Results of the Observation of the Condition of Museum Cotta Cinna

Field observations were conducted directly in the environment of Museum Cotta Cinna to identify the physical condition of the museum, available spaces, representable objects, pathways between locations, and points that have the potential to be included in the virtual tour system. The observation activities resulted in the identification of eight locations used as the basis for scene creation in the system. Each point has different visual characteristics and location functions, so 360-degree panorama documentation is needed to represent the museum environment. Observations were also conducted on the interconnections between locations so that user movement in the virtual environment can follow the identified spatial structure. The results of the observation were then used to determine the points for panorama image capture, the placement of navigation hotspots, and the structuring of the scene. In addition to the 360-degree panorama, field documentation produced supporting images and textual information materials used in presenting information at specific points. The eight points that were successfully identified were subsequently coded S01 to S08 to facilitate the management of multimedia assets and the integration process into the system.

Table 4. Results of the Observation of Virtual Tour Location Points at the Cotta Cinna Museum

Scene Code	Represented Location	Observed Conditions	Main Asset
S01	Museum Front Area	Initial access area	360-degree panorama
S02	Entrance	Visitor entrance pathway	360-degree panorama
S03	Main Room	Activity/exhibition space	360-degree panorama
S04	Collection Area	Museum collections	360-degree panorama
S05	Exhibition Room	Exhibition objects and information	360-degree panorama
S06	Central Area	Connecting area between rooms	360-degree panorama
S07	Information Area	Information point	360-degree panorama
S08	End-of-Visit Area	Final exploration point	360-degree panorama

Based on Table 4, the virtual tour system represents eight locations that include the museum's front area, entrance, main room, collection area, exhibition room, central area, information area, and end-of-visit area. Each location uses a 360-degree panorama as the main visual asset. The panorama documentation becomes part of the system development materials, which are then integrated into the scene structure. In locations that have a direct connection with other locations, navigation hotspots are provided as a means of transitioning between scenes. In addition, several points are equipped with additional information related to the location or object displayed. The documentation results also include supporting images and textual materials used to complement the presentation of information in the system.

4.4. Results of the Development of a 360-Degree Panorama-Based Virtual Tour System

The development process resulted in an interactive virtual tour information system based on a 360-degree panorama for the Cotta Cinna Museum. The system was developed using the Multimedia Development Life Cycle (MDLC) method, with the final product being a digital product that integrates visual representations of the museum environment, inter-location navigation, interactive hotspots, system menus, panorama lists, and location information. This product allows users to access visual representations of the museum environment through panorama views and explore using the available interactive controls. The panorama component serves as the main visual element used to display the museum's environmental conditions in each scene. Users can change their viewpoint to see the environment around the panorama capture point. Thus, each scene presents a view of the environment that can be explored through user interaction, rather than just a static image displayed without control.

On the initial page, the system provides access to start the virtual tour. After the user activates this feature, the system displays the predetermined initial scene. Users can then explore by changing the viewing direction of the panorama and selecting the available hotspots. Hotspots in the system function as connectors between scenes or as access points to display additional information. In addition to using hotspots, users can utilize the menu and panorama list to select specific locations. The system also provides a back button and display controls to support the operation of the available features.

Table 5. Main Features of the Virtual Tour System

No.	Feature	System Function
1	Homepage	Provides initial access to the system
2	360-Degree Panorama	Displays the museum environment in panoramic view
3	Scene Navigation	Allows users to move between different locations
4	Interactive Hotspots	Provides access to navigation and information
5	Menu	Provides system controls and access to features
6	Panorama List	Displays available location options
7	Location Information	Displays information related to specific points of interest
8	Panorama Controls	Allows users to adjust their viewing direction

Table 5 shows that the research product produces eight main features that support the operation of the virtual tour. The 360-degree panorama feature is used to display the museum environment, while scene navigation and hotspots are used to connect the represented locations. The menu and panorama list provide access to features and location options. Next, location information is used to provide additional details at specific points, while the panorama control allows users to adjust the viewing direction. All of these features are part of the system implementation produced through the development process.

In the system structure, eight panoramas are placed as interconnected scenes based on the design of inter-location relationships. Hotspots are displayed as interactive elements at specific points and perform functions according to the set configuration. When the user selects the navigation hotspot, the system opens the target panorama. If the hotspot is configured for information, the system displays descriptions related to a specific location or object. Additionally, the panorama list allows users to select the location they want to view without always having to navigate through hotspots. The result of this development produces a system with several exploration access paths, namely through hotspots, menus, and a panorama list.

4.5. Results of BlackBox Testing Functional Testing

Functional testing of the system is conducted using the black-box testing method. This testing is conducted by providing input to the available features, then comparing the actual system output with the expected output based on the test scenarios. The testing includes access to the homepage, the process of starting a virtual tour, panorama display, panorama rotation, navigation hotspots, scene transitions, system menu, panorama list, location selection, location information, back button, and display controls. Overall, there are 12 test scenarios used to examine the main functions of the system. Each scenario produces a status based on the alignment between the designed function and the actual output when the feature is executed.

Table 6. Result of Black-Box Testing

No.	Tested Feature	Expected Result	Actual Result	Status
1	Homepage Access	The homepage is displayed	The homepage is displayed	Successful
2	Starting the Virtual Tour	The initial scene opens	The initial scene opens	Successful
3	360-Degree Panorama	The panorama is displayed	The panorama is displayed	Successful
4	Panorama Rotation	The viewing direction can be changed	Functions properly	Successful
5	Navigation Hotspot	The destination scene opens	The scene opens	Successful
6	Inter-Scene Navigation	Users can move between scenes	Functions properly	Successful
7	System Menu	The menu can be opened	Functions properly	Successful
8	Panorama List	The list of locations is displayed	The list is displayed	Successful
9	Location Selection	The scene corresponding to the selected location opens	Functions properly	Successful
10	Location Information	Information can be displayed	Information is displayed	Successful
11	Back Button	Users return to the previous scene	Functions properly	Successful
12	Display Controls	The controls can be used	Functions properly	Successful

The test results in Table 6 show that all the tested features produced outputs in accordance with the expected results. In the initial page access test, the system successfully displayed the initial page. When the virtual tour start feature was run, the system successfully opened the initial scene. The panorama test showed that the 360-degree panorama image could be displayed, while the rotation test showed that users could change the viewing direction. In the navigation hotspot test, the system successfully opened the target scene according to the configuration. The inter-scene navigation function could also be executed. Next, the system

menu was successfully opened and the list of panoramas could be displayed. Location selection generates a scene that matches the user's choice. Location information can be displayed, the backbutton functions, and the display controls can be used according to the designed functions.

Table 7. Recap of Functional Testing Results

Description	Number
Total Test Scenarios	12
Successful Test Scenarios	12
Failed Test Scenarios	0
Success Rate	100%

The success percentage of the testing is calculated based on the comparison of the number of successful scenarios with the total testing scenarios using the formula:

$$P = \frac{S_b}{S_t} \times 100\% \quad (1)$$

Explanation:
(P) = Success percentage.
(S_b) = Number of successful scenarios.
(S_t) = Total test scenarios.
Based on the test results:

$$P = \frac{12}{12} \times 100\% = 100\% \quad (2)$$

Thus, the results of the functional testing recorded 12 successful scenarios out of 12 tested scenarios, with a success rate of 100%. There were no scenarios that showed failure based on the documented test results.

4.6. Results of User Evaluation of the Virtual Tour System

User evaluation was conducted involving 30 people after each user tried the virtual tour system of the Cotta Cinna Museum. In the evaluation process, users were given the opportunity to access the system, view 360-degree panoramas, use navigation, select hotspots, access the panorama list, and read information available at specific points. After using the system, users provided feedback on four evaluation aspects: ease of use, navigation, interaction, and system acceptance. User responses are classified into five assessment categories: very good, good, fair, poor, and very poor. The evaluation results are then recapitulated based on the number of users who provided ratings in each category**.**

Table 8. Distribution of User Responses to the Virtual Tour System (n = 30)

Evaluation Aspect	Very Good	Good	Fair	Poor	Very Poor
Ease of Use	18	10	2	0	0
Navigation	17	11	2	0	0
Interaction	19	9	2	0	0
System Acceptance	20	8	2	0	0

Based on Table 8, in the aspect of ease of use, there are 18 users who provided very good responses, 10 users provided good responses, and two users provided sufficient responses. There were no responses in the categories of poor or very poor. In the aspect of navigation, 17 users provided very good responses, 11 users provided good responses, and two users provided sufficient responses. The distribution of responses in the aspect of interaction shows that 19 users rated it as very good, nine users rated it as good, and two users rated it as sufficient. Meanwhile, in the aspect of system acceptance, 20 users provided very good responses, eight users provided good responses, and two users provided sufficient responses.

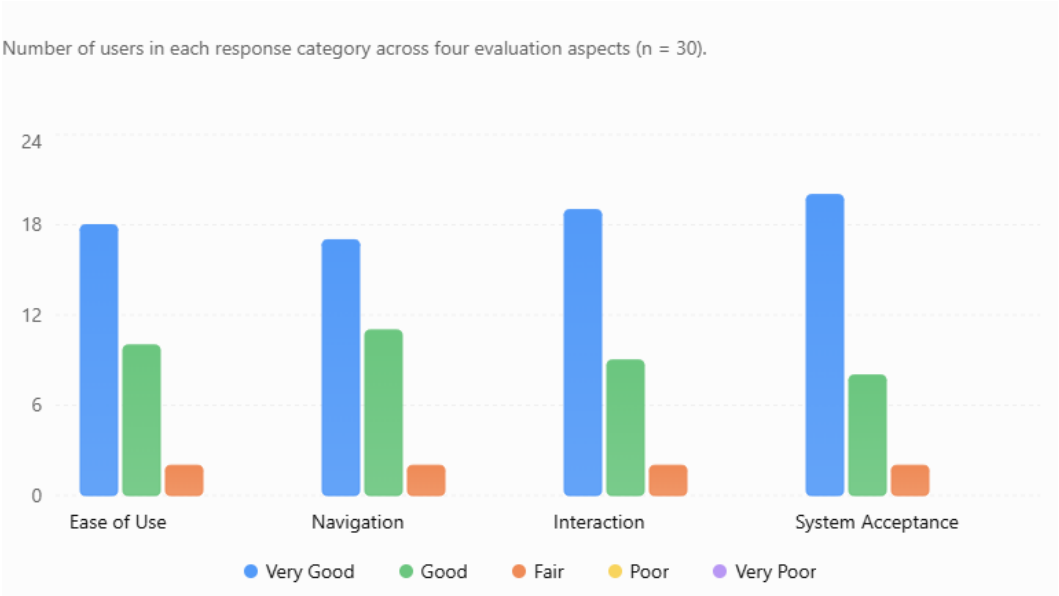


Fig 2. Distribution of User Responses by Evaluation Aspect

Figure 1 shows that the "very good" category is the category with the highest number of responses across all evaluation aspects. The system acceptance aspect has the highest number of very good responses, with 20 users. Next, the interaction aspect received 19 very good responses, the ease of use aspect received 18 very good responses, and the navigation aspect received 17 very good responses. In all aspects, the number of adequate responses recorded was two users. There were no users who gave a poor or very poor rating.

In addition to providing ratings based on the available categories, users also made several notes during the evaluation process. The notes are related to the panorama view, the use of hotspots, and the information presented at specific points. User U07 provided feedback regarding the panorama's ability to show the environment from various angles. Their statement was recorded as follows: "the display allows me to see parts of the room from different directions" (U07, user evaluation). User U15 provided feedback regarding the function of the hotspot as a means of moving between locations in the system. Their statement was: "the hotspot is quite helpful when wanting to move to the next place" (U15, user evaluation).

Next, user U23 provided feedback regarding the information available at specific points in the virtual tour. Their statement was recorded as follows: "the information at specific points helps to know the object being displayed" (U23, user evaluation). The three quotes are documentation of user responses related to the use of panoramas, navigation hotspots, and location information. The quotes are presented using user codes to maintain identity confidentiality.

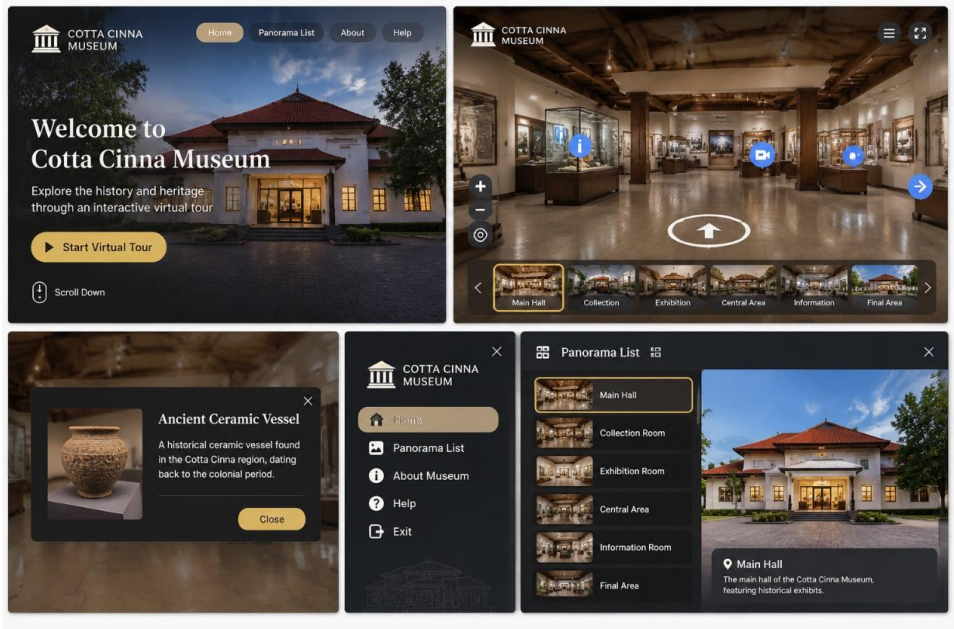


Fig 3. UI/UX Mockup of the Cotta Cinna Museum Virtual Tour Information System

CONCLUSION

This research produces an interactive virtual tour information system for the Cotta Cinna Museum that integrates 360-degree panorama technology and interactive multimedia elements using the Multimedia Development Life Cycle (MDLC) method. The system development is based on the results of observations, interviews with five informants, field documentation, and the identification of user needs for digital-based museum information media. The research results in eight scenes that represent various locations in the museum, starting from the front area, entrance, main room, collection area, exhibition room, central area, information area, to the end of the visit area. The system is equipped with eight main features, namely the homepage, 360-degree panorama, inter-scene navigation, interactive hotspots, menu, panorama list, location information, and panorama control. The results of the functional testing using the black-box testing method show that all 12 test scenarios were successfully executed according to the expected functions, with a success rate of 100%. Evaluation of 30 users also showed a distribution of positive responses across the four assessed aspects, namely ease of use, navigation, interaction, and system acceptance. In the ease of use aspect, 18 users rated it as very good, while in the navigation aspect, 17 users rated it as very good. Furthermore, the interaction aspect received 19 very good ratings, and the system acceptance aspect received 20 very good ratings. No responses were found in the categories of poor or very poor in all aspects of the evaluation. Overall, this research results in the implementation of a museum information system that combines environmental representation through a 360-degree panorama with navigation mechanisms and interactive information presentation. The contribution of this research lies in the development of virtual information media that allows users to access the spatial representation of the Cotta Cinna Museum through a digital environment. The results of this research provide a foundation for the implementation of panorama technology and interactive multimedia in the development of museum information systems as well as the digital documentation of museum objects and spaces.

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