Immersive Living Museum with Augmented Reality Technology, integrated Traditional Art and Digital Art to Enhance Historical Knowledge and Learning Attraction

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***Abstract*—This experimental research aimed to conduct a bibliometric analysis of museum development, develop an Immersive Living Museum Augmented Reality application integrating traditional and digital art, and study its effects on historical knowledge and learning attraction among users. A sample of 60 tourists visiting the Ayutthaya Historical Study Centre Museum was selected using purposive sampling, with participants divided into an experimental group (*n* = 30) using the AR application and a control group (*n* = 30) experiencing the traditional museum. Data were analyzed through a systematic literature review using PRISMA, bibliometric analysis, descriptive statistics, independent t-tests, and simple correlation. The results indicated that the bibliometric analysis emphasized the role of "digital heritage" in connecting cultural heritage, augmented reality, museums, and 3D models, underscoring the significance of digital technology in museum development and cultural preservation. The AR application's quality was rated as excellent, and the experimental group demonstrated significantly higher historical knowledge and learning attraction than the control group, with a positive correlation between knowledge and learning attraction.**

***Keywords*—augmented reality, digital art, historical knowledge, historical learning attraction immersive museum, traditional art**

I. Introduction

Ayutthaya, currently known as Phra Nakhon Si Ayutthaya Province in Thailand, served as the capital of Siam from 1350 to 1767, a period spanning 417 years. As a testament to its illustrious past, Ayutthaya holds a significant place in history, reflecting its pivotal role as a center of power, governance, and cultural traditions. The city's multicultural character, shaped by extensive interactions with foreign powers, further enriches its historical importance. The Ayutthaya Historical Study Centre (AHSC) plays a crucial role in preserving and disseminating the rich history of Ayutthaya. Established in 1986, the AHSC functions as a research institute, museum, and national history library, with a focus on the Ayutthaya period. The center's interdisciplinary approach encompasses various fields within the social sciences and humanities, including anthropology, economics, political science, linguistics, literature, art, and archaeology [1].

The current challenge lies in the fact that traditional museums, including the AHSC, often fail to captivate visitors, particularly younger audiences, due to their reliance on passive forms of learning and static exhibits. This issue is compounded by the evolving expectations of museum-goers in the digital age, who seek interactive and immersive experiences that traditional museum displays are not equipped to provide. Without innovative approaches to museum exhibition, the preservation and dissemination of historical knowledge may falter, risking the loss of cultural heritage in future generations.

Historically, the AHSC has relied on traditional art forms—such as research illustrations, historical murals, sculptures, and architectural models—to convey historical narratives. While these methods were once effective in capturing the essence of Ayutthaya's history, they may no longer fully engage contemporary audiences, particularly those who are deeply immersed in the digital age. In response, modern cultural museums must evolve by adopting the concept of a 'living museum,' which is characterized by interactive and dynamic exhibits that foster deeper engagement [2].

The advent of modern digital technologies has revolutionized the way historical narratives are created and presented in museum settings. Digital art, in particular, has emerged as a powerful tool for engaging audiences and enhancing educational experiences. The integration of multimedia techniques, such as 3D Computer-Generated Imagery (CGI) and parallax animation, allows museums to bring historical artifacts and stories to life in ways that resonate with contemporary learners. For instance, 3D CGI can be used to create realistic models of historical objects and sites, enabling visitors to explore these artifacts interactively and gain a comprehensive understanding of their construction and historical significance [2]. Similarly, parallax animation introduces movement and depth to traditional artworks, creating a more immersive and engaging experience for viewers. The combination of digital multimedia with traditional art forms provides a diverse array of learning pathways, catering to various learning styles and preferences. By embracing these technological advancements, museums can transform historical exhibitions into dynamic, interactive experiences that not only captivate audiences but also foster a deeper appreciation for the past [3]. To achieve this, traditional museums can be transformed into 'living museums' by integrating digital and traditional art through the

application of Augmented Reality (AR) technology. AR technology utilizes concepts from Virtual Reality (VR) to superimpose virtual elements onto the physical world, typically accessed via smartphones. This capability allows museums to present digital art in the form of animated images and audio narration, immersing visitors in a captivating and educational experience known as immersive art [4]. Immersive art creates an environment that enhances the visitor's comprehension of the subject matter they are exploring or engaging with.

While there has been considerable advancement in the use of digital technologies such as virtual VR and AR in museums worldwide, there is still a lack of comprehensive integration of these technologies with traditional art forms to enhance historical learning and engagement Most existing applications tend to focus on either fully digital experiences or simple augmented overlays, without effectively blending digital art with traditional museum artifacts to create a cohesive and enriched visitor experience.

The development of the Immersive Living Museum application is driven by the need to address the gap in museum learning experiences and to align with the evolving cultural policies of Phra Nakhon Si Ayutthaya Province. By combining traditional and digital art, the application aims to revitalize the AHSC, making it more appealing to contemporary audiences and thus fostering a deeper interest in historical exploration. Furthermore, this approach supports the educational mission of museums to preserve and convey historical knowledge in ways that resonate with modern learners, ultimately contributing to the sustainable preservation of cultural heritage. Motivated by these considerations, this research proposes a novel approach to the presentation of history through the fusion of traditional art and diverse digital art forms, enhanced by augmented reality technology. This innovative approach aims to revitalize the Ayutthaya Historical Study Centre Museum in alignment with the cultural policies of Phra Nakhon Si Ayutthaya Province. The envisioned museum will serve as a prototype for living museums, offering an enriching artistic experience while preserving the historical significance of traditional museum exhibits. Moreover, this approach is anticipated to pioneer new methods for showcasing Ayutthaya's history by seamlessly integrating technology, art, and historical narratives, thereby enhancing visitors' historical knowledge and fostering a deeper interest in historical exploration. The Research Objectives were to (1) conduct a bibliometric analysis of research related to museum development. (2) develop an Immersive Living Museum Augmented Reality application integrating traditional and digital art., and (3) study the effects of historical knowledge and learning attraction on users of the Immersive Living Museum application integrating traditional and digital art.

II. Theoretical Foundation

A. Ayutthaya Historical Study Centre Museum

The Ayutthaya Historical Study Centre (AHSC) functions as a research institution and museum focused on the Ayutthaya Kingdom. Its objectives are threefold: (1) to serve as a national research institute specializing in Ayutthaya studies, especially during its period as the capital of Thailand; (2) to act as a national museum presenting research-derived replicas; and (3) to be a center for historical information and a history library. Its scope covers interdisciplinary studies in social sciences and humanities, including anthropology, economics, political science, literature, art, archaeology, language, and the evolution of Thai society and culture in comparison with other countries and contexts. The permanent historical exhibitions are divided into five themes: (1) Ayutthaya as the capital city, (2) Ayutthaya as a port city, (3) Ayutthaya as a center of political power and governance, (4) life of Thai villagers in the past, and (5) Ayutthaya's foreign relations. The museum uses art to recreate life, society, and culture during the Ayutthaya period [1].

B. Immersive Living Museum

An immersive living museum is a distinctive type of museum that allows visitors to experience living and dynamic interactions, enabling them to learn about the museum closely [5]. Through immersive technology, it creates environments or experiences that provide visitors with a deep understanding of what they are exploring or accessing [4]. This is achieved through immersive tools using digital technologies such as virtual reality, augmented reality, mixed reality, 3D modeling, and various multimedia forms [6], which are effective tools for supporting learning and creating engaging educational experiences [7]. The use of digital technology can present cultural heritage within museums [8] through virtual museum experiences [9]. These technologies offer more diverse visiting experiences and detailed access to museum objects from various perspectives, allowing greater interactivity with the artifacts [10]. This approach is crucial for preserving and promoting historical artifacts to the public [11].

C. Traditional Art

The use of traditional art involves incorporating art into the presentation of cultural stories to enhance realism and interest [8]. Art museums provide opportunities for people to learn about art and culture through various forms, including art exhibitions, educational activities, and displays [12]. For example, cultural heritage images can be both photographs and paintings. Photographs are typically taken from real places or objects using a camera, while paintings are created using art and drawing techniques to express the artist's ideas or feelings. Both forms can be significant and valuable cultural heritage passed down over time [13]. Additionally, ancient artifacts can help us understand past cultures, daily life, art, religion, and historical sites. Exhibiting ancient artifacts in museums also helps preserve memories and create meaningful learning experiences for visitors, making these artifacts crucial for conserving and transmitting the cultural heritage of humanity [14].

D. Digital Art

Digital art involves the use of digital technology to create and enhance the appeal and educational value in historical museums [15]. It enhances the visiting and learning experience in traditional museums by integrating digital technology with ancient art, such as 2D digital images or digital reproductions to create photographs or animations that present unique and interesting works [3]. It can be used to

study and analyze art and architecture [16] or employ 3D technology to create and sustain historical heritage by modeling historical objects or places, allowing people to see and access historical heritage in a realistic and engaging manner [2]. For instance, creating historical cities [17]. Studying objects and art in museums enables researchers to obtain detailed and accurate information about historical sites [3], and it enhances the tourism and learning experience related to historical sites [18]. Techniques include 3D modeling, 3D printing, motion capture, 3D visualization, 360-degree panoramas [19], projection mapping [20], AR, VR, and Interactive Application [20–22]. These rapidly developing technologies can preserve cultural heritage at risk of disappearing or deteriorating for future generations [23]. The application of technology benefits learning by making it easier for students to understand [24] and it can be used to create digital art that enhances the interest and impression of displaying artifacts in museums [25], creating more realistic and reliable environments [16]. This diversity and interest enrich the museum visitor experience, offering new opportunities for accessing art, history, and culture [26], effectively providing the public with memorable and realistic tourism experiences [19]. Using digital art to preserve traditional art is one method that leverages technology to sustain and conserve cultural heritage. Digital art helps create learning experiences and participation in preserving and sustaining traditional art without the limitations of place and time [27]. Presenting multimedia exhibitions is a standard method for improving museums and display venues. It is an important part of creating experiences that incorporate images, videos, sounds, and texts to engage and interest museum visitors [28, 29]. By using digital storytelling that combines cinematic narrative techniques with design, it creates immersive experiences for exploring and learning about cultural sites [30].

E. Augmented Reality Technology

Augmented Reality (AR) refers to technology that overlays information and virtual simulations onto the real-world view, allowing users to see the real world with augmented data displayed through technology devices [28]. AR plays a significant role in presenting cultural heritage in an interesting and exciting manner by integrating supplementary information such as images, videos, and text into the real environment. Visitors can view this augmented information through AR devices like smartphones or tablets, making cultural heritage more realistically presented and easily accessible [31]. AR can also showcase local art and culture by combining digital elements with the real world, creating new experiences for visitors [32]. By displaying 3D images or augmented information at real locations, AR enhances users' experiences and understanding of their surroundings [33]. It can create animated scenes and provide additional information about displayed artifacts through 3D modeling, animation, and textual data about ancient objects. Additionally, AR can reconstruct and visualize complete artifacts [34].

Furthermore, AR creates interactive systems at various locations, enabling users to see augmented information on real images or objects, allowing them to view additional data such as historical or tourist information when looking at real objects or places [35]. Using Augmented Reality in museums is an intriguing trend with great potential to enhance visitor experiences in exploring and learning about cultural heritage at historical and cultural sites [20, 32]. It is an essential tool for enriching cultural experiences in museums and heritage sites by providing visitors with realistic and engaging information and experiences [36]. Integrating AR with real locations or museums is crucial for developing strategies that create diverse and historically connected experiences [37]. AR also helps create engaging and realistic learning experiences for visitors by presenting supplementary information such as history, scientific data, or related cultural heritage stories [30]. This enhances visitors' learning and engagement with artifacts and cultural objects [27]. Using AR markers in museums, supplemented with content through AR, can be an interesting option. Visitors can view augmented digital art or objects realistically on their devices by scanning markers on their mobile devices [3]. This allows museum visitors to engage closely and effectively with cultural stories [2], while also protecting museum objects from damage [38], creating realistic and imaginative experiences in presenting cultural information in museums [39]. AR technology can use traditional art as markers and augment with digital art to enhance museum visits [20]. This helps bridge the gap between the virtual and real worlds, creating interesting and realistic travel experiences for museum visitors [19]. Thai cultural art is particularly notable in many areas, such as beautiful architecture, traditional dress, paintings, and advanced artistic crafts [40].

III. Research Conceptual Framework

The conceptual framework depicted in Fig. 1 outlines the key components and processes involved in the development of the Immersive Living Museum, which integrates AR technology with traditional and digital art to enhance historical knowledge and learning attraction.

As illustrated in Fig. 1, the conceptual framework is structured around three main components:

Traditional Art: This component encompasses the traditional art forms presented in the museum, including historical paintings, narrative paintings, photography, and diorama displays. These traditional mediums serve as the foundational elements of the museum's exhibits.

Augmented Reality Technology: The AR technology component includes the application of mobile hardware compatible with both Android and iOS operating systems. This technology employs markers associated with the traditional art displayed in the museum, enabling the visualization of digital art. The AR application facilitates various interactive experiences, enriching the visitor's engagement with the exhibits.

Digital Art: The digital art component is developed using advanced multimedia technologies and is showcased through the AR application. This includes the use of parallax animation, 3D modeling, 3D animation, and voice-over narration to enhance the traditional art displays, providing a more dynamic and immersive learning experience.

Process: The conceptual framework envisions a process

where users engage with historical content through traditional art, which is augmented by digital art using the AR technology developed for the Immersive Living Museum. This integration aims to create an enriched educational experience for museum visitors.

Output: As a result of interacting with the developed Immersive Living Museum, users are expected to achieve enhanced historical knowledge and an increased attraction to learning through the immersive media provided.

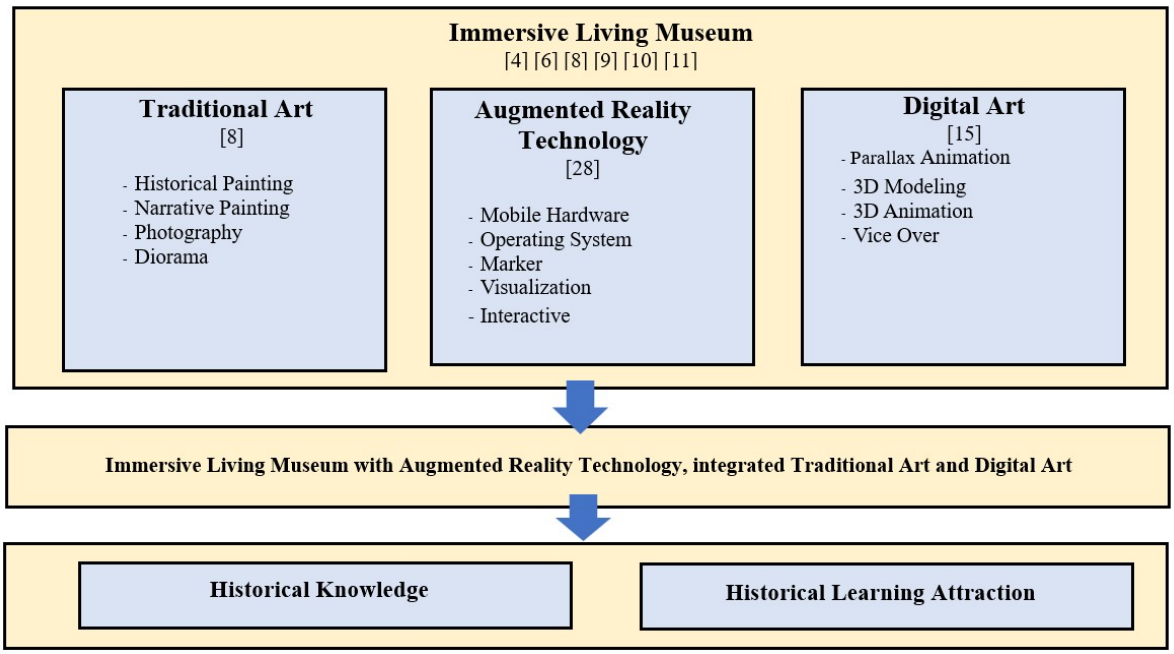


Fig. 1. Conceptual framework of immersive living museum with augmented reality technology, integrated traditional art and digital art to enhance historical knowledge and learning attraction.

IV. Research Methodology

A. PRISMA and Bibliometric Analysis

The research methodology for this study on museum development was executed in the following steps:

Step 1: Systematic Review (PRISMA Analysis): A systematic review was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. Keywords were carefully selected for bibliometric analysis from the Scopus database. The search criteria included terms such as "Article Title, Abstract, Keywords," with specific emphasis on "Digital Heritage." The screening process was restricted to the year range 2018-2023, focusing on document types classified as "Articles." Additional screenings were applied to include terms such as "Augmented Reality," "Immersive," and "Museum" to ensure the relevance of the literature.

Step 2: Data Exportation: Upon completion of the PRISMA analysis, relevant data were exported from the Scopus research database. The exported files included comprehensive details such as citation information, bibliographical information, abstracts, keywords, funding details, and other pertinent metadata.

Step 3: Bibliometric Analysis: The exported data were then analyzed using VOSViewer software to perform a bibliometric analysis of museum development. This analysis generated graphical diagrams illustrating the connections between key terms, which were subsequently used to summarize and interpret the findings.

B. Development and Quality Evaluation of the Immersive Living Museum Application Integrating Traditional Art and Digital Art

1) Development of the immersive living museum application integrating traditional art and digital art

Historical Content and Organization: The development of the Immersive Living Museum application focuses on incorporating the rich historical information of Ayutthaya, as depicted through various traditional art forms within the museum. The content is organized into five primary topics: Ayutthaya as the royal capital, Ayutthaya as the center of political power and governance, the lives of Thai villagers in the past, Ayutthaya's foreign relations, and Ayutthaya as a port city. These topics are presented through traditional art forms such as historical paintings, narrative paintings, photography, and diorama models. The research further explores the application of Augmented Reality (AR) technology in enhancing these exhibits, as well as the use of advanced multimedia technologies, including 3D modeling and animation, to transform the museum into a living, interactive experience. The study also examines effective methodologies for generating historical knowledge and engaging visitors in the museum environment.

Pre-Production: The pre-production phase involves a detailed design process to ensure alignment between the AR application and the museum's historical content. This includes specifying the characteristics of markers within the museum that will trigger digital content, writing scripts for narration, designing model sheets for creating 3D models, drafting storyboards, and developing animatics to plan the

multimedia elements of the application.

Digital Media Production: In this phase, digital media are produced in various forms, with careful attention to the specifics of each type. This includes the creation of parallax animations, 3D media, and voice-over narrations. These multimedia elements are meticulously integrated to form cohesive digital art pieces suitable for historical presentations within the AR application.

Development of the AR Application: This stage entails the technical development of the Immersive Living Museum application, integrating the previously developed multimedia content into the AR platform. Unity serves as the core development engine, complemented by Vuforia for marker-based tracking and AR Foundation for marker-less AR experiences, ensuring compatibility across platforms such as iOS and Android. The application allows users to engage with traditional art in the museum using AR markers, with certain features utilizing marker-less technology. Furthermore, the application includes interactive photography capabilities, enabling users to capture and share their experiences on social media. The finalized version of the application is designed to be intuitive and widely accessible, available for download by tourists visiting the Ayutthaya Historical Study Center.

2) Evaluation the quality of the immersive living museum application integrating traditional art and digital art

Quality Evaluation Process: Following the development of the Immersive Living Museum application, which integrates traditional and digital art, a comprehensive quality evaluation was conducted. This evaluation was performed by experts from provincial cultural agencies and involved both qualitative and quantitative assessments. The process included focus group discussions to gather in-depth qualitative insights and the use of a standardized Quality Assessment Form to collect quantitative data. The Quality Assessment Form employed a 5-level rating scale to systematically evaluate various aspects of the application, ensuring that both the content and user experience met high standards of educational and cultural value. The combination of qualitative and quantitative methods provided a robust evaluation of the application's effectiveness in enhancing historical knowledge and learning attraction.

C. Study on the Historical Knowledge and Learning Attraction of Museum Visitors

1) Research hypotheses

H1: The historical knowledge of the experimental group will be significantly higher than that of the control group, with a significance level of .05.

H2: The historical learning attraction of the experimental group will be significantly higher than that of the control group, with a significance level of .05.

H3: There will be a significant positive correlation between historical knowledge and historical learning attraction, with a significance level of .05.

2) Research variables

Independent Variables: the immersive living museum application integrating traditional art and digital art.

Dependent Variables: historical knowledge and historical learning attraction.

3) Population and samples group

The population comprises tourists visiting the Ayutthaya Historical Study Centre (AHSC) museum. The research sample consisted of 60 tourists visiting the AHSC museum, selected through purposive sampling. These participants were divided into two groups: an experimental group comprising 30 participants who studied history through the Immersive Living Museum AR application integrating traditional and digital art, and a control group comprising 30 participants who studied through the traditional museum experience.

4) Research design

This study employs an experimental research design involving two distinct groups: an experimental group and a control group. The design follows a posttest-only control group format, which is particularly effective for minimizing pretest sensitization and controlling for extraneous variables that could influence the outcomes. The experimental group was exposed to the Immersive Living Museum application, which integrates augmented reality with traditional and digital art, while the control group experienced the traditional museum setup without the use of augmented reality. This design allows for a direct comparison of the effects of the augmented reality application on historical knowledge and learning attraction, isolating the impact of the intervention.

The posttest-only control group design was chosen because it eliminates the potential biases that might arise from a pretest, such as participants becoming overly familiar with the material or developing expectations about the outcomes. By only measuring outcomes after the intervention, the design ensures that any differences observed between the two groups can be attributed to the intervention itself rather than to any pre-existing differences or testing effects. This approach is especially useful in educational research, where the introduction of new learning technologies can dramatically alter participant engagement and learning outcomes. Additionally, this design simplifies the logistics of the study, as it requires fewer measurements and reduces the burden on participants.

The experimental plan, detailed in Table 1, involves the random assignment of participants to either the experimental or control group, ensuring that each group is comparable at the start of the experiment. Random assignment is crucial in experimental research as it helps to evenly distribute any confounding variables that could affect the results, thereby increasing the internal validity of the study. In this research, participants in the experimental group used the Immersive Living Museum application during their visit to the Ayutthaya Historical Study Centre, while the control group experienced the museum's exhibits without the application. Both groups were then assessed on their historical knowledge and learning attraction using standardized posttests, ensuring that the results reflect the true impact of the augmented reality application.

The outcomes of this experimental design are measured through carefully designed posttests that evaluate both historical knowledge and learning attraction. The historical knowledge test consists of 30 multiple-choice questions, while the learning attraction assessment uses a 5-level rating scale with behavioral evaluation items. These measures were

selected for their reliability and validity in assessing educational outcomes, with a high level of internal consistency indicated by a Cronbach's alpha of 0.89. By using these robust assessment tools, the study aims to provide clear evidence on the effectiveness of the Immersive Living Museum application in enhancing historical education in a museum setting. The experimental plan is as follows Table 1

Table 1. Experimental design

Group	Experimental	Historical Knowledge Test	Historical Learning Attraction Assessment
E	X_E	T_E	A_E
C	X_C	T_C	A_C

E represents the Experimental Group, studying history through the Immersive Living Museum (X_E).

C represents the Control Group, studying through the traditional museum (X_C).

T_E and T_C are the post-tests for Historical Knowledge.

A_E and A_C are the assessments for Historical Learning Attraction.

5) Research instruments

Historical Knowledge Test: The test comprises 30 multiple-choice questions. The quality of the test was evaluated using the following criteria: Index of Content Validity (*IOC* > 0.5), Difficulty Index (p = 0.2–0.8), Discrimination Index (r > 0.2), and Reliability, with a Cronbach's alpha value of 0.89.

Historical Learning Attraction Assessment: This assessment utilizes a 5-level rating scale with an additional section for suggestions. The assessment consists of 9 behavioral evaluation items. The quality of the assessment was determined by the Index of Content Validity (*IOC* > 0.5).

6) Data collection

The data collection process involves the following steps:

Briefing the Sample Groups: The study was explained to the sample groups. The experimental group studied history through the Immersive Living Museum application, which integrates traditional art and digital art, while the control group studied history through traditional methods.

Testing: Both groups then completed the historical knowledge test and the historical learning attraction assessment.

Data Analysis: The collected data were analyzed to compare historical knowledge and learning attraction between the experimental and control groups. Additionally, the relationship between historical knowledge and historical learning attraction was examined.

V. Research Findings

A. Results of the Bibliometric Analysis of Research Related to Museum Development

The systematic review results for museum development research are illustrated in Fig. 2

Fig. 2 presents a PRISMA flow diagram illustrating the systematic review process conducted to identify relevant studies for the immersive museum research. The process involved several critical stages, including record screening and assessment for eligibility, to ensure that only pertinent studies were included in the final analysis. This thorough approach helps to enhance the reliability and validity of the bibliometric analysis by focusing on high-quality, relevant literature.

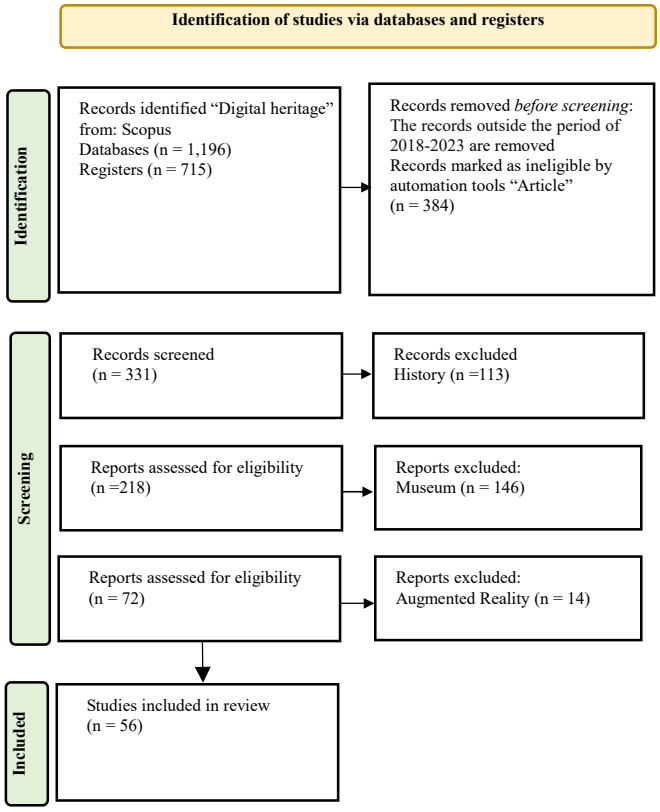


Fig. 2. PRISMA of research related to the immersive museum.

1) Record screening

The initial step involved screening records retrieved from the Scopus database using specific keywords such as "Digital Heritage," "Augmented Reality," "Immersive," and "Museum." This search yielded a total of 1,911 records. During the record screening phase, 384 records were automatically excluded based on pre-determined criteria, such as being outside the publication date range of 2018-2023 or not classified as articles. Additionally, further manual screening excluded another 331 records due to irrelevance, with many being categorized under "History" rather than focusing directly on museum development or immersive technology. The remaining 1,196 records proceeded to the next phase of evaluation.

2) Reports assessed for eligibility

In the next phase, 218 reports were assessed for eligibility based on more refined inclusion and exclusion criteria. The primary inclusion criteria required studies to focus on museum development involving digital heritage or immersive technologies such as augmented reality. Reports were also included if they specifically discussed the integration of these technologies with traditional museum practices. Conversely, the exclusion criteria targeted studies that did not directly address the research topic or lacked empirical data. Consequently, 160 reports were excluded at this stage, including 146 that did not pertain to museums and 14 that lacked relevance to augmented reality or digital heritage. This thorough assessment process ensured that only the most relevant and high-quality studies were included in the final

review.

By rigorously applying these inclusion and exclusion criteria during both the record screening and eligibility assessment phases, the systematic review effectively narrowed down the selection to 56 studies. These studies were deemed highly relevant to the research focus, ensuring a robust foundation for the subsequent bibliometric analysis. This structured approach provides a comprehensive overview of the current state of research in immersive museum technologies and helps to identify key trends and gaps in the literature.

From the process of screening research articles on museum development through PRISMA analysis and analyzing the data using VOSViewer software, a bibliometric graphic diagram was generated, as shown in Fig. 3.

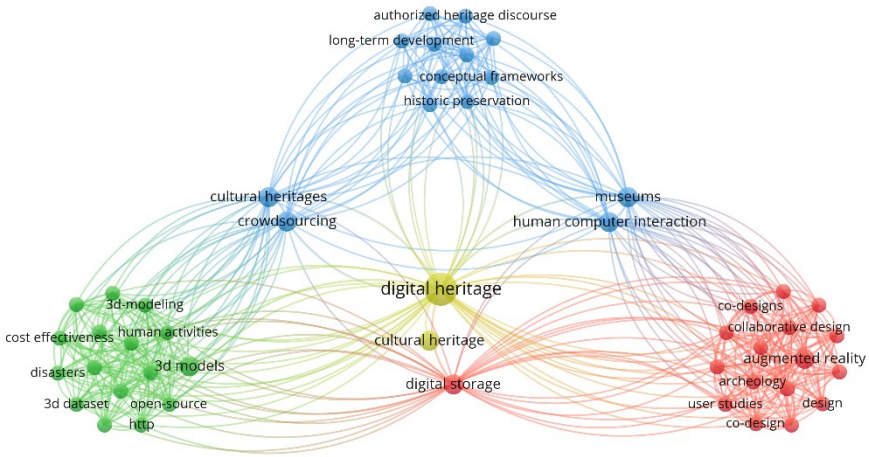


Fig. 3. The bibliometric analysis of the immersive museum.

Fig. 3 presents a bibliometric analysis conducted using VOSviewer, a software tool for constructing and visualizing bibliometric networks. This analysis focuses on the trends in digital heritage research from 2018 to 2023, utilizing overlay visualization to highlight the evolution of key topics and their interconnections over time. The overlay visualization provides a dynamic view of how various themes have emerged and developed, reflecting the growing interest in integrating digital technologies with cultural heritage and museum practices.

3) Current trends in digital heritage

The analysis reveals that "digital heritage" has become an increasingly prominent topic within academic and professional circles. Over the last five years, there has been a significant shift towards exploring how digital tools can enhance the preservation, presentation, and interpretation of cultural heritage. The most recent trends indicate a growing emphasis on utilizing advanced technologies, such as augmented reality (AR), virtual reality (VR), and 3D modeling, to create more interactive and engaging experiences for museum visitors. These technologies allow for the creation of immersive environments where users can explore cultural artifacts and historical sites in ways that were previously not possible. As seen in the overlay visualization, the frequency of terms such as "AR," "immersive," and "3D modeling" has increased markedly, indicating their rising importance in the field of digital heritage.

4) Connections between digital heritage, AR, and immersive museums

The bibliometric analysis also highlights the strong connections between digital heritage and augmented reality, particularly in the context of developing immersive museum experiences. Augmented reality is increasingly being used to overlay digital information onto the physical world, thereby enhancing the educational and entertainment value of museum exhibits. This approach not only helps in preserving cultural artifacts by providing digital replicas but also in offering additional contextual information that enriches the visitor's understanding. For example, keywords such as "augmented reality," "cultural heritage," and "interactive learning" are closely linked, suggesting that AR is seen as a valuable tool for making cultural heritage more accessible and engaging.

Moreover, the term "immersive museum" frequently co-occurs with "digital heritage," reflecting the growing trend of transforming traditional museums into interactive spaces where visitors can engage with exhibits in a more meaningful way. Immersive museums utilize a combination of digital and physical elements to create a holistic experience that captivates visitors and enhances their learning. The use of AR and VR technologies within these settings allows for dynamic storytelling, where historical narratives can be brought to life through interactive simulations and augmented environments. This trend is underscored by the clustering of keywords related to "digital storytelling," "visitor engagement," and "museum innovation" in the visualization, indicating a concerted effort within the field to leverage technology for enhancing the visitor experience.

5) Broader implications and emerging trends

Beyond the immediate connections to AR and immersive museums, the overlay visualization from VOSviewer shows emerging trends that are shaping the future of digital heritage. There is a noticeable increase in research focused on "user experience," "digital archives," and "remote access," highlighting the shift towards making cultural heritage more accessible to a global audience. This trend is particularly relevant in the context of the COVID-19 pandemic, which has accelerated the adoption of digital solutions for remote

learning and virtual tourism. Researchers are increasingly exploring how digital technologies can be used to create virtual exhibitions, allowing users to experience museums and heritage sites from anywhere in the world.

In conclusion, the bibliometric analysis captured in Fig. 2 provides a comprehensive overview of the current trends in digital heritage and its interconnectedness with augmented reality, immersive museums, and other technological advancements. The use of overlay visualization not only demonstrates the evolution of these themes over time but also underscores the potential for future innovations in preserving and presenting cultural heritage through digital means.

B. Results of the Development and Quality Evaluation of the AR Application Immersive Living Museum Integrating Traditional and Digital Art

1) The system architecture of the immersive living museum with AR application

The system architecture of the immersive living museum with AR application, integrates traditional art and digital art for the AHSC museum show in the Fig. 4.

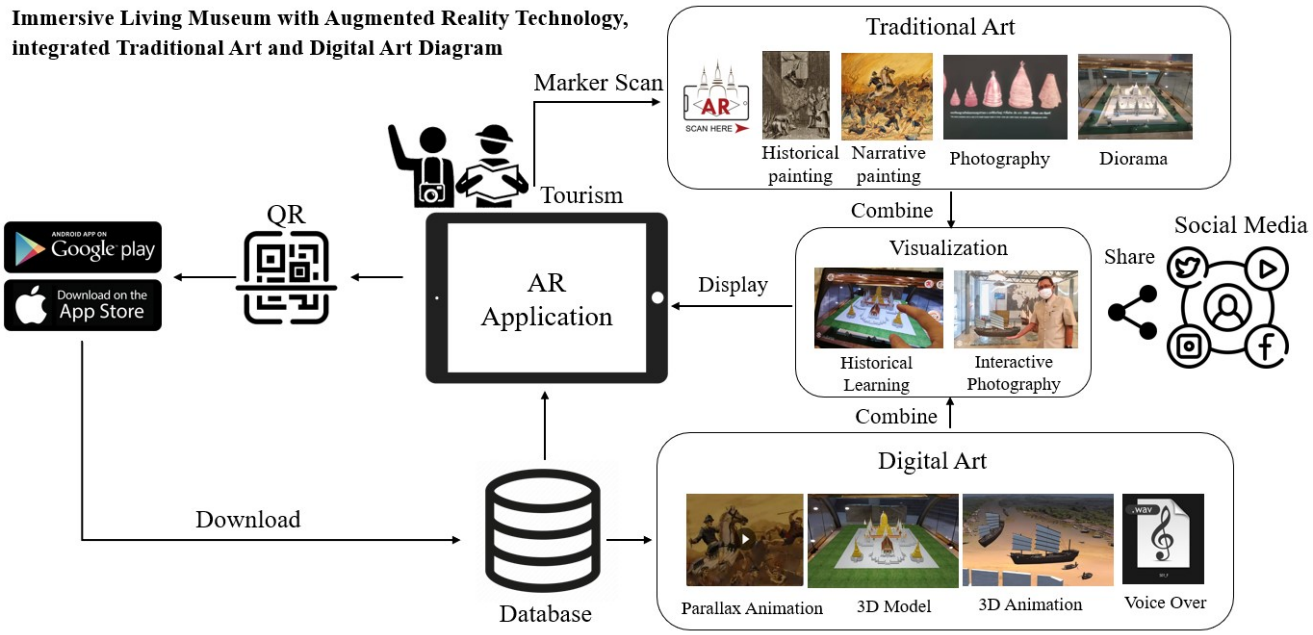


Fig. 4. the system architecture of the immersive living museum with AR application.

From Fig. 4, the image illustrates the system architecture of the Immersive Living Museum with an AR application, integrating both traditional and digital art elements to enhance the visitor experience. It consists of five components as follows:

a) AR application

Central Role: The AR application serves as the core of the system, acting as the platform through which visitors interact with both traditional and digital art. The application is accessible via smartphones, and users can download it from app stores such as Google Play and the Apple App Store.

b) Traditional art

Content: The traditional art section includes historical paintings, narrative paintings, photography, and diorama displays. These art forms are scanned using the AR application's marker scanning feature, which triggers the display of additional digital content.

Visualization: This content is combined with digital elements to create enhanced visual experiences. For example, historical paintings might be overlaid with interactive animations or additional narrative elements.

c) Digital art

Components: The digital art aspect of the system includes parallax animation, 3D models, 3D animations, and voice-over narration. These elements are integrated into the AR application to augment the traditional art displays, providing a richer and more immersive experience.

Purpose: The digital content enhances the understanding and engagement of visitors by bringing static traditional art to life through interactive and dynamic features.

d) System interactions

Tourism Integration: Visitors scan markers placed near traditional art displays using the AR application. This scanning process activates the display of digital content on their devices.

Social Media Sharing: The AR application includes features that allow users to share their experiences on social media platforms such as Facebook, Instagram, and Twitter, enhancing the reach and impact of the museum experience.

Database Connectivity: The system is connected to a database where all digital content and user interactions are stored. This database supports the continuous updating and management of the AR application's content.

e) User access and engagement

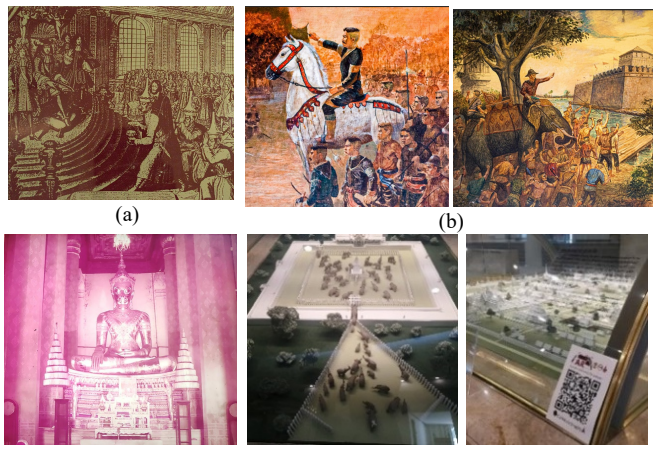
QR Code Access: Users can easily access the AR application by scanning a QR code, which directs them to the download page on their preferred app store.

Interactive Features: Once the application is downloaded, users can engage with both traditional and digital art through various interactive features, enhancing their learning and overall experience.

The use of the immersive living museum with the AR

application is as follows:

1) Downloading the AR Application: Tourists can download the AR application directly from Google Play by scanning the QR code available within the museum. For Android users, the application can also be accessed through this Google Play link https://play.google.com/store/apps/details?id=com.mmt.rus. This makes it convenient for visitors to quickly download and install the app on their devices, enhancing their museum experience with interactive augmented reality features.
2) Historical Learning through the AR Application: Tourists can use the AR application to scan markers representing traditional art within the museum, such as historical paintings, narrative paintings, photography, and dioramas. Areas where the application can be used will have designated scan symbols. Examples of traditional art are shown in Fig. 5.



(a) (b) (c) (d)

Fig. 5. The traditional art: (a) historical paintings; (b) narrative paintings; (c) photographs; (d) dioramas.

Application: The application includes a title section, a menu section, and interactive features such as zooming, rotating, toggling audio narration, and taking photos. These photos can be saved by tourists or immediately shared on social media. See the example in Fig. 6.

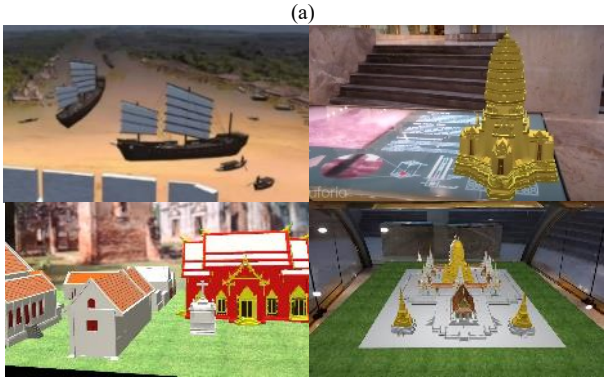
Fig. 6. the use of the immersive living museum with AR application.

Markers: Within the AHSC Museum, there are 25 markers strategically placed to represent various traditional art forms. These markers are equipped with specific symbols that indicate areas where visitors can use the AR application to scan and unlock additional digital content. By using these markers, the museum enhances the interactive experience, allowing visitors to engage more deeply with the exhibits. The marker symbols of the immersive living museum with AR application show in Fig. 7.

Fig. 7. The marker symbols of the immersive living museum with AR application.

Visualization: The digital art visualization is presented in a multimedia format with parallax animation and accompanying narration at 15 locations. Additionally, there are 10 locations where 3D technology is used along with narration. See the examples in Fig. 8.

(a)



(b)

Fig. 8. The digital art visualization: (a) the content presentation using Parallax Animation Video; (b) The content presentation of 3D technology.

The quality evaluation of the AR application, Immersive Living Museum, integrating traditional and digital art, involved nine experts from the Ayutthaya Historical Study Centre Museum. They tested and critiqued the application in focus group meetings and evaluated it using a quality assessment form. The results of the evaluation are shown in Table 2.

The Table 2 shows that the overall quality of the AR application is rated as "Excellent," with a mean score of 4.67 and a standard deviation of 0.52. The high mean scores across

most categories suggest that the AR application is well-regarded for its integration of traditional and digital art forms, as well as its use of AR technology to enhance the museum experience.

Table 2. Results of the quality evaluation

Quality Item	Mean	S.D.	Quality Level
AR Technology in the Museum	4.67	0.5	Excellent
Markers Using Traditional Art	4.56	0.53	Excellent
Presenting Digital Art with Parallax Animation	4.56	0.53	Excellent
3D Technology	4.78	0.44	Excellent
Content Presented Through the Media	4.44	0.73	Good
Voice Narration	4.89	0.33	Excellent
AR Application	4.44	0.73	Good
Preserving the Value of Traditional Art Using Digital Art	4.78	0.44	Excellent
Media for Disseminating Historical Knowledge	4.89	0.33	Excellent
Total	**4.67**	**0.52**	**Excellent**

AR Technology in the Museum received a mean score of 4.67, indicating a high level of satisfaction with how the technology is implemented within the museum setting. This score reflects the experts' appreciation for the seamless integration of AR features that enhance the visitor experience by providing interactive and engaging content.

Markers Using Traditional Art and **Presenting Digital Art with Parallax Animation** both received scores of 4.56, classified as "Excellent." These scores highlight the effective use of markers to facilitate AR interactions and the impactful use of parallax animation to bring traditional artworks to life. These elements are crucial in making the exhibits more dynamic and appealing to visitors, thereby enhancing educational outcomes.

3D Technology scored the highest mean (4.78) among all items, underscoring its effectiveness in providing a realistic and immersive experience. The use of 3D technology allows visitors to explore historical artifacts and environments in detail, fostering a deeper understanding of the exhibits.

Voice Narration and **Media for Disseminating Historical Knowledge** also achieved high scores (4.89), indicating that these elements significantly contribute to the application's educational value. The use of clear and informative voice narration helps to convey historical knowledge effectively, making the content more accessible to a wider audience.

Content Presented Through the Media and **AR Application** both received slightly lower scores (4.44), rated as "Good." While these scores are still positive, they suggest that there is room for improvement in these areas, perhaps by further refining the content presentation and enhancing the application's usability.

Preserving the Value of Traditional Art Using Digital Art also scored high (4.78), emphasizing the application's ability to enhance traditional artworks without compromising their historical value. This approach aligns with the museum's mission to preserve and promote cultural heritage in innovative ways.

Overall, the results in Table 2 demonstrate that the AR application is highly effective in enhancing the museum experience through the integration of digital and traditional art forms. The high ratings across various criteria indicate that the application successfully meets its objectives of providing an engaging, educational, and immersive experience for museum visitors.

C. Results of the Study on Historical Knowledge and Learning Attraction of Museum Visitors

The study aimed to assess the impact of the immersive living museum application on visitors' historical knowledge and learning attraction compared to traditional museum methods. To evaluate the effectiveness of the AR application, an independent t-test was conducted to compare the historical knowledge and learning attraction between the experimental group, who used the AR application, and the control group, who experienced the traditional museum setup without digital enhancements.

Table 3 provides a statistical summary of the comparison results for historical knowledge between the two groups:

Table 3. Comparison of historical knowledge

Group	N	Mean	S.D.	T	df	Sig
Experimental Group (E)	30	23.83	3.36	2.38	58	0.021*
Control Group (C)	30	21.67	3.68			

* $p < 0.05$

From Table 3, The experimental group (E), which used the AR application, comprised 30 participants, as did the control group (C). The mean score of historical knowledge for the experimental group was 23.83 with a standard deviation of 3.36, while the control group had a mean score of 21.67 with a standard deviation of 3.68. These mean scores indicate that the participants who engaged with the AR application demonstrated higher levels of historical knowledge compared to those who experienced the traditional museum exhibits.

The independent t-test yielded a t-value of 2.38 with 58 degrees of freedom, and a significance level of 0.021. Since the p-value is less than .05, the result is statistically significant. This indicates that the difference in historical knowledge between the two groups is not due to chance but is likely attributable to the intervention, i.e., the use of the AR application.

The findings from Table 3 suggest that the AR application has a significant positive impact on enhancing historical knowledge among museum visitors. The higher mean score in the experimental group demonstrates that the immersive and interactive elements of the AR application effectively support learning and retention of historical information. By providing a more engaging and dynamic way to explore historical content, the AR application encourages deeper understanding and interest, which is not as easily achieved through traditional museum methods.

Overall, the results indicate that integrating digital technology such as augmented reality into museum exhibits can substantially improve educational outcomes. These findings support the ongoing efforts to modernize museum experiences to better engage contemporary audiences and enhance their learning experiences through innovative technological solutions.

To evaluate the effectiveness of the Immersive Living Museum application on enhancing learning attraction among

museum visitors, an independent t-test was conducted to compare the learning attraction scores between the experimental group, who used the AR application, and the control group, who experienced the traditional museum setup. The results of this comparison are presented in Table 4.

Table 4. Comparison of historical learning attraction

Group	N	Mean	S.D.	T	df	Sig
Experimental Group (E)	30	40.36	3.90	8.18	58	0.000*
Control Group (C)	30	30.10	5.56			

* $p < 0.05$

The experimental group (E), consisting of 30 participants who used the AR application, had a mean learning attraction score of 40.36 with a standard deviation of 3.90. The control group (C), also consisting of 30 participants who studied in a traditional manner, had a lower mean score of 30.10 with a standard deviation of 5.56. These mean scores indicate a substantial difference in learning attraction between the two groups, with the experimental group showing a significantly higher level of attraction to learning.

The independent t-test produced a t-value of 8.18 with 58 degrees of freedom, and a significance level of 0.000. Given that the p-value is well below the .05 threshold, the results are statistically significant. This significant p-value indicates that the difference in learning attraction between the experimental and control groups is not due to random chance but can be attributed to the use of the AR application.

The findings in Table 4 demonstrate that the Immersive Living Museum application significantly enhances the learning attraction of visitors compared to traditional museum experiences. The high mean score in the experimental group suggests that the interactive and immersive elements of the AR application greatly contribute to increasing visitors' interest and engagement with the museum content. By providing an enriched learning environment that combines digital and traditional elements, the AR application fosters a more engaging and memorable museum experience, which can lead to improved educational outcomes.

Overall, the results highlight the potential of augmented reality and other digital technologies in transforming the way museums present historical content. By making learning more interactive and engaging, these technologies can attract a broader audience, including those who might not typically be interested in traditional museum visits, thereby enhancing both the educational and entertainment value of museum exhibits.

The correlation between historical knowledge and learning attraction for both the experimental and control groups was studied using a simple correlation analysis. The statistical summary is shown in Table 5, and the correlation graph is shown in Fig. 9.

Table 5. Correlation between historical knowledge and learning attraction

Variable	Historical Knowledge	Historical Learning Attraction
Historical Knowledge	1	0.454*
Historical Learning Attraction	-	1

* Correlation is significant at the .05 level.

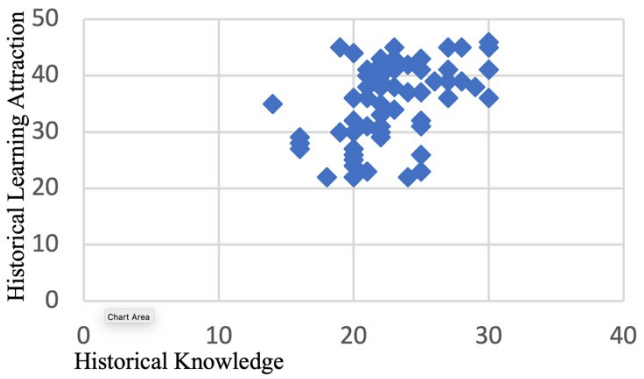


Fig. 9. Graph of the correlation between historical knowledge and learning attraction.

From Table 5, it can be observed that the correlation between historical knowledge and learning attraction is positive, with a value of 0.450. This moderate correlation suggests that as historical knowledge increases, learning attraction also tends to increase among museum visitors. This correlation is statistically significant at the .05 level (one-tailed), which supports the hypothesis that engaging learning experiences, such as those provided by the AR application, can enhance both knowledge retention and interest in learning. This finding illustrates a positive correlation between historical knowledge on the X-axis and learning attraction on the Y-axis.

VI. Discussion

The results of this study indicate that the use of the Immersive Living Museum application, which integrates Augmented Reality (AR) with traditional and digital art forms, significantly enhances both historical knowledge and learning attraction among museum visitors. The experimental group, which utilized the AR application, demonstrated higher levels of historical knowledge and learning attraction compared to the control group, which experienced the museum through traditional means. These findings suggest that AR technology can play a crucial role in transforming museum experiences into more engaging and educational activities.

The findings are consistent with those reported in other studies exploring the impact of digital technologies in museum settings. For example, Zhang *et al*. [15] also found that AR technologies significantly increased visitor engagement and knowledge retention in heritage tourism contexts. Their study showed that AR could provide a deeper understanding of historical content by making it more interactive and visually stimulating, which aligns with our findings that the AR application enhanced both historical knowledge and learning attraction. Similarly, a study by Luigini *et al.* [7] demonstrated that immersive and interactive digital environments, such as those created with AR and VR, could significantly improve educational outcomes. Their research highlighted that these technologies offer new ways of presenting information that resonate more with contemporary audiences, who are increasingly accustomed to digital and interactive experiences. This supports our conclusion that integrating AR technology in museums not only enhances educational outcomes but also increases visitor engagement.

Furthermore, Boboc *et al*. [32] examined the use of AR in

cultural heritage presentations and found a positive correlation between the use of interactive AR elements and increased visitor satisfaction and educational value. Their findings corroborate our results, which showed a significant improvement in both knowledge and attraction to learning when visitors interacted with AR-enhanced exhibits.

Tourists in the experimental group who studied history through the AR application integrated with the traditional museum artifacts had greater historical knowledge and Learning Attraction than the control group who studied in a traditional manner. There is also a correlation between historical knowledge and Learning Attraction in studying history. Overall, the research aligns with the bibliometric analysis, which shows that augmented reality technology and the use of digital art play significant roles in current and future museum development. Integrating AR technology with traditional and digital art in museums will enhance visitors' historical knowledge and Learning Attraction. The results can be discussed as follows:

Using the Immersive Living Museum application, which integrates traditional art and digital art through AR technology, enhanced historical knowledge more effectively than the traditional museum approach. This indicates that the Immersive Living Museum method is an effective way to communicate content to museum visitors, aligning with the research by Luigini *et al.*, which stated that immersive technology plays a crucial role in creating engaging and effective learning experiences by providing realistic scenarios that support learning through understanding and creating effective learning experiences. [41]

In terms of presentation using various technologies, including Augmented Reality (AR) as a medium in cultural heritage museums to enhance visitors' learning experiences, the integration of AR with traditional museums presents both visible and invisible elements, bringing lifeless objects to life through communication devices. This is important for cultural heritage, consistent with the research by Zhang *et al.*, which found that using AR to present historical information in museums enhances communication and learning efficiency for tourists, making their museum visit more engaging and memorable, and increasing their satisfaction with the historical museum experience. [15] Using art in museums as markers is an interesting way to present content, as visitors can see both traditional and digital art enhanced by AR technology. This aligns with the research by Caciora *et al.*, which stated that using art in museums as markers can enhance visitors' learning experiences, making the museum more interesting and effectively linking art and technology. Additionally, using art as markers enhances the museum visit experience, making it more engaging and memorable for visitors. [19] Moreover, using 3D technology to present content creates interest at the intersection of reality and virtuality, providing immersive experiences and enhancing reality with digital content, helping people perceive digital content as real around them. This aligns with the research by S. Muenster, which stated that using 3D imagery helps in presenting realistic models and animations of historical objects, supporting learning, and creating knowledge and interest effectively in fields related to history and culture through processes that create engaging learning experiences, understanding content, and creating multimedia learning experiences. [26]

The implications of these findings for museum practices are significant. By incorporating AR and other digital technologies, museums can create more engaging and educational experiences that cater to the needs and preferences of modern audiences. This study adds to a growing body of literature suggesting that digital technologies, when effectively integrated with traditional museum exhibits, can enhance learning outcomes and visitor engagement. As museums continue to evolve in response to technological advancements and changing visitor expectations, the integration of AR and similar technologies will likely become increasingly important.

VII. Conclusion

The development of traditional Cultural Heritage museums can be enhanced by using digital technologies such as AR. Visitors can view traditional art within the museum, supplemented by digital art in the form of multimedia, including animations, 3D technology, accompanied by sound and various interactions. This approach creates an immersive experience, increases interest in studying history, and effectively enhances historical knowledge.

the Immersive Living Museum application demonstrates that augmented reality technology can significantly enhance both historical knowledge and learning attraction among museum visitors. By integrating traditional art forms with digital enhancements, the application provides a more engaging and educational experience that resonates with contemporary audiences. As museums continue to evolve and embrace digital innovations, the findings from this study offer a valuable framework for incorporating AR into museum practices, ensuring that cultural heritage remains relevant and accessible in the digital age.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

S.S.: Led the conceptualization and development of the research study, including the bibliometric analysis of museum development. Coordinated the team in conducting the systematic literature review and the development of the Augmented Reality (AR) application for the Immersive Living Museum. Actively contributed to the writing and editing of the manuscript. A. K.: Acted as the corresponding author, facilitating communication with the journal. Played a central role in the research design and methodology, especially the experimental setup and statistical analysis of historical knowledge and learning attraction. Supervised the AR application development, ensuring technical integration of traditional and digital art. N. W.: Assisted in the implementation and testing of the AR application in the museum context. Managed the coordination with the Ayutthaya Historical Study Centre and local cultural agencies. Contributed to data collection and the focus group evaluation for the quality assessment of the AR application. C. C.: Responsible for the pre-production and production of digital

media, including parallax animations, 3D models, and voice-over narrations. Contributed to the analysis and interpretation of the experimental findings, especially regarding the educational impacts of the AR application. S. L.: Participated in the systematic review and bibliometric analysis, focusing on the integration of AR in cultural heritage. Assisted in the development of markers and interactive features within the AR application. Contributed to the manuscript's discussion and conclusion sections. P. W.: Provided guidance on the theoretical foundation of immersive learning ecosystems. Reviewed the research methodology and supervised the quality evaluation of the AR application. Assisted in the final review of the manuscript and contributed significantly to ensuring the research aligns with broader educational and cultural heritage frameworks. all authors had approved the final version.

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