

Article

Enabling Inclusive Access to Restricted Sacred Spaces: A Real-World Comparison of VR360 and AI-Driven Virtual Reality

Phimphakan Thongthip ¹, Darin Poollapalin ², Songpon Khanchai ², Pakinee Ariya ¹ and Phichete Julrode ^{2,*} 

¹ College of Arts, Media and Technology, Chiang Mai University, Chiang Mai 50200, Thailand

² Department of Library and Information Science, Faculty of Humanities, Chiang Mai University, Chiang Mai 50200, Thailand

* Correspondence: phichete.j@cmu.ac.th

Abstract

This study investigates how virtual reality systems can support inclusive access to culturally restricted sacred heritage sites. Two extended reality (XR) approaches were developed and deployed in a real-world setting: a VR360 virtual tour and an AI-driven immersive virtual reality prototype with conversational interaction. A research-in-the-wild, between-subjects study was conducted with 136 participants using mixed methods, including standardized questionnaires (System Usability Scale, User Engagement Scale, and Igroup Presence Questionnaire), retrospective interviews, and exhibition staff observations. The results reveal clear trade-offs between the two systems. The VR360 system demonstrated higher usability and operational reliability, requiring minimal supervision and technical resources, whereas the AI-driven immersive VR system supported embodied exploration and conversational inquiry, which was associated with higher spatial presence and helped visitors address questions during exploration. Qualitative findings further indicate that conversational interaction enhanced user experience but also introduced greater technical complexity and staffing requirements. Overall, the study provides empirical insights for designing and deploying XR systems in heritage contexts and highlights how different levels of immersion and interaction influence usability, presence, and operational feasibility when supporting inclusive access to culturally restricted sites.

Keywords: AI-driven immersive VR; VR360; sacred heritage sites; spatial presence; conversational AI; virtual museums; inclusive access

1. Introduction

Access to cultural heritage sites is essential for supporting cultural understanding, historical interpretation, and sustainable heritage tourism. However, physical access to such sites is frequently constrained by conservation requirements, architectural fragility, safety concerns, or long-established ritual and cultural practices [1,2]. In particular, sacred architectural spaces are often governed by traditional norms that restrict access to specific areas or to certain visitor groups. These access constraints are not exceptional cases limited to individual sites, but rather represent a recurring structural condition observed across different religious and cultural contexts worldwide [3]. As a result, a persistent gap exists between the cultural value of sacred heritage sites and the ability of all visitors to experience and interpret them directly.

To address this challenge, Virtual Reality (VR) technologies have increasingly been adopted as alternative access mechanisms for cultural heritage interpretation [4]. VR-based



Academic Editor: Roberto Theron

Received: 8 February 2026

Revised: 25 March 2026

Accepted: 7 April 2026

Published: 9 April 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

systems enable visitors to explore heritage spaces remotely, mitigate physical impact on fragile structures, and provide access to sites that are geographically distant or culturally restricted. Among existing approaches, VR360 systems are widely used due to their relatively low development cost, straightforward deployment, and ability to present high-fidelity panoramic visual content [5]. However, prior studies have noted that VR360 systems typically rely on predefined viewpoints and fixed informational hotspots, resulting in largely passive user experiences with limited interactivity and minimal support for user-driven inquiry [6]. In contrast, immersive VR systems based on fully navigable three-dimensional reconstructions allow greater spatial exploration and user agency, but demand more complex content production pipelines and interaction design considerations [7]. Presence and spatial experience have therefore become key evaluation dimensions in virtual heritage research, often assessed using standardized presence measurement instruments [8].

Recent advances in artificial intelligence, particularly Large Language Models (LLMs), further extend the capabilities of immersive VR by enabling conversational and adaptive interaction within virtual environments [9]. AI-driven conversational interfaces allow users to pose natural language questions and receive context-sensitive explanations, transforming VR from a static visualization medium into an interactive information system. Despite growing interest in AI-enhanced virtual heritage, empirical comparisons between conventional VR360 systems and AI-driven immersive VR systems remain limited, especially in real-world heritage contexts characterized by ritual access restrictions [10]. Three limitations in the current literature can be identified. First, many studies examine immersive VR and panoramic VR360 systems separately, without conducting controlled comparisons between different access paradigms within the same heritage context. Second, a substantial portion of AI-enhanced virtual heritage research focuses on technical prototypes or laboratory-based demonstrations, leaving limited empirical evidence from real-world heritage deployments where operational constraints and visitor diversity influence system use. Third, although conversational AI has been proposed as a mechanism to enrich interpretation and visitor engagement, little empirical evidence exists regarding how conversational interaction influences user experience outcomes compared with established VR360 system.

To address these gaps, this study adopts a comparative research-in-the-wild approach to examine two virtual heritage access paradigms—a VR360 system and an AI-driven immersive VR system with conversational interaction—deployed in an access-restricted sacred heritage site. To strengthen the theoretical grounding of this study, we adopt an interaction-driven perspective in which VR360 and AI-driven immersive VR are conceptualized as distinct interaction modalities that shape user experience through differences in interaction characteristics, including user agency, system responsiveness, and cognitive load. This perspective is situated within the context of access-restricted sacred spaces, where virtual reality functions as a mediated access mechanism.

The research contributes to the literature in three ways: theoretically, by clarifying how interaction modality influences presence and user experience in culturally constrained heritage environments; methodologically, by demonstrating the value of real-world comparative evaluation for XR heritage systems; and practically, by identifying design and operational trade-offs between VR360 and AI-driven immersive VR to inform heritage institutions seeking to balance inclusivity, experiential depth, and deployment feasibility. To guide the comparative analysis, this study addresses the following research questions:

RQ1: How do VR360 systems and AI-driven immersive VR systems differ in terms of perceived usability and user engagement when applied to an access-restricted sacred heritage context?

RQ2: How do VR360 systems and AI-driven immersive VR systems differ in terms of presence and perceived spatial presence in an access-restricted sacred heritage context?

RQ3: What system-level design and operational trade-offs emerge when transitioning from VR360-based heritage access systems to AI-driven immersive VR systems for access-constrained cultural heritage sites?

2. Related Work

2.1. Virtual Reality for Cultural Heritage Access

VR has become a widely adopted approach for extending access to cultural heritage when physical visitation is constrained by distance, conservation requirements, or site fragility. In cultural heritage practice, VR is used not only for visual reproduction but also as a mediated access layer that supports interpretation, navigation, and contextual information delivery within reconstructed heritage environments. Recent evidence from systematic reviews indicates that VR in cultural heritage has matured from early demonstrations into a structured research area with clearer taxonomies of goals (e.g., access, preservation, education, tourism) and evaluation practices spanning usability and user experience. In particular, comprehensive reviews emphasize that VR can improve perceived accessibility and engagement, but outcomes depend strongly on system design choices, interaction mechanisms, and the degree of immersion provided by the hardware and software stack [11,12].

More recent work further highlights a shift toward immersive, content-rich heritage experiences and the need to evaluate VR systems as information systems that mediate visitors' spatial understanding and interpretive depth. For example, systematic and bibliometric syntheses of virtual exhibitions and heritage VR research show sustained growth in the field, with increasing attention to interaction design, presence, and deployment realism (i.e., beyond lab-only prototypes) [13]. At the application level, recent implementations in venues such as museums and archaeological sites demonstrate how immersive VR pipelines are being operationalized for preservation and visitor experience, while also surfacing practical trade-offs in cost, content creation, and usability—factors that directly affect how VR supports “access” in real settings [14,15].

2.2. VR360-Based Heritage Documentation

VR360-based heritage documentation (e.g., 360° panoramas and hotspot-based virtual tours) is widely adopted as a pragmatic approach to extend public access to cultural heritage when time, budget, or modeling constraints limit full 3D reconstruction. Recent work emphasizes that VR360 virtual tours can deliver high visual realism and fast content production, making them attractive for museums and heritage settings seeking scalable online access. For example, empirical evaluation studies of online museum virtual tours propose and validate measurement frameworks for assessing perceived quality and effectiveness, highlighting that VR360 can be a viable access medium when designed with clear navigation and interpretive cues [16]. In parallel, recent museum-focused evaluations comparing immersive technologies (including VR360) report that VR360 can meaningfully support visitor experience, but outcomes depend strongly on interaction design and the alignment between narrative structure and exploratory behavior [17].

However, more recent syntheses and implementations also underscore recurring limitations of VR360 as a documentation-oriented paradigm: fixed viewpoints and predefined hotspots can constrain user agency, reduce the depth of information inquiry, and limit adaptive interpretation compared to interactive, reconstructed environments. Bibliometric and systematic analyses of virtual exhibitions and digital heritage systems identify a growing emphasis on interactivity, presence, and “beyond-static” engagement, suggesting that VR360 increasingly functions as a baseline reference condition rather than an end-state solution [18]. Likewise, real-world digital heritage pipelines (e.g., digitization of exhibitions

as online-accessible “digital twins”) illustrate how VR360 can be integrated into broader documentation workflows, while also revealing practical trade-offs related to metadata, interoperability, and long-term maintenance [19]. Recent comparative research on physical versus virtual museum behavior further supports the need to evaluate virtual tour formats as information systems that shape user engagement and interaction patterns, rather than treating VR360 as purely visual documentation [20]. Accordingly, up-to-date scoping work on UX evaluation in virtual museum tours consolidates recent methods and reinforces the need for comparative studies that connect VR360 design choices to measurable experience outcomes and interaction behaviors [21,22]. These findings motivate the present study’s use of VR360 as a documented baseline for comparing against more interactive AI-driven immersive VR approaches in access-constrained heritage contexts.

2.3. Immersive Virtual Reality Systems for Cultural Heritage

Immersive Virtual Reality (iVR) systems for cultural heritage increasingly move beyond panoramic viewing toward interactive, model-based experiences that emphasize presence, embodied navigation, and situated learning. Recent synthesis work shows that iVR cultural heritage reconstructions typically combine 3D data acquisition (e.g., photogrammetry/laser scanning), real-time rendering, and interaction mechanics to support exploration, interpretation, and experiential storytelling, while also reporting recurring design trade-offs between visual fidelity, performance, locomotion comfort, and usability in public-facing deployments [23]. Empirical case studies likewise demonstrate that immersive heritage VR can meaningfully enhance perceived realism and engagement when interaction is carefully scaffolded (e.g., guided tasks, assistance cues, and optimized navigation) and when content is aligned with museum constraints such as short session time and first-time user needs [24,25].

Up-to-date evaluation research also highlights a methodological shift: immersive heritage systems are increasingly assessed through multi-dimensional user experience constructs (e.g., presence, engagement, motivation, perceived authenticity, and behavioral intention), rather than relying on ad hoc satisfaction questions. Comparative work in museum contexts that contrasts multiple XR modalities (VR, VR360, MR) provides evidence that immersion level and interaction design jointly shape visitor outcomes—supporting the rationale for controlled comparisons between immersive VR and lower-interactivity baselines in heritage access scenarios [26]. In parallel, technical contributions broaden evaluation beyond self-report by integrating objective–subjective frameworks (e.g., computer vision + iVR for visual perception assessment in heritage sites) and by formalizing design/evaluation pipelines and HCI methods for cultural heritage XR applications [27,28]. Beyond visitor interpretation, immersive VR systems have also been explored for professional applications such as remote inspection and monitoring of cultural heritage structures. Recent review studies indicate that VR environments combined with AI-assisted visual analysis can enable experts to examine architectural conditions and structural details remotely, reducing the need for continuous on-site access while supporting conservation and documentation activities [29]. Collectively, this recent literature positions immersive VR as a robust platform for heritage interpretation and access, while reinforcing the need for comparative studies that tie specific interaction affordances (e.g., embodied interaction, conversational guidance, adaptive information delivery) to measurable outcomes in real-world heritage visitation constraints [30–32].

2.4. AI-Driven Interaction and Conversational Systems in Cultural Heritage

AI-driven interaction has become an increasingly prominent design direction in digital cultural heritage, particularly as museums and virtual heritage experiences shift from static

content delivery toward dialogue-based interpretation and personalized guidance. Recent scholarship on generative AI in cultural heritage emphasizes that conversational systems can support scalable interpretation (e.g., automated explanations, adaptive narration, and visitor support), while also raising practical requirements around accuracy, provenance, and curatorial oversight in AI-generated content [33]. Within VR-oriented heritage applications, LLM-enabled chatbots have been proposed as a mechanism to move beyond fixed hotspot narratives, enabling visitors to ask natural-language questions and receive contextual responses that align better with individual curiosity and exploration styles [34].

In immersive and virtual museum contexts, recent studies and systems research further examine how the form of conversational interaction (text chatbot, voice interaction, embodied avatar/agent) affects engagement, trust, and perceived experience quality [35,36]. Empirical work comparing LLM-empowered chatbots and avatar-based conversational interfaces indicates that interaction modality can meaningfully influence user engagement and perceived experience outcomes, suggesting that “conversational AI” should be treated as an interaction design variable rather than a purely technical add-on [35]. Complementary HCI-oriented research on embodied conversational agents in virtual museums highlights that embodiment and agent behavior can shape social presence and visitor perception, reinforcing the need to design conversational systems with attention to role, persona, and museum communication goals [36]. Beyond lab studies, recent deployment-focused work in virtual museum tour agents shows that agent responsiveness (answering questions) and situational awareness (navigational support) can measurably affect visitor experience, providing practical evidence for designing conversational guides as integrated components of the virtual tour system [37]. Large-scale heritage initiatives also report integrating AI-driven components (including chatbots and context-aware tools) as part of broader digital heritage ecosystems, further motivating rigorous comparative evaluations of conversational interaction designs in cultural heritage access settings [38].

2.5. Conceptual Framework

This study is grounded in an interaction-driven theoretical perspective that conceptualizes virtual reality systems as mediated access mechanisms within culturally constrained environments. In the context of access-restricted sacred spaces, where physical access is governed by ritual norms and cultural boundaries, virtual reality is not merely a visualization technology but an interpretive interface that shapes how users experience and engage with otherwise inaccessible environments. Within this framework, VR360 and AI-driven immersive VR are conceptualized as distinct interaction modalities that structure user experience through their underlying interaction characteristics, including user agency, system responsiveness, and perceived cognitive load. These interaction characteristics function as mediating mechanisms that explain how different interaction modalities influence user experience outcomes. In this process, interaction modality shapes user interaction characteristics, which in turn influence user experience responses such as presence and engagement, ultimately affecting overall user experience. The conceptual framework is illustrated in Figure 1. Specifically, more interactive and conversational systems are expected to enhance engagement and presence, while potentially introducing greater interaction complexity that may affect usability. Based on this framework, the study compares VR360 and AI-driven immersive VR systems to examine how differences in interaction characteristics drive variations in usability, engagement, and presence.

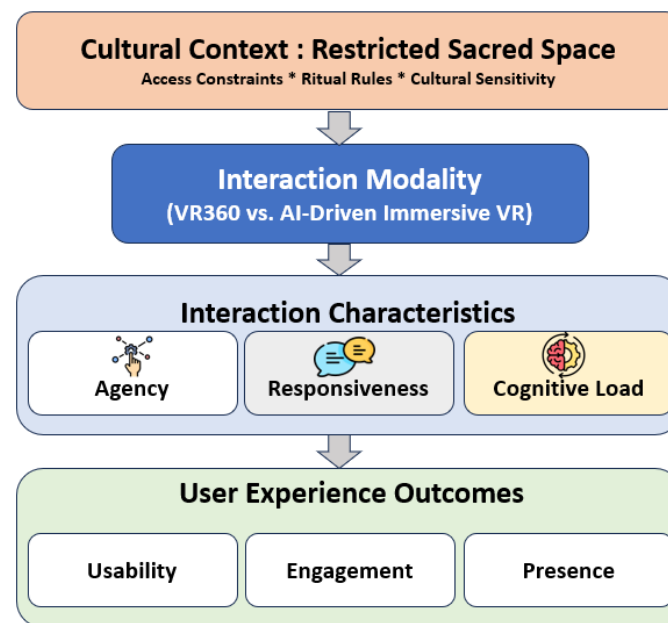


Figure 1. Conceptual framework of interaction modality and user experience in access-restricted sacred heritage contexts.

3. System Overview

3.1. Cultural Heritage Context of Restricted Sacred Spaces

The Silver Ubosot at Wat Sri Suphan is a culturally significant sacred structure rooted in Northern Thai (Lanna) Buddhist tradition and the long-standing silver-craft heritage of the Wua-Lai community. The temple dates back to the sixteenth century during the Lanna period and has historically functioned as both a religious center and a focal point of neighborhood identity shaped by local silversmiths and artisanal guilds [39,40]. The contemporary Silver Ubosot, distinguished by its elaborate silver repoussé decoration, reflects the continuity of this craft tradition and incorporates symbolic and cosmological elements embedded in its architectural design. As the ritual core of the temple, the ubosot is governed by customary practices associated with monastic ceremonies, within which physical access is traditionally restricted for women. This restriction reflects local interpretations of ritual purity and the preservation of sacred boundaries, rather than contemporary notions of exclusion or discrimination, and is closely intertwined with the historical role of male silversmiths in the construction and ritual stewardship of the site. These access constraints are explicitly communicated at the site through architectural boundaries and on-site signage (Figure 2), illustrating a structural limitation on physical visitation. In this context, virtual reality systems provide an ethical access layer that enables inclusive cultural interpretation and engagement with the site's artistic and historical value without violating established religious norms.

3.2. Overall System Architecture and Design Rationale

The overall system architecture was designed to provide culturally respectful access to a ritually restricted sacred space while enabling a structured comparison between two virtual reality paradigms: a VR360-based heritage access system and an AI-driven immersive virtual reality (VR) system. As illustrated in Figure 3, both systems are built upon a shared cultural heritage data pipeline, ensuring that differences in user experience and interaction can be attributed primarily to system design choices rather than content inconsistency. This approach supports a fair comparative analysis while maintaining consistency in heritage representation across system conditions.



Figure 2. The Silver Ubosot at Wat Sri Suphan (left) and on-site signage indicating traditional access restrictions to the sacred space (right).

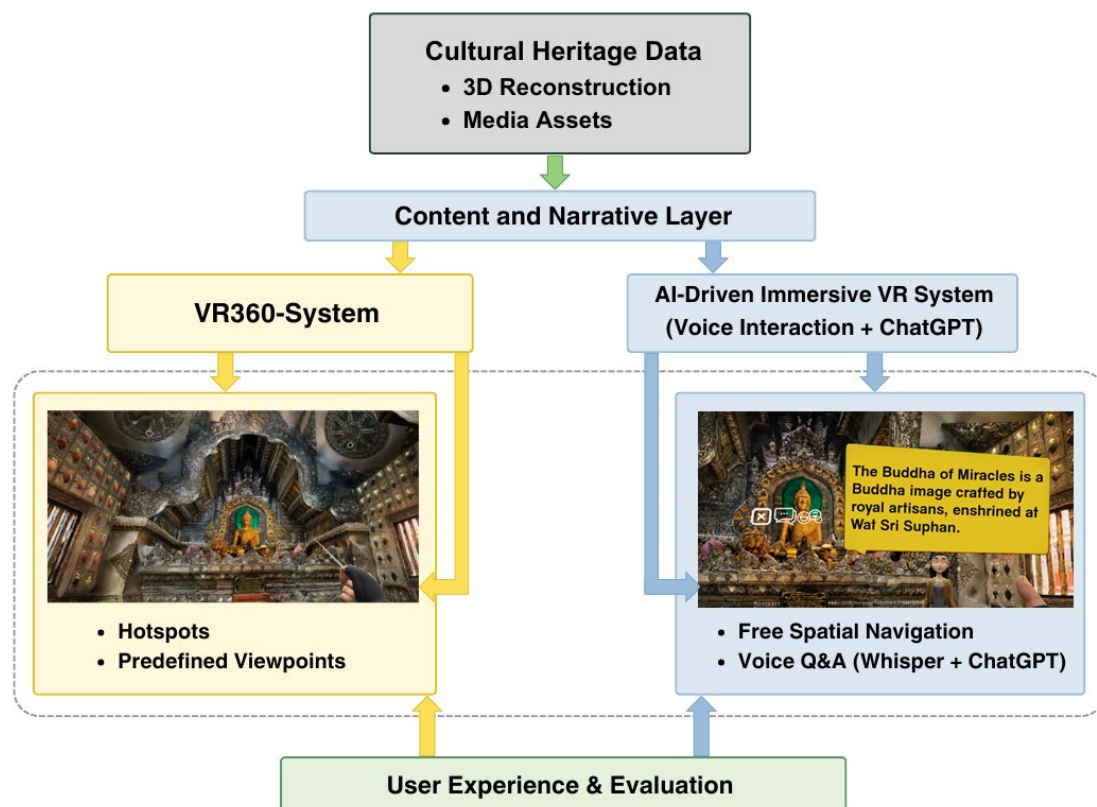


Figure 3. Overall system architecture showing the shared content layer and two virtual access systems: VR360-based heritage access and AI-driven immersive VR.

At the architectural level, the system is organized around a common content and narrative layer derived from the three-dimensional reconstruction and curated media assets of the Silver Ubosot. From this shared foundation, the architecture branches into two distinct interaction pathways. The VR360 system emphasizes panoramic visualization through predefined viewpoints and informational hotspots, prioritizing visual authenticity, narrative stability, and ease of deployment. In contrast, the AI-driven immersive VR system enables free spatial navigation within a fully navigable virtual environment and integrates an LLM-based conversational interface to support user-initiated inquiry and context-aware interpretation. This dual-system design was intentionally adopted to examine key design trade-offs between simplicity and interactivity, narrative control and user agency, and static versus conversational information delivery within the context of access-restricted cultural heritage.

3.3. 3D Reconstruction of Wat Sri Suphan Silver Ubosot

The three-dimensional digital model of the Silver Ubosot was created using a photogrammetry-based reconstruction workflow to support immersive virtual reality interaction. High-resolution photographic data were captured on-site using an iPhone 15 Pro Max, with approximately 1200 images collected across the exterior and interior areas of the ubosot to ensure sufficient coverage of architectural geometry and decorative details. The image set was processed using Agisoft Metashape (Agisoft LLC, St. Petersburg, Russia) to generate a dense point cloud, polygonal mesh, and texture maps, resulting in a detailed 3D representation that preserves both structural form and surface characteristics of the silver repoussé craftsmanship. This approach was selected to balance reconstruction fidelity with practical feasibility in a real-world heritage environment.

As illustrated in Figure 4, the photogrammetry pipeline produces a structured wireframe mesh that captures the geometric complexity of the ubosot (Figure 4), a fully textured exterior visualization suitable for real-time rendering, and a reconstructed interior space that retains spatial layout and ornamental detail for immersive exploration (Figure 5). The resulting 3D model is used exclusively within the AI-driven immersive VR system described in this study, enabling free spatial navigation and interactive engagement with the sacred space. In contrast, the VR360-based heritage access system relies on photographic 360-degree imagery rather than reconstructed geometry. By clearly separating photogrammetry-based 3D reconstruction for immersive VR from image-based VR360 content, the system design ensures technical appropriateness for each access paradigm while maintaining consistency in cultural representation across the comparative study.

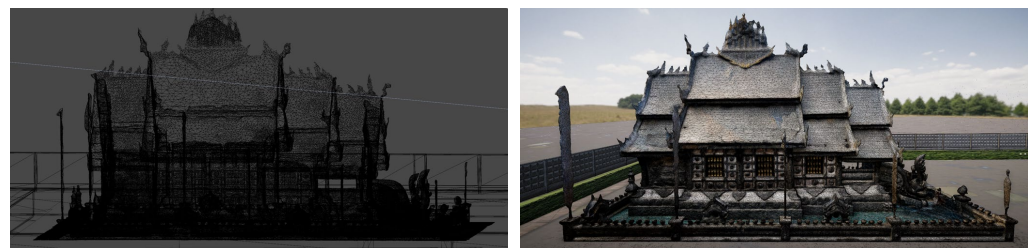


Figure 4. Photogrammetry-derived wireframe (left) and immersive VR-rendered 3D model (right) of the Silver Ubosot at Wat Sri Suphan.

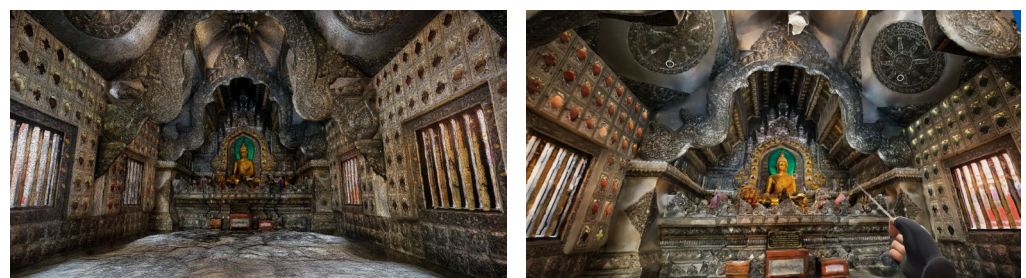


Figure 5. Interior view of the photogrammetry-based 3D reconstruction of the Silver Ubosot at Wat Sri Suphan rendered in the immersive VR environment.

3.4. VR360-Based Heritage Access System

The VR360-based heritage access system was implemented as a node-based virtual tour using photographic 360-degree imagery captured at selected locations within and around the Silver Ubosot. Rather than enabling continuous free navigation, the system allows users to move between predefined viewpoints that correspond to physically meaningful positions within the sacred space, thereby preserving spatial coherence while respecting access constraints. This node-to-node navigation model provides a guided yet flexible exploration experience that resembles a structured on-site walkthrough (Figure 6).

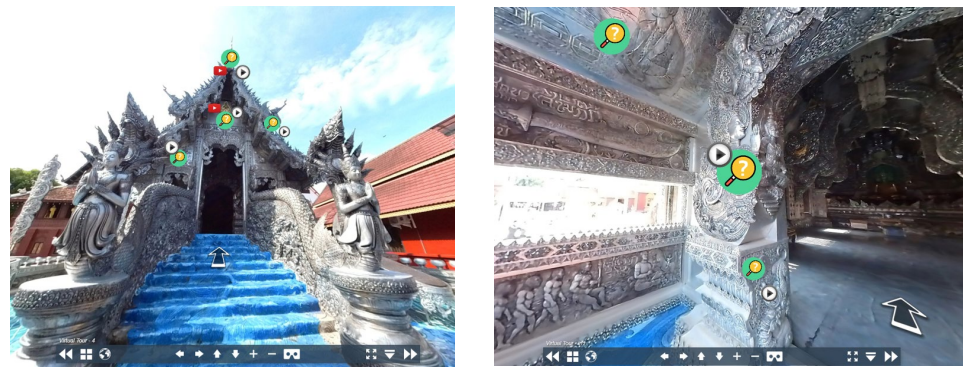


Figure 6. VR360-based heritage access system showing node-based navigation and interactive icons for information access and narrated storytelling at Wat Sri Suphan.

Within each panoramic scene, interaction is mediated through embedded visual icons that support different layers of interpretation (Figure 6). Three types of interactive icons are provided. Blue information icons display textual descriptions of architectural elements, silver repoussé patterns, and decorative motifs directly linked to their spatial context. White play icons activate narrated audio explanations describing historical and cultural aspects of the site. Red icons link to YouTube-based video narratives presenting historical background, religious symbolism, and community-based storytelling related to specific features of the ubosot. By combining static panoramic visualization with layered interpretive media, the VR360 system emphasizes narrative control and consistency while maintaining high visual authenticity, thereby serving as a stable baseline for comparison with the AI-driven immersive VR system. Additional demonstration materials are provided in the Supplementary Materials.

3.5. AI-Driven Immersive VR System with LLM-Based Interaction

The AI-driven immersive VR system supports multimodal conversational interaction within a fully navigable three-dimensional reconstruction of the Silver Ubosot, enabling inquiry-driven exploration beyond predefined narratives. In addition to free spatial navigation, visitors can engage with the virtual environment by asking spoken questions to an AI-based tour guide assistant while examining architectural structures, religious elements, and artistic details at close range. This interaction paradigm allows users to initiate information requests based on personal interest and spatial context, rather than following a fixed storytelling sequence. As illustrated in Figure 7, spoken queries are captured during exploration and processed in real time, allowing conversational interaction to be seamlessly embedded within the immersive experience without interrupting navigation or visual engagement. By integrating voice-based inquiry directly into spatial exploration, the system aims to enhance user agency and support more natural and intuitive access to cultural heritage interpretation. This interaction model is designed as a context-aware interpretive interface rather than an open-domain conversational system, in which user queries are intentionally constrained within culturally and contextually relevant topics associated with the heritage site.

The conversational interaction pipeline integrates speech recognition, retrieval-based knowledge grounding, and large language model generation. As illustrated in Figure 8, Spoken input is transcribed using the Whisper speech-to-text model (OpenAI, San Francisco, CA, USA; version accessed in 2025) and matched against curator-prepared heritage content and structured metadata. Relevant information is inserted into a prompt template and processed by the ChatGPT-4o model (OpenAI, San Francisco, CA, USA; version accessed in 2025) to generate context-specific responses. This retrieval-augmented and prompt-constrained design functions as a safeguard mechanism to reduce the likelihood

of hallucinated or culturally inappropriate outputs. Generated responses are delivered through both synthesized speech and on-screen text panels anchored to spatial elements within the virtual environment, supporting comprehension and allowing users to revisit explanations during exploration.

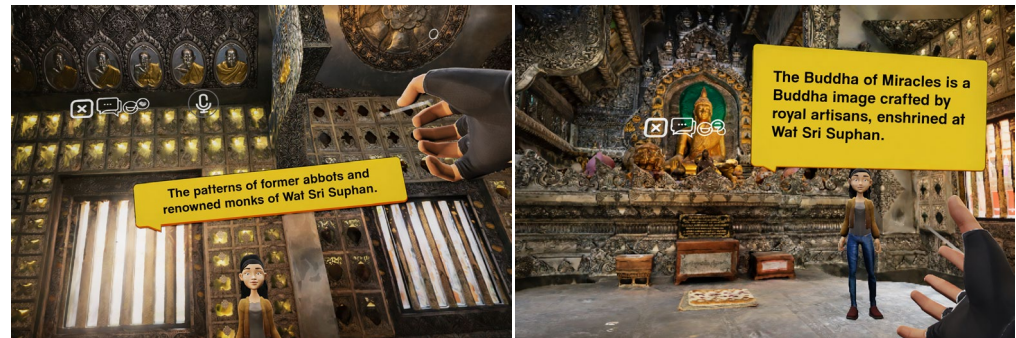


Figure 7. AI-driven immersive VR interaction with voice-based questioning and on-screen responses at Wat Sri Suphan.

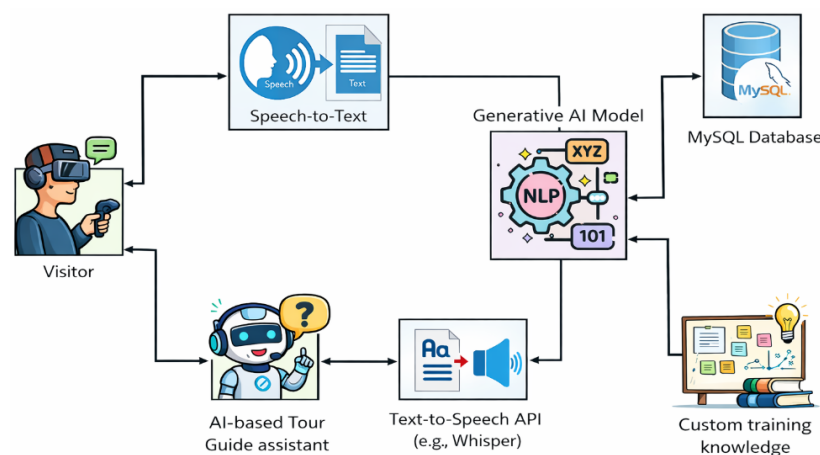


Figure 8. System architecture of the AI-driven immersive VR platform with LLM-based conversational interaction.

In this study, the AI component is evaluated at the system level, focusing on its operational performance and response reliability within a constrained, domain-specific knowledge environment, rather than benchmarking the underlying language model. Evaluation therefore emphasizes interaction-based metrics, including response latency, query frequency, and interaction duration, together with qualitative expert validation of generated responses. A subset of AI-generated answers was reviewed by domain experts to assess factual accuracy, contextual relevance, and cultural appropriateness, particularly in relation to sensitive or restricted content. Through this design, the AI-based tour guide functions as an interactive interpretive layer that supports inquiry-driven engagement while maintaining contextual coherence within the immersive virtual heritage experience.

3.6. AI Interaction Pipeline and Reliability Safeguards

The conversational functionality of the immersive VR system follows a retrieval-grounded generation pipeline. When visitors ask a spoken question, the audio input is first transcribed using the OpenAI Whisper speech-to-text model. The resulting text query is then processed by a retrieval component that searches a curated heritage knowledge base consisting of curator-prepared descriptions, historical documentation, and structured meta-data related to the Silver Ubosot. The most relevant passages are inserted into a prompt template and provided as contextual grounding for the ChatGPT-4o model (OpenAI, San

Francisco, CA, USA; version accessed in 2025), which generates the final natural-language response. This retrieval-grounded prompting approach functions similarly to a lightweight retrieval-augmented generation (RAG) mechanism, constraining the model to respond using verified heritage information rather than generating unconstrained answers. This design also reduces the risk of hallucinated responses by grounding generation in curated knowledge sources. This architecture reflects a constrained, context-aware conversational design in which user queries are interpreted within predefined cultural and informational boundaries, ensuring that system responses remain aligned with domain-specific knowledge and cultural sensitivity requirements.

Several safeguards were implemented to improve response reliability. The prompt template explicitly instructs the model to avoid generating information beyond the retrieved knowledge context, and when relevant information cannot be identified the system returns a refusal message indicating that the question cannot be answered with sufficient confidence. During real-world deployment, the conversational pipeline relied on cloud-based AI services and therefore required stable internet connectivity. The observed average end-to-end response latency—including speech transcription, retrieval, and LLM generation—was approximately 6.3 s under typical network conditions. When connectivity was unstable, the system occasionally failed to return responses, in which case conversational interaction was temporarily unavailable while users continued visual exploration within the virtual environment. To assess response quality, a small sample of generated answers was periodically reviewed by domain experts and exhibition staff to verify factual accuracy and cultural appropriateness. In addition, system-level interaction logs, including query frequency, response latency, and interaction duration, were collected to support analysis of system performance and user interaction behavior. Conversational logs were stored in anonymized form for system monitoring purposes, and no personally identifiable information was recorded in accordance with the ethical guidelines approved by the Chiang Mai University Research Ethics Committee.

4. Research Methodology

4.1. Research Method

This study adopts a research-in-the-wild approach [41,42] to examine user interaction and experience with virtual heritage systems under real-world conditions. Rather than imposing tightly controlled laboratory tasks, the systems were deployed in a realistic context that allows participants to explore freely according to their interests, thereby preserving ecological validity. This method is particularly suitable for cultural heritage applications, where user experience is shaped by situational context, intrinsic motivation, and exploratory behavior. By observing naturalistic interaction patterns and collecting experiential feedback in situ, the study aims to generate insights that reflect practical use and real-world deployment of extended reality systems for cultural heritage access. This approach also enables the collection of behavioral interaction data, such as interaction duration and frequency, which can be used to further examine user engagement patterns during system use.

4.2. Participants

Participants were recruited through on-site and community-based outreach using a convenience sampling approach, in which visitors who were present near the exhibition area during the study period were invited to voluntarily participate in the study. Participants were then assigned to two experimental groups corresponding to the system conditions, with each group consisting of 68 participants ($N = 136$ in total). To obtain consistent experiential feedback within the operational constraints of the study site, partici-

pation was limited to individuals who self-identified as female at the time of recruitment, reflecting the predominant visitor group engaging with the virtual heritage systems during the study period. The participants' mean age was $M = 37.87$ years ($SD = 7.74$). One group interacted with the VR360-based heritage access system, while the other group experienced the AI-driven immersive VR system with conversational interaction.

Gender identity beyond self-identification was not assessed, and sexual orientation was not collected or analyzed, as these factors were outside the scope and objectives of the study, which focused on system interaction and experiential feedback. All participants provided informed consent prior to participation, and no personally identifiable information was collected. The experimental sessions were conducted in a designated small room located directly opposite the Silver Ubosot. As shown in Figure 9, this setup allowing participants to engage with the virtual systems in close proximity to the physical heritage site while avoiding interference with religious activities (Figure 10). The study was carried out during official working hours to ensure appropriate supervision and compliance with site management regulations.



Figure 9. Experimental setup of the virtual heritage systems in a designated room opposite the Ubosot: a female participant using the system (left) and a monk serving as exhibition operation staff (right).



Figure 10. Exhibit setting room opposite the Ubosot.

4.3. Instruments and Measures

The measurement instruments used in this study were based on widely validated scales in human–computer interaction and virtual reality research. Specifically, the study employed the System Usability Scale (SUS), the User Engagement Scale (UES), and the Igroup Presence Questionnaire (IPQ), which have been extensively used in prior studies to evaluate usability, engagement, and presence in interactive systems.

4.3.1. System Usability Scale

SUS was used to assess participants' perceived usability of the virtual heritage systems [43,44]. SUS consists of ten items rated on a five-point Likert scale, covering aspects such as ease of use, learnability, and overall satisfaction. It provides a single usability score that enables reliable comparison between system conditions and is widely validated across interactive and immersive systems. The full questionnaire items are provided in Appendix A.

4.3.2. User Engagement Scale

User engagement was measured using the UES, which captures multiple dimensions of engagement, including focused attention, perceived usability, aesthetic appeal, and reward [45,46]. The UES is particularly suitable for immersive and exploratory systems, as it reflects both cognitive and affective aspects of user interaction beyond task performance. The full questionnaire items are provided in Appendix A.

4.3.3. Presence and Spatial Experience

Participants' sense of presence and spatial experience (here referring to perceived spatial presence) was evaluated using the IPQ. The IPQ measures perceived spatial presence, involvement, and experienced realism within virtual environments [47]. This instrument is well established in virtual reality research and supports the assessment of how convincingly users perceive and inhabit the reconstructed cultural space. The full questionnaire items are provided in Appendix A.

4.3.4. Retrospective Interview

To complement the quantitative measures, retrospective interviews were conducted with a subset of participants following system use [48]. The interviews focused on participants' subjective experiences, perceived strengths and limitations of the systems, and reflections on interaction, interpretation, and cultural understanding. This qualitative component supports deeper interpretation of questionnaire results and provides contextual insights aligned with the research-in-the-wild methodology. Interview responses were transcribed and reviewed by two researchers, who identified recurring patterns and grouped them into thematic categories. Representative anonymized quotes are provided in the Section 5 to illustrate participants' perspectives.

4.4. Experimental Design and Procedure

The study employed a between-subjects comparative design, with each participant experiencing only one system condition to avoid learning effects and cross-condition bias. Participants first received a brief introduction explaining the study purpose and system usage, after which they were asked to provide informed consent prior to participation. The experimental setup utilized a Meta Quest 3 head-mounted display for both system conditions; the VR360 system was operated directly on the standalone headset, while the AI-driven immersive VR system was rendered using a high-performance personal computer connected to the headset, equipped with an NVIDIA GeForce RTX 4060 graphics card (NVIDIA Corporation, Santa Clara, CA, USA), 16 GB of RAM, and an AMD-based CPU to ensure stable real-time rendering and AI interaction. Following consent, participants were allowed to explore the virtual heritage environment freely according to their interests for a maximum duration of 30 min, with no fixed task sequence imposed in order to preserve naturalistic exploration behavior consistent with a research-in-the-wild approach. Interaction duration, navigation behavior, and conversational usage were recorded automatically by the system throughout the session.

4.5. Data Collection and Analysis

Quantitative data were collected using standardized questionnaires, including the SUS, UES, and IPQ. All quantitative analyses were conducted using IBM SPSS Statistics (Version 27). Descriptive statistics (means and standard deviations) were computed for all measures. Prior to conducting inferential analyses, standard statistical assumptions for independent-samples *t*-tests were examined, including normality of distributions and homogeneity of variance. Independent-samples *t*-tests were performed to compare overall scores between the two system conditions, with statistical testing pre-specified for overall composite scores only to reduce the risk of inflated Type I error. This statistical approach was selected because the study employed a between-subjects experimental design comparing two independent system conditions (VR360 and AI-driven immersive VR). The objective of the analysis was therefore to examine differences in user experience outcomes between the two groups rather than to model relationships among latent constructs. Effect sizes were calculated using Cohen's *d*, and a significance level of $p < 0.05$ was adopted for all inferential analyses. Structural equation modeling was not applied because the study did not aim to test causal relationships among variables, but instead focused on comparing user experience measures across experimental conditions.

In addition to independent-samples *t*-tests, regression analysis was conducted to further examine the relationship between interaction behavior and user experience outcomes. Specifically, system condition and interaction duration were included as predictors, with perceived presence specified as the dependent variable. This analysis examines whether perceived presence is influenced not only by system type but also by the extent of user engagement. This approach enables a more nuanced interpretation of how interaction behavior contributes to variations in perceived presence beyond differences between system conditions. Qualitative data were obtained through retrospective interviews conducted after the experimental sessions. Interview responses were transcribed and analyzed using thematic analysis, following an iterative coding process to identify recurring patterns and themes across participants.

5. Results

5.1. Result of System Usability Scale and User Engagement Scale

As shown in Figure 11, the SUS results demonstrate measurable differences in perceived usability between the two systems. The VR360 system achieved a mean SUS score of 81, whereas the AI-driven immersive VR system obtained a mean score of 74. According to standard SUS benchmarks, both scores fall within the acceptable usability range and correspond to the good adjective rating, indicating that participants generally perceived both systems as usable. However, the distribution of scores shows that the VR360 system reached a higher position within the good range, approaching the upper boundary associated with higher usability classifications. In contrast, the AI-driven immersive VR system was positioned lower within the same usability range, reflecting comparatively reduced usability scores across participants.

As summarized in Table 1, descriptive results of the UES indicate comparable engagement levels between the two system conditions across multiple dimensions. For Focus Attention, the VR+AI system showed a slightly higher mean score than the VR360 system (3.79 vs. 3.64), while Perceived Usability was higher for the VR360 system (4.17) compared to the VR+AI system (3.81). In terms of Aesthetic Appeal, the VR+AI system achieved a marginally higher mean score (4.24) than the VR360 system (4.04). Similarly, the Reward dimension showed higher scores for the VR+AI system (4.07) compared to the VR360 system (3.77). For the overall UES score, the VR+AI system demonstrated a slightly higher mean (3.98) than the VR360 system (3.91); however, the independent-samples *t*-test revealed no

statistically significant difference between the two conditions ($p = 0.20$), with a small effect size (Cohen's $d = 0.22$).

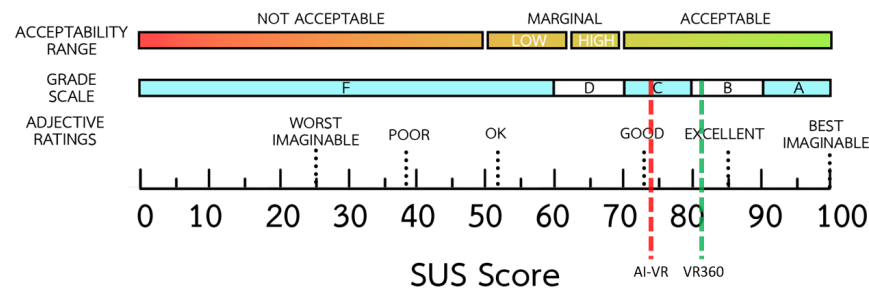


Figure 11. SUS scores for the VR360 and AI-driven immersive VR systems, interpreted using standard acceptability ranges and adjective ratings.

Table 1. Results of UES Using an Independent-Samples t -Test.

UES Dimension	VR360 (N = 68)		VR+AI (N = 68)		Statistic Test	
	Mean	SD	Mean	SD	P	Cohen's d
Focus Attention	3.64	0.65	3.79	0.66	N/A	N/A
Perceived Usability	4.17	0.73	3.81	0.67	N/A	N/A
Aesthetic Appeal	4.04	0.57	4.24	0.61	N/A	N/A
Reward	3.77	0.78	4.07	0.61	N/A	N/A
Overall	3.91	0.32	3.98	0.34	0.20	0.22

Note: Statistical testing was pre-specified for the overall UES score. Dimension-level values are reported descriptively to avoid inflated Type I error from multiple comparisons.

5.2. Result of Presence and Spatial Presence

As illustrated in Figure 12 and summarized in Table 2, the IPQ results indicate comparable patterns of perceived presence across the two system conditions, with consistently higher mean scores observed for the AI-driven immersive VR system across all dimensions. For Spatial Presence, the VR+AI system achieved a higher mean score (3.75) than the VR360 system (3.57), while similar trends were observed for Involvement (3.68 vs. 3.53) and Experienced Realism (3.81 vs. 3.71). With respect to overall presence, the VR+AI system also demonstrated a higher mean score (3.75) compared to the VR360 system (3.60). Statistical testing, which was pre-specified for the overall IPQ score only, revealed a statistically significant difference between the two conditions ($p = 0.027$), with a small-to-moderate effect size (Cohen's $d = 0.38$). Dimension-level results are therefore reported descriptively, while the overall IPQ findings indicate a measurable difference in perceived presence between the two systems.

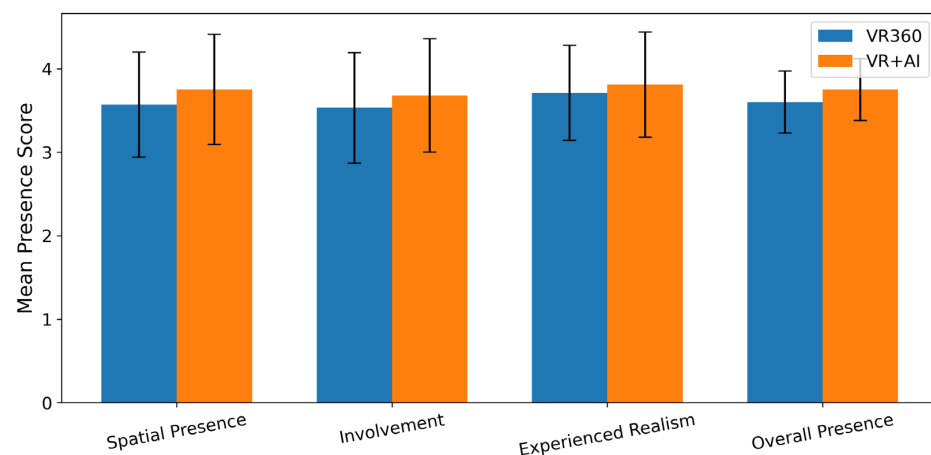


Figure 12. Mean presence scores comparing VR360 and AI-driven immersive VR across presence dimensions.

Table 2. Results of IPQ Using an Independent-Samples *t*-Test.

IPQ Dimension	VR360 (N = 68)		VR+AI (N = 68)		Statistic Test	
	Mean	SD	Mean	SD	<i>P</i>	Cohen's <i>d</i>
Spatial Presence	3.57	0.63	3.75	0.66	N/A	N/A
Involvement	3.53	0.66	3.68	0.68	N/A	N/A
Experienced Realism	3.71	0.57	3.81	0.63	N/A	N/A
Overall Presence	3.60	0.37	3.75	0.37	0.027	0.38

Note: Statistical testing was pre-specified for the overall IPQ. Dimension-level values are reported descriptively to avoid inflated Type I error from multiple comparisons.

5.3. Result of Behavioral Interaction

Behavioral interaction metrics provide additional insight into user engagement patterns across the two systems (Table 3). Participants using the AI-driven immersive VR system spent longer exploring the environment (mean 9.4 min) compared with the VR360 system (6.8 min). Interaction frequency was also higher in the immersive VR condition (mean 14.4 interactions) than in the VR360 condition (12.3 interactions). In addition, participants asked an average of 6.6 questions during exploration, with a mean response latency of approximately 6.3 s.

Table 3. Behavioral Interaction metrics.

Metric	VR360	AI-Driven Immersive VR
Mean session duration	6.8 min	9.4 min
Mean number of user interactions	12.3	14.4
Mean number of AI questions	-	6.6
Mean response latency	-	6.3 s

Note: “User interactions” refer to recorded interaction events such as navigation actions, hotspot selections, and conversational queries.

To further examine the relationship between interaction behavior and user experience outcomes, a linear regression analysis was conducted with perceived presence as the dependent variable and system condition and interaction duration as predictor variables. The regression model was statistically significant ($p < 0.05$), indicating that both system condition and interaction duration significantly predicted perceived presence. These findings suggest that perceived presence is not determined solely by system type, but is also influenced by the extent of user interaction during the experience. In particular, interaction duration showed a positive effect on perceived presence, indicating that extended engagement contributes to immersive experience beyond structural differences between VR modalities. This result supports an interaction-driven interpretation of presence, in which experiential outcomes are shaped by user activity and engagement patterns rather than by immersion level alone.

5.4. Result of Retrospective Interviews

Following the experimental session, retrospective interviews were conducted with 28 participants (14 from each experimental group) to further explore subjective experiences and to contextualize the quantitative findings. The interviews focused on perceived usability, realism, interaction experience, and practical considerations related to exhibition deployment. Thematic analysis revealed four recurring themes across the two system conditions.

5.4.1. The Usability–Realism Trade-Off

Participants consistently indicated that the perceived level of experiential realism was broadly comparable between the two systems, as both relied on visual materials derived

directly from real-world environments. The use of authentic imagery in both the VR360 and AI-driven immersive VR systems contributed to a similar sense of visual credibility and environmental authenticity, reducing noticeable differences in realism from the participants' perspectives. Consequently, experiential realism was not identified as the primary differentiating factor when users reflected on their overall experience. Instead, participants' evaluations increasingly centered on how easily they could interact with and navigate the systems, shifting attention from visual realism to practical usability considerations.

The VR360 system was consistently described as easy to use and immediately understandable, requiring little to no instruction. Participants indicated that they were able to navigate and engage with the content intuitively from the first use, allowing them to focus primarily on the heritage information rather than on system operation. In contrast, the AI-driven immersive VR system was frequently characterized as more complex. Participants reported challenges related to interaction mechanics, including difficulties in understanding how to initiate and manage conversations with the AI, occasional delays in AI responses, confusion regarding available interaction functions, and inconsistencies in the AI's voice tone. These usability-related issues increased cognitive effort during interaction and shaped overall user impressions, helping to explain why similar levels of perceived realism did not translate into higher engagement or usability scores in the quantitative results.

5.4.2. Perceived Control and Interaction Experience

Participants generally reported that basic system control was manageable and did not present major difficulties in either condition. Both the VR360 and AI-driven immersive VR systems were perceived as controllable, and users indicated that they were able to understand how to navigate the environments and operate the systems without significant problems. This suggests that, at a fundamental level, participants felt a sufficient sense of control when interacting with both systems.

However, notable differences emerged in relation to interaction experience, particularly in the AI-driven immersive VR condition. While participants found the conversational AI feature interesting and engaging, they also reported that interaction with the AI required further refinement. Several participants indicated that the process of initiating and managing AI-based interactions was not always intuitive, highlighting issues such as uncertainty when using the voice-recording button, delays in AI response time, and waiting periods before receiving answers. Despite these challenges, participants acknowledged that the AI was capable of providing diverse and contextually appropriate responses, and that the conversational interaction added value to the experience. Overall, while the interaction concept was viewed positively, participants emphasized the need for improvements in interaction flow, responsiveness, and feedback mechanisms to enhance perceived control and usability in the AI-driven immersive VR system.

5.4.3. Exhibition Operations and Social Context

Participants indicated that locating the experimental setup in close proximity to the physical heritage site enabled them to more easily understand the contextual relationship between the virtual content and the real environment. Being situated near the site helped reduce uncertainty and curiosity about what was inside the restricted space, allowing participants to form clearer expectations before engaging with the virtual systems. In this regard, no notable differences were reported between the VR360 and AI-driven immersive VR conditions, as both systems were perceived as effective in supporting contextual understanding and addressing visitors' questions about the interior of the site. Overall,

participants viewed the exhibition arrangement as a practical solution that successfully enhanced interpretability while maintaining appropriate separation from the sacred space.

5.4.4. Operational Insights from Exhibition Staff

From the perspective of exhibition staff, substantial differences were observed between the two systems in terms of operational manageability. The VR360 system was consistently described as easy to manage, requiring minimal setup and little to no staff intervention during operation. Staff reported that users were able to engage with the system independently from the first use, and no major technical or operational issues were encountered. In contrast, the AI-driven immersive VR system was perceived as considerably more challenging to manage. Staff noted that users frequently requested assistance, particularly when interacting with the AI features. Operational issues such as intermittent internet connectivity occasionally prevented the AI from responding to user queries, further increasing the need for staff support. Additionally, the initial system setup for the AI-driven immersive VR was described as more complex compared to the VR360 system. Overall, staff emphasized that the immersive VR system required continuous supervision and technical oversight, whereas the VR360 system operated reliably with minimal staff involvement.

6. Discussion

6.1. Usability and Engagement Trade-Offs in Access-Restricted Sacred Heritage Contexts

The following discussion interprets the empirical findings in relation to prior virtual heritage and immersive media research. Addressing RQ1, the findings of this study reveal a clear trade-off between perceived usability and user engagement when comparing VR360 systems and AI-driven immersive VR systems in an access-restricted sacred heritage context. These findings are consistent with the proposed conceptual framework, in which interaction modality shapes user experience through interaction characteristics, particularly user agency and perceived cognitive load. Consistent with the quantitative results, the VR360 system demonstrated higher usability, while overall engagement levels between the two systems remained comparable. Qualitative insights further contextualize these findings, as participants frequently noted that the VR360 system could be used immediately without prior instruction, enabling them to focus on heritage content rather than on system operation. The higher usability observed in the VR360 system reflects its lower interaction complexity and constrained navigation structure, which reduce perceived cognitive load and support immediate user comprehension. In contrast, although the AI-driven immersive VR system was often described as interesting and engaging, participants reported additional interaction demands, including uncertainty in managing AI-based conversations, delays in system responses, and confusion related to voice interaction functions. These findings indicate that increased user agency and conversational interaction introduce additional cognitive demands that constrain the effectiveness of engagement. As a result, the increased interaction complexity did not translate into proportionally higher engagement. This pattern supports prior work suggesting that, in heritage and museum contexts, ease of interaction plays a critical role in shaping user experience, particularly when systems are deployed in real-world, time-limited settings [12,23]. Behavioral interaction metrics further support this interpretation, as participants in the VR360 condition demonstrated shorter session durations and slightly fewer interaction actions compared with the immersive VR condition, reflecting the simpler interaction structure that likely contributed to the higher usability scores observed in the SUS results. These patterns indicate that increased interaction effort does not necessarily improve user experience outcomes, but instead reflects differences in interaction demands across system conditions.

Existing literature on virtual heritage and immersive media similarly reports a tension between interaction richness and usability. Lightweight VR approaches, such as panoramic or VR360 systems, have been shown to reduce cognitive load and lower barriers to entry, making them suitable for public exhibitions and first-time users [49]. In contrast, immersive VR systems that incorporate advanced interaction techniques, including embodied navigation and conversational interfaces, can enhance experiential depth but often introduce usability challenges that require additional learning and ongoing support [50,51]. This comparison suggests that the benefits of advanced interaction mechanisms may only become meaningful when interaction complexity remains manageable for first-time users in public exhibition settings. The trade-offs observed in this study align with these findings and demonstrate that interaction complexity functions as a mediating constraint between interaction modality and user experience outcomes. Within the proposed framework, this trade-off reflects the balance between reduced cognitive load in simpler interaction modalities and increased user agency in more complex systems. One possible explanation is that visitors in heritage contexts often prioritize interpretive clarity and ease of access over technological novelty, particularly when the interaction occurs during short exhibition visits. This suggests that design decisions for access-restricted sacred heritage sites should carefully balance engagement ambitions with usability and operational constraints, rather than assuming that increased immersion alone will lead to substantially improved user experiences. From a design perspective, these results reinforce the importance of aligning interaction complexity with the situational context of use, where simplicity and reliability may be more valuable than advanced interaction capabilities in supporting inclusive heritage access. Overall, these findings provide empirical support for an interaction-driven model of immersive experience, in which user experience outcomes are shaped by the balance between interaction capability and cognitive demand.

6.2. Presence and Perceived Spatial Presence Across VR Modalities

Addressing RQ2, the findings indicate that the AI-driven immersive VR system elicited higher levels of overall presence and a stronger perceived spatial presence than the VR360 system, although the magnitude of this difference remained small to moderate. These findings are consistent with the proposed conceptual framework, in which interaction modality influences perceived presence through interaction characteristics such as user agency and embodied engagement. Quantitative results from the IPQ demonstrate a consistent directional advantage for the immersive VR condition in overall presence, while differences at the dimension level were modest. The relatively small effect size suggests that differences in presence between immersive VR and VR360 are likely moderated by factors such as visual fidelity and content realism rather than immersion level alone. Qualitative feedback indicates that this difference was not primarily driven by visual realism, as participants frequently noted that both systems appeared similarly realistic due to their reliance on imagery captured from real-world environments. Because both systems were derived from real-world visual capture, the perceptual gap typically observed between panoramic VR and fully navigable VR environments may have been reduced in this deployment context. Instead, perceived presence is shaped by interaction modalities, spatial navigation, and the degree of embodied engagement supported by each system. In particular, higher user agency and the ability to navigate freely within the immersive VR environment support stronger experiential involvement, which contributes to increased perceived presence. Behavioral interaction metrics further support this interpretation, as participants in the immersive VR condition spent longer exploring the environment and engaged in more interaction actions during each session, patterns that are consistent with the higher spatial presence scores observed in the IPQ results. Regression analysis

further confirms this relationship, indicating that interaction duration significantly predicts perceived presence, demonstrating that extended interaction contributes to immersive experience beyond differences between system conditions. These results indicate that perceived presence is not solely determined by system type, but is partially explained by interaction behavior, particularly sustained engagement. This finding provides empirical support for the proposed mediation mechanism, in which interaction characteristics—particularly sustained engagement—serve as a key pathway linking interaction modality to perceived presence.

Qualitative insights further clarify that participants in the immersive VR condition often described a stronger sense of “being inside” the environment, which they associated with embodied exploration and freedom of movement. In contrast, participants interacting with the VR360 system characterized their experience as more observational, frequently describing it as viewing or “looking around” the space rather than occupying it. Similar distinctions between observational and embodied forms of presence have been reported in recent immersive VR and cultural heritage research, which emphasizes the role of interaction and spatial engagement in shaping presence beyond visual fidelity alone [31,52]. However, participants also reported that interaction complexity and occasional system delays in the immersive VR system disrupted their sense of immersion, consistent with studies showing that usability issues and system responsiveness can moderate perceived presence and overall user experience in immersive environments [53,54]. Within the proposed framework, this suggests that while increased interactivity enhances presence through greater user agency, it also introduces interaction friction that constrains the overall experiential effect. This observation highlights an important design implication: technological immersion alone does not guarantee stronger presence if interaction friction or system latency interrupts the experiential flow. Taken together, results from the real-world deployment indicate that AI-driven immersive VR is associated with higher spatial presence than VR360 by combining embodied navigation with conversational interaction. Participants reported that the ability to ask questions and receive contextual explanations during exploration helps resolve uncertainties as they emerge, contributing to a more continuous and immersive experience. This finding reinforces an interaction-driven account of immersive experience, in which presence is shaped not only by visual realism but by the depth and continuity of user interaction with the virtual environment.

6.3. Design Implications for Inclusive and Respectful Heritage Access

Addressing RQ3, the real-world deployment of both systems revealed substantive design and operational trade-offs that extend beyond immersion level alone. These findings can be interpreted through the proposed conceptual framework, where differences in interaction modality shape not only user experience outcomes but also operational requirements through variations in interaction characteristics. From an operational perspective, the AI-driven immersive VR system required substantially greater technical and human resources, including high-performance PCs, stable high-bandwidth internet connectivity, and continuous staff supervision. Qualitative feedback from participants and exhibition staff indicated that visitors frequently requested assistance when interacting with the AI-based conversational interface, particularly in managing voice input, understanding interaction cues, and coping with response delays caused by network instability. Within this framework, increased user agency and conversational interaction are associated with higher interaction complexity, which translates into greater technical and operational demands. At the same time, participants consistently reported that the ability to ask questions freely and receive contextual explanations during exploration helped them resolve uncertainties as they emerged, especially when encountering unfamiliar or culturally complex elements

of the sacred space. This inquiry-driven interaction contributed to a more continuous and immersive experience and a stronger sense of presence, aligning with prior work emphasizing the role of interaction and interpretive support—rather than visual immersion alone—in shaping presence and user experience in heritage VR systems [12,23]. In this context, inclusive access should not be interpreted as unrestricted physical access to sacred spaces. Instead, inclusive access in this study refers to interpretive and informational access that enables visitors to engage with culturally restricted areas while respecting community-defined boundaries and ritual practices. The deployment of the systems was coordinated with local stakeholders, including temple representatives and exhibition staff, to ensure that the virtual experience complemented existing cultural norms rather than challenging them.

In contrast, the VR360 system demonstrated clear advantages in usability, reliability, and operational sustainability under real-world conditions. Observations and interview data showed that participants were able to use the VR360 system immediately without instruction, and exhibition staff reported that the system operated consistently without requiring ongoing supervision. The node-based navigation structure and predefined informational hotspots were sufficient to address most visitors' common questions, particularly those related to visual access and basic interpretation of the restricted space. This finding is consistent with previous research showing that lightweight VR and panoramic-based approaches can effectively reduce cognitive load and support accessible interpretation in public-facing heritage contexts [49,50]. Within the proposed framework, this reflects how lower interaction complexity and constrained interaction structures reduce cognitive load and support stable, scalable deployment in real-world settings. Taken together, the findings suggest that AI-driven immersive VR is most appropriate for institutions with sufficient resources and dedicated personnel, such as museums and curated exhibitions, where deep, inquiry-driven engagement is a priority, whereas VR360 systems provide a more practical and sustainable solution for general heritage and tourism sites, enabling inclusive and respectful access without imposing excessive operational demands. However, the design implications identified in this study should be interpreted within the specific cultural and institutional context of the case site. While the underlying design principles may be transferable to other heritage environments with access constraints, their implementation must remain sensitive to local cultural norms, governance structures, and stakeholder expectations. To further contextualize these findings within the broader landscape of virtual heritage access approaches, Table 4 summarizes the key strengths and limitations of commonly used VR approaches for cultural heritage interpretation, including VR360 virtual tours, immersive VR environments, and the AI-driven immersive VR approach developed in this study.

Table 4. Comparison of VR Approaches for Cultural Heritage Access.

Approach	Strengths	Limitations
VR360 Virtual Tours	Easy deployment, high visual realism, low development cost, minimal supervision required	Limited interactivity, fixed viewpoints, passive exploration
Immersive VR Reconstruction	High spatial presence, free navigation, interactive exploration	Higher development cost, complex content production
AI-Driven Immersive VR	Conversational interaction, inquiry-driven exploration, enhanced perceived spatial presence	Higher technical complexity, infrastructure dependency, need for operational support

6.4. Limitations and Future Work

This study has several limitations that should be acknowledged when interpreting the findings. First, the evaluation was conducted in a single real-world heritage context involving an access-restricted sacred site, which may limit the generalizability of the results to other cultural, institutional, or spatial settings. In addition, all participants self-identified as female, reflecting the primary visitor group engaging with the virtual systems during the study period and the cultural constraints of the site. While this focus was appropriate for examining inclusive access under ritual restrictions, it constrains the applicability of the findings to broader visitor populations with different demographic characteristics or interaction preferences. Furthermore, the AI-driven immersive VR system depended on stable internet connectivity and cloud-based AI services, which occasionally resulted in response delays and required staff intervention during deployment. In addition, AI-driven immersive VR systems may require substantial computational resources and technical support to ensure stable operation in real-world heritage environments. These technical dependencies may have influenced usability perceptions and moderated the experiential advantages observed for AI-driven interaction. Moreover, the study does not aim to quantitatively benchmark the performance of the underlying language model; instead, the AI component is evaluated at the system level within a constrained, domain-specific knowledge environment.

Future work should extend this research in several directions to address these limitations. Comparative studies across multiple heritage sites, including secular museums, outdoor attractions, and sites with different access constraints, would help validate and refine the proposed design implications. Expanding participant demographics beyond female-only groups would further support broader generalization of the findings. In addition, future system development could explore hybrid design approaches that integrate the operational simplicity of VR360 with selectively activated AI-driven features, such as optional conversational assistance, to balance cost, usability, and engagement. Future research may also incorporate more formal evaluation metrics for AI-generated responses, such as response accuracy assessment, consistency analysis, or hallucination detection, to provide a more comprehensive validation of AI performance. Finally, advances in edge computing and offline or lightweight AI models may reduce infrastructure and staffing requirements, making AI-enhanced immersive VR more feasible for a wider range of heritage and tourism contexts.

7. Conclusions

This study provides empirical evidence from a real-world deployment showing how different virtual reality approaches support inclusive access to ritually restricted sacred heritage sites. The findings indicate that VR360 systems offer high usability, operational stability, and low maintenance requirements, making them effective for addressing visitors' curiosity and providing basic interpretive access with minimal infrastructure and staffing. In contrast, AI-driven immersive VR was associated with a stronger perceived spatial presence and sense of presence by supporting embodied exploration and conversational inquiry, allowing visitors to ask questions and resolve uncertainties in situ. This capability enhances perceived spatial presence and interpretive engagement, particularly in contexts involving culturally complex or unfamiliar heritage elements.

Beyond user experience outcomes, this work contributes informatics-oriented insights that support system selection, deployment decisions, and institutional planning for virtual heritage applications. The results demonstrate that immersive technologies alone do not guarantee improved experience; rather, meaningful spatial presence emerges when interaction design, interpretive support, and system reliability are aligned with opera-

tional feasibility and institutional capacity. By grounding the comparison in real-world deployment and qualitative feedback, the study provides evidence-based guidance for heritage institutions and cultural organizations to adopt VR strategies that balance inclusivity, cultural respect, experiential depth, and long-term system sustainability.

Supplementary Materials: VR360 tour: https://angkaew.com/Wat_Srisupan/vtour/ (accessed on 25 March 2026); AI–VR interaction video: <https://www.youtube.com/watch?v=K6oNwLYBuHo> (accessed on 25 March 2026).

Author Contributions: Conceptualization, P.A. and P.J.; methodology, P.A. and P.J.; software, P.T.; validation, S.K.; formal analysis, P.A. and P.J.; investigation, S.K.; resources, P.T.; data curation, D.P.; writing—original draft preparation, P.A. and P.J.; writing—review and editing, P.A.; visualization, D.P.; supervision, P.J.; project administration, P.T.; funding acquisition, P.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research project was supported by the Fundamental Fund 2026, Chiang Mai University, and also Thailand Science Research and Innovation 2026.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Committee of Research Ethics, Chiang Mai University Research Ethics Committee, Chiang Mai University (COA No. 244/68, approved on 9 September 2025).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author due to privacy and ethical restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. The System Usability Scale Questionnaire.

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

Table A2. The User Engagement Scale Questionnaire.

Dimension	Questionnaire
Focused attention	I was fully focused on the interaction with the VR360/VR+AI during the VR task. I lost track of time while interacting with the VR360/VR+AI.
Perceived Usability	I was deeply concentrated on the information provided by the VR360/VR+AI. The VR360/VR+AI was easy to interact with during the VR task. The interaction with the VR360/VR+AI felt smooth and well-organized. I could interact with the VR360/VR+AI without confusion or difficulty.

Table A2. Cont.

Dimension	Questionnaire
Aesthetic appeal	The presentation of the VR360/VR+AI was visually appealing in the VR environment.
Reward	The VR360/VR+AI interface enhanced my overall VR experience. Interacting with the VR360/VR+AI was enjoyable. I felt motivated to continue interacting with the VR360/VR+AI. The VR360/VR+AI made the museum experience more interesting.

Table A3. Presence and Spatial Experience Questionnaire.

Dimension	Questionnaire
Spatial Presence	I felt like I was really inside the virtual environment. The virtual environment seemed like a place I could actually visit. I had a sense of being physically present in the virtual space. The virtual environment surrounded me.
Involvement	I felt like I was inside the virtual world rather than just looking at it. I was completely focused on the virtual environment. I was deeply involved in the virtual experience. I did not notice my real surroundings while using the system.
Experienced Realism	My attention was fully captured by the virtual environment. The virtual environment seemed realistic to me. The experience felt believable. The virtual environment gave me a convincing impression of reality. The way the virtual environment responded to my actions felt realistic.

References

- Chong, H.T.; Lim, C.K.; Ahmed, M.F.; Tan, K.L.; Mokhtar, M. Virtual Reality Usability and Accessibility for Cultural Heritage Practices: Challenges Mapping and Recommendations. *Electronics* **2021**, *10*, 1430. [\[CrossRef\]](#)
- Bekele, M.K.; Pierdicca, R.; Frontoni, E.; Malinvernì, E.S.; Gain, J. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *J. Comput. Cult. Herit.* **2018**, *11*, 1–36. [\[CrossRef\]](#)
- Timothy, D.J.; Boyd, S.W. Heritage tourism in the 21st century: Valued traditions and new perspectives. *J. Herit. Tour.* **2006**, *1*, 1–16. [\[CrossRef\]](#)
- Roussou, M.; Katifori, A. Flow, Staging, Wayfinding, Personalization: Evaluating User Experience with Mobile Museum Narratives. *Multimodal Technol. Interact.* **2018**, *2*, 32. [\[CrossRef\]](#)
- Rodríguez-García, B.; Guillén-Sanz, H.; Checa, D.; Bustillo, A. A Systematic Review of Virtual 3D Reconstructions of Cultural Heritage in Immersive Virtual Reality. *Multimed. Tools Appl.* **2024**, *83*, 89743–89793. [\[CrossRef\]](#)
- Sylaiou, S.; Mania, K.; Karoulis, A.; White, M. Exploring the Relationship between Presence and Enjoyment in a Virtual Museum. *Int. J. Hum.-Comput. Stud.* **2010**, *68*, 243–253. [\[CrossRef\]](#)
- Champion, E. *Critical Gaming: Interactive History and Virtual Heritage*; Routledge: London, UK, 2015.
- Schubert, T.; Friedmann, F.; Regenbrecht, H. The Experience of Presence: Factor Analytic Insights. *Presence Teleoper. Virtual Environ.* **2001**, *10*, 266–281. [\[CrossRef\]](#)
- Sánchez-Berriel, I.; Pérez-Nava, F.; Pérez-Rosario, L. Natural Interaction in Virtual Heritage: Enhancing User Experience with Large Language Models. *Electronics* **2025**, *14*, 2478. [\[CrossRef\]](#)
- Lombardo, V.; Pizzo, A.; Damiano, R. Safeguarding and Accessing Drama as Intangible Cultural Heritage. *J. Comput. Cult. Herit.* **2016**, *9*, 1–26. [\[CrossRef\]](#)
- Chong, H.T.; Lim, C.K.; Ahmed, M.F.; Tan, K.L.; Mokhtar, M. Comprehensive Systematic Review on Virtual Reality for Cultural Heritage Practices: Coherent Taxonomy and Motivations. *Multimed. Syst.* **2022**, *28*, 481–507. [\[CrossRef\]](#)
- Li, J.; Zheng, X.; Watanabe, I.; Ochiai, Y. A Systematic Review of Digital Transformation Technologies in Museum Exhibition. *Comput. Hum. Behav.* **2024**, *161*, 108407. [\[CrossRef\]](#)
- Skublewska-Paszkowska, M.; Milosz, M.; Powroznik, P.; Lukasik, E. 3D Technologies for Cultural Heritage: A Review. *Appl. Sci.* **2022**, *12*, 61. [\[CrossRef\]](#)

14. Marto, A.; Gonçalves, A.; Melo, M.; Bessa, M. A Survey of Multisensory VR and AR Applications for Cultural Heritage. *Comput. Graph.* **2022**, *102*, 426–440. [\[CrossRef\]](#)
15. Haddad, N.A. Insight on 3D virtual reconstruction of architectural and archaeological cultural heritage: Critical assessment, comprehensive guidelines, and recommendations. *Stud. Conserv.* **2025**. [\[CrossRef\]](#)
16. Kabassi, K.; Amelio, A.; Komianos, V.; Oikonomou, K. Evaluating a Virtual Tour in a Museum Based on the Visitor's Experience. *PLoS ONE* **2022**, *17*, e0261607. [\[CrossRef\]](#)
17. Ariya, P.; Sirilertworakul, N.; Angskun, T. Immersive Realities in Museums: Evaluating the Impact of VR, VR360, and Mixed Reality Technologies on Visitor Presence, Engagement and Motivation. *Virtual Real.* **2025**, *29*, 117. [\[CrossRef\]](#)
18. Cui, H.; Wu, J. Virtual Exhibitions of Cultural Heritage: Research Landscape and Future Directions. *Appl. Sci.* **2025**, *15*, 12287. [\[CrossRef\]](#)
19. Balzani, M.; Maietti, F. Saving Temporary Exhibitions in Virtual Environments: The Digital Renaissance of Ulisse Aldrovandini—Acquisition and Digitisation of Cultural Heritage Objects. *Digit. Appl. Archaeol. Cult. Herit.* **2023**, *32*, e00309. [\[CrossRef\]](#)
20. Shehade, M.; Stylianou-Lambert, T. Virtual Reality in Museums: Exploring the Experiences of Museum Professionals. *Appl. Sci.* **2020**, *10*, 4031. [\[CrossRef\]](#)
21. Vaz, R.; Fernandes, P.O.; Veiga, A.C. Interactive Technologies in Museums: How Digital Installations and Media Are Enhancing the Visitors' Experience. In *Handbook of Research on Technological Developments for Cultural Heritage and eTourism Applications*; Rodrigues, J.M.F., Ramos, C.M.Q., Cardoso, P.J.S., Henriques, C., Eds.; IGI Global: Hershey, PA, USA, 2018; pp. 30–53. [\[CrossRef\]](#)
22. Teppati Losè, L.; Rinaudo, F. A Systematic Literature Review to Assist in Defining New Guidelines and Practical Handbooks for the Documentation of Built Heritage. *Heritage* **2025**, *8*, 249. [\[CrossRef\]](#)
23. Sun, X.; Ch'ng, E. Beyond the screen: Enhancing ethnic cultural representation and engagement through immersive 360° documentary experiences in museums. *Humanit. Soc. Sci. Commun.* **2025**, *12*, 1014. [\[CrossRef\]](#)
24. Vosinakis, S.; Koutsabasis, P.; Anastassakis, G.; Papasalouros, A.; Damianidis, K. Designing and evaluating an immersive VR experience of a historic sailing ship in museum contexts. *Comput. Graph.* **2025**, *133*, 104439. [\[CrossRef\]](#)
25. Iacono, S.; Scaramuzzino, M.; Martini, L.; Panelli, C.; Zolezzi, D.; Perotti, M.; Traverso, A.; Vercelli, G.V. Virtual Reality in Cultural Heritage: A Setup for Balzi Rossi Museum. *Appl. Sci.* **2024**, *14*, 3562. [\[CrossRef\]](#)
26. Guan, H.; Chen, P.; Kwon, C.L. Virtual Museums as Meaning-Modeling Systems in Digital Heritage. *Heritage* **2025**, *8*, 484. [\[CrossRef\]](#)
27. Wang, Y.; Wang, S.; Pan, Y.; Li, C.; Chen, C.; Wang, J. Immersive virtual reality and computer vision for heritage: Visual evaluation and perception of the industrial heritage sites along the Yunnan–Vietnam railway (Yunnan section). *Herit. Sci.* **2024**, *12*, 36. [\[CrossRef\]](#)
28. Tromp, J.; Schofield, D.; Raeisian Parvari, P.; Poyade, M.; Eaglesham, C.; Torres, J.C.; Johnson, T.; Jürivete, T.; Lauer, N.; Reyes-Lecuona, A.; et al. Designing and Evaluating XR Cultural Heritage Applications Through Human–Computer Interaction Methods: Insights from Ten International Case Studies. *Appl. Sci.* **2025**, *15*, 7973. [\[CrossRef\]](#)
29. Mishra, M.; Doria, E. Virtual Reality and Artificial Intelligence-Assisted Visual Inspections for Cultural Heritage Structures: A Review. *Int. J. Archit. Herit.* **2026**. [\[CrossRef\]](#)
30. Ke, P.; Lin, G.; Hui, Y.-F. Immersive Virtual Reality Design for the Architectural Heritage of Rovigo, Italy: Digital Preservation and Interactive Exploration Based on Embodied Interaction. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* **2025**, *XLVIII-M-9-2025*, 659–666. [\[CrossRef\]](#)
31. Mohammed-Amin, R.K.; Economou, M.; Katifori, A.; Rasool, K.K.; Raouf, T.L.; Ibrahim, N.H.; Radha, R.A.; Ali, K.O. Nobody's Listening: Evaluating the Impact of Immersive VR for Engaging with Difficult Heritage and Human Rights. *Heritage* **2025**, *8*, 474. [\[CrossRef\]](#)
32. Zhang, J.; Yahaya, W.A.J.W.; Sanmugam, M. The Impact of Immersive Technologies on Cultural Heritage: A Bibliometric Study of VR, AR, and MR Applications. *Sustainability* **2024**, *16*, 6446. [\[CrossRef\]](#)
33. Spennemann, D.H.R. Generative Artificial Intelligence, Human Agency and the Future of Cultural Heritage. *Heritage* **2024**, *7*, 3597–3609. [\[CrossRef\]](#)
34. DaCosta, B. Speaking with the Past: Constructing AI-Generated Historical Characters for Cultural Heritage and Learning. *Heritage* **2025**, *8*, 387. [\[CrossRef\]](#)
35. Zhang, S.; Ma, M.; Li, Y.; Man, K.L.; Smith, J.; Yue, Y. The Effects of LLM-Empowered Chatbots and Avatar Guides on the Engagement, Experience, and Learning in Virtual Museums. *Int. J. Hum. Comput. Interact.* **2025**. [\[CrossRef\]](#)
36. Garcia, I.L.; Schott, E.; Gohsen, M.; Bernhard, V.; Stein, B.; Fröhlich, B. Speaking with Objects: Conversational Agents' Embodiment in Virtual Museums. In *Proceedings of the 2024 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, Bellevue, WA, USA, 21–25 October 2024; pp. 281–286. [\[CrossRef\]](#)
37. Upadhyay, A.; Yang, F.-C.; Mousas, C. Virtual Museum Tour Agent: Effects of Responsiveness and Awareness. *Comput. Animat. Virtual Worlds* **2023**, *34*, e2155. [\[CrossRef\]](#)

38. Mazzanti, P.; Ferracani, A.; Bertini, M.; Principi, F. Reshaping Museum Experiences with AI: The ReInHerit Toolkit. *Heritage* **2025**, *8*, 277. [\[CrossRef\]](#)
39. Tiansawang, K.; Monvucharin, P.; Kongjarern, T.; Thamboon, P.; Saelee, C.; Riyaprao, O. Archaeoastronomical Analysis of Sri Suphan Temple. *ASEAN J. Sci. Technol. Rep.* **2025**, *28*, e257483. [\[CrossRef\]](#)
40. Pumketkao-Lecourt, P.; Teeraparb Wong, K.; Tansukanun, P. Silver craft and Buddhist temple in the shaping of neighbourhood communities in Wua-Lai, Chiang Mai, Thailand. *Asia Pac. Viewp.* **2022**, *63*, 379–395. [\[CrossRef\]](#)
41. Rogers, Y. Interaction Design Gone Wild: Striving for Wild Theory. *Interactions* **2011**, *18*, 58–62. [\[CrossRef\]](#)
42. Chamberlain, A.; Crabtree, A.; Rodden, T.; Jones, M.; Rogers, Y. Research in the Wild: Understanding “In the Wild” Approaches to Design and Development. In *Proceedings of the Designing Interactive Systems Conference (DIS)*; ACM: New York, NY, USA, 2012; pp. 795–796. [\[CrossRef\]](#)
43. Brooke, J. SUS: A “Quick and Dirty” Usability Scale. In *Usability Evaluation in Industry*; Jordan, P.W., Thomas, B., Weerd-Meester, B.A., McClelland, I.L., Eds.; Taylor & Francis: London, UK, 1996; pp. 189–194.
44. Vlachogianni, P.; Tselios, N. Perceived usability evaluation of educational technology using the System Usability Scale (SUS): A systematic review. *J. Res. Technol. Educ.* **2022**, *54*, 392–409. [\[CrossRef\]](#)
45. O’Brien, H.L.; Toms, E.G. The development and evaluation of a survey to measure user engagement. *J. Am. Soc. Inf. Sci. Technol.* **2010**, *61*, 50–69. [\[CrossRef\]](#)
46. O’Brien, H.L.; Cairns, P.; Hall, M. A practical approach to measuring user engagement with the refined User Engagement Scale (UES) and new UES short form. *Int. J. Hum. Comput. Stud.* **2018**, *112*, 28–39. [\[CrossRef\]](#)
47. Tran, T.Q.; Langlotz, T.; Young, J.; Schubert, T.W.; Regenbrecht, H. Classifying presence scores: Insights and analysis from two decades of the Igroup Presence Questionnaire (IPQ). *ACM Trans. Comput. Hum. Interact.* **2024**, *31*, 1–26. [\[CrossRef\]](#)
48. Rieman, J. The diary study: A workplace-oriented research tool to guide laboratory efforts. In *Proceedings of the INTERACT’93 and CHI’93 Conference on Human Factors in Computing Systems*; ACM: New York, NY, USA, 1993; pp. 321–326.
49. Lee, C.-Y.; Chen, Y.-C.; Huang, Y.-M. Development of a VR360 Ecological System for Learning Indigenous Cultures and Environmental Conservation. *Appl. Sci.* **2024**, *14*, 10582. [\[CrossRef\]](#)
50. Radianti, J.; Majchrzak, T.A.; Fromm, J.; Wohlgenannt, I. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Comput. Educ.* **2020**, *147*, 103778. [\[CrossRef\]](#)
51. Ho, H.P.; Ramesh, V.; Zaloudek, I.; Rikhtehgar, D.J.; Wang, S. Enhancing Visitor Engagement in Interactive Art Exhibitions with Visual-Enhanced Conversational Agents. In *Proceedings of the 30th International Conference on Intelligent User Interfaces (IUI 2025)*; ACM: New York, NY, USA, 2025; pp. 660–671.
52. Pietroni, E. Experience Design, Virtual Reality and Media Hybridization for the Digital Communication of Cultural Heritage. *Appl. Sci.* **2019**, *9*, 1963. [\[CrossRef\]](#)
53. Weech, S.; Kenny, S.; Barnett-Cowan, M. Presence and Cybersickness in Virtual Reality Are Negatively Related: A Review. *Front. Psychol.* **2019**, *10*, 158. [\[CrossRef\]](#)
54. Wang, H.; Liu, Y. Gamifying Cultural Heritage: Exploring the Potential of Immersive Virtual Exhibitions. *J. Cult. Herit.* **2024**, *68*, 45–58. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.