

Article

Immersive Technologies in Built Heritage Spaces: Understanding Tourists' Continuance Intention Toward Sustainable AR and VR Applications at the Terracotta Warriors Museum

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Abstract

As sustainable tourism practices gain traction globally, immersive technologies such as augmented reality (AR) and virtual reality (VR) have emerged as effective tools to enrich visitor experiences while supporting heritage site preservation. Particularly within built cultural environments, these technologies facilitate non-invasive interpretation of architectural spaces, enabling sustainable interaction with fragile historical structures. Despite growing scholarly attention, existing research has primarily focused on the pre-adoption phase or the technical affordances of AR/VR, with limited understanding of user behavior in the post-adoption phase. To address this gap, this study integrates the Expectation Confirmation Model (ECM) with the experiential attributes of AR/VR-enabled heritage applications, proposing an integrated theoretical model to identify key determinants of tourists' continuance intention. Based on 434 valid survey responses collected at the Terracotta Warriors Museum, a UNESCO World Heritage Site, and analyzed using structural equation modeling (SEM), the results reveal that perceived usefulness, perceived ease of use, satisfaction, and confirmation directly influence continuance intention, while visual appeal, entertainment, enjoyment, interactivity and confirmation exert indirect effects through mediating mechanisms. The findings contribute theoretically by extending ECM to the heritage tourism domain and empirically by providing robust evidence from a high-profile non-Western site. Practically, this study offers actionable implications for designing immersive experiences that enhance post-visit continuance intention and align with broader sustainability objectives.

Keywords: built heritage environments; immersive technologies; sustainable tourism; augmented reality (AR); virtual reality (VR); continuance intention; Expectation Confirmation Model (ECM)



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1. Introduction

Since the early 21st century, the emergence of adaptive and interactive technologies has profoundly transformed the tourism industry and its sub-sectors. Immersive digital tools, particularly augmented reality (AR) and virtual reality (VR), have become increasingly relevant to built cultural heritage, offering new spatial narratives and sustainable engagement strategies for visitors. One of the most notable developments has been the integration of

information and communication technologies into the field of cultural heritage [1]. For tourism destinations, including cultural heritage sites, investing in and adopting new technologies has become an effective means of gaining competitive advantages [2]. Among these technological innovations, immersive technologies, particularly AR and VR, have significantly enhanced both accessibility and the perceived experiential value of cultural assets and spatial exhibits [3].

However, the outbreak of the COVID-19 pandemic posed an unprecedented challenge to the sustainability of traditional tourism models [4]. These conventional approaches not only lacked appeal and competitiveness but also fell short in resilience, making them vulnerable to large-scale disruptions [5]. In response, cultural heritage site managers have increasingly recognized the emergence of a new museum paradigm, one that embraces the adoption of digital technologies [6]. Within this evolving context, AR and VR have offered innovative solutions for redefining visitor engagement while supporting heritage conservation objectives [7]. Given the possibility of recurring crises such as COVID-19 [8], the integration of technological innovations into tourism has been regarded as a viable strategy to improve the sector's resilience and long-term sustainability [9].

The Terracotta Warriors Museum, a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site and a symbolic representation of ancient Chinese civilization, is situated in Qinling Town, Lintong District, Xi'an, Shaanxi Province. As an expansive and archeologically significant built environment, the site presents considerable challenges in balancing public accessibility with the conservation of its fragile architectural and sculptural elements. It comprises a vast collection of life-sized clay sculptures that depict the army of Qin Shi Huang, the first Emperor of China. The mausoleum, dating back to 210–209 BCE, contains over 8000 soldiers, 130 chariots, 670 horses, and a variety of non-military figurines. Each warrior figure is uniquely detailed, making both physical preservation and interpretive display highly complex within the museum's architectural layout. These characteristics make the site particularly suitable for the application of AR and VR technologies. According to official sources, AR/VR-based digital reconstructions of the Terracotta Warriors were introduced as early as 2017, bringing the figures to life for visitors through immersive experiences [10].

In the cultural heritage sector, AR has been widely acknowledged for enriching the visitor experience while preserving the physical integrity of sites and enhancing historical understanding [1]. Moreover, fully immersive VR environments significantly deepen users' sense of presence and learning by enabling them to virtually travel back in time—creating a powerful tool that integrates both education and experience [7]. Numerous studies have shown that AR and VR technologies contribute positively to visitor satisfaction, enjoyment, and immersion [11–18]. These tools not only support deeper comprehension of cultural narratives but also promote more sustainable modes of interacting with heritage architecture. Importantly, AR/VR enables non-contact engagement with fragile artifacts, offering critical support for conservation, interpretation, and educational initiatives [19]. Nonetheless, existing research has predominantly focused on the technological implementation of immersive technologies [20–23], with comparatively limited attention to tourists' continuance intention, particularly in the post-adoption phase. Recent cross-cultural studies have begun to highlight this issue. For instance, Qiu et al. [24] investigated VR games based on intangible cultural heritage and found that visual attractiveness, interactivity, and immersion significantly influence continuance intention, mediated by perceived usefulness and enjoyment. Liu and Sutunyarak [25] examined museum contexts in China and confirmed that perceived usefulness, ease of use, enjoyment, and concentration jointly shape visitor attitudes and satisfaction, ultimately affecting behavioral intention. More recently, Wang et al. [26] proposed a multidimensional framework for VR-enhanced mu-

seum environments, showing that while traditional factors such as usefulness and ease of use remain critical, experiential affordances like interactivity, cultural atmosphere, and regional characteristics also play a decisive role in immersive experience quality. Distinct from prior studies that focus on initial adoption or on immersive experiences in general museums, this study focuses on the experiential attributes of AR/VR and offers a broader perspective on how post-adoption continuance intention is shaped within a high-stakes built heritage space.

The ECM, a widely adopted post-adoption theoretical framework, has been applied across various domains, including education, business, management, hospitality, information science, and sustainable tourism [27–39]. Prior studies, for example, combined ECM with value-based frameworks to explain luxury consumption and e-loyalty [32,40], or examined how destination performance shapes tourist satisfaction and loyalty in historic districts [39]. While these applications highlight the model’s versatility, most investigations emphasize consumer goods, e-commerce, or general tourism settings, leaving immersive AR/VR technologies in heritage contexts underexplored. Notably, user attitudes, satisfaction, and acceptance may shift significantly between the pre-adoption and post-adoption stages [41]. Accordingly, this study extends ECM by incorporating the spatial and experiential affordances of AR/VR-based sustainable tourism innovations, resulting in a conceptual model that examines continuance intention in immersive heritage environments.

The study pursues the following objectives:

Research Objective 1 (RO1): To identify the key factors influencing tourists’ continuance intention toward sustainable AR and VR applications at the Terracotta Warriors Museum.

Research Objective 2 (RO2): To examine the relationships between key factors and tourists’ continuance intention toward sustainable AR and VR applications at the Terracotta Warriors Museum.

Research Objective 3 (RO3): To develop a theoretical model explaining tourists’ continuance intention toward sustainable AR and VR applications at the Terracotta Warriors Museum.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature and presents the research hypotheses; Section 3 describes the research model and the development of the hypotheses; Section 4 depicts the research methodology; Section 5 reports on the data analysis and the empirical findings using structural equation modeling (SEM); Section 6 presents and interprets the research findings and summarizes practical implications and potential avenues for further exploration; Section 7 concludes the paper.

2. Literature Review

2.1. Sustainable Tourism Innovation

Sustainable tourism innovation encompasses two interconnected dimensions: sustainability in tourism and innovation within the tourism sector [42]. Rooted in the United Nations’ 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs), this framework emphasizes minimizing negative ecological and socio-cultural externalities caused by tourism activities [43–48]. As the global tourism industry rapidly expands, issues such as overtourism [49–51] and rising carbon footprints contribute to ecological imbalances. This compels policymakers to prioritize green practices to drive sustainable transformations in the tourism sector [52].

However, the outbreak of the COVID-19 pandemic posed a severe threat to the sustainability of global tourism [53]. International travel restrictions and heightened concerns over tourists’ health and safety severely disrupted the industry [11]. Such extreme crises require agile and precise responses to manage uncertainty effectively [54]. In the post-pandemic era, the scope of sustainable tourism has expanded to include the systematic planning for

emerging challenges, problems, and policy frameworks [55]. Specifically, tourism practitioners and policymakers are increasingly adopting innovations in business models [56] and technology [56–62] to revitalize the sector sustainably. Under this broader definition, “sustainability” not only includes carbon reduction and environmental preservation [52] but also extends to enhancing the resilience of tourism systems and their ability to sustain operations during extreme crises [60].

Innovation, broadly defined, involves the planning, design, and implementation of new applications, technologies, or processes aimed at improving current practices or preparing for future contingencies [42,55,63]. In tourism, innovation serves as a key pathway for achieving sustainability by optimizing resource use and minimizing negative impacts on destinations [42]. Although prior studies have focused on eco-friendly practices, organizational innovation, business model innovation, and carbon management [55], the role of technological innovations such as AR/VR in sustainable tourism has only recently received attention [42]. However, most research remains limited to descriptions of technological applications, with little in-depth analysis of their operational pathways or practical outcomes.

This study addresses this gap by investigating how immersive technologies affect tourists’ continuance intention, especially when deployed in architectural heritage settings. It contributes to the discourse by exploring how these technologies facilitate non-invasive engagement, immersive interpretation, and potential value co-creation between users and built environments.

2.2. Expectation Confirmation Model (ECM) in Post-Adoption Research

The ECM is an extension of Expectation Confirmation Theory (ECT), originally proposed by Oliver [64]. This model evaluates users’ continuance intention and post-adoption consumers behavior by examining relationships among five main constructs, including expectation, perceived performance, confirmation (CNF), satisfaction (SAT) and repurchase intention, as shown in Figure 1 [65]. ECT posits that consumers’ continuance decisions follow a sequential cognitive–affective process. Before adoption, individuals form expectations about a product or service. After actual use, they evaluate its perceived performance. The comparison between prior expectations and subsequent performance generates a level of confirmation (or disconfirmation). This confirmation shapes consumers’ satisfaction, both directly and in combination with initial expectations. Finally, satisfaction serves as the primary determinant of repurchase or continuance intention.

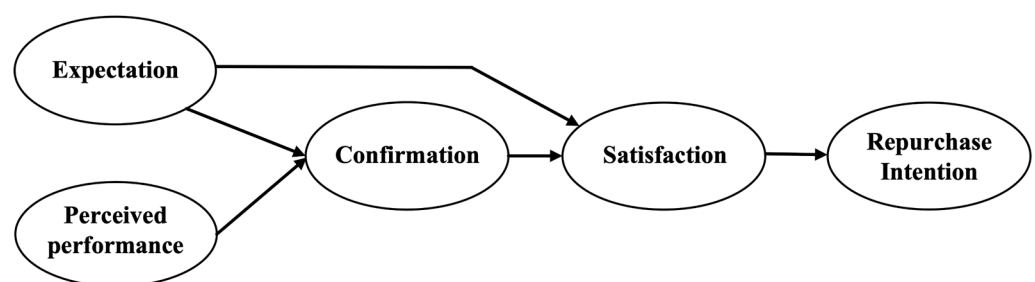


Figure 1. Expectation Confirmation Model.

While ECM provides a robust framework for explaining satisfaction and continuance, its limitations lie in treating users’ expectations and post-adoption beliefs as relatively static, without fully capturing system-specific beliefs such as perceived usefulness. The extended ECM-IS model addresses these gaps by incorporating information systems constructs, thereby offering a more dynamic and context-sensitive explanation of continuance intention [66], as illustrated in Figure 2. Developed by Bhattacharjee, ECM-IS has become

a widely used theoretical framework for understanding users' post-adoption behaviors across technology contexts. According to Bhattacharjee [67], users' willingness to continue using a new form of technology is directly influenced by SAT and perceived usefulness (PU), and indirectly influenced by CNF.

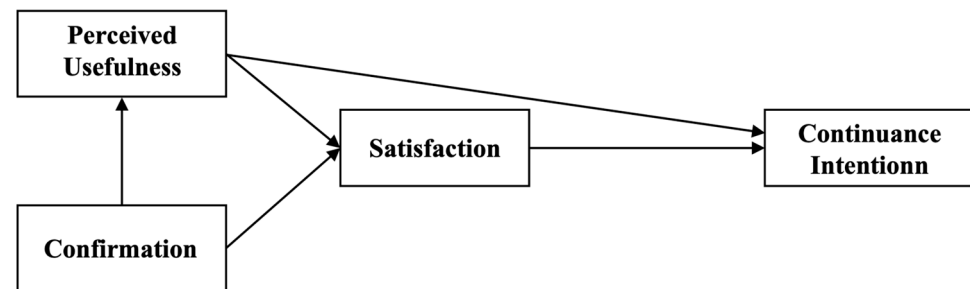


Figure 2. The Expectation-Confirmation Model of Information Systems (Source: Bhattacharjee [66]).

ECM-IS framework includes four core constructs, as presented in Figure 2 [66]:

Continuance Intention (CI): a user's willingness to continue using a specific technology or service [66].

Satisfaction (SAT): a user's overall psychological state, formed by combining emotions regarding unmet expectations with actual usage experiences [68].

Confirmation (CNF): the cognitive assessment formed by comparing pre-usage expectations with the technology's actual performance, leading to specific emotional or psychological outcomes [66].

Perceived Usefulness (PU): a user's belief about the instrumental value or benefits of using the technology; a critical post-adoption determinant of continuance intention [66].

In addition to above factors, perceived ease of use has been studied and proven to be positively related to continuance intention in post-adoption context [69]. In built-heritage AR/VR, continuance depends not only on expectation performance confirmation but also on the effort required to operate time-bounded, queue-managed, and often shared devices. Recent empirical studies in museums and heritage settings show that PEOU elevates perceived usefulness (PU) and, through PU and satisfaction (SAT), increases continuance or revisit intention [25]. Evidence from interactive devices in a major museum further shows that PEOU has a direct positive influence on PU and CI, supporting its inclusion as an antecedent in post-adoption models [70]. Complementing these results, a socio-technical study of AR in heritage museums demonstrates that technical/usability factors shape post-experience usage intentions directly and via satisfaction. Thus this study combines PEOU with the four core constructs of ECM-IS.

Perceived Ease of Use (PEOU): the degree to which users believe that using a system requires minimal cognitive effort [69].

To date, ECM has been extensively applied in multiple academic fields, including education [28,31], business [27,32,33], management [34,35], hospitality and leisure sport tourism [29,36], information and library science [30,37], and sustainable tourism [38,39,71–76]. In sustainable tourism research, the expectation confirmation framework (ECT/ECM) has been widely adopted over the past five years to explain post-experience outcomes such as satisfaction, continuance intention, and loyalty. In cultural-heritage and historic-district settings, extended ECMs integrate destination performance with confirmation and perceived value to explain long-term loyalty formation [39]. In digital and immersive contexts, ECM clarifies how confirmation and perceived usefulness translate into immersion, satisfaction, and continued use in VR exhibitions and museum-based VR content [73,74]. Within ecotourism, ECM-based models have been combined with destination image and satisfaction—and further enriched with moderators such as social-media influence—to pre-

dict loyalty [71,72]. In sustainable/green hotels, ECT coupled with big-data text analytics contrasts expectations with perceived service performance to identify drivers of “green satisfaction” and repurchase intentions [76]. Nature-based and low-impact tourism, such as camping, has likewise been modeled through ECT to illuminate a “relaxation/novelty, confirmation, well-being/satisfaction, loyalty” pathway [75]. Taken together, this literature shows that ECT/ECM travels well across themes (cultural heritage, digital/VR experiences, ecotourism, green hotels, camping) and populations (museum visitors, international tourists, ecotourists, hotel guests, campers), while accommodating meaningful extensions (e.g., perceived performance, social-media effects, well-being) and retaining strong explanatory power for sustainable behavioral outcomes.

Despite extensive application across domains, including sustainable tourism, research using ECM to examine continuance intention toward sustainable tourism innovations remains limited, particularly in the post-adoption phase involving AR/VR technology. To address this gap, the present study adopts ECM as the primary theoretical framework and integrates it with the unique characteristics of AR and VR technologies. The goal is to identify the key factors and underlying mechanisms that influence tourists’ continuance intention toward innovative technologies in sustainable tourism.

2.3. *Experiential Attributes of AR/VR*

AR refers to overlaying computer-generated digital content onto the physical environment to enhance users’ information-processing capabilities [7,77]. It enhances users’ perceptual experience by integrating contextual information, interpretive content, and interactive elements into real-world settings [7,15,19,78], thus strengthening the connection between users and physical space [79]. AR’s advantages include reducing visitor costs, overcoming informational barriers, and improving interactivity [80,81]. It also significantly enhances the educational value of cultural heritage interpretation [82]. However, while AR has shown promise in improving service quality and commercial value [79], its high implementation and maintenance costs require careful assessment before deployment [83].

Despite this, the full potential of AR to support sustainable tourism remains under-explored [7]. From a spatial perspective, AR overlays enable layered interpretation of architectural structures without physical alteration, preserving material authenticity while enhancing visitors’ understanding of the site’s spatial and functional history. Beyond single-site demonstrations, recent cross-regional syntheses show that AR/VR has been investigated and deployed across countries, site types, and audiences at scale. A 2014–2024 bibliometric analysis of 1214 publications maps the global uptake of immersive technologies in cultural heritage and profiles countries, institutions, and themes, evidencing wide geographic dispersion and cross-cultural relevance of AR/VR applications [23]. Focusing specifically on AR, a 2012–2021 overview of 1201 documents identifies eight recurring, cross-site themes—3D reconstruction, digital heritage, virtual museums, user experience, education, tourism, intangible heritage, and gamification [84]—indicating that the experiential mechanisms studied here are not idiosyncratic to a single case but recur across settings. Empirical studies have identified three key variables in the user experience of AR technologies [15]:

Visual Appeal (VA): the user’s perception of a technology through basic senses such as sight, hearing, taste, and touch [85].

Entertainment (ENT): the user’s appreciation of dramatic or spectacular elements within the service delivery [85].

Enjoyment (ENJ): The intrinsic pleasure derived from engaging with the activity or interaction [86]. Yung and Khoo-Lattimore [77] define VR as “the use of computer-generated 3D environments that the user can navigate and interact with, resulting in

real-time simulation of one or more of the user's five senses". According to Beck et al. [87], VR can be divided into three types by the extent of involvement: fully immersive, semi-immersive, and non-immersive VR. The first type places users entirely within a virtual environment using head-mounted displays and handheld devices, enabling full interaction with virtual content, while non-immersive VR typically involves lower engagement and immersion, and is cost-effective and accessible via applications on phones or desktop screens [11,88]. In comparison, semi-immersive VR enhances presence through large screens, projectors, or immersive environments such as VR Caves [7].

As a leading immersive technology, VR has seen widespread adoption in tourism, particularly accelerated by the pandemic [7,78]. For areas restricted or deemed unsafe due to COVID-19, VR offered a safe alternative for virtual visitation [89]. It also allowed people to maintain cognitive connections and emotional aspirations toward destinations during periods of reduced travel, potentially influencing future travel intentions [90]. For instance, Quan Jing Wang (QJK), China's largest VR platform for tourism, provided over 60,000 panoramic images and VR videos. In the early stages of the pandemic, its "Beautiful China" app recorded 40 million unique visitors and 150 million page views [91]. Beyond single-site demonstrations, recent multi-site evaluations reinforce the generalizability of AR/VR for heritage: a comparative field study in Catalonia contrasted two heritage sites and showed that VR and AR elicit distinct emotional profiles across cognitive, affective, physiological, motivational, and expressive dimensions [92]. Likewise, a two-museum comparative case study in the Netherlands demonstrates transferable design principles for AR/VR interpretation in different institutional settings [93]. Complementing these venue-level comparisons, a recent assessment contrasting HMD-based VR museums with HMD-based AR museums reports consistently higher immersion and empathy for VR across implementations, suggesting cross-context robustness of VR's experiential advantage [94]. At the same time, socio-technical analyses from heritage museums indicate that post-use AR intentions are jointly shaped by technical, individual, and situational factors—frameworks that can be replicated across sites to test cultural and organizational contingencies [95]. Taken together, these multi-site and cross-context findings extend the argument beyond a single case and motivate continued, post-pandemic investigation into tourists' perceptions and acceptance of AR/VR in heritage settings. Therefore, the necessity of further research on tourist perceptions and acceptance of VR in the post-pandemic era is highlighted in this context [91]. Previous studies have identified two significant variables influencing tourists' continuance intention in VR-based cultural heritage tourism [96]:

Interactivity (INT): The degree of communication and interaction between the user and the VR system [15].

Involvement (INV): The extent to which individuals perceive relevance or personal connection to the content based on their intrinsic needs, values, and interests [97].

Collectively, AR and VR enhance tourists' spatial perception, engagement, and memory retention, making them valuable for built heritage applications [21,79,82,83]. Studies suggest that their influence on tourist behavior is multidimensional, encompassing VA, ENT, ENJ, INT, and INV [15,96]. These factors shape tourists' experiences and behavioral intentions.

2.4. AR/VR in Built Cultural Heritage Contexts

In recent years, immersive technologies have emerged as pivotal instruments for the digital representation and safeguarding of cultural heritage. Unlike traditional linear narratives, the principal value of AR and VR lies in their capacity to superimpose digital content and reconstruct immersive environments, enabling audiences to engage with historical contexts interactively while preserving fragile artifacts. Scholarly evidence suggests

that AR is particularly effective for exhibition enhancement and real-time interpretation, whereas VR excels in panoramic reconstruction and fully immersive virtual touring [84]. In Europe and North America, initiatives such as Rome Reborn and Sutton House Stories have demonstrated the potential of virtual reconstructions and interactive narratives, although their integration into on-site visitor experiences remains relatively constrained [98]. By contrast, researchers have concentrated on architectural and landscape scales, integrating Heritage Building Information Modeling (HBIM) with AR/VR to generate interactive models that emphasize immersion, interoperability, and information exchange as novel paradigms of heritage management [99]. Similarly, Bolognesi et al. [100] underscored the interpretive value of AR by combining stereographic surveys with holographic projection to juxtapose the “past and present” of heritage sites, demonstrating the epistemic potential of digital overlays in shaping historical understanding.

Systematic reviews and bibliometric analyses offer broader comparative insights. Boboc et al. [84] identified eight dominant application domains of AR in heritage contexts, including 3D reconstruction, digital heritage, virtual museums, user experience, education, tourism, intangible cultural heritage, and gamification. Marto et al. [101] further emphasized the importance of multi-sensory design, contending that haptic and olfactory cues can significantly enhance presence and authenticity beyond visual immersion. Complementary, Zhang et al. [23] conducted a large-scale bibliometric investigation of VR/AR/MR scholarship and revealed that research hotspots are increasingly concentrated in education, tourism, and user experience, with cross-disciplinary integration emerging as a critical frontier. Despite these advances, extant literature has predominantly focused on technological affordances, with comparatively limited attention to post-adoption user behavior.

Research on user acceptance highlights a similar imbalance. Wen, Sotiriadis, and Shen [102], drawing on the UTAUT2 framework, demonstrated that performance expectancy, price value, and facilitating conditions are the most salient drivers of AR/VR adoption in Chinese cultural heritage sites. Yet, such studies largely attend to the adoption phase and rarely address tourists’ continuance behavior. In other words, existing work tends to explain why tourists initially adopt immersive technologies but insufficiently examines why they continue to use them after their visit. Within this context, the Terracotta Warriors Museum offers distinctive insights. Early collaborations with Baidu in 2017 employed AR and ultra-high-resolution panoramic imaging to reconstruct the layout of Pit 2, while the 2025 VR interactive film *Terracotta Warriors: A Magical Night* integrated physical environments with digital storytelling to animate warriors from Pits 1–3, providing a multi-sensory cultural experience. Unlike many international cases that privilege either virtual reconstruction or educational applications, the Terracotta Warriors projects illustrate a more integrated model that interweaves on-site visitation, immersive interaction, and cultural consumption (see Figure 3). Nevertheless, despite these innovations, current scholarship has yet to systematically examine how post-visit continuance intention is generated in this context, underscoring a significant theoretical and empirical gap.

In sum, AR/VR applications in cultural heritage have evolved from exhibition augmentation to multi-sensory immersion, user acceptance, and interdisciplinary convergence. However, a critical research gap persists: the limited exploration of tourists’ post-adoption continuance behavior. To address this gap, the present study integrates the Expectation Confirmation Model with experiential attributes to advance understanding of sustained visitor engagement with immersive technologies in built heritage spaces.



Figure 3. AR/VR applications in the Terracotta Warriors Museum.

2.5. Research Gap and Contribution

Although AR and VR applications in cultural heritage have proliferated, the extant literature reveals several critical gaps. First, prior studies have predominantly emphasized the technical affordances of immersive tools—such as reconstruction accuracy, visualization techniques, and gamified experiences—while offering limited insight into user behavior in the post-adoption phase [23,84]. Most empirical investigations focus on adoption drivers, including performance expectancy, price value, and facilitating conditions [102], but fail to systematically explain how visitors sustain engagement with immersive technologies after their initial exposure. This lacuna restricts the ability of cultural institutions to design strategies that promote continued use, which is vital for aligning immersive interventions with broader heritage sustainability objectives.

Second, continuance intention in cultural heritage contexts has been particularly underexplored compared to other domains. In education, AR/VR continuance is generally examined in relation to course completion and knowledge retention; in entertainment, it is linked to hedonic value, repeated play, and immersive enjoyment; and in retail, it is tied to conversion rates, shopping convenience, and habitual purchase behavior [23]. Cultural heritage, however, presents distinct dynamics: AR/VR applications are often experienced on-site, mediated by shared devices, queuing systems, and staff guidance, and situated within fragile environments under conservation constraints. Continuance intention in this context is not merely a matter of habitual usage or repeated consumption but is directly tied to sustaining cultural connection, deepening historical understanding, and supporting long-term safeguarding of heritage values. This complexity underscores why continuance intention in heritage AR/VR cannot be fully explained by models developed in commercial or educational domains, yet empirical evidence on this issue remains scarce.

Third, comparative analyses across heritage sites remain scarce. While international cases—such as Rome Reborn or VR-enhanced museums in Europe—have demonstrated the potential of AR/VR for education and interpretation, these studies often treat heritage sites as homogeneous testbeds for technological experimentation [100,101]. Few investigations examine high-value UNESCO sites in non-Western contexts, and even fewer address the interplay between local cultural practices, tourist expectations, and immersive engagement. Consequently, there is insufficient evidence to assess the external validity and cultural specificity of findings generated in single-site or laboratory-based settings.

Forth, the majority of prior research adopts a technology-centered perspective, overlooking the experiential and affective dimensions of heritage encounters. Although some scholars have highlighted the role of multi-sensory design in strengthening presence and authenticity [101], systematic integration of constructs such as visual appeal, entertainment, enjoyment, and interactivity into behavioral models remains limited. This gap hinders the development of holistic frameworks that capture both cognitive evaluations and experiential attributes in shaping tourists' continuance intention.

Against this backdrop, the present study makes three distinct contributions. Theoretically, it advances heritage technology adoption research by integrating the Expectation Confirmation Model (ECM) with experiential attributes of immersive applications, providing a comprehensive model that bridges cognitive and affective determinants of continuance intention. Empirically, it contributes novel evidence from the Terracotta Warriors Museum—a UNESCO World Heritage site and a globally recognized cultural symbol—thus addressing the paucity of research in high-profile non-Western contexts. Methodologically, the study employs structural equation modeling (SEM) to validate twelve systematically developed hypotheses, offering robust statistical insights into both direct and mediated pathways influencing post-visit continuance intention. Collectively, these contributions extend current knowledge beyond the pre-adoption stage, offering a nuanced understanding of how immersive technologies can support sustainable engagement in built heritage spaces.

3. Research Model and Hypotheses Development in Built Cultural Heritage Contexts

3.1. Research Model

Traditional built-heritage visits typically rely on linear, expository media—static displays, wall labels, and standard audio guides—where interaction is minimal and learner control is limited; empirical work shows that visitors' use of labels is brief and selective, constraining depth of processing in physical-only settings [103–107]. In contrast, AR/VR reconfigures the encounter from passive reception to active exploration: layered overlays, embodied interaction, and narrative reconstruction elevate presence, perceived vividness, and exploratory behavior. Comparative evidence indicates that HMD-VR yields higher immersion and empathy than HMD-AR in museum settings [94], and that VR, VR360, and MR produce distinct profiles of presence, engagement, and motivation [108]. Cross-context analyses further document systematic behavioral differences between virtual and physical museums [109], underscoring that modality shapes attention and movement patterns. Within heritage museums specifically, a socio-technical study shows that post-use AR intentions are jointly driven by technical, individual, and situational factors via satisfaction—mechanisms that generalize across institutional settings [95]. Taken together, these contrasts justify extending ECM with experiential constructs (visual appeal, enjoyment, entertainment, interactivity, involvement). In immersive heritage contexts, confirmation and perceived usefulness operate alongside sensory–affective drivers to shape satisfaction and post-visit continuance intention.

Based on the literature review, this study develops an extended conceptual model by integrating ECM with the characteristics of sustainable tourism innovation technologies. As shown in Figure 4, the model includes the following variables: visual appeal (VA), entertainment (ENT), enjoyment (ENJ), involvement (INV), interactivity (INT), satisfaction (SAT), continuance intention (CI), confirmation (CNF), perceived usefulness (PU), and perceived ease of use (PEOU).

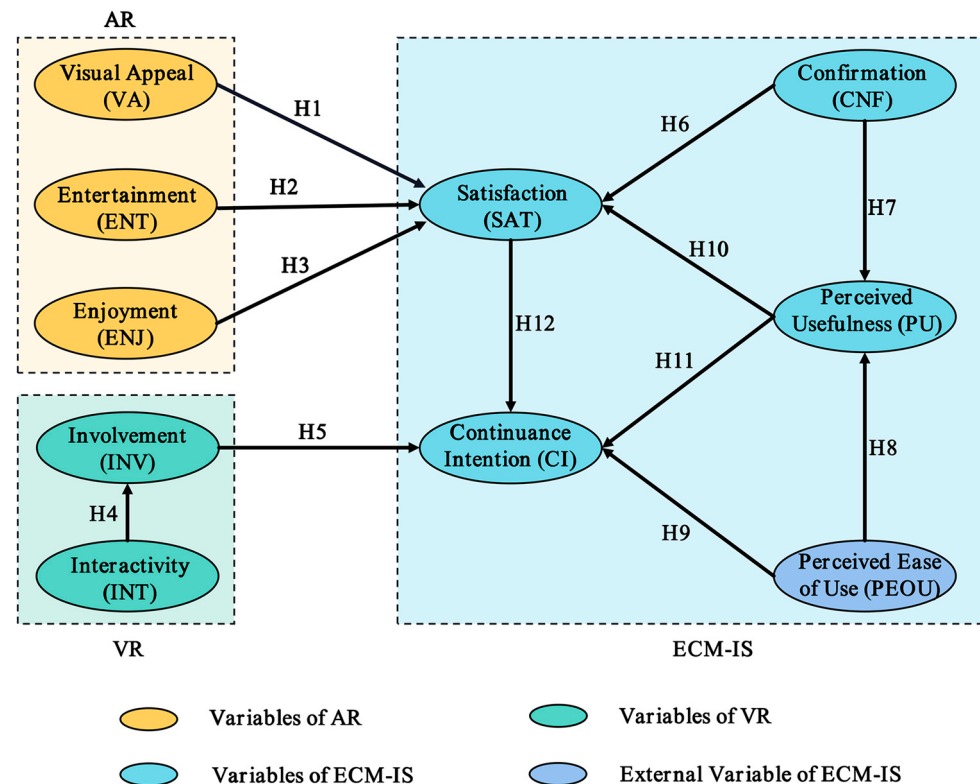


Figure 4. Research model.

3.2. Hypotheses Development

Visual appeal (VA) is initially defined as perception acquired through fundamental senses such as sight, hearing, taste, and touch [85]. In this study, VA refers to tourists' immediate sensory impressions derived from AR-based visual and auditory information. Satisfaction (SAT), in a consumer context, is defined by Oliver [68] as a psychological state resulting from emotions triggered by unmet expectations combined with prior consumption experience. In this study, satisfaction reflects the emotional response generated from the gap between tourists' expectations and their actual experiences while using AR. When perceived benefits exceed initial expectations, satisfaction tends to improve. Han et al. [15] found that VA has a significant positive effect on satisfaction in cultural heritage tourism. Thus, the following hypothesis is proposed:

H1. *Visual appeal (VA) of AR has a positive effect on tourist satisfaction (SAT).*

Entertainment (ENT) reflects the user's appreciation of dramatic or spectacular elements in service performance [85]. In this study, ENT refers to tourists' enjoyment of dramatic or grand visual effects presented through AR technology. Han et al. [15] confirmed that ENT significantly enhances satisfaction in AR-based heritage experiences. Accordingly, the hypothesis is formulated as:

H2. *Entertainment (ENT) of AR has a positive effect on tourist satisfaction (SAT).*

Enjoyment (ENJ) is defined as the intrinsic pleasure derived from engaging in interactive activities [86]. In this study, ENJ refers to the inner joy tourists experience while interacting with AR content. According to Han et al. [15], ENJ significantly enhances satisfaction in AR-based cultural heritage applications. Therefore, the following hypothesis is proposed:

H3. *Enjoyment (ENJ) of AR has a positive effect on tourist satisfaction (SAT).*

Compared to AR, VR offers greater interactivity (INT) and involvement (INV), enhancing tourists' experiential depth. Interactivity refers to the communication between users and the VR system [15]. Involvement, as defined by Zaichkowsky [97], is the degree to which individuals perceive relevance to an object based on internal needs, values, and interests, and the extent of their concern for surrounding events or outcomes. In this study, INV reflects the immersive engagement tourists feel during VR interaction. Prior research shows that INT has a significant impact on INV in adult users [96]. Hence, this study proposes the following hypothesis:

H4. *Interactivity (INT) of VR has a positive effect on involvement (INV).*

In ECT, Continuance Intention (CI) refers to users' intention to repurchase or continue using a service [66]. In this study, CI denotes tourists' intention to continue using AR/VR technologies. Huang et al. [96] demonstrated that INV significantly predicts CI in VR contexts among adults. Thus, the following hypothesis is proposed:

H5. *Involvement (INV) in VR has a positive effect on continuance intention (CI).*

Confirmation (CNF) is defined as the cognitive assessment and resulting emotional or psychological state derived from comparing pre-use expectations with actual performance [66]. In this study, CNF refers to tourists' evaluation of the congruence between expected and actual AR/VR experiences. CNF is inversely related to expectation level and positively associated with the quality of real-life experience. Xie et al. [110] found that confirmation significantly influences elderly users' satisfaction with healthcare services. Similarly, Gupta et al. [111] showed that CNF affects SAT in the use of wearable fitness technologies. Hence, the sixth hypothesis is put forward:

H6. *Confirmation (CNF) positively influences tourist satisfaction (SAT).*

Perceived Usefulness (PU) refers to users' belief in the instrumental value or benefit of using an information system and is the most salient post-adoption expectation linked to continuance intention [66]. In this study, PU reflects tourists' cognitive appraisal of the usefulness of AR/VR technologies. Xie et al. [110] and Shen et al. [112] both reported significant positive relationships between CNF and PU in digital service contexts. Therefore, the seventh hypothesis is put forward:

H7. *Confirmation (CNF) has a positive effect on perceived usefulness (PU).*

Perceived ease of use (PEOU) is defined as the degree to which a person believes that using a system requires minimal cognitive effort [69]. In this study, PEOU refers to tourists' perception of the ease of use of AR/VR technologies. Mishra et al. [113] confirmed that PEOU significantly influences PU in information systems. Xie et al. [110] and Shen et al. [112] also demonstrated that PEOU significantly affects both PU and CI in healthcare and mobile check-in services. Thus, the eighth hypothesis is put forward:

H8. *Perceived ease of use (PEOU) positively influences perceived usefulness (PU).*

H9. *Perceived ease of use (PEOU) positively influences continuance intention (CI).*

Numerous studies have verified the interrelationships among PU, SAT, and CI [112,114]. To illustrate, researchers proved that PU positively impacts both SAT and CI in e-government services [114]. Shen et al. [112] also showed that PU positively affects SAT and jointly influences CI with SAT. Similarly, Hung et al. [115] confirmed that PU significantly influences both SAT and CI, and that SAT positively affects CI in the context of social media and e-government services. Based on this evidence, the final hypotheses are proposed:

H10. *Perceived usefulness (PU) has a positive effect on tourist satisfaction (SAT).*

H11. *Perceived usefulness (PU) has a positive effect on continuance intention (CI).*

H12. *Tourist satisfaction (SAT) has a positive effect on continuance intention (CI).*

4. Research Methodology

4.1. Structural Equation Modeling (SEM)

SEM is a powerful multivariate statistical analysis technique that enables simultaneous the testing of multiple and complex relationships among variables [116]. SEM has been widely applied in information systems and tourism behavior research to validate theoretical models involving various independent and dependent constructs [117–120]. Accordingly, SEM is highly suitable for the analytical needs of this study.

There are two primary SEM approaches: Partial Least Squares SEM (PLS-SEM) and Covariance-Based SEM (CB-SEM) [116]. These approaches differ in terms of application contexts, data requirements, and implementation strategies.

PLS-SEM

The choice between PLS-SEM and CB-SEM is typically guided by three key considerations: data distribution characteristics, sample size, and research objectives. First, PLS-SEM is a non-parametric method that does not require observed data to follow a strict multivariate normal distribution [121], whereas CB-SEM imposes stronger distributional assumptions. Second, PLS-SEM is better suited for handling complex models involving numerous variables [121]. Third, PLS-SEM emphasizes the model's predictive and explanatory power, while CB-SEM is more appropriate for theory confirmation [116]. Given that the dataset is not normally distributed, and that the proposed model integrates the ECM with ten external variables, PLS-SEM is more appropriate for this research, which prioritizes explanatory and predictive capacity over confirmatory validation.

4.2. Survey Instrument

This research employed an online survey to gather data. Online surveys have been extensively used and validated in prior studies within this domain [36,91,119,120], demonstrating high levels of reliability and validity. As a well-established and frequently adopted method, the online questionnaire is suitable for collecting large-scale, structured responses in tourism and information systems research.

Two primary parts consisted of the questionnaire. The first part gathered respondents' demographic details, while the second part included items for measuring the study variables. The second section contained measurement items corresponding to the study variables. These items were adapted and refined from existing validated scales to suit the specific context of AR/VR applications at the Terracotta Warriors Museum. Necessary modifications were made to align with the museum setting and the conceptual framework of this study. A comprehensive list of measurement items and their literature sources is presented in Table 1. All constructs were measured using a seven-point Likert scale ranging

from 1 (“strongly disagree”) to 7 (“strongly agree”) to facilitate precise data capture and rigorous analysis.

Table 1. Measurement items.

Construct	Item	Question (Responses Based on 7-Point Likert Scale)	References
Continuance Intention (CI)	CI1	After using the Augmented Reality (AR) and Virtual Reality (VR) technologies at the Terracotta Army Museum, I plan to continue using AR/VR technologies in future museum visits.	[66,112,114,115]
	CI2	I am likely to recommend the AR and VR experiences at the Terracotta Army Museum to others.	
	CI3	My positive experience with the AR and VR systems at the Terracotta Army Museum makes me more inclined to continue using such technologies.	
	CI4	If given the opportunity, I would choose to visit the Terracotta Army Museum again using AR and VR technologies.	
Confirmation (CNF)	CNF1	The AR and VR experiences at the Terracotta Army Museum meet my expectations.	[66,110,111]
	CNF2	The functions provided by the AR and VR systems exceeded my expectations.	
	CNF3	The AR and VR functions of the Terracotta Army Museum were as interesting as I expected.	
	CNF4	Most of what I saw of the Terracotta Army Museum through AR and VR lived up to my expectations.	
Enjoyment (ENJ)	ENJ1	I thoroughly enjoyed the cultural heritage tourism experience at the Terracotta Army Museum through AR.	[15,86]
	ENJ2	I felt completely immersed in the AR activities at the Terracotta Army Museum.	
	ENJ3	The AR experience at the Terracotta Army Museum was an unforgettable and pleasant way to learn about history.	
	ENJ4	The AR content display at the Terracotta Army Museum made me very happy.	
	ENJ5	I found the dynamic content of the AR at the Terracotta Army Museum consistently fascinating.	
Entertainment (ENT)	ENT1	I found the AR experience at the Terracotta Warriors Museum highly entertaining.	[15,85]
	ENT2	The AR experience at the museum was very engaging.	
	ENT3	The AR experience made museum visits much more interesting.	
	ENT4	The AR experience was so entertaining that it motivated me to explore more of the museum’s content.	
Interactivity (INT)	INT1	When using the VR system at the Terracotta Warriors Museum, I could actively control and choose the content I wanted to explore.	[15,96]
	INT2	The VR interactive system responded quickly to my operations.	
	INT3	I felt a strong sense of immersion during the VR experience.	
	INT4	Throughout the VR experience, I felt like a participant, not just a spectator.	

Table 1. Cont.

Construct	Item	Question (Responses Based on 7-Point Likert Scale)	References
Involvement (INV)	INV1	When experiencing the VR content at the Terracotta Warriors Museum, I felt highly engaged.	[96,97]
	INV2	I remained highly focused while participating in the VR sustainable tourism functions.	
	INV3	Even after leaving the museum, I kept thinking about the VR experience.	
	INV4	Experiencing VR made me feel closely connected to the museum's culture and history.	
Perceived ease of use (PEOU)	PEOU1	The AR and VR systems at the Terracotta Warriors Museum were very easy to understand.	[69,110,112,113]
	PEOU2	I could flexibly use the museum's AR and VR systems to explore different exhibitions.	
	PEOU3	Learning and understanding how to use the AR and VR systems was easy.	
	PEOU4	Operating the AR and VR systems at the Terracotta Warriors Museum was very easy.	
Perceived usefulness (PU)	PU1	Using AR and VR technologies allowed me to obtain tourism information about the Terracotta Warriors Museum more quickly.	[66,110,112,113]
	PU2	Using AR and VR technologies helped me save travel costs (e.g., time, money) when visiting the Terracotta Warriors Museum.	
	PU3	AR and VR technologies provided me with more options for learning about the Terracotta Warriors Museum.	
	PU4	Using AR and VR technologies enhanced my understanding of the Terracotta Warriors Museum and improved the overall quality of my visit.	
Satisfaction (SAT)	SAT1	I was satisfied with the overall experience of using AR and VR technologies at the Terracotta Warriors Museum.	[15,68]
	SAT2	AR and VR technologies contributed to my satisfaction with the visiting experience at the Terracotta Warriors Museum.	
	SAT3	The museum's AR and VR experiences provided a high-quality and pleasant experience overall.	
	SAT4	I was satisfied with the interactivity and immersive features of the AR and VR systems at the Terracotta Warriors Museum.	
Visual appeal (VA)	VA1	The AR experience at the Terracotta Warriors Museum offered impressive visual effects of the exhibits.	[15,85]
	VA2	AR displays enhanced the visual appeal of the historical relics in the Terracotta Warriors Museum.	
	VA3	The AR experience at the Terracotta Warriors Museum featured high visual quality.	
	VA4	The views of the Terracotta Warriors Museum seen through AR enhanced the overall esthetic quality of the museum environment.	

Two independent bilingual translators conducted forward translations into Simplified Chinese—one with information systems/user-experience expertise and the other with museum/heritage expertise. A reconciliation meeting resolved discrepancies and standardized terminology. A third translator, a native English speaker, then produced a back translation; this version was compared to the originals to ensure semantic equivalence rather than word-for-word symmetry. An expert panel reviewed the reconciled Chinese items and the back-translated English for conceptual clarity and domain accuracy.

4.3. AR and VR Systems in Context

To clarify the technological context in which the survey was conducted, this study describes the specific AR and VR applications employed at the Terracotta Warriors Museum. Two representative systems were selected as they embody the museum's current digital engagement strategies: a large-scale, location-based VR/XR system and a mobile AR restoration application.

The VR component was based on the "Empire Code: Mausoleum of Qin Shi Huang" full-scale XR experience space, a state-of-the-art, location-based virtual environment delivered through head-mounted displays (HMDs) within a physically defined area exceeding 50 square meters [122]. This system integrates multiple advanced technologies, including 5K ultra-high-definition rendering for millimeter-level detail reproduction, six degrees of freedom (6 DoF) tracking and gesture recognition that enable natural bodily interaction without handheld controllers, and spatial audio coupled with haptic feedback to reinforce multisensory realism (e.g., ground vibrations simulating earth tremors) [123]. Furthermore, an AI-driven dynamic content engine reconstructs historically informed scenarios such as the mercury circulation system or ancient astronomical charts, drawing on archeological data from the National "863 Program".

The VR interface was designed to maximize immersion through a diegetic UI paradigm, in which interactive elements were embedded within the environment rather than displayed as external overlays. A virtual guide, "Qin Xiangdong", provided instructions through gaze, gesture, and narration, while environmental cues (e.g., glowing artifacts, sound signals) directed user attention. Content was structured as a cinematic narrative journey, allowing participants to assume the role of archeological explorers who physically opened the palace gates, walked among terracotta formations, and experienced scientifically informed reconstructions of celestial ceilings and subterranean waterways.

The AR application was represented by the Baidu AI Terracotta Warriors Restoration Project, a marker-based mobile AR system accessible via smartphones [124]. This system employed image recognition and tracking to anchor digital overlays to predefined visual markers, such as pit layout diagrams or lightbox displays of kneeling archers. Once activated, the application superimposed 3D models, animations, and textual information onto the live camera feed, enabling interactive exploration of artifacts.

The AR interface followed a conventional mobile AR paradigm, with the smartphone screen serving as the primary viewport [124]. Users interacted with content via touch-based inputs, such as tapping on overlaid color-coded blocks to reveal different military units or triggering animations of warrior color restoration. Content design emphasized educational augmentation, including (a) digital colorization of warriors to demonstrate hypothesized original appearances, (b) disassembly and reassembly of bronze chariots to explain ancient casting techniques, and (c) visualization of pit layouts with 3D overlays of military formations to illustrate tactical organization.

Together, these AR and VR applications demonstrate two complementary approaches to immersive engagement at the Terracotta Warriors Museum. While the VR system provides a deeply embodied, narrative-driven reconstruction of the mausoleum space, the AR application enhances artifact interpretation through accessible, mobile-based restoration and visualization tools. Collectively, these systems form the technological basis for the survey conducted in this study and inform the contextual framing of the measurement items described in Section 4.2.

4.4. Pilot Study

To ensure the validity and reliability of the research instrument and to accurately capture tourists' intentions when experiencing AR/VR-based sustainable tourism inno-

uations at the Terracotta Warriors Museum, a pilot study was conducted before formal data collection, supplemented by expert validation. The process involved the following steps: first, 30 respondents with diverse tourism experiences, age ranges, and backgrounds were recruited for a pre-test of the survey, which focused on the AR/VR-based sustainable tourism innovations and their impact on tourists' continuance intention. After completing the survey, participants offered in-depth comments on the relevance of the questionnaire content to the AR/VR theme, the clarity and fluency of the item phrasing, and the difficulty level of the questions. Secondly, three experts specializing in AR/VR technology applications and tourism research were invited to conduct a systematic review of the questionnaire. The experts focused on the accuracy of terminology usage, academic rigor, logical coherence, offering professional recommendations for improvements. Based on the feedback from the pilot respondents and expert suggestions, targeted revisions were made to the questionnaire.

4.5. Respondents

The respondents were visitors aged 18 or above who had previously visited the Terracotta Warriors Museum. To ensure data validity, respondents were required to confirm their previous experience with AR/VR technology during their visit and express their willingness to provide feedback and opinions. Before participating, all respondents were thoroughly briefed on the study's aim and content, ensuring informed consent and had a clear understanding of the research context and goals.

4.6. Sample Size

To determine the required sample size for the study on "AR/VR-based sustainable tourism innovations and tourists' continuance intention", Cochran's formula was applied [125]. This formula is a classic method for handling large-scale sampling issues and ensures sample representativeness and statistical power under a specified confidence level. The mathematical expression is as follows:

$$n = \frac{z^2 \cdot p \cdot (1 - p)}{e^2} \quad (1)$$

where n represents the minimum required respondent count, z is the critical value from the standard normal distribution corresponding to the given confidence level, p represents the approximated fraction of the relevant characteristic within the population and e is the acceptable sampling error. Given the nature of this study and its requirements, the confidence level was set at 95%, corresponding to a z -value of 1.96, with an expected distribution proportion $p = 0.5$ and a margin of error set at $\pm 5\%$ (i.e., $e = 0.05$). Substituting these parameters into the formula, the sample size calculation is as follows:

$$n = \frac{1.96^2 \cdot 0.5 \cdot (1 - 0.5)}{0.05^2} \approx 384 \quad (2)$$

The final valid dataset comprised 434 responses, exceeding this threshold. While the "10-times rule" is a commonly applied heuristic in SEM, recent scholarship emphasizes that adequacy also depends on model complexity, construct reliability, and effect sizes. In sustainable tourism and related SEM research, comparable or even smaller samples have been employed effectively: for example, Wani et al. [126] analyzed 368 responses to test a sustainable tourism framework. Darda and Bhuiyan [127] validated an ecotourism SEM model with 310 cases and Munir et al. [128] conducted a PLS-SEM analysis on 250 responses across five districts. Against this backdrop, our sample of 434 exceeds the norm in recent SEM studies in tourism and sustainability, thereby providing sufficient statistical power.

4.7. Sampling Procedure

This study utilized a convenience sampling technique for data collection. This method selects samples based on the accessibility and willingness of respondents to participate. It is efficient, cost-effective, and enables easy access to specific target groups, making it widely adopted in social science research [129,130]. Previous studies in this field have also predominantly employed this method, providing a solid basis for the choice of sampling technique in this study [130–135]. However, it is essential to note that convenience sampling is a non-probability sampling method, which may introduce selection bias, potentially affecting the representativeness of the sample and the generalizability of the research findings.

To minimize bias, several control measures were implemented during the sampling and data processing. First, to attenuate social-desirability pressures and the short-lived “tourist excitement” effect, we guaranteed anonymity in the consent statement, administered a self-completed questionnaire in locations physically removed from museum staff, employed neutral (non-leading) wording throughout, randomized the presentation order of items, and instructed respondents to begin the survey only after a brief cool-down period outside the exhibition exit. Second, during respondent recruitment, efforts were made to ensure a diverse sample, including individuals from different genders, ages, education, and occupations, to increase sample heterogeneity and coverage. Third, the inclusion criteria for research respondents were clearly defined to ensure that the selected sample was highly relevant to the study theme, enhancing the relevance and explanatory power of the data. Through these methods, the study sought to balance sampling feasibility and efficiency while improving data quality and the scientific robustness of the results.

4.8. Data Collection

Data for this study were collected using WJX, a widely used online survey platform in China [91]. Researchers designed the questionnaire on the WJX platform, which automatically generated a QR code link to the survey. Respondents could conveniently access the background of the study, review the research purpose, read the informed consent form online, and begin the survey. Before starting, respondents were asked to read and acknowledge a comprehensive informed consent form that detailed the study’s objectives, explained the voluntary nature of participation, assured the confidentiality of their answers, and outlined their rights. In addition, a thorough explanation of the privacy protection measures to ensure data anonymity and security was provided. Respondents were notified that their involvement was completely optional, and respondents could exit the survey at any point without explanation. All collected data were handled in strict confidence and used exclusively for academic purposes. Respondents could proceed only after thoroughly reading and understanding the informed consent document.

A combination of online and on-site data collection methods was adopted. On-site surveys were conducted at the exit area of the Terracotta Warriors Museum in Xi’an to ensure the authenticity and relevance of the responses. Only visitors who confirmed that they had used AR/VR technologies during their visit and expressed willingness to participate were invited to complete the questionnaire. Researchers presented the survey QR code for respondents to scan and respond via their smartphones. Data were collected over ten days from 1 July to 10 July 2025. The research team conducted the surveys daily from 9:00 AM to 5:00 PM at the museum’s north gate. In total, 453 responses were collected. After cleansing the collected data using SPSS 24.0 and Excel—removing responses with unrealistically short completion times or identical answers across all scale items—434 valid responses remained. The final sample size exceeded ten times the number of measurement items (41 items), meeting the minimum sample size recommendation by Hair et al. [121] for SEM analysis.

5. Data Analysis and Results

The data analysis process consisted of two major phases. First, the raw data collected from field research at the Terracotta Warriors Museum were cleansed, coded, and analyzed using SPSS. Second, SmartPLS 4.0 was employed to identify the key factors influencing tourists' continuance intention toward sustainable AR and VR applications, to examine the relationships among these factors, and to develop a theoretical model explaining tourists' continuance intention at the Terracotta Warriors Museum.

The SEM analysis followed the standard two-stage analytical approach. The first stage involved the measurement model assessment, focusing on evaluating internal consistency reliability, convergent validity, and discriminant validity to ensure the quality of construct measurement. The second stage entailed the structural model assessment, which tested the proposed hypotheses and evaluated explanatory power, predictive relevance, and overall model fit.

5.1. Demographic Information

Table 2 presents the demographic profile of the respondents. Age distribution was relatively balanced, with the largest group being those aged 25–34 (43.3%), followed by the 35–50 age group (30.9%). By gender, females made up a slight majority (54.1%) compared with males (45.9%). Regarding education, 63.3% of respondents held a bachelor's degree or higher—specifically, 41.9% held bachelor's degrees and 21.4% held master's degrees or above. In terms of occupation, employees of private or foreign enterprises constituted the largest group (32.9%), followed by freelancers (22.1%). For monthly income, most respondents (69.6%) reported earning between RMB 5000 and 8000.

Table 2. Demographic information of respondents.

Sample	Category	Frequency	Percentage (%)
Age	18–24	78	18
	25–34	188	43.3
	35–50	134	30.9
	>50	34	7.8
Gender	Male	199	45.9
	Female	235	54.1
Education Level	Middle school education or below	25	5.8
	High school/technical secondary school/technical school	35	8.1
	Junior college	99	22.8
	Bachelor's degree	182	41.9
	Master's degree or above	93	21.4
Occupation	Student	88	20.3
	Private or foreign-funded enterprises	143	32.9
	Public sector or state-owned enterprises	92	21.2
	Freelance	96	22.1
	Retired	15	3.5
Monthly Income Level	5000 RMB or below	155	35.7
	5001–8000 RMB	149	34.3
	8001–10,000 RMB	79	18.2
	10,000 RMB or above	51	11.8

5.2. SEM Analysis

5.2.1. Data Analysis for the Measurement Model

(1) Multicollinearity Test

In empirical research, high correlations among explanatory variables may cause multicollinearity problems [136]. This issue can result in unstable parameter estimates, reduced model reliability, and weakened predictive power [137]. Therefore, it is crucial to rigorously test and control multicollinearity. The academic literature widely recommends using the Variance Inflation Factor (VIF) to detect multicollinearity, with a commonly accepted critical threshold of 3.33 [138]. To ensure analytical, the research team conducted a VIF test for all explanatory variables related to tourists' continuance intention. As shown in Table 3, the VIF values for all indicators ranged from 1 to 1.695, which are all below 3.33, indicating that this study does not suffer from severe multicollinearity.

(2) Reliability and validity test

Reliability and validity of the measurement model were assessed using SmartPLS 4.0 software. The reliability test results (Table 4) indicate that the Cronbach's alpha values for all constructs exceeded 0.7. This result meets the widely accepted reliability standard in the academic literature [139], demonstrating that the questionnaire used in this study has good internal consistency reliability, providing a solid foundation for subsequent analysis of tourists' continuance intention. For validity, the Average Variance Extracted (AVE) for all constructs was greater than 0.5. This result meets the standard proposed by Fornell and Larcker [140], confirming good convergent validity of the measurement model.

Table 3. Multicollinearity Test.

Construct	CI	CNF	ENJ	ENT	INT	INV	PEOU	PU	SAT	VA
Continuance Intention (CI)										
Confirmation (CNF)								1.381	1.606	
Enjoyment (ENJ)									1.695	
Entertainment (ENT)									1.619	
Interactivity (INT)						1.000				
Involvement (INV)	1.395									
Perceived Ease of Use (PEOU)	1.482							1.381		
Perceived Usefulness (PU)	1.425								1.543	
Satisfaction (SAT)	1.491									
Visual Appeal (VA)									1.601	

Table 4. Reliability test results.

Construct	Item	Factor Loading	Cronbach's Alpha	Rho_A	Composite Reliability	AVE
Continuance Intention (CI)	CI 1	0.836	0.862	0.864	0.906	0.707
	CI2	0.837				
	CI3	0.839				
	CI4	0.851				

Table 4. Cont.

Construct	Item	Factor Loading	Cronbach's Alpha	Rho_A	Composite Reliability	AVE
Confirmation (CNF)	CNF1	0.851	0.876	0.876	0.915	0.728
	CNF2	0.854				
	CNF3	0.856				
	CNF4	0.852				
Enjoyment (ENJ)	ENJ1	0.86	0.898	0.899	0.925	0.711
	ENJ2	0.841				
	ENJ3	0.841				
	ENJ4	0.838				
	ENJ5	0.835				
Entertainment (ENT)	ENT1	0.859	0.884	0.884	0.92	0.741
	ENT2	0.861				
	ENT3	0.865				
	ENT4	0.859				
Interactivity (INT)	INT1	0.862	0.888	0.888	0.923	0.749
	INT2	0.875				
	INT3	0.862				
	INT4	0.862				
Involvement (INV)	INV1	0.831	0.864	0.865	0.907	0.71
	INV2	0.84				
	INV3	0.848				
	INV4	0.852				
Perceived Ease of Use (PEOU)	PEOU1	0.85	0.881	0.882	0.918	0.738
	PEOU2	0.848				
	PEOU3	0.864				
	PEOU4	0.873				
Perceived Usefulness (PU)	PU1	0.844	0.873	0.874	0.913	0.723
	PU2	0.844				
	PU3	0.848				
	PU4	0.865				
Satisfaction (SAT)	SAT1	0.839	0.864	0.867	0.907	0.71
	SAT2	0.823				
	SAT3	0.865				
	SAT4	0.845				
Visual Appeal (VA)	VA1	0.866	0.891	0.892	0.925	0.754
	VA2	0.874				
	VA3	0.865				
	VA4	0.869				

Referring to related studies, the Heterotrait-Monotrait (HTMT) ratio is advisable to be controlled below 0.90 [141]. The data presented in Table 5 show that all core constructs in this study meet this standard, indicating that the variables exhibit good discriminant validity.

Table 5. Heterotrait–Monotrait ratio (HTMT).

Construct	CI	CNF	ENJ	ENT	INT	INV	PEOU	PU	SAT	VA
Continuance Intention (CI)										
Confirmation (CNF)	0.585									
Enjoyment (ENJ)	0.572	0.559								
Entertainment (ENT)	0.494	0.543	0.591							
Interactivity (INT)	0.470	0.527	0.538	0.522						
Involvement (INV)	0.499	0.446	0.525	0.559	0.520					
Perceived Ease of Use (PEOU)	0.515	0.597	0.556	0.544	0.509	0.501				
Perceived Usefulness (PU)	0.561	0.524	0.500	0.525	0.447	0.473	0.492			
Satisfaction (SAT)	0.551	0.533	0.609	0.534	0.477	0.489	0.543	0.521		
Visual Appeal (VA)	0.489	0.540	0.555	0.496	0.537	0.473	0.598	0.551	0.535	

Note: All values must be <0.90. Darker colors indicate larger values.

Additionally, the study conducted a discriminant validity test, and the results are shown in Table 6. As can be seen, the constructs in this study exhibit good discriminant validity.

Table 6. Correlation matrix among the constructs and square root of AVEs.

Construct	CI	CNF	ENJ	ENT	INT	INV	PEOU	PU	SAT	VA
Continuance Intention (CI)	0.841									
Confirmation (CNF)	0.509	0.854								
Enjoyment (ENJ)	0.505	0.498	0.843							
Entertainment (ENT)	0.434	0.478	0.527	0.861						
Interactivity (INT)	0.413	0.465	0.480	0.462	0.865					
Involvement (INV)	0.433	0.388	0.464	0.488	0.456	0.843				
Perceived Ease of Use (PEOU)	0.451	0.525	0.496	0.479	0.451	0.437	0.859			
Perceived Usefulness (PU)	0.489	0.460	0.444	0.461	0.396	0.411	0.433	0.851		
Satisfaction (SAT)	0.477	0.466	0.538	0.468	0.417	0.423	0.473	0.454	0.843	
Visual Appeal (VA)	0.429	0.477	0.497	0.440	0.478	0.415	0.529	0.485	0.470	0.869

Note: The bold diagonal values represent the square root of the AVEs. Darker colors indicate larger values.

5.2.2. Data Analysis for the Structural Model

This study employed SmartPLS 4.0 for hypothesis testing and model validation. The model fit evaluation was primarily based on explanatory power (R^2) and predictive relevance (Q^2).

Regarding explanatory power (R^2), prior studies [121,142] suggest that an R^2 value greater than or equal to 0.26 for endogenous latent variables is considered to be within a reasonable range. An R^2 value above 0.20 is deemed acceptable in terms of exploratory research. In this study, the R^2 values for core endogenous latent variables including tourists' behavioral intention, perceived usefulness, and perceived ease of use in the context of AR/VR-based sustainable tourism innovations at the Terracotta Warriors Museum were all greater than 0.20, indicating sufficient explanatory capacity.

Regarding predictive relevance (Q^2), scholars have noted [121,142] that when the Q^2 value is greater than 0, it demonstrates the model's predictive relevance. In this study, the Q^2 values for all relevant endogenous latent variables satisfied the condition of $Q^2 > 0$, confirming that the model possesses strong predictive capability (Table 7).

Table 7. Model fit.

Construct	R ²	Q ²
Continuance Intention (CI)	0.372	0.312
Interactivity (INT)	0.208	0.202
Perceived Usefulness (PU)	0.262	0.254
Satisfaction (SAT)	0.401	0.375

Additionally, Henseler and Sarstedt [143] proposed that the Goodness of Fit (GoF) index can be useful for assessing the explanatory power of PLS models across different datasets. The specific formula for calculating GoF is as follows [144]:

$$GoF = \sqrt{AVE \times R^2} = \sqrt{0.727 \times 0.311} \approx 0.475 \quad (3)$$

The GoF value of 0.475 exceeds the critical threshold of 0.36 proposed by Tenenhaus et al. [144], indicating that the overall model fit is satisfactory.

5.3. Hypothesis Testing Analysis

This study employed SmartPLS 4.0 and used the bootstrapping method to test the research hypotheses. Prior studies have suggested that a standardized root mean square residual (SRMR) value below 0.08 is acceptable [30]. In the context of this study on AR/VR-based sustainable tourism innovations at the Terracotta Warriors Museum, the obtained SRMR value was 0.037, well within the recommended threshold.

Figure 5 and Table 8 present the specific outcome of different model paths, all of which are statistically meaningful. The result highlights the vital role of the model in explaining tourists' continuance intention toward the innovative technologies at the Terracotta Warriors Museum.

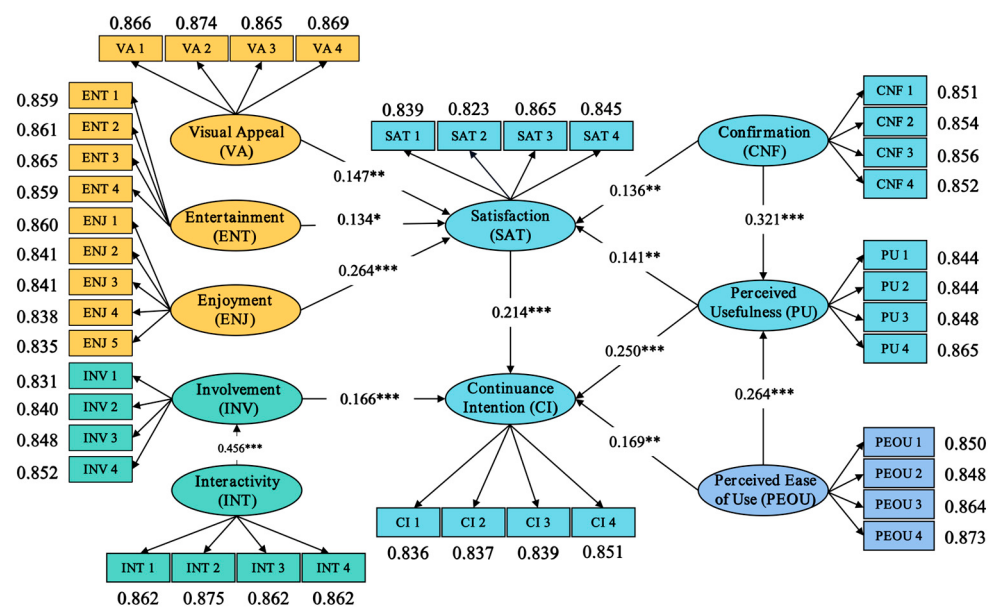


Figure 5. Research Model Results. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Table 8. Model path analysis results.

Hypothesis	Path	Standardized Coefficient (β)	t-Statistics	p-Value	Hypothesis Status
H1	VA $\rightarrow$ SAT	0.147	2.998	0.003	✓
H2	ENT $\rightarrow$ SAT	0.134	2.559	0.011	✓
H3	ENJ $\rightarrow$ SAT	0.264	4.512	0.000	✓
H4	INT $\rightarrow$ INV	0.456	11.85	0.000	✓
H5	INV $\rightarrow$ CI	0.166	3.512	0.000	✓
H6	CNF $\rightarrow$ SAT	0.136	2.596	0.009	✓
H7	CNF $\rightarrow$ PU	0.321	6.307	0.000	✓
H8	PEOU $\rightarrow$ PU	0.264	5.112	0.000	✓
H9	PEOU $\rightarrow$ CI	0.169	3.277	0.001	✓
H10	PU $\rightarrow$ SAT	0.141	2.898	0.004	✓
H11	PU $\rightarrow$ CI	0.250	4.935	0.000	✓
H12	SAT $\rightarrow$ CI	0.214	4.075	0.000	✓

6. Discussion

6.1. Interpretation and Implications of Findings

Among the 12 hypotheses proposed in this study, all were supported by the data. The findings provide empirical evidence for understanding the mechanisms influencing tourists' continuance intention toward sustainable AR and VR applications at the Terracotta Warriors Museum. Beyond confirming the hypotheses, each result offers implications for both theory and practice and suggests directions for future research in cultural heritage and immersive technology adoption.

H1: The result indicates that visual appeal has a positive impact on satisfaction ($\beta = 0.147$, $p = 0.003$), which is consistent with the findings of Han et al. [15]. Similar effects are observed in online commerce [145]. Therefore, in the efforts made by cultural heritage destination managers to enhance visitor satisfaction, increasing visual appeal is a crucial component. This finding underscores the need for ongoing investment in both artistic design and technological innovation to improve visual appeal and esthetic quality, while maintaining a prudent balance between costs and anticipated benefits. For researchers, this highlights the importance of treating visual appeal as a measurable construct that can be incorporated into models of technology adoption in heritage contexts.

H2: The result confirms that entertainment has a positive effect on satisfaction ($\beta = 0.134$, $p = 0.011$). This finding aligns with the research of Han et al. [15], which confirmed that in AR application scenarios, entertainment significantly impacts satisfaction. This study verifies that, in the context of sustainable tourism innovation technologies, entertainment similarly exerts a positive influence on satisfaction. This suggests that heritage applications must combine pedagogical value with entertaining features to sustain engagement. Future researchers may further examine the balance between entertainment and educational outcomes to determine optimal design strategies.

H3: The result of this study indicates that enjoyment has a positive effect on satisfaction ($\beta = 0.264$, $p = 0.000$). This is consistent with the findings of Han et al. [15] and Binowo et al. [146]. This study extends this result to the field of sustainable tourism innovation technologies, confirming that tourists' enjoyment of AR is a significant determinant of satisfaction. Practically, this suggests that developers should focus on intuitive and playful interaction designs. For other scholars, this highlights enjoyment as a transferable construct

across different digital heritage environments and calls for comparative studies to test its generalizability.

H4: The result shows that interactivity has a positive impact on involvement ($\beta = 0.456$, $p = 0.000$). This conclusion supports the findings of Huang et al. [96] in the context of VR applications for older adults, and effectively extends it to the cultural heritage tourism setting. This result suggests that the high interactivity provided by VR technology can effectively enhance tourists' deep immersion in the content of cultural heritage sites. For practitioners, enhancing interactive features can increase experiential depth. For researchers, this underscores the value of examining interactivity not only as a usability factor but also as a pathway to psychological involvement.

H5: The result reveals that involvement has a positive effect on continuance intention ($\beta = 0.166$, $p = 0.000$). This finding is consistent with the research by Huang et al. [96] and Shiao and Luo [147]. This study emphasizes that the deep immersion created by VR technology is critical in cultivating tourists' willingness to continue using the technology to explore cultural heritage in the future. It provides direct evidence for technology developers to design more engaging and immersive VR experiences. Future research could investigate involvement as a mediating factor across different cultural and demographic contexts.

H6: The result confirms that confirmation has a positive effect on satisfaction ($\beta = 0.136$, $p = 0.009$), consistent with previous research [110,112]. In the context of this study, tourists' confirmation of expectations regarding their AR/VR technology experiences is an essential antecedent of their satisfaction. Given the inverse relationship between tourists' initial expectations and the confirmation of their experiences, cultural heritage destination managers should carefully manage visitor expectations by providing authentic, consistent promotional information and real experiences to enhance satisfaction effectively. For researchers, this implies that future models should integrate expectation management variables to explain variations in satisfaction outcomes.

H7: The result demonstrates that confirmation has a positive effect on perceived usefulness ($\beta = 0.321$, $p = 0.000$). This echoes the findings of Xie et al. [110] and Shen et al. [112] in healthcare and online payment contexts. This study confirms that, within the context of sustainable tourism technology, tourists' confirmation of whether AR/VR technologies meet or exceed their expectations is a key factor shaping their perception of the technology's usefulness. This insight encourages managers to align system performance with realistic visitor expectations. For future studies, it highlights confirmation as a universal construct applicable across digital service domains.

H8: The result confirms that perceived ease of use has a positive effect on perceived usefulness ($\beta = 0.264$, $p = 0.000$), which has been repeatedly verified in various fields, such as healthcare, online payment, and information systems [110,112,113]. This significant path suggests that improving the ease of use of AR/VR technologies can directly enhance tourists' perception of their usefulness, providing clear directions for cultural heritage technology developers to optimize user interfaces and operational processes. For researchers, this finding strengthens the rationale for examining user experience design principles within heritage-specific contexts.

H9: The analysis result shows that perceived ease of use has a positive effect on continuance intention ($\beta = 0.169$, $p = 0.001$). This finding is consistent with previous academic work [110,112], revealing that perceived ease of use is one of the crucial factors influencing users' continuance intention. Therefore, to promote the continued use of AR/VR, cultural heritage technology developers should prioritize improving the perceived ease of use of the technologies. For other researchers, this underscores the need to test ease-of-use effects across diverse immersive technologies and platforms.

H10: The result shows that perceived usefulness has a significant impact on satisfaction ($\beta = 0.141, p = 0.004$). When users perceive that AR/VR technologies help them better understand cultural heritage, they are more likely to derive satisfaction from using the technologies. This suggests that destination managers should focus more on the substantive value of the technology and its integration with cultural heritage, rather than solely seeking novelty in form. For researchers, this opens a pathway to explore how perceived usefulness mediates between interpretive depth and visitor satisfaction.

H11: This study confirms that perceived usefulness has a significant impact on continuance intention ($\beta = 0.250, p = 0.004$). This finding is supported by previous research [112,114,115]. For example, in the fields of e-government services and electronic ticketing systems, studies by Shen et al. [112], Mandari et al. [114], and Hung et al. [115] have confirmed the significance of this path. In sustainable tourism, perceived usefulness directly influences tourists' likelihood of continuing to engage with AR/VR technologies. This offers actionable insights for developers: ensuring the interpretive relevance of digital applications is central to sustained engagement. For scholars, this result highlights the cross-domain robustness of perceived usefulness in predicting continuance behaviors.

H12: The result confirms that satisfaction has a significant impact on continuance intention ($\beta = 0.214, p = 0.004$). This conclusion is also supported by previous research [112,114,115]. This study extends these findings to the context of sustainable tourism innovation technologies, confirming that tourists' satisfaction with AR/VR technologies is a critical determinant of their continuance intention. For practitioners, this emphasizes the need for ongoing system updates and content enrichment to maintain satisfaction levels. For future research, it underscores satisfaction as a pivotal construct that links immediate experiences with potential behavioral outcomes.

Collectively, these findings contribute to theory by integrating the Expectation-Confirmation Model with experiential constructs, demonstrating that continuance intention in heritage tourism is shaped by both cognitive evaluations (usefulness, ease of use, confirmation, perceived ease of use) and affective experiences (visual appeal, entertainment, enjoyment, interactivity, involvement). Practically, heritage destination managers and technology developers should design visually appealing and entertaining interfaces, maximize interactivity, manage visitor expectations, and ensure usability and educational relevance. These insights apply beyond the Terracotta Warriors Museum and can guide other cultural-heritage sites seeking to implement immersive technologies as part of sustainable tourism innovation.

6.2. Practical Implications

This research reveals the differentiated pathways through which both direct and indirect factors influence tourists' continuance intention to use AR/VR-based sustainable tourism innovation technologies at the Terracotta Warriors Museum. Direct factors demonstrate an intuitive and immediate relationship with continuance intention, which suggesting they are most effective during the early stages of AR/VR adoption when heritage sites aim for quick and visible outcomes. Indirect factors, in contrast, act through mediating variables and require carefully designed experiential strategies that sustain engagement beyond the immediate visit. Building on these results, the study offers practical implications for tourists, destination managers, technology developers, and policymakers, translating empirical findings into actionable recommendations acceptable to other cultural heritage contexts.

6.2.1. For Tourists

Tourists increasingly seek experiences that are both educational and emotionally rewarding. The findings suggest that satisfaction is heightened when AR/VR applications are visually appealing, entertaining, and easy to use. Tourists should therefore prioritize destinations that demonstrate innovation in digital storytelling and interface esthetics. For example, visitors can evaluate heritage sites based on their integration of interactive AR layers, multisensory VR environments, or accessible mobile platforms. This empowers tourists to make more informed choices and encourages demand for higher-quality immersive heritage experiences, indirectly pressuring providers to maintain high design standards.

6.2.2. For Destination Managers

Destination managers carry the primary responsibility for ensuring that AR/VR technologies translate into meaningful, sustainable visitor experiences. To improve satisfaction, managers should commission professionally designed digital content that combines historical accuracy with esthetic appeal. This requires allocating resources not only for high-resolution visualizations but also for continuous maintenance and calibration of projection systems and headsets, ensuring that blurriness, latency, and technical failures do not disrupt immersion. Spatial planning should also be treated as an essential managerial task: immersive zones must be carefully integrated into visitor circulation routes, with clear entry and exit flows, appropriate lighting, and crowd management strategies that prevent bottlenecks and minimize physical stress on heritage structures.

In addition, expectation management is a central strategy for avoiding gaps between promotional promises and actual experiences. Managers should design multimodal communication campaigns—such as demonstration videos, in-museum previews, and staff-led orientation sessions—that accurately represent the AR/VR capabilities while transparently acknowledging technological limitations. By framing immersive applications as scientifically informed reconstructions rather than “time machines”, managers can build trust and improve confirmation, which in turn strengthens satisfaction.

Interactivity and multisensory design should be prioritized to foster deeper involvement. Managers can integrate auditory feedback (battle drums, ancient markets, environmental sounds), tactile cues (haptic vibrations when pushing open virtual gates), and even olfactory simulations (scents of incense, soil, or stone) to stimulate multiple senses simultaneously. Designing interactive narratives further strengthens emotional engagement: for example, tourists might be assigned historical missions such as commanding a military unit or reconstructing ceremonial rituals, where their decisions alter narrative trajectories. This “choice–consequence” design model transforms passive observation into active cultural participation, reinforcing both enjoyment and knowledge retention.

Finally, managers should adopt feedback-driven iteration cycles. By systematically collecting visitor feedback through post-experience surveys, analyzing behavioral data such as time spent in specific modules, and adjusting content accordingly, managers can continuously refine AR/VR offerings. Establishing interdisciplinary advisory panels of historians, designers, and psychologists can further ensure that the experiences remain scientifically accurate, esthetically engaging, and psychologically meaningful.

6.2.3. For Sustainable Tourism Innovation Technology Developer

Developers play a pivotal role in transforming theoretical constructs such as perceived ease of use and perceived usefulness into practical design outcomes. First, usability must be prioritized through intuitive interfaces and naturalistic interaction models. Implementing gesture recognition, gaze-based controls, and minimalistic diegetic interfaces can reduce learning barriers for first-time users. Iterative prototyping and multi-demographic user

testing—covering children, older adults, and international tourists—are necessary to ensure accessibility across diverse audiences.

Second, entertainment and educational value should be deliberately integrated rather than separated. Developers can embed gamified features such as cultural quizzes within VR storylines, design time-limited challenges where teams reconstruct virtual artifacts, or simulate dialogs with AI-driven historical avatars capable of adaptive responses. Such approaches simultaneously enhance enjoyment and deepen cultural understanding, directly addressing the dual goals of satisfaction and continuance intention.

Third, personalization must become a design principle. AI-driven adaptive systems can tailor experiences in real time, offering simplified explanations for novice users while providing expert-level archeological data for advanced learners. Developers could design modular content layers—basic, intermediate, advanced—that adapt dynamically to the user’s knowledge level and interests. Extending engagement beyond the physical site, developers should also provide post-visit continuity tools, such as mobile applications or VR portals that allow users to revisit content remotely, thereby sustaining long-term involvement.

Finally, developers must commit to sustainability in technological design. Lightweight, energy-efficient headsets, recyclable materials, and cloud-based content delivery systems can minimize environmental impact. Open-source frameworks could further ensure replicability and scalability across different heritage sites, democratizing access to immersive technologies while reducing costs.

6.2.4. For Policymakers

Policymakers have a crucial enabling role in aligning technological innovation with sustainable cultural tourism. One concrete strategy is to establish dedicated funding programs that support interdisciplinary collaborations among heritage institutions, universities, and technology firms. Such programs should prioritize projects that produce transferable toolkits and open-access platforms, ensuring scalability across regions rather than isolated case studies.

In addition, regulators should implement standards for transparency and authenticity in AR/VR marketing. Clear guidelines ought to require heritage sites to disclose which reconstructions are based on verified archeological data and which are speculative, thus preventing visitor dissatisfaction caused by inflated expectations. Regulatory bodies could also certify immersive applications with “authenticity labels”, signaling to tourists that the content meets minimum scientific and educational standards.

Sustainability should be embedded in all policy frameworks. AR/VR should be promoted not only as tools for enhancing interpretation but also as mechanisms to reduce physical strain on fragile heritage environments by offering virtual access to restricted or endangered areas. Policymakers can incentivize such practices through tax benefits, awards, or international recognition schemes that reward sites demonstrating environmental responsibility. Beyond funding, capacity-building initiatives are equally important: training programs for museum staff, grants for digital literacy among heritage professionals, and international knowledge-sharing platforms can ensure that immersive technologies are effectively implemented and continuously updated.

6.3. Limitations and Suggestions

Although this study provides empirical insights into tourists’ continuance intention toward sustainable tourism innovation technologies in the post-adoption phase, several limitations point to promising directions for future research.

First, this research employed a quantitative approach, which offers advantages such as high objectivity, reproducibility, scalability, and the ability to generalize findings through statistical inference. However, exclusive reliance on self-reported survey data risks overlooking deeper social, cultural, and psychological dynamics that shape individual decisions. For instance, intrinsic motivations, affective reactions, and identity-related dimensions of technology use are not easily captured through standardized questionnaires. To address this limitation, future research could adopt mixed-method approaches that combine large-scale surveys with qualitative techniques such as in-depth interviews, ethnographic observation, or focus groups discussions, thereby capturing the nuanced meanings tourists attribute to immersive experiences. Beyond self-reports, additional data sources should be incorporated to strengthen validity of findings. Behavioral usage logs and system analytics—including frequency of use, interaction duration, navigation patterns, and module completion rates—could provide objective measures of engagement that complement subjective perceptions. Similarly, physiological and biometric indicators such as gaze tracking, heart rate variability, or galvanic skin response could yield fine-grained evidence of real-time immersion and cognitive load. By triangulating quantitative, qualitative, behavioral, and physiological data, future studies could construct a more comprehensive explanatory framework that captures both the conscious evaluations and unconscious responses shaping continuance intention in immersive tourism contexts.

Second, this study relied on convenience sampling. Although this approach is widely used in tourism and technology adoption research, it inevitably introduces bias and may not perfectly represent the overall tourist population. We did not apply post-stratification or weighting adjustments because comparable population margins were unavailable for validation, and hypothetical adjustments might introduce model bias. Given that our objective was to test theoretically driven relationships (H1–H12) rather than to estimate population-level parameters, convenience sampling was deemed acceptable. Nevertheless, future research could mitigate such bias by adopting stratified sampling, quota sampling, or by applying weighting when population benchmarks are available, thereby increasing the representativeness of results.

Third, the study is limited to a single site—the Terracotta Warriors Museum in Xi'an. While this UNESCO World Heritage site provides a globally significant and symbolically rich context, its unique cultural profile restricts the external validity of findings. Future research should therefore pursue cross-cultural replication and comparative case studies across multiple heritage sites, both within China and internationally. In particular, it is important to test whether the determinants of continuance intention identified here—such as perceived usefulness, satisfaction, and interactivity—hold consistent explanatory power in Western museums, where visitor expectations may emphasize individualized learning and interactive autonomy, or in less digitally developed contexts, where infrastructural constraints, limited device availability, and differing digital literacy levels may alter technology acceptance pathways. Such comparative analyses would clarify whether the mechanisms observed in a high-profile, technologically advanced UNESCO site like the Terracotta Warriors Museum are transferable to institutions with different cultural missions, governance models, or resource capacities. Moreover, multi-site longitudinal research could trace how tourists' engagement evolves across repeated exposures and over time, offering insight into whether stated continuance intentions translate into actual sustained usage. Expanding the scope to include diverse visitor demographics—such as older adults, international tourists, or educational groups—would further enrich understanding of heterogeneous adoption mechanisms and reveal how individual differences mediate the influence of technology attributes on long-term engagement.

Fourth, potential response bias should also be acknowledged. Social desirability bias or the excitement effect of visiting a world-renowned heritage site may have influenced respondents' answers. To minimize this, we assured anonymity, allowed respondents to complete the survey independently in settings away from museum staff, employed neutral wording, and randomized item presentation. Furthermore, data were collected at the museum exit after visitors had some time to calm down, which helped mitigate immediate emotional intensity. Future research could further address response bias by employing indirect questioning techniques, implicit measures, or triangulation with behavioral and physiological data.

Finally, the data collection period was relatively short—ten consecutive days in July 2025. While this ensured efficiency and consistency, it may not capture seasonal variation in visitor demographics, motivations, or experiential patterns. Future research should therefore consider multi-seasonal or year-round data collection to assess how continuance intention may fluctuate across different tourism cycles, holidays, or climatic conditions.

In sum, future research should move beyond single-site, convenience-sample, and survey-only approaches to incorporate mixed methods, behavioral usage data, cross-cultural comparative designs, and multi-seasonal sampling strategies. Such methodological and contextual diversification would not only strengthen the robustness and external validity of findings but also generate more holistic insights into the mechanisms that drive sustained engagement with AR/VR-based sustainable tourism innovations.

7. Conclusions

This study examined the determinants of tourists' continuance intention toward AR/VR applications in the Terracotta Warriors Museum, offering empirical evidence from a UNESCO World Heritage context. By integrating the Expectation Confirmation Model (ECM) with experiential attributes of immersive technologies—namely visual appeal, entertainment, enjoyment, interactivity, and involvement—this study developed and validated a hybrid model that advances understanding of post-adoption behavior in sustainable heritage tourism. The findings indicate that involvement, perceived usefulness, and satisfaction exert the strongest direct influences on continuance intention, while enjoyment, confirmation, and interactivity play significant indirect roles via mediating pathways. These results enrich theoretical perspectives on technology adoption by demonstrating how cognitive evaluations and experiential dimensions jointly shape sustained engagement with immersive heritage applications.

Overall, this study contributes a comprehensive theoretical framework that bridges information systems theory and cultural heritage practice. It not only advances academic discourse on post-adoption behavior in immersive tourism technologies but also provides a foundation for future research examining the integration of spatial heritage attributes and digital media in promoting sustainable visitor engagement.

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Abbreviations

The following abbreviations are used in this manuscript:

ECM	Expectation Confirmation Model
ECM-IS	Expectation-Confirmation Model-Information System
SEM	Structural Equation Model
AR	Augmented reality
VR	Virtual reality
VA	Visual appeal
ENT	Entertainment
ENJ	Enjoyment
INV	Involvement
INT	Interactivity
SAT	Satisfaction
CI	Continuance Intention
CNF	Confirmation
PU	Perceived usefulness
PEOU	Perceived ease of use

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