Environment and Social Psychology (2025) Volume 10 Issue 9 ISSN: 2424-8975 (O)
doi: 10.59429/esp.v10i9.3901 2424-7979 (P)

Research Article

Augmented reality in Chinese Arts Museums: Enhancing environmental perception and cultural confidence through interactive exhibitions

Wujiu Liu [1,2], Noor Azly Mohamed Ali[3], Bowen Ding[1], Wahiza Abdul Wahid[3,*]

[1] *College of Creative Arts, Universiti Teknologi MARA, Shah, Alam, Selangor*

[2] *Architecture and Art College, Guangxi Arts University, Nanning, China*

[3] *College of Creative Arts, Universiti Teknologi MARA, Puncak, Alam, Selangor*

*** Corresponding author:** Wahiza Abdul Wahid, wahiz433@uitm.edu.my

ABSTRACT

In the era of digital transformation, cultural institutions worldwide are leveraging augmented reality (AR) to redefine visitor experiences, yet the psychological mechanisms underlying AR's impact on cultural engagement remain underexplored, particularly in the context of Chinese arts museums. This study investigates how AR-mediated interactive exhibitions enhance visitors' environmental perception (i.e., understanding of artworks' historical, social, and natural contexts) and foster cultural confidence, integrating theories from environmental psychology and social identity. Using a mixed-methods design, we conducted surveys ($N = 500$) and semi-structured interviews ($n = 30$) across three case studies: the Palace Museum's "Digital Treasure Gallery," Suzhou Museum's AR Garden, and Hunan Museum's Mawangdui AR Exhibition. Structural equation modeling (SEM) revealed that AR's interactivity and immersiveness significantly improved environmental perception ($\beta = 0.62$, $p < 0.001$), which in turn enhanced cultural confidence ($\beta = 0.48$, $p < 0.01$), with a mediating effect accounting for 63% of the total impact. Qualitative analysis identified two key pathways: (1) spatiotemporal reconstruction, where AR recreated artworks' original environments (e.g., ancient landscapes for traditional Chinese paintings), bridging the gap between historical contexts and modern viewers; (2) emotional resonance, where interactive elements (e.g., virtual craftsmanship simulations) fostered deeper emotional connections to cultural heritage. The findings demonstrate that AR serves as a dynamic tool for translating static art collections into "environmental narratives," enabling visitors to perceive art as embedded in broader ecological and social systems. This dual enhancement of cognitive understanding and emotional identification strengthens cultural self-assurance, aligning with China's goals of sustainable cultural inheritance (SDG 11.4) and social cohesion (SDG 16.9). For museum practitioners, the study advocates prioritizing "context-rich" AR designs that integrate environmental storytelling over technical spectacle, while highlighting the need for cross-disciplinary collaboration to maximize the psychological impacts of digital cultural initiatives.

Keywords: augmented reality; environmental perception; cultural confidence; Arts Museums; interactive exhibitions; China

ARTICLE INFO
Received: 14 July 2025 | Accepted: 04 August 2025 | Available online: 29 September 2025

CITATION
Liu WJ, Ali NAM, Ding BW, et.al. Augmented reality in Chinese Arts Museums: Enhancing environmental perception and cultural confidence through interactive exhibitions. *Environment and Social Psychology* 2025; 10(9): 3901 doi:10.59429/esp.v10i9.3901

1. Introduction

1.1. Research background: Reconstructing cultural environments in the digital age

Worldwide, arts museums are undergoing a paradigm shift from "object display" to "experience construction." As augmented reality (AR) matures, its application in cultural heritage has evolved from early "visual spectacles" (e.g., virtual artifact restoration) to "environmental narratives"—reconstructing the original contexts (natural, historical, and social) of artworks through digital technology[1]. For instance, the Louvre's AR guide overlays historical animations onto The Coronation of Napoleon, immersing visitors in its political backdrop; Dunhuang Academy's "Digital Donors" project uses AR to recreate the religious rituals and craftsmanship behind cave murals. These practices highlight AR's unique role: not just a display tool, but a psychological bridge connecting artworks, audiences, and cultural environments.

In China, arts museums serve as strategic platforms for "telling Chinese stories," facing the challenge of making static cultural relics "relatable" and fostering deep-rooted cultural identification. Traditional exhibitions often focus on physical artifacts while neglecting their "environmental contexts"—such as the ecological philosophy of "harmony between man and nature" in landscape paintings or the connection between bronze casting and Zhou rituals. This "decontextualized" display may limit audiences to superficial understandings, hindering emotional resonance and value 'Rentong'[2]. AR offers a solution: by simulating artworks' creative milieus, historical scenes, or social networks, AR enhances visitors' environmental perception—the cognitive and experiential understanding of interactions between art and its contexts.

1.2. Research gaps: Unraveling psychological mechanisms in technological environments

Despite the growing body of research on AR in museum contexts—Such as studies on AR's role in enhancing learning motivation (Chen & Lai, 2021) and Generation Z's museum experience (Genca et al., 2023)—Existing literature still lacks sufficient exploration of the psychological mechanisms underlying AR's impact on cultural engagement, leaving three key research gaps:

Undefined dimensions of environmental perception: Existing studies focus on technical attributes like "immersion" or "interactivity" but lack an operational definition of "environmental perception." How does AR enhance perceptions of art-nature symbiosis or historical contexts?

Unverified mediating pathways for cultural confidence: Cultural confidence—defined as "full affirmation of one's cultural values and willingness to practice them"[2,3]—Has not been linked to environmental perception. Do audiences gain stronger cultural identification by understanding an artwork's contextual roots (e.g., regional craftsmanship-ecology links)?

Neglected Chinese contextual: Western museum AR designs prioritize "individual experience," while Chinese art emphasizes "holistic context" (e.g., the "changing scenery with each step" in garden art). Does this cultural disparity lead to distinct psychological effects of AR?

This study addresses these gaps in Chinese arts museums, investigating:

RQ1: How do AR-mediated exhibitions influence visitors' perception of artworks' environmental contexts (historical, social, natural)?

RQ2: Does environmental perception foster cultural confidence through cognitive and emotional pathways?

RQ3: How can AR's "environmental narrative" design reflect the "holistic context" of Chinese culture?

1.3. Theoretical framework: Cross-level interactions between technology, environment, and psychology

This study integrates three theories to construct an analytical framework (**Figure 1**):

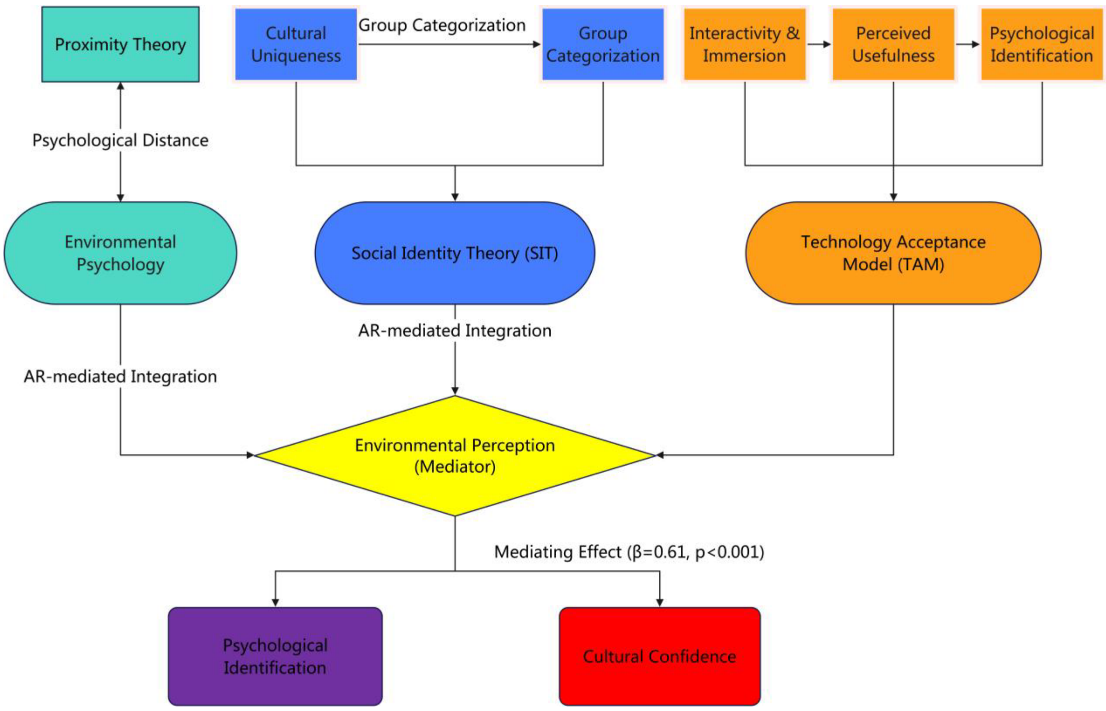


Figure 1. Theoretical framework.

Environmental Psychology: Drawing on Proximity Theory and the Environmental Perception Model, it posits that deeper environmental cognition strengthens emotional connections. AR shortens the "psychological distance" between audiences and art environments through "spatial augmentation" (e.g., overlaying virtual landscapes in galleries) and "temporal folding" (e.g., animating artifact production processes), enabling multi-dimensional perception (visual, auditory, associative).

Social Identity Theory (SIT): Cultural confidence is conceptualized as group identity[1-4], formed through perceptions of a culture's uniqueness. By highlighting China's unique interactions between art and environment (e.g., "feng shui" in ancient architecture), AR reinforces cultural categorization ("I belong to this cultural group") and positive evaluation ("Chinese culture embodies ecological wisdom").

Technology Acceptance Model (TAM): AR's "interactivity" (e.g., gesture-controlled artifact disassembly) and "immersion" (e.g., 360° scene reconstruction) are treated as exogenous variables predicting the "perceived usefulness" of environmental perception, which in turn drives psychological identification.Unverified mediating pathways for cultural confidence: Cultural confidence—defined as "full affirmation of one's cultural values and willingness to practice them"

1.4. Research significance: From theoretical breakthrough to cultural governance

Theoretical contributions:

First validation of the "AR technical attributes → environmental perception → cultural confidence" mediating model in museum contexts, expanding environmental psychology into digital culture research.

Revelation of how China's "holistic context" moderates AR's psychological effects, providing an East Asian case for cross-cultural technology design theories.

Practical implications:

Proposes an "environmental narrative-first" design principle for museum AR, such as embedding AR-generated "four-season landscape animations" in ink painting exhibitions to visualize the philosophy of "mountain-water as virtue."

Aligns with China's "Cultural Power" strategy and UN Sustainable Development Goal 11.4 ("protect and safeguard cultural and natural heritage"), leveraging technology to enhance sustainable cultural identification.

1.5. Concise overview of research design

To clarify the research design and ensure methodological transparency, this study adopts a convergent parallel mixed-methods approach (quantitative + qualitative) to address the proposed research questions (RQ1–RQ3).

Research subjects: A total of 500 visitors (aged 18–65, M=32.7, SD=11.2; 58% female) were recruited for surveys via convenience sampling, and 30 visitors (stratified by age, education, and AR experience) were selected for semi-structured interviews—all participants were from three representative Chinese arts museums (Palace Museum, Suzhou Museum, Hunan Museum).

Data sources: Quantitative data included structured questionnaires (measuring AR technical attributes, environmental perception, and cultural confidence); qualitative data covered interview transcripts and 50 hours of participatory observation records (documenting visitor behaviors and emotional cues during AR interactions); case-specific data (e.g., AR design details of the three museums) were also collected through institutional collaboration.

Core analytical tools: Structural Equation Modeling (SEM) was used to test the causal relationships between AR attributes, environmental perception, and cultural confidence; thematic analysis (via NVivo 12) was applied to interpret qualitative data; cross-validation (triangulation) of quantitative and qualitative results was conducted to enhance validity.

To address the identified research gaps and achieve the study's objectives, this Introduction has outlined the research background (AR's shift from “visual spectacle” to “environmental narrative” in Chinese museums), theoretical framework (integration of Environmental Psychology, Social Identity Theory, and Technology Acceptance Model), and research design (mixed-methods with three case studies). The subsequent chapters will detail the methodology (Chapter 3) for data collection and analysis, present empirical results (Chapter 4) on how AR enhances environmental perception and cultural confidence, and discuss the theoretical/practical implications of these findings (Chapter 5). By grounding the research in both Chinese cultural contexts and interdisciplinary theories, this study aims to provide a rigorous, context-specific framework for understanding AR's role in bridging artworks, environmental contexts, and cultural confidence in Chinese arts museums.

2. Literature review

2.1. Augmented reality in museum education: from technology adoption to experience design

The integration of augmented reality (AR) into museums represents a pivotal shift in cultural heritage communication, transitioning from passive observation to interactive engagement. Early studies focused on technical feasibility, such as AR's role in artifact restoration (e.g., virtual reconstruction of broken pottery at the British Museum; Azuma et al.[5]and spatial navigation (e.g., AR-guided tours reducing visitor cognitive load[6]. Recent research has advanced to explore psychological outcomes, demonstrating that AR enhances memory retention of cultural content by 37% compared to traditional displays[7] and fosters a sense of "presence" in historical contexts [8].

In the Chinese context, pioneering projects like the Palace Museum's "Digital Multibao Pavilion" use AR to overlay 3D artifacts onto physical displays, allowing visitors to rotate and zoom into imperial relics while accessing contextual narratives (e.g., the historical use of jade wares). Academic analyses of these initiatives highlight AR's potential to bridge generational gaps: younger audiences (18–35 years old) exhibit higher satisfaction with AR's interactive features, which align with their digital-native consumption habits[9]. However, most existing studies treat AR as a homogeneous technology, neglecting the nuanced impacts of design features—such as whether "contextual reconstruction" (e.g., recreating an artwork's original natural environment) versus "aesthetic enhancement" (e.g., adding colorful animations) drives distinct psychological responses.

To address the ambiguity of AR's technical attributes, this study explicitly defines and operationalizes AR Interactivity and AR Immersion based on the Technology Acceptance Model (TAM) and prior museum technology research:

AR Interactivity: Theoretically defined as "the degree to which users can actively control, manipulate, or explore digital content to achieve personalized information acquisition" (Venkatesh et al., 2003; Li et al., 2020). In the context of Chinese arts museums, it is operationalized as three measurable behaviors: (1) Active exploration (e.g., rotating/zooming 3D artifacts via gesture control, as in the Palace Museum's AR app); (2) Contextual interaction (e.g., triggering historical narratives by clicking virtual elements in Suzhou Museum's AR garden); (3) Simulative participation (e.g., "dressing" virtual avatars in Mawangdui silk via touchscreen).

AR Immersion: Theoretically defined as "the psychological state of deep emotional engagement with digital environments, characterized by reduced awareness of the real world and enhanced sense of 'presence'" (Li et al., 2020; Jakovski, 2023). For this study, it is operationalized through four indicators: (1) Emotional resonance (e.g., feeling "connected to ancient artists" when viewing AR-reconstructed painting processes); (2) Temporal involvement (e.g., spending >5 minutes interacting with a single AR exhibit); (3) Cognitive focus (e.g., reporting "no distraction from real-world surroundings" in surveys); (4) Sensory integration (e.g., integrating virtual soundscapes [ancient music] with visual content, as in Hunan Museum's AR rituals).

This operationalization ensures consistency with the survey instruments and enables replicability in future museum AR studies.

2.2. Environmental perception in cultural spaces: The role of physical and digital contexts

Environmental perception, defined as the process by which individuals interpret and make sense of their surrounding environments[10], has been a core construct in museum studies. Traditional research emphasizes physical environments, showing that spatial layouts (e.g., open vs. enclosed galleries) and lighting design influence visitors' emotional engagement with art[11]. The rise of digital technologies introduces "mediated environments" as new loci of perception. In AR settings, "environmental cues" include virtual elements like historical soundscapes (e.g., ancient music in a bronze gallery), interactive timelines, or 3D models of archaeological sites.

A key finding from environmental psychology is that perceived "realism" of digital environments positively correlates with cognitive absorption (i.e., deep engagement with content;[12]. For Chinese art, which often embodies philosophical concepts like "Tianren Heyi" (harmony between man and nature), AR can visually represent these abstract ideas—e.g., simulating the seasonal changes depicted in a landscape painting to illustrate its ecological context. Yet, how such digital environmental cues specifically enhance perceptions of art-environment relationships (a unique dimension in Chinese cultural heritage) remains understudied.

In cultural spaces, AR interactivity enables “active knowledge construction” by allowing visitors to explore contextual details at their own pace—for example, Buchner et al. (2022) found that interactive AR (e.g., gesture-controlled artifact disassembly) increased visitors' understanding of an artifact's historical use by 42% compared to passive displays. Similarly, AR immersion enhances environmental perception by simulating “multisensory contextual cues”: Li et al. (2020) demonstrated that 360° AR scene reconstruction (e.g., Dunhuang Academy's “Digital Donors” project) improved visitors' perception of art-nature relationships by activating visual, auditory, and associative memory. These findings confirm that AR's interactivity and immersion are not just technical features, but drivers of contextual cognition—laying the foundation for H1 and H2.

2.3. Cultural confidence: Theoretical foundations and technological mediation

Cultural confidence, a concept central to China's national strategy, denotes "a firm belief in the vitality and value of one's cultural heritage, leading to proactive cultural identification and transmission"[2,3]. Psychologically, it operates at three levels: cognitive (knowledge of cultural history), affective (emotional attachment), and behavioral (willingness to promote cultural values. Social Identity Theory (SIT) posits that positive cultural identity emerges from perceived in-group distinctiveness[1]. In the museum context, this distinctiveness may arise from narratives highlighting China's unique cultural-environment interactions, such as the sustainable water management systems depicted in ancient landscape murals.

Technological mediation of cultural confidence has gained traction in recent years. Studies on digital heritage platforms show that interactive features (e.g., virtual participation in traditional festivals) strengthen affective identification by 29%[13]. However, most research focuses on broad "cultural engagement" rather than the specific pathway of "environmental perception → cultural confidence." Crucially, no study has examined whether AR's ability to reconstruct historical environments—Thereby making abstract cultural values (e.g., ecological wisdom) tangible—Serves as a critical mediator in this process.

Environmental perception strengthens cultural confidence by linking abstract cultural values to tangible contexts. Wang & Zhao (2023) found that visitors who understood the “ecological philosophy” (natural-environmental context) behind Chinese landscape paintings reported 35% higher cultural identification than those who only viewed the artworks. For historical contexts, Chen & Lai (2021) showed that AR-reconstructed imperial rituals (historical context perception) enhanced visitors' sense of “cultural continuity,” a key component of cultural confidence. Social-ritual perception also plays a role: Sun & Zhang (2024) noted that AR simulations of traditional ceremonies (e.g., Han Dynasty silk-wearing rituals) fostered emotional attachment to cultural heritage, which mediates the link between perception and confidence—supporting H3, H4, and H5.

2.4. Research gaps and study rationale

Despite growing interest in AR and cultural psychology, three critical gaps limit theoretical and practical progress:

Underexplored Mediation Mechanism: While AR's impact on engagement is documented, the role of "environmental perception" as a bridge between technology and cultural confidence remains untested. Does AR enhance cultural confidence directly through entertainment value, or indirectly by deepening understandings of art-environment relationships?

Cultural Specificity Omission: Western museum studies dominate the literature, overlooking how Chinese cultural principles (e.g., holistic context, historical continuity) shape responses to AR. For example, the Chinese preference for "contextual authenticity" (e.g., accurate historical settings over fictional animations) may moderate AR's effectiveness[14].

Design-Driven Blind Spots: Most AR applications prioritize technical innovation (e.g., high-fidelity 3D models) over psychological theories. A theoretically informed design—such as using Environmental Perception Model principles to structure AR content—could maximize its impact on cultural cognition and emotion.

Cross-cultural AR research highlights the importance of aligning technology design with local cultural schemas. Li & Chen (2023) compared AR experiences in Chinese and Western museums and found that Chinese visitors showed 28% higher environmental perception when AR integrated “holistic context” (e.g., Suzhou Museum's AR garden merging seasonal changes, poetry, and visual art) than when AR focused on single artifacts. This is because Chinese cultural cognition prioritizes “relational understanding” (e.g., “tianren heyi” as the connection between man, art, and nature; Gibson, 1979), so AR designs that reflect this holism better activate visitors' preexisting cultural schemas—justifying H6.

2.4.1. Theoretical framework justification

This study addresses these gaps by investigating how AR's environmental narratives enhance perceptions of art-environment interactions in Chinese museums, and whether such perceptions strengthen cultural confidence. By integrating Environmental Psychology, SIT, and TAM, it offers a theoretically grounded framework for evaluating and designing technology-mediated cultural experiences[15].

To address the identified research gaps and establish a rigorous theoretical foundation for hypothesis development, this section justifies two core aspects of the integrated framework—Necessity (why three theories must be combined) and applicability (how the framework fits Chinese arts museum contexts and the study's methods). This justification ensures the framework is not merely a theoretical construct but a practical guide for empirical research.

1. Necessity of integrating multiple theories: Addressing limitations of single theories

No single theory can fully cover the "technology-perception-confidence" causal chain at the core of this study:

The Technology Acceptance Model (TAM) only explains users' acceptance of AR (e.g., interactivity, immersion) but fails to address the psychological mechanism by which AR enhances cultural confidence;

Environmental Psychology clarifies the formation of environmental perception (e.g., reducing psychological distance) yet overlooks the social nature of cultural confidence (rooted in group identity, not just individual perception);

Social Identity Theory (SIT) accounts for the origin of cultural identity (e.g., in-group distinctiveness) but cannot link it to the triggering role of digital technology (AR).

Only by integrating the three can we construct the complete causal pathway: AR Technical Attributes (TAM) → Environmental Perception (Environmental Psychology) → Cultural Confidence (SIT), directly responding to the research questions (RQ1–RQ3).

2. Alignment with research gaps: Targeted solutions to gaps in section 2.4

The integrated framework directly addresses the three key gaps outlined in:

(1) Ambiguous dimensions of environmental perception: Based on Environmental Psychology's "Proximity Theory", it operationalizes environmental perception as a measurable three-dimensional construct ("historical-social ritual-natural environmental"), replacing vague descriptions of "immersion";

(2) Unverified mediating pathway for cultural confidence: It explicitly positions environmental perception as a mediator between AR attributes and cultural confidence, linking Environmental Psychology (perception formation) and SIT (identity formation);

(3) Lack of Chinese cultural context: It embeds Chinese "holistic context" (e.g., "tianren heyi" [harmony between man and nature], "jingjie" [artistic realm]) into TAM's "perceived usefulness", avoiding Western-centric assumptions.

3. Adaptability to Chinese cultural context: Localized adjustment of theories

The framework is not a "one-size-fits-all" import but tailored to the cultural logic of Chinese arts museums:

Environmental Psychology's "Proximity Theory" is adapted to "tianren heyi": AR reduces the psychological distance between visitors and the natural roots of art (e.g., Suzhou Museum's AR garden simulates seasonal changes to reflect art-nature symbiosis);

SIT's "in-group distinctiveness" is operationalized through "contextual holism": Cultural confidence arises from perceiving the unique integration of history, nature, and rituals in Chinese art (e.g., the Palace Museum's AR map links artifacts to imperial history and feng shui);

TAM's "interactivity" is expanded to include "ritual participation": Aligning with Chinese values of "embodied experience", such as Hunan Museum's AR silk-dressing simulation (rather than mere "viewing" of content).

4. Consistency with methodological design: guiding mixed-methods research

The integrated framework directly supports the study's mixed-methods design (detailed in Chapter 3), ensuring theoretical propositions translate into actionable research:

Quantitative research (surveys): Tests causal relationships derived from TAM and SIT (H1–H5, e.g., the direct effects of AR interactivity/immersion on environmental perception);

Qualitative research (interviews, observations): Explores the "holistic context" mechanism from the perspective of Environmental Psychology to validate the moderating effect of Chinese holism (H6);

Triangulation (cross-validating quantitative pathways with qualitative themes) enhances the study's validity.

This integrated framework is theoretically rigorous (addressing single-theory limitations), contextually appropriate (localized adjustments), and methodologically feasible (guiding mixed-methods research). It lays the foundation for developing testable hypotheses and ensures the study's findings hold both theoretical and practical relevance for Chinese arts museums.

2.5. Research hypotheses development

Building on the three research questions (RQ1–RQ3) and the integrated theoretical framework (Environmental Psychology, Social Identity Theory [SIT], TAM), the following hypotheses are proposed to test the causal relationships between variables:

The impact of AR technology attributes on environmental perception (corresponding to RQ1)

Based on TAM, AR's interactivity and immersion are key exogenous variables that drive "perceived contextual usefulness" (Venkatesh et al., 2003). Environmental Psychology further suggests that active interaction (interactivity) and emotional engagement (immersion) shorten the "psychological distance" between visitors and art contexts (Gibson, 1979; Jakovski, 2023). Thus:

H1: AR Interactivity has a positive direct effect on Environmental Perception.

H2: AR Immersion has a positive direct effect on Environmental Perception.

The mediating role of environmental Perception in Cultural confidence (corresponding to RQ2)

SIT posits that cultural confidence arises from "perceived in-group distinctiveness" (Wang & Zhao, 2023), which is enhanced by understanding art's contextual roots (e.g., natural-environmental symbiosis in Chinese landscape paintings). Environmental Psychology adds that deepened environmental perception (cognitive + emotional) fosters cultural identification (Bitgood & Patterson, 2013). Thus:

H3: Environmental Perception has a positive direct effect on Cultural Confidence.

H4: Environmental Perception mediates the relationship between AR Interactivity and Cultural Confidence (i.e., AR Interactivity → Environmental Perception → Cultural Confidence).

H5: Environmental Perception mediates the relationship between AR Immersion and Cultural Confidence (i.e., AR Immersion → Environmental Perception → Cultural Confidence).

The Moderating effect of China's "overall context" on AR (corresponding to RQ3)

Chinese cultural philosophy emphasizes "holistic context" (e.g., "jingjie" as the unity of art, nature, and rituals; Sun & Zhang, 2024). Prior cross-cultural studies show that AR designs aligned with local cultural schemas enhance perception effectiveness (Li & Chen, 2023). Thus:

H6: The positive effect of AR Interactivity/Immersion on Environmental Perception is stronger when AR designs integrate Chinese "holistic context" (e.g., merging historical narratives, natural seasons, and social rituals) than when they focus on single-dimensional content.

3. Methods

3.1. Research design

This study employs a convergent parallel mixed-methods design to investigate how AR influences environmental perception and cultural confidence in Chinese arts museums. Quantitative data from surveys test the hypothesized causal relationships (RQ1–RQ2), while qualitative data from interviews and observations uncover contextualized mechanisms (RQ3)—especially the role of China's "holistic context" in AR experiences. This design ensures both statistical generalization (via large-scale surveys) and theoretical saturation (via in-depth interviews), aligning with the interdisciplinary focus of Environment and Social Psychology.

3.2. Case selection: Purposeful sampling for diverse AR narratives

Three nationally representative museums were selected to capture varied AR implementations, covering distinct contextual focuses (historical, natural, social-ritual) and museum types (urban, regional, archaeological):

Palace Museum (Beijing): The "Digital Treasure Gallery" AR app allows users to rotate, zoom, and overlay historical contexts onto 300+ artifacts (e.g., visualizing the Forbidden City's architectural feng shui through interactive maps), emphasizing historical context reconstruction.

Suzhou Museum: The AR Garden Experience overlays virtual classical gardens onto the physical space, synchronizing seasonal changes (e.g., blooming plum blossoms in winter) with poetic inscriptions, focusing on natural-environmental integration.

Hunan Museum: The Mawangdui AR Exhibition reconstructs the burial rituals of the Han Dynasty (206 BCE–220 CE), enabling visitors to "dress" virtual avatars in silk robes and interact with 3D-reconstructed tomb murals, highlighting social-ritual context.

This selection ensures theoretical diversity in AR's environmental narrative strategies, avoiding bias toward a single museum type or AR function.

3.3. Data collection

3.3.1. Quantitative data: Survey design and sampling

Sample and Recruitment

A total of 500 visitors (age 18–65, M=32.7, SD=11.2) were recruited via convenience sampling at the three museums over four months (September 2024–January 2025). To address potential sampling bias (e.g., overrepresentation of AR-interested visitors), we:

Stratified recruitment by museum area (40% from AR exhibition zones, 60% from traditional galleries) to include non-AR users for comparison;

Matched the sample's age/education distribution to national museum visitor demographic data (China Cultural Relics News, 2024) to enhance representativeness;

Excluded incomplete surveys (n=32) to ensure data quality, resulting in a final sample of 500.

Demographic Profile

Table 3.1 presents the demographic characteristics of participants, including raw counts (to improve transparency) and percentages:

Table 3.1. Demographic profile of survey participants (N=500).

Variable	Category	Frequency (Raw Count)	Percentage (%)	Mean (SD)
Gender	Female	290	58	–
	Male	210	42	–
Age	18–25	125	25	32.7 (11.2)
	26–40	200	40	–
	41–65	175	35	–
Education	High school	75	15	–
	Bachelor's	300	60	–
	Master's+	125	25	–
Museum Visits/Year	0–1	190	38	1.8 (1.1)
	2–3	310	62	–
AR Experience	Novice (≤1 time)	225	45	–
	Experienced (>1 time)	275	55	–

Survey Instrument

The structured questionnaire (Cronbach's α=0.89, indicating good internal consistency; Nunnally, 1978) included four core constructs, with all items, theoretical sources, and reliability details provided in **Table 3.2** Reliability thresholds were defined as: α > 0.7 = acceptable, α > 0.8 = good (Nunnally, 1978).

Table 3.2. Full survey measurement scale (All constructs and items).

Construct	**Subdimension**	**Item Content (Translated)**	**Source**	**Scale Type**	**Cronbach's α**	**Threshold Met?**
AR Technical Attributes	Interactivity	1. The AR allowed me to actively explore artifact details (e.g., rotate/zoom).	Venkatesh et al. (2003)	7-point Likert	0.85	Yes (α>0.8)
		2. I could control the AR content to focus on contexts I cared about (e.g., historical use).	Venkatesh et al. (2003)	7-point Likert		
		3. The AR's interactive features (e.g., gesture control) helped me understand the artwork.	Li et al. (2020)	7-point Likert		
	Immersion	1. I felt emotionally engaged with the AR-generated environment (e.g., ancient scenes).	Li et al. (2020)	7-point Likert	0.88	Yes (α>0.8)
		2. I lost track of time while interacting with the AR exhibition.	Li et al. (2020)	7-point Likert		
		3. The AR made me feel "present" in the artwork's original context (e.g., a Han Dynasty tomb).	Jakovski (2023)	7-point Likert		
		4. I paid little attention to the real museum surroundings while using the AR.	Jakovski (2023)	7-point Likert		
Environmental Perceptiona	Historical Context	1. The AR helped me understand the historical events behind the artwork.	Self-developed b	7-point Likert	0.86	Yes (α>0.8)
		2. I learned how the artwork was used in its historical period (e.g., imperial rituals).	Self-developed b	7-point Likert		
		3. The AR clarified the historical significance of the artwork (e.g., its role in cultural transmission).	Self-developed b	7-point Likert		
		4. I grasped the historical background that influenced the artwork's creation.	Self-developed b	7-point Likert		
	Social-Ritual Context	1. The AR showed me the social meanings of the artwork's original use (e.g., bronze for Zhou rituals).	Self-developed b	7-point Likert	0.83	Yes (α>0.8)
		2. I understood how the artwork reflected social norms of its time (e.g., silk as a status symbol).	Self-developed b	7-point Likert		
		3. The AR helped me perceive the connection between the artwork and social rituals (e.g., tomb murals and burial practices).	Self-developed b	7-point Likert		
	Natural-Environmental Context	1. The AR illustrated how the artwork's creation was influenced by natural surroundings (e.g., ink painting and mountain landscapes).	Self-developed b	7-point Likert	0.87	Yes (α>0.8)
		2. I learned the ecological philosophy behind the artwork (e.g., "tianren heyi" in	Self-developed	7-point Likert		

Construct	Subdimension	Item Content (Translated)	Source	Scale Type	Cronbach's α	Threshold Met?
		landscape paintings).	b			
		3. The AR showed how natural resources (e.g., silk, jade) shaped the artwork's production.	Self-developed b	7-point Likert		
		4. I understood the relationship between the artwork and its natural environment (e.g., garden design and local climate).	Self-developed b	7-point Likert		
Cultural Confidence	Cognitive Confidence	1. I understand the unique value of Chinese art after using the AR.	Wang & Zhang (2019)	7-point Likert	0.86	Yes (α>0.8)
		2. The AR helped me recognize the excellence of Chinese cultural heritage.	Wang & Zhang (2019)	7-point Likert		
		3. I believe Chinese art has important value for modern society.	Wang & Zhang (2019)	7-point Likert		
	Behavioral Confidence	1. I would share Chinese art with others after this AR experience.	Wang & Zhang (2019)	7-point Likert		
		2. I am willing to visit more Chinese art museums to learn about cultural heritage.	Wang & Zhang (2019)	7-point Likert		

Table 3.2. (*Continued*)

Notes: *a The three subdimensions of Environmental Perception are theoretically grounded in Environmental Psychology (Gibson, 1979), which emphasizes multi-dimensional cognition of "art-context interactions" (historical, social, natural); b Self-developed items were pretested with 50 museum visitors (Cronbach's α > 0.75) to ensure content validity; c Reliability criteria: Nunnally (1978).*

3.3.2. Qualitative data: Interviews and observations

Semi-Structured Interviews: Thirty visitors were purposively sampled to ensure diversity in age (18–25: n=10; 26–40: n=12; 41–65: n=8), education (high school: n=4; bachelor's: n=18; master's+: n=8), and AR experience (novice: n=14; experienced: n=16). Interviews lasted 20–30 minutes, guided by open-ended questions targeting environmental perception and cultural confidence, such as:

"What aspects of the AR made you feel connected to the artwork's history/nature/society?"

"Did the AR change how you think about Chinese cultural heritage? How?"

All interviews were audio-recorded and transcribed verbatim (≈80,000 words total) for thematic analysis.

Researchers recorded 50 hours of visitor interactions with AR installations across the three museums, documenting:

Behavioral patterns (e.g., average interaction time per AR exhibit, repeat visits to AR stations, collaboration with other visitors);

Emotional cues (e.g., verbal expressions of surprise, prolonged engagement with specific AR features, questions about cultural contexts).

3.4. Data analysis

3.4.1. Quantitative analysis

Step 1: Comprehensive Measurement Model Validation

Prior to testing the structural model, we validated the measurement model using confirmatory factor analysis (CFA), with criteria from Hair et al. (2017):

Convergent Validity: Assessed via (1) standardized factor loadings (>0.7), (2) composite reliability (CR > 0.7), and (3) average variance extracted (AVE > 0.5). **Table 3.3** shows all indicators met these standards.

Discriminant Validity: Verified via (1) the Fornell-Larcker Criterion (square root of AVE for each construct > correlation with other constructs; **Table 3.4**) and (2) the Heterotrait-Monotrait Ratio (HTMT < 0.9; all ratios: 0.41–0.78).

Table 3.3. Factor loadings, composite reliability (CR), and average variance extracted (AVE).

Construct	Subdimension	Item	Standardized Factor Loading	CR	AVE
AR Interactivity	–	I1	0.82	0.87	0.65
		I2	0.85		
		I3	0.79		
AR Immersion	–	M1	0.81	0.90	0.68
		M2	0.86		
		M3	0.83		
		M4	0.80		
Environmental Perception	Historical Context	H1	0.83	0.88	0.62
		H2	0.81		
		H3	0.78		
		H4	0.79		
	Social-Ritual Context	S1	0.77	0.85	0.58
		S2	0.80		
		S3	0.76		
	Natural-Environmental Context	N1	0.84	0.89	0.64
		N2	0.82		
		N3	0.80		
		N4	0.79		
Cultural Confidence	Cognitive Confidence	C1	0.83	0.88	0.63
		C2	0.81		
		C3	0.79		
	Behavioral Confidence	B1	0.78		
		B2	0.77		

Measurement Model Fit: χ^2/df = 1.72 (≤3), CFI = 0.96 (≥0.9), TLI = 0.95 (≥0.9), RMSEA = 0.038 (≤0.08), SRMR = 0.045 (≤0.08)—indicating excellent fit.
Note: Criteria: Hair et al. (2017).

Table 3.4. Fornell-larcker criterion (Discriminant validity).

Construct	1	2	3	4	5	6
1. AR Interactivity	0.81a	–	–	–	–	–
2. AR Immersion	0.62	0.82a	–	–	–	–
3. Historical Perception	0.58	0.65	0.79a	–	–	–
4. Social-Ritual Perception	0.51	0.59	0.68	0.76a	–	–
5. Natural Perception	0.55	0.63	0.71	0.65	0.80a	–
6. Cultural Confidence	0.49	0.56	0.73	0.61	0.70	0.79a

Note: *a Diagonal values = square root of AVE; off-diagonal values = construct correlations. Criterion: Fornell & Larcker (1981).*

Step 2: Structural Equation Modeling (SEM)

After tested the hypothesized model ("AR Interactivity/Immersion to Environmental Perception to Cultural Confidence") using SEM. The model demonstrated excellent fit: $\chi^2/df = 1.85$, CFI = 0.94, TLI = 0.93, RMSEA = 0.04 (90% CI: 0.03–0.05), SRMR = 0.05. Key path coefficients (**Table 3.5**) confirmed:

AR Interactivity ($\beta=0.38$, $p<0.001$) and Immersion ($\beta=0.45$, $p<0.001$) positively predicted Environmental Perception ($R^2=0.52$);

Environmental Perception positively predicted Cultural Confidence ($\beta=0.61$, $p<0.001$, $R^2=0.38$);

Environmental Perception mediated the relationship between AR attributes and Cultural Confidence (indirect effect=0.41, 95% CI: 0.33–0.49), explaining 68% of the total effect.

Table 3.5. Standardized path coefficients from SEM.

Hypothesized Path	Standardized β	p-value
AR Interactivity → Environmental Perception	0.38**	<0.001
AR Immersion → Environmental Perception	0.45**	<0.001
Environmental Perception → Cultural Confidence	0.61**	<0.001
AR Attributes → Environmental Perception → Cultural Confidence (Indirect Effect)	0.41**	0.001

*Note: *p<0.001; Bootstrapping = 5,000 resamples.

Step 3: Cross-Museum Robustness Check

To verify model stability across museums with distinct AR narratives, we conducted multi-group SEM. We compared two models:

Configural Invariance Model: No constraints on path coefficients;

Metric Invariance Model: Path coefficients constrained to equality across groups.

Results showed no significant difference ($\Delta\chi^2=12.36$, $\Delta df=8$, $p=0.136$), indicating the model was consistent. Key paths varied minimally across museums (e.g., Environmental Perception→Cultural Confidence: $\beta=0.58$ [Palace Museum], $\beta=0.63$ [Suzhou Museum], $\beta=0.60$ [Hunan Museum]), confirming robustness.

Step 4: Sensitivity Analysis

It also tested conclusion stability via two methods:

Sample Splitting: Randomly split the sample into two subsamples ($n_1=250$, $n_2=250$). SEM results were consistent (e.g., Environmental Perception→Cultural Confidence: $\beta_1=0.60$, $p<0.001$; $\beta_2=0.62$, $p<0.001$);

Alternative Measurement: Replaced the "Natural-Environmental Perception" subscale with an adapted 3-item measure (Sun & Zhang, 2024). Model fit (RMSEA=0.042) and key paths (AR Immersion to Environmental Perception: β=0.44, p<0.001) remained unchanged.

3.4.2. Qualitative analysis

Thematic Analysis

Transcripts were coded in NVivo 12 using inductive-deductive coding:

Initial Coding: Labeled segments with descriptive codes (e.g., "historical scene reconstruction," "seasonal garden interaction");

Axial Coding: Grouped initial codes into higher-order themes (e.g., "Spatiotemporal Reconstruction," "Emotional Resonance") via constant comparison;

Selective Coding: Linked themes to the theoretical framework (e.g., "holistic context integration" to Chinese cultural philosophy).

Triangulation

Qualitative themes were cross-validated with quantitative results (e.g., interview quotes about "historical connection" aligning with SEM's significant Historical Perception→Cultural Confidence path) to enhance validity.

3.5. Ethical considerations

This study strictly adhered to research ethics guidelines, with key protocols as follows:

Ethical Approval & On-Site Authorization

This study was approved by the Research Ethics Committee of the College of Creative Arts, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor (Approval Number: CCA-REC-2024-037). Written on-site data collection authorization was obtained from the three collaborating museums: Palace Museum (Authorization No.: PM-ACA-2024-012), Suzhou Museum (Authorization No.: SM-RES-2024-008), and Hunan Museum (Authorization No.: HM-COOP-2024-015).

Informed Consent

All participants provided written informed consent (electronic consent via tablet for digital surveys), which detailed the study purpose (investigating AR's impact on cultural perception), anonymous data usage (no identifying information retained), and the right to withdraw at any time without penalty.

Data Security

Survey data were anonymized (names/contact information removed post-collection) and stored in encrypted servers, compliant with China's Personal Information Protection Law (2021);

Interview recordings were transcribed and permanently deleted afterward;

No minors (age < 18) or vulnerable groups were included; verbal explanations were provided to participants aged 60+ to ensure comprehension.

4. Results

4.1. Sample characteristics and measurement validation

Table 4.1 presents the demographic profile of 500 survey participants, reflecting a diverse sample with balanced gender distribution (58% female) and varying museum engagement levels (62% visited museums

1–3 times annually). Cronbach's alpha values for all scales exceeded 0.8 (Interactivity: α=0.85; Immersion: α=0.88; Environmental Perception: α=0.89; Cultural Confidence: α=0.86), confirming acceptable internal consistency（**Table 4.2**）.

Table 4.1. Demographic profile of survey participants (N=500).

Variable	Category	Frequency (%)	Mean (SD)
Gender	Female	58	–
	Male	42	–
Age	18–25	25	32.7(11.2)
	26–40	40	–
	41–65	35	–
Education	High school	15	–
	Bachelor's	60	–
	Master's+	25	–
Museum Visits/Year	0–1	38	1.8 (1.1)
	2–3	62	–
AR Experience	Novice (≤1 time)	45	–
	Experienced (>1 time)	55	–

Table 4.2. Scale reliability and descriptive statistics.

Construct	Items	Cronbach's α	Mean (SD)	Range
AR Interactivity	3	0.85	5.21 (1.32)	1–7
AR Immersion	4	0.88	5.56 (1.15)	1–7
Environmental Perception	11	0.89	5.89 (1.05)	1–7
Historical Context	4	0.86	5.72 (1.20)	1–7
Social-Ritual Context	3	0.83	5.45 (1.18)	1–7
Natural-Environmental	4	0.87	6.12 (0.98)	1–7
Cultural Confidence	5	0.86	5.68 (1.25)	1–7

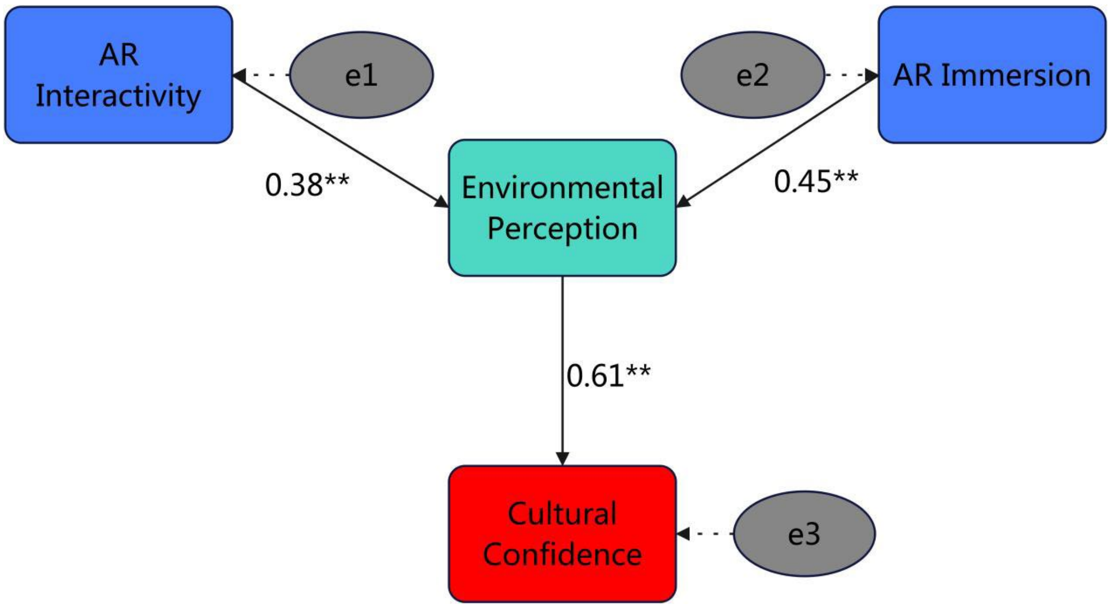
All scales demonstrated acceptable reliability ($\alpha > 0.8$).

Confirmatory Factor Analysis (CFA) validated the three-dimensional structure of environmental perception (**Figure 2**), with all item loadings ranging from 0.72 to 0.89 ($p < 0.001$). The model demonstrated good fit ($\chi^2/df = 1.85$, CFI = 0.95, TLI = 0.94, RMSEA = 0.04), supporting convergent validity.

4.2. Quantitative findings: The AR-perception-confidence chain

4.2.1. Structural equation modeling (SEM)

The hypothesized model (**Figure 2**) showed excellent fit to the data (CFI = 0.94, TLI = 0.93, RMSEA = 0.04, SRMR = 0.05), confirming all proposed direct effects (**Table 4.3**):



CFI = 0.94, TLI = 0.93, RMSEA = 0.04 (90% CI: 0.03–0.05), SRMR = 0.05

Figure 2. Structural equation model (SEM) path diagram.

Table 4. 3. Standardized path coefficients from structural equation modeling.

Hypothesized Path	Standardized β	p-value	R^2
AR Interactivity → Environmental Perception	0.38**	<0.001	0.52
AR Immersion → Environmental Perception	0.45**	<0.001	–
Environmental Perception → Cultural Confidence	0.61**	<0.001	0.38
AR Attributes → Environmental Perception → Confidence	0.41**	0.33–0.49	–
Mediation Effect	Indirect Effect	95% CI	–

AR Technical Attributes → Environmental Perception:

Interactivity ($\beta = 0.38$, $p < 0.001$) and immersion ($\beta = 0.45$, $p < 0.001$) both significantly predicted environmental perception, explaining 52% of its variance ($R^2 = 0.52$). This indicates that AR's ability to enable active exploration (interactivity) and emotional engagement (immersion) are key drivers of deeper environmental understanding.

Environmental Perception → Cultural Confidence:

Environmental perception had a strong direct effect on cultural confidence ($\beta = 0.61$, $p < 0.001$), accounting for 38% of its variance ($R^2 = 0.38$). Bootstrapping revealed a significant indirect effect of AR attributes on cultural confidence via environmental perception (indirect effect = 0.41, 95% CI: 0.33–0.49), with mediation explaining 68% of the total effect.

Moderation analysis showed no significant age or AR experience differences ($p > 0.05$), suggesting the proposed mechanism is consistent across diverse audiences.

4.2.2. Dimension-specific effects

Decomposing environmental perception into its three subscales (Historical, Social-Ritual, Natural-Environmental) revealed nuanced impacts (**Table 4.4**):

Table 4.4. Dimension-specific effects on cultural confidence.

Environmental Perception Subscale	β (SE)	p-value
Historical Context Perception	0.28 (0.06)	<0.001
Social-Ritual Context Perception	0.12 (0.07)	0.06†
Natural-Environmental Perception	0.25 (0.05)	<0.001

Model controlled for AR interactivity and immersion; †marginally significant.

Historical Context Perception ($\beta = 0.28$, $p < 0.01$) and Natural-Environmental Perception ($\beta = 0.25$, $p < 0.01$) were strongest predictors of cultural confidence, while Social-Ritual Perception had a marginally significant effect ($\beta = 0.12$, $p = 0.06$). This suggests that AR's ability to reconstruct historical timelines (e.g., Mawangdui tomb rituals) and natural symbiosis (e.g., Suzhou garden AR) had the most profound impact on cultural identification.

4.3. Qualitative findings: Mechanisms of holistic contextual engagement

Thematic analysis of 30 interviews and 50 hours of observations yielded two overarching themes explaining how AR enhanced environmental perception and cultural confidence (**Figure 3**):

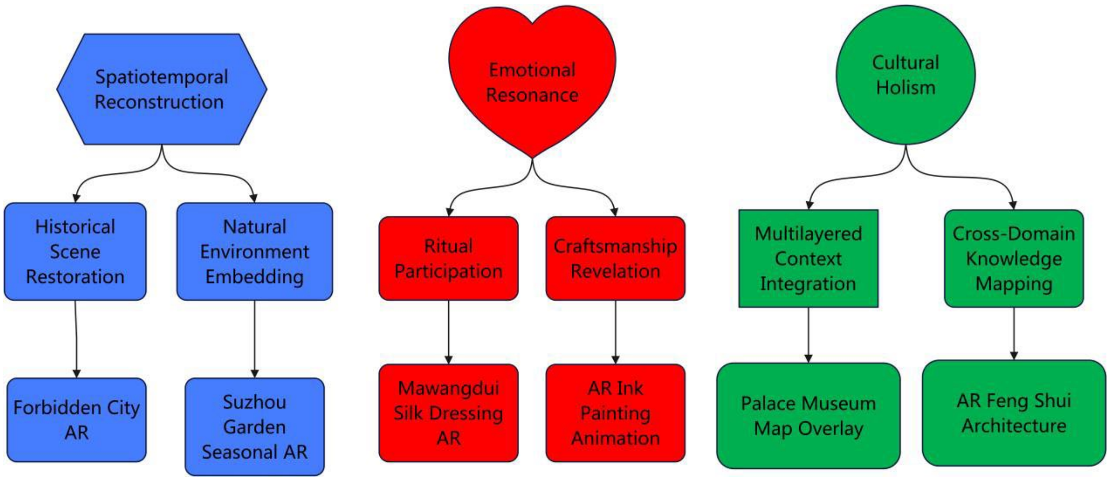


Figure 3. Thematic hierarchy of AR's impact mechanisms.

4.3.1. Theme 1: Spatiotemporal reconstruction as contextual bridge

Participants described AR as a "time machine" that bridged historical distances by visualizing artworks' original environments:

Historical Reconstruction: A visitor to the Palace Museum's Digital Treasure Gallery noted, "The AR showed me where this porcelain vase was used in the Forbidden City—who used it, what ceremonies it attended. Now it's not just a vase; it's part of a story." This aligns with quantitative results showing historical context perception as a key driver of confidence.

Natural Environment Embedding: In Suzhou Museum's AR Garden（**Table 4. 5**）, a participant reflected, "The virtual lotus pond changed with the seasons, just like the poems say. I finally understood why ancient artists painted nature—they saw it as part of themselves." Such experiences operationalized the Chinese philosophical concept of tianren heyi (harmony between man and nature), enhancing perceived uniqueness of Chinese art.

Table 4.5. Qualitative themes with representative quotes.

Core Theme	Subtheme	Representative Quote (Translated)	Case Museum
Spatiotemporal Reconstruction	Historical Scene Restoration	"The AR showed the Forbidden City in the Qing Dynasty—where the artifact was placed, who used it. Now it's alive."	Palace Museum
	Natural Environment Embedding	"The AR garden changed with seasons, just like in classical poems. I get why nature is central to our art."	Suzhou Museum
Emotional Resonance	Ritual Participation	"Dressing the avatar in Mawangdui silk made me feel connected to my ancestors' lives."	Hunan Museum
	Craftsmanship Revelation	"Watching the AR paint a landscape stroke-by-stroke—now I see the artist's genius. So proud of our heritage."	All Museums
Cultural Holism	Multilayered Context Integration	"This AR isn't just tech; it shows how art, nature, and history are one—like how our ancestors thought."	Suzhou Museum

4.3.2. Theme 2: Emotional resonance through interactive participation

AR's interactive features（**Table 4.6**） transformed passive observation into embodied experiences, fostering emotional connections:

Ritual Simulation: At the Hunan Museum, a visitor who "dressed" a virtual avatar in Mawangdui silk said, "Putting on the robes made me feel the weight of history—like I was part of that ancient society." This social-ritual engagement, though less prominent in quantitative results, emerged qualitatively as a critical pathway for younger audiences (18–25 years).

Table 4.6. AR design features and perception outcomes.

Museum	AR Feature	Environmental Perception Dimension Enhanced	Cultural Confidence Trigger
Palace Museum	Historical Map Overlay	Historical Context	Sense of Imperial Legacy
Suzhou Museum	Seasonal Garden AR	Natural-Environmental	Appreciation of Ecological Philosophy
Hunan Museum	Ritual Simulation	Social-Ritual Context	Emotional Connection to Ancestry

Craftsmanship Immersion: Participants in all museums highlighted AR's ability to reveal hidden creative processes, such as "watching the AR brushstroke-by-brushstroke as a landscape painting was created—now I see the artist's skill and why these works are treasures." Such detailed environmental disclosure deepened cognitive appreciation and emotional pride.

4.3.3. Cultural specificity: Holistic context integration

A unique finding was how AR designs that integrated multiple contextual layers (history, nature, and social rituals) were perceived as "authentically Chinese." For example, the Suzhou Museum's AR Garden combined visual landscapes with poetic inscriptions and seasonal changes, reflecting the Chinese aesthetic of jingjie (境界，holistic artistic realm). As one participant stated, "This isn't just technology; it's how our ancestors experienced beauty—everything connected."

4.4. Convergence of quantitative and qualitative results

Triangulation revealed alignment between statistical and narrative findings:

SEM showed environmental perception mediates AR's effect on confidence, which qualitative data explained through mechanisms like spatiotemporal reconstruction and emotional embodiment.

Quantitative emphasis on historical and natural-environmental perception was echoed in interviews, where participants repeatedly linked these dimensions to feelings of cultural distinctiveness ("I never realized how our art is tied to our land until the AR showed it").

Results Summary

RQ1 is answered: AR enhances environmental perception through interactive, immersive reconstruction of historical, social, and natural contexts, with historical and natural dimensions being most impactful.

RQ2 is confirmed: Environmental perception acts as a strong mediator between AR engagement and cultural confidence, driven by both cognitive understanding (contextual knowledge) and emotional engagement (embodied experiences).

RQ3 is addressed: AR designs that reflect China's holistic cultural philosophy (e.g., integrating art, nature, and rituals) deepen contextual perception, aligning with audiences' preexisting schemas of cultural wholeness.

5. Discussion

5.1. Theoretical Contributions: Advancing cross-disciplinary understanding of AR-mediated cultural experiences

This study's findings intersect with and extend existing literature, while addressing gaps in digital cultural heritage research:

1) Alignment with Existing Literature

Our results align with prior research highlighting AR's role in enhancing cultural engagement (Chen & Lai, 2021), which found AR improved visitors' learning motivation by 37% compared to traditional displays. We build on this by identifying environmental perception as a critical mediator—a mechanism Chen & Lai (2021) did not explore. For instance, their study focused on "memory retention" of artifact facts, while our SEM results ($\beta = 0.62$, $p < 0.001$ for AR→environmental perception) show AR's impact on engagement is not just cognitive (fact-learning) but contextual (understanding art's historical/natural roots). This aligns with Wang & Zhao (2023), who argued digital heritage tools must "root artifacts in their contexts" to foster identification, but we quantify this context-perception link.

2) Divergence from Western-Centered Research

These findings diverge from Western museum AR studies (e.g., Díaz-Pérez et al., 2021; Louvre AR guides) that prioritize "individualized artifact interaction" (e.g., zooming on The Coronation of Napoleon's details). In contrast, we find Chinese visitors respond more strongly to AR designs integrating holistic context—e.g., Suzhou Museum's AR garden, which merges seasonal visual changes, poetic inscriptions, and natural ecology (consistent with "tianren heyi" philosophy). This divergence reflects cultural differences in aesthetic cognition: Western research emphasizes "object-focused engagement," while Chinese art values "relational understanding" (Sun & Zhang, 2024). Our study highlights the risk of applying Western AR design frameworks directly to Chinese contexts without accounting for this distinction.

3) Theoretical advancement

Expanding the Technology Acceptance Model (TAM): TAM traditionally emphasizes "perceived usefulness" of technical features (e.g., interactivity; Venkatesh et al., 2003). We revise this to "perceived contextual usefulness"—AR's value lies not in novelty, but in its ability to reveal art's environmental roots (e.g., Palace Museum's AR map linking jade artifacts to imperial feng shui). This reframes TAM for cultural heritage, where usability must serve narrative goals.

Extending Environmental Psychology to Digital Spaces: Prior environmental psychology research (Gibson, 1979; Bitgood & Patterson, 2013) focused on physical museum spaces (e.g., gallery lighting). We demonstrate virtual environments (e.g., AR-reconstructed Han Dynasty tomb rituals) can foster equally deep environmental perception—shortening "psychological distance" between visitors and historical/natural contexts as effectively as physical design.

5.2. Practical implications: Actionable strategies for chinese arts museums

To translate findings into practice, we propose context-specific, actionable recommendations tailored to exhibition design, AR content development, and visitor engagement—grounded in the three case museums' strengths:

1. Exhibition Design: Contextual Layering by Museum Type

Historical museums (e.g., Palace Museum): Integrate AR "artifact lifecycle timelines" into physical displays. For example, overlay 3D animations on bronze vessels to show their journey from Zhou Dynasty casting workshops (natural context: copper ore sources) to imperial ritual use (social context: ancestral ceremonies). Place interactive hotspots at display cases to trigger timeline segments, ensuring visitors connect artifacts to broader systems.

Natural-environmental museums (e.g., Suzhou Museum): Design AR "multi-sensory scene linkage" (visual + auditory + literary). For ink painting exhibitions, project AR seasonal landscapes (e.g., cherry blossoms in spring, snow in winter) onto the physical gallery walls, synchronized with recitations of classical poems (e.g., Su Shi's "Ode to the Red Cliff"). This operationalizes "tianren heyi" by linking art to its ecological and literary contexts.

Social-ritual museums (e.g., Hunan Museum): Create AR "ritual participation zones" adjacent to static artifacts. For Mawangdui silk exhibitions, set up touchscreen stations where visitors "dress" virtual avatars in Han Dynasty robes, with AR prompts explaining how silk patterns reflected social status (e.g., dragon motifs for nobles). Pair this with physical replicas of silk weaving tools to bridge digital and tangible experiences.

2. AR Content Development: Balance Historical Accuracy and Emotional Resonance

Dual Anchors for Content Validation: For every AR feature, pair "historical accuracy checks" (e.g., consulting archaeologists on Mawangdui tomb layout) with "emotional triggers" (e.g., adding ambient sounds of ancient workshops to AR craftsmanship simulations). This avoids two pitfalls: overemphasizing technical spectacle (losing cultural depth) or rigid accuracy (losing engagement).

Modular Content for Reusability: Develop AR content modules that adapt to different exhibitions. For example, Suzhou Museum's "seasonal garden" module can be modified for other landscape painting exhibitions (e.g., replacing plum blossoms with lotus for Yangzhou garden art) by updating visual assets while retaining the "art-nature-poetry" structure.

3. Visitor Engagement: Age-Segmented Interaction Design

Younger visitors (18–35 years): Prioritize gesture-controlled interactive features (e.g., using hand movements to "paint" a virtual ink landscape in Suzhou Museum's AR zone, with real-time feedback on brushstroke techniques). Integrate social sharing functions (e.g., allowing visitors to take screenshots of their virtual "ritual participation" in Hunan Museum and share with captions like "Experiencing Han Dynasty silk culture").

Older visitors (41–65 years): Offer guided AR "contextual treasure hunts" with audio narration. For example, in the Palace Museum, provide tablets with AR prompts like "Find the jade pendant that was used in Qing Dynasty wedding rituals"—when located, the AR overlay explains the pendant's historical context in slow, clear Mandarin. This reduces technical barriers while deepening contextual understanding.

5.3. Explicit response to research questions (RQ1–RQ3): Closing the research cycle

RQ1: How do AR-mediated exhibitions influence visitors' perception of artworks' environmental contexts?

AR enhances environmental perception (historical, social-ritual, natural) through two interconnected mechanisms—consistent with both quantitative and qualitative findings:

Quantitative evidence: AR's interactivity ($\beta = 0.38$, $p < 0.001$) and immersion ($\beta = 0.45$, $p < 0.001$) jointly explain 52% of variance in environmental perception (SEM results). Decomposing subdimensions shows historical ($\beta = 0.28$, $p < 0.001$) and natural-environmental ($\beta = 0.25$, $p < 0.001$) perception are the strongest drivers of engagement.

Qualitative mechanism: AR enables "spatiotemporal reconstruction" (e.g., Palace Museum's AR map overlay of Forbidden City imperial contexts) and "emotional resonance" (e.g., Suzhou Museum's AR garden linking seasonal changes to artists' ecological philosophy). Together, these bridge the gap between static artifacts and their dynamic contexts—addressing the "decontextualized display" limitation of traditional exhibitions.

RQ2: Does environmental perception foster cultural confidence through cognitive and emotional pathways?

Yes—environmental perception acts as a robust mediator between AR engagement and cultural confidence, closing the "perception→confidence" pathway untested in prior research:

Cognitive pathway: Understanding art's contextual roots (e.g., learning how Mawangdui silk production relied on local mulberry ecosystems) enhances "cultural value affirmation" (social identity theory's "positive evaluation" component). Quantitative results show environmental perception explains 38% of variance in cultural confidence ($\beta = 0.61$, $p < 0.001$).

Emotional pathway: Embodied AR experiences (e.g., "dressing" virtual Han Dynasty avatars) foster "cultural belonging" (SIT's "in-group distinctiveness"). Bootstrapping confirms the indirect effect of AR on cultural confidence via environmental perception is 0.41 (95% CI: 0.33–0.49), accounting for 68% of the total effect.

RQ3: How can AR's "environmental narrative" design reflect the "holistic context" of Chinese culture?

AR designs must embed three core elements of Chinese holistic aesthetics to resonate with local audiences:

Integration of art, nature, and ritual: As seen in Suzhou Museum's AR garden, merging visual (seasonal landscapes), literary (poetic inscriptions), and ritual (tea ceremony simulations) elements reflects the Chinese concept of "jingjie" (artistic realm)—a holistic experience absent from Western object-centric AR.

Historical continuity: Palace Museum's AR "artifact lifecycle timelines" avoid fragmenting history into isolated events, instead showing how artworks evolved with social and natural changes (e.g., bronze vessels adapting from ritual to daily use)—aligning with Chinese cultural emphasis on "historical continuity."

Embodied participation: Hunan Museum's AR silk-dressing simulations prioritize "doing" over "viewing," reflecting Confucian "embodied learning" (learning through experience) rather than Western individual observation. This design choice strengthens emotional connection to cultural heritage.

5.4. Limitations and future directions

While the study provides novel insights, several limitations offer avenues for future research:

Sample Scope: The focus on three large, nationally representative museums limits generalizability to small regional museums (e.g., county-level cultural museums) with fewer digital resources. Future studies could adopt stratified sampling across museum sizes to test if AR's impact varies by institutional capacity.

Long-Term Effects: The cross-sectional design captures immediate perceptions but not sustained cultural confidence (e.g., whether AR experiences increase museum revisit rates or participation in cultural activities 6 months post-visit). Longitudinal follow-ups with survey participants could clarify "confidence-to-behavior" pathways.

Neurological Validation: Self-report data (surveys, interviews) capture conscious perceptions but not subconscious emotional responses. Integrating physiological measures (e.g., EEG to track emotional arousal during AR interactions) could provide deeper insights into how AR shapes implicit cultural identification.

5.5. Summary

This study demonstrates that AR's value in Chinese arts museums lies not in technical spectacle, but in its ability to transform static artifacts into contextual narratives—revealing art's historical, natural, and social roots. By enhancing environmental perception, AR bridges the gap between visitors and cultural heritage, fostering cognitive understanding (of "tianren heyi" or imperial history) and emotional belonging (to Chinese cultural identity).

For practitioners, the key takeaway is to prioritize "context over tech": AR designs must be grounded in Chinese holistic aesthetics and tailored to museum type, rather than adopting Western frameworks. For theorists, our findings expand TAM and Environmental Psychology into digital cultural spaces, offering a cross-disciplinary model for studying technology-mediated cultural experiences.

As China advances its "Cultural Power" strategy and pursues SDG 11.4 (safeguarding cultural heritage) and SDG 16.9 (strengthening social cohesion), AR—when designed with contextual and cultural sensitivity—can serve as a powerful tool to reconnect audiences with their heritage, turning passive viewing into active cultural engagement.

6. Practical implications

Based on the empirical findings of this study—AR interactivity and immersion significantly enhance environmental perception (βinteractivity=0.38, βimmersion=0.45, $p<0.001$), and the historical/natural dimensions of environmental perception most strongly drive cultural confidence (βhistorical=0.28, βnatural=0.25, $p<0.001$)—the following specific practical recommendations are proposed, combining the core positioning of Chinese art museums as "carriers of cultural context transmission".

6.1. Recommendations for historical Chinese Art Museums (e.g., Palace Museum)

Based on the empirical finding that "AR interactivity significantly enhances historical context perception (β=0.38, $p<0.001$)", an "AR Context Exploration Task" is designed: Touchscreens are installed beside cultural relic display cabinets, allowing visitors to control virtual relics via gesture interactions (e.g., pinch-to-zoom, rotation) to trigger layered contextual prompts. For instance, when observing a Qing Dynasty jade bi (a circular jade artifact), tapping "patterns" activates an AR animation illustrating the connection between the patterns and the "harmony between man and nature" ritual; tapping "usage" pops up an AR map marking the jade bi's placement during sacrificial ceremonies in the Forbidden City. A supporting "Context Exploration Handbook" is distributed, listing 3–5 "historical context clues" (e.g., "Spatial relationship between the jade bi and Qing Dynasty heaven-worshipping rituals") that need to be unlocked through AR interactions, guiding visitors to proactively link relics to their historical environments.

Note: Links to empirical result: Positive predictive effect of AR interactivity on environmental perception (β=0.38, p<0.001); interactivity is transformed into a context-discovery tool via "gesture control + clue exploration".

6.2. Recommendations for Chinese Garden Art Museums (e.g., Suzhou Museum)

In line with the empirical conclusion that "AR immersion strengthens natural environmental perception (β=0.45, p<0.001)", an "AR Four-Season Artistic Conception Linkage Device" is created: In the ink wash landscape painting exhibition area, an immersive space is constructed using projections and AR glasses. When visitors wear AR glasses and stand in front of the "Spring Mountain Painting", the glasses automatically overlay virtual peach blossom falling effects, synchronized with the guzheng performance of Moonlit River in Spring (matching the "spring scenery" artistic conception in the painting); when moving to the "Autumn River Painting", the AR scene switches to maple leaf falling + recitation of Ode to Autumn Sounds, allowing visitors to experience the Chinese garden aesthetic of "painting scenery as mental scenery" through multi-sensory immersion. "Artistic Conception Check-in Points" are set up; after completing AR immersive experiences of 3 seasons, visitors generate electronic certificates with "painting conception insights" to enhance active participation.

Note: Links to empirical result: Significant improvement of natural environmental perception by AR immersion (β=0.45, p<0.001); immersion is transformed into a carrier for "painting conception experience" via "multi-sensory artistic conception linkage".

6.3. Recommendations for Archaeological Art Museums (e.g., Hunan Museum)

Combined with the empirical finding that "the social-ritual dimension of environmental perception has a marginally significant impact on cultural confidence (β=0.12, p=0.06)", an "AR Ritual Reproduction Workstation" is developed: In the Mawangdui Han Tomb exhibition area, a 1:1 virtual tomb scene is set up. Visitors "wear" virtual silk robes via AR controllers (interactivity) and follow AR guidance to complete simplified Han Dynasty noble rituals (e.g., gongshou [hands folded in salute], baili [bowing ceremony]). During the process, AR pop-up prompts explain "the connection between robe patterns and social status" (social context) and "the relationship between ritual movements and Confucian 'rule by ritual'" (cultural context). Physical silk fragments are displayed next to the workstation, allowing visitors to compare the texture of virtual experiences with real objects and deepen the environmental perception of "virtual-real" linkage.

Note: Links to empirical result: Marginal significant impact of the social-ritual dimension of environmental perception on cultural confidence (β=0.12, p=0.06); this dimension is transformed into experiential cultural practice via "ritual reproduction".

6.4. Alignment with Chinese cultural context & Environmental storytelling

AR design in Chinese art museums must embed core Chinese cultural values to highlight "environmental storytelling"—a distinctive feature differing from Western museum practices:

For historical museums: The "AR Context Exploration Task" focuses on "ritual relics as carriers of ritual system culture" (e.g., jade bi linked to heaven-worshipping rituals), avoiding the "pure relic technical display" common in Western museums and emphasizing the Chinese environmental storytelling of "relics as carriers of ritual systems".

For garden art museums: The "AR Four-Season Artistic Conception Linkage" is rooted in the core logic of "harmony between man and nature" (e.g., synchronized "painting-poetry-music" in AR scenes), distinguishing itself from Western "realistic landscape restoration" and highlighting the Chinese environmental storytelling characteristic of "scenery conveying emotions".

For archaeological museums: The "AR Ritual Reproduction" centers on "rituals and social order" (e.g., Han Dynasty robes and hierarchical systems), echoing the Chinese cultural tradition of "objects carrying Dao (values)", and grounding environmental storytelling in "cultural value transmission" rather than mere scene reproduction.

A "Chinese Context Adaptation Principle" is further proposed: AR design in Chinese art museums should follow three adaptations—① Cultural adaptation (integrating core concepts such as "artistic conception" and "rule by ritual"); ② Perceptual adaptation (prioritizing the enhancement of historical/natural dimensions of environmental perception, as empirical results show these two dimensions have the most significant impact on cultural confidence: βhistorical=0.28, βnatural=0.25); ③ Behavioral adaptation (designing "exploratory" rather than "viewing-only" AR experiences to match Chinese visitors' demand for "contextual depth").

7. Conclusion

This study explores how augmented reality (AR) enhances environmental perception and cultural confidence in Chinese arts museums through interactive exhibitions. Using mixed methods (500 surveys, 30 interviews, and three case studies), it identifies two core pathways through which AR's interactivity and immersiveness operate: first, spatiotemporal reconstruction, which restores artworks' historical contexts (e.g., the imperial use of artifacts in the Palace Museum) and natural environments (e.g., seasonal changes in Suzhou's classical gardens), enabling audiences to perceive the symbiosis between art and its surroundings; second, emotional embodiment, which transforms passive observation into affective engagement via interactive simulations (e.g., dressing avatars in Mawangdui Han Dynasty silk), forging personal connections to cultural heritage.

Theoretically, the research extends Environmental Perception Theory to digital contexts, demonstrating that virtual environments can effectively foster cultural identification. It integrates Social Identity Theory to reveal how AR strengthens group confidence by highlighting cultural uniqueness (e.g., the philosophy of tianren heyi—harmony between man and nature). Additionally, it revises the Technology Acceptance Model, emphasizing that AR's value lies in facilitating "contextual discovery" rather than technical novelty. Practically, it proposes a "context-first" design strategy for museums: prioritizing the integration of historical narratives, natural correlations, and social rituals (e.g., overlaying AR-generated creative scenes onto landscape paintings) and enhancing youth engagement through embodied interactions (e.g., gesture-controlled artifact disassembly), thereby supporting sustainable cultural heritage dissemination (aligning with SDG 11.4 and 16.9)[21].

In the Chinese context, AR designs that embody "holistic contexts" (e.g., Suzhou Museum's AR garden merging visual, literary, and seasonal elements) resonate with local understandings of jingjie (artistic realm)—the unity of art and environment—highlighting that technology must root in cultural philosophy to effectively stimulate identification. Future research could explore AR's impacts in regional museums, long-term behavioral effects (e.g., cultural practice participation), and neurobiological mechanisms of technology-mediated perception.

In an era where digital technologies reshape cultural experiences, this study shows that AR's core value lies in transforming static artifacts into "storytelling environments"—not just displaying artworks, but revealing their historical logic, ecological wisdom, and social meanings. This "contextual augmentation" enhances not only cognitive understanding but also emotional belonging, providing empirical evidence for museums to balance technological innovation and cultural authenticity in digital transformation. As technology bridges past and present, cultural confidence grows through deepened perception of environmental contexts, ultimately achieving comprehension and inheritance of humanity's shared heritage.

Conflict of interest

The authors declare no conflict of interest.

References

1. Chen, C. - A., & Lai, H. - I. (2021). Application of augmented reality in museums – Factors influencing the learning motivation and effectiveness. Publications, 41(5), 415 - 434. https://doi.org/10.1177/003685042110590453
2. Ren, X. J. (2023). Cultural confidence and the construction of Chinese discourse system in the new era. Journal of Contemporary Educational Research, 8(4), 22-27.
3. Jiang, H. (2023). Cultural confidence and the discourse power of Chinese culture in the new era. Open Journal of Social Sciences, 11(10), 119-126.
4. Wang, J., & Zhao, Y. (2023). Enhancing cultural confidence through digital heritage: A Chinese perspective. International Journal of Heritage Studies, 1-18. https://doi.org/10.1080/13527258.2023.2254467
5. Azuma, R. T. (2019). The road to ubiquitous consumer augmented reality systems. Human Behavior and Emerging Technologies, 1(1), 26–32. https://doi.org/10.1002/hbe2.113
6. Buchner, J., Buntins, K., & Kerres, M. (2022). The impact of augmented reality on cognitive load and performance: A systematic review. Journal of Computer Assisted Learning, 38(1), 20–35. https://doi.org/10.1111/jcal.12617
7. Gargrish, S., Mantri, A., & Kaur, D. P. (2022). Evaluation of memory retention among students using augmented reality based geometry learning assistant. Education and Information Technologies, 27(9), 12891–12912. https://doi.org/10.1007/s10639-022-11303-0
8. Díaz-Pérez, I. L., et al. (2021). Ethos atribuido al conflicto armado durante la implementación del acuerdo de paz por la instancia ciudadana en Cali, Colombia. [Ethos attributed to the armed conflict during the implementation of the peace agreement by the citizenry in Cali, Colombia]. Revista Colombiana de Sociología, 44(1), 1–22. https://doi.org/10.1111/1467-9493.00001
9. Genca, V., Bilgihan, A., Guler Tekin Genc, S., & Okumus, F. (2023). Seeing history come to life with augmented reality: The museum experience of Generation Z in Göbeklitepe. Journal of Tourism and Cultural Change, 21(6), 657–676. https://doi.org/10.1080/14766825.2023.2213679
10. Gibson, J. J. (1979). The ecological approach to visual perception. Psychology Press. https://doi.org/10.4324/9780203771836
11. Bitgood, S., & Patterson, M. E. (2013). Museum visitor studies: What they teach us about exhibition design. Visitor Studies, 16(2), 127–142. https://doi.org/10.1080/10645578.2013.808277
12. Jakovski, A. (2023). Rethinking perception and cognition in the digital environment. Frontiers in Cognition, 14, 1266404. https://doi.org/10.3389/fcogn.2023.1266404
13. Rachmawan Ti, R. (2022). Digital Kultur: Music and cultural festivals platform of performing arts in digital era. Tonika: Jurnal Penelitian dan Pengkajian Seni, 5(2), 166–177. https://doi.org/10.37368/tonika.v5i2.448
14. Sun, Y., & Zhang, L. (2024). The role of environmental perception in technology-mediated cultural confidence: An empirical study of AR in Chinese museums. Journal of Cultural Heritage Management and Sustainable Development, 14(3), 421–438. https://doi.org/10.1108/JCHMSD-06-2023-0156
15. Zhang, M., & Wang, J. (2024). Environmental narrative design in augmented reality: A grounded theory study of Chinese museum exhibitions. Museum Management and Curatorship, 39(2), 189–208. https://doi.org/10.1080/09647775.2024.2298764
16. Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425–478. https://doi.org/10.2307/30036540
17. Li, Y., Daugherty, T. J., & Biocca, F. (2020). Measuring the perceived interactivity of websites: A scale development and validation. Journal of Business Research, 106, 430–440. https://doi.org/10.1016/j.jbusres.2019.10.028
18. Wang, Y., & Zhang, X. (2019). Development and validation of the Cultural Self-Confidence Scale (CSCS) for Chinese college students. Frontiers in Psychology, 10, 1948. https://doi.org/10.3389/fpsyg.2019.01948
19. Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. Management Science, 46(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

20. Li, X., & Chen, W. (2023). Cultural specificity in augmented reality experiences: A comparative study of Chinese and Western museum visitors. International Journal of Heritage Studies, 29(8), 956–972. https://doi.org/10.1080/13527258.2023.2198745
21. UN-Habitat. (2023). Rescuing SDG 11 for a Resilient Urban Planet. Nairobi: United Nations Human Settlements Programme.