https://doi.org/10.1038/s40494-025-02069-z

Adopting AR wayfinding in heritage tourism: extending the UTAUT in cultural contexts

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This study examines visitor acceptance of augmented reality (AR) wayfinding systems in open historic districts, addressing the challenge of balancing technological innovation with cultural heritage experience. Based on the Unified Theory of Acceptance and Use of Technology (UTAUT) and extended variables including perceived pleasure, self-efficacy, interactivity, risk, and trust, a comprehensive behavioural intention model is proposed. Using survey data and structural equation modelling, results reveal a strong "ease-of-use preference," with effort expectancy outweighing performance expectancy. Perceived interactivity boosts behavioural intention directly and via perceived pleasure, while risk and social influence act through perceived trust, highlighting institutional trust's importance. Self-efficacy also drives intention indirectly through pleasure. An implementation pathway—"technical ease of use – content gamification – trust-oriented management"—is proposed, offering theoretical and practical insights for AR design, digital heritage preservation, and enhanced visitor experience.

The safeguarding and transmission of cultural heritage face multifaceted challenges on a global scale, particularly in reconciling the application of emerging technologies with the optimisation of visitor experience, the judicious allocation of resources, and the adoption of innovative methodological approaches. As vital repositories of urban memory and cultural identity, historic districts occupy a pivotal role in negotiating the dynamic equilibrium between tourism development and heritage conservation. While traditional wayfinding systems provide essential navigational functions, their inherent static nature—coupled with a lack of interactivity and immersive engagement—often results in limited information delivery and insufficient visitor participation[1]. Such constraints not only risk fostering incomplete or distorted understandings of a site's cultural significance but also diminish its attractiveness and potential for sustainable development. In this context, Augmented Reality (AR) technology, with its capacity to superimpose digital content seamlessly onto the physical environment[2], offers an innovative avenue for reimagining historical narratives and revitalising spatial experiences. By enabling more vivid, interactive, and personalised modes of interpretation[3], AR serves to bridge the deficiencies of conventional wayfinding systems and enhance the interpretive depth of historic districts.

In recent years, the integration of digital technologies into the field of cultural heritage has emerged as an inevitable trajectory, particularly in enhancing visitor engagement and cultural comprehension. A substantial body of research has examined the potential of Augmented Reality (AR) and Virtual Reality (VR) technologies in heritage interpretation. Scholars have observed that AR, through its capacity for spatial augmentation, offers an effective means of addressing the issue of information overload commonly associated with traditional signage systems[4], thereby deepening the level of interaction between visitors and heritage architectures[5]. Its interactive features contribute to reducing cognitive load, improving spatial cognition efficiency, and fostering greater emotional engagement[6]. Furthermore, AR supports the real-time retrieval of historical and cultural information, thereby significantly enhancing visitors' understanding of the background knowledge associated with heritage sites[7]. For example, Gek-Siang, Tan et al.[8] reported in their study on AR-guided museum applications that performance expectancy significantly influences user adoption intentions, and underscored the role of effective human–computer interaction and synergy between technological and organisational components in elevating the overall visitor experience and satisfaction. Tang & Zhou further explored how AR applications, by intensifying immersion, can effectively stimulate visitors' curiosity and motivation to explore and learn about cultural heritage[9]. Collectively, these studies provide a robust theoretical and empirical foundation for the application of AR in the cultural heritage domain.

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Nevertheless, despite AR's demonstrable capacity to enhance visitor experiences, its practical application and user acceptance within the context of wayfinding design in historic districts remain challenged[10]. A critical question persists: how can AR technology be effectively integrated into the complex and open spatial configurations of historic districts, while ensuring sustained user willingness to adopt and engage with such technologies? This issue extends beyond the realm of technical design, encompassing the need for a nuanced understanding of visitor behavioural patterns and psychological acceptance mechanisms. Existing studies on technology acceptance—particularly those employing the Unified Theory of Acceptance and Use of Technology (UTAUT) framework—have predominantly focused on enclosed, controlled environments such as museums or exhibition centres within the cultural heritage sector, with comparatively limited attention to the distinctive behavioural characteristics of visitors in open-air historic districts[11]. This spatial heterogeneity—namely, the contrast between open and enclosed settings—can engender significant differences in visitor behaviour, modes of technological interaction, and influencing factors. Specifically, while the traditional UTAUT model emphasises utilitarian objectives such as efficiency improvement and task completion, visits to historic districts are, by nature, experience-driven and non-utilitarian, with visitors placing greater emphasis on cultural immersion, entertainment value, and affective resonance[12]. Consequently, the explanatory capacity of conventional theoretical frameworks may be limited when accounting for visitors' willingness to adopt AR-based wayfinding systems in open-air historic districts.

On this basis, the present study seeks to address the following research questions:

1. Within the context of open-air historic districts, how do the core constructs of the Unified Theory of Acceptance and Use of Technology (UTAUT)—namely, performance expectancy, effort expectancy, social influence, and facilitating conditions—affect visitors' intention to use AR-based wayfinding systems?

2. Beyond the traditional UTAUT constructs, which affective and cognitive factors—such as perceived enjoyment, self-efficacy, perceived interactivity, perceived risk, and perceived trust—play salient roles in visitors' acceptance of AR wayfinding systems, and how do these factors influence their usage intentions?

3. How can a more context-appropriate "experience–technology acceptance" model be developed for cultural heritage settings, in order to illuminate the role of affective motivation in technology adoption?

To address these questions, this study draws upon the UTAUT framework as its theoretical foundation, while integrating perspectives from both cultural heritage tourism and digital technology. It incorporates extended variables—namely, perceived enjoyment, self-efficacy, perceived interactivity, perceived risk, and perceived trust—into the model, thereby constructing a more adaptive and contextually tailored evaluation framework. The study aims to elucidate the key psychological mechanisms and socio-contextual factors that shape visitors' adoption of AR-based wayfinding systems in historic districts. By refining the conceptual definitions of these variables in alignment with the specific characteristics of AR wayfinding systems, and by conducting an empirical analysis through structural equation modelling, the research seeks to bridge the current theoretical gap concerning AR technology acceptance in open-air historic district scenarios. The findings are expected to provide not only a robust theoretical and practical foundation for the intelligent management of historic districts, but also to advance the sustainable digital transmission of cultural heritage and the synergistic development of the experience economy.

Methods

Application of AR technology in cultural heritage wayfinding

With the rapid progression of information technologies, digital innovations have become essential tools for the safeguarding, transmission, and revitalisation of cultural heritage. Among these, Augmented Reality (AR) technology—owing to its distinctive capability for the seamless integration of the virtual and the real—has shown considerable potential in enhancing visitor experiences and enriching the delivery of cultural information. AR not only enables the seamless overlay of digital content onto the physical world but also facilitates real-time interaction, thereby offering immersive experiences that transcend the limitations of traditional interpretive approaches.

AR technology may be defined as a system that superimposes virtual information—such as text, images, three-dimensional models, and audiovisual media—onto real-world scenes in real time, enabling users to perceive both the physical environment and the digital layer simultaneously. Unlike Virtual Reality (VR), which entirely replaces the physical environment, AR focuses on augmenting reality, rendering it inherently advantageous in wayfinding scenarios that require interaction with actual heritage sites. Within the context of cultural heritage wayfinding, AR can be conceptualised as an interactive, context-aware digital tool that utilises mobile devices and related platforms to integrate historical reconstructions, cultural background information, and artistic details with tangible relics, architectural structures, or exhibits. In doing so, it provides personalised and in-depth pathways for learning and experiencing heritage.

Historic districts form a key component of the cultural heritage domain. In addition to physical conservation and adaptive reuse, the application of digital technologies has become an inevitable strategy for the preservation and presentation of such districts[13]. A substantial body of research has confirmed the promising potential of AR in cultural heritage contexts. O'dwyer et al.[14] highlighted AR's capacity to deliver rich media content and enhance narrative experiences in museums and historic sites. Through case-based analysis, Amakawa & Westin[15] demonstrated how AR can allow visitors to "travel" into historical settings, fostering an intuitive understanding of a site's past. In the development of urban landscapes featuring heritage architecture, studies have indicated that AR can increase visitor interaction with heritage buildings, particularly in guided interpretation[16].

The enhancement of interactive processing through AR and VR technologies for the restoration and visual reconstruction of tangible heritage[17] has emerged as one solution for supporting visitor engagement. The spatial augmentation[18] capability intrinsic to such systems effectively mitigates the problem of information overload associated with traditional signage. Some studies have also shown that AR-based interactions can reduce cognitive load[19] and improve visitors' spatial cognition efficiency, thereby enhancing affective engagement[20]. By employing AR technology, visitors can access an array of services that provide real-time historical information, cultural narratives, and relevant tourism recommendations about buildings during their visit. Such access not only increases the breadth and richness of available information resources but also enables deeper interpretation and perceptual understanding of heritage artefacts[21].

Despite AR's substantial potential in cultural heritage wayfinding, its widespread adoption in open-air historic districts remains challenging. Although the technology is available, the underlying motivational mechanisms influencing visitors' willingness to adopt and continue using AR systems are not yet well understood. Existing literature has tended to focus predominantly on the technical capabilities of AR, with less emphasis on the specific psychological and socio-contextual factors that may affect visitor acceptance in complex, non-linear, open spaces. In particular, there has been a lack of systematic, multidimensional analyses that take into account the experiential characteristics of visitors when evaluating AR acceptance within the distinct context of open-air historic districts.

Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT) is one of the most influential technology acceptance models within the field of information systems. Developed by Venkatesh et al.[22], the model synthesises the core elements of eight mainstream technology acceptance theories—such as the Theory of Planned Behaviour (TPB), the Technology Acceptance Model (TAM), and Social Cognitive Theory (SCT)—with the aim of providing a more comprehensive and explanatory framework for predicting user acceptance and use of new technologies. The theoretical structure of UTAUT comprises four principal constructs: *performance expectancy*, *effort expectancy*, *social influence*, and *facilitating conditions* (FC). These dimensions collectively provide a robust explanation of users' information technology adoption behaviours and their subsequent patterns of use.

Performance expectancy (PE) refers to the degree to which users believe that using a particular technology will help them accomplish tasks or improve performance. In the context of AR-based wayfinding in historic districts, PE denotes the extent to which visitors perceive that an AR wayfinding system can effectively enhance their understanding of history and culture, provide access to interpretive information, improve the efficiency of their visit, or enrich the overall experience.

In technology acceptance research, PE encapsulates users' perceptions of the extent to which an information system enhances their work or learning performance—its perceived usefulness and contribution to their goals[23]. Empirical studies have shown that PE exerts a significant influence on tourists' acceptance of AR technologies in media-related tourism contexts[24]. According to Samaddar and Mondal[25], PE and other key constructs serve as preconditions for behavioural intention in the adoption of technologies such as AR in tourism products.

Within the historic district wayfinding scenario, PE reflects the belief that an AR system can enable more efficient access to information, a deeper understanding of cultural heritage, and more convenient route planning—especially in open settings characterised by large volumes of information and insufficient traditional signage—thereby substantially improving the overall efficiency of the visit[21].

Based on this reasoning, the following hypothesis is proposed:

H1: Performance expectancy has a positive effect on visitors' behavioural intention to use AR wayfinding systems in historic districts.

Effort expectancy (EE) refers to the degree to which users perceive a technology as easy to operate and understand. Prior research indicates that the more readily a technology can be understood, the stronger users' intention to engage with services underpinned by that technology[26]. Similarly, if visitors perceive AR technology as easy to use during their experience, they are more likely to hold high performance expectations, anticipating that it will significantly improve the efficiency and quality of the wayfinding process; conversely, perceived complexity may diminish such expectations. Previous studies[27–29] have confirmed that EE exerts a significant positive effect on behavioural intention[30]. Furthermore, EE also influences PE[31], with PE acting as a mediator between EE and behavioural intention, thereby shaping users' willingness to adopt a given technology.

In this study, EE is defined as the extent to which visitors believe that minimal effort is required to learn and use an AR wayfinding system—where operation is intuitive and straightforward—encompassing ease of application download and installation, as well as the clarity and accessibility of its interface and functions. For the general visitor, particularly while travelling, there is a distinct preference for tools that are simple to use and require no additional learning effort. On this basis, the following hypothesis is proposed:

H2: Effort expectancy has a positive effect on visitors' behavioural intention to use AR wayfinding systems in historic districts.

Within technology acceptance models, EE may not only exert a direct influence on behavioural intention but also act indirectly through its impact on PE. When users perceive a technology as easy to use, they are more likely to recognise its benefits and utility, thereby enhancing their evaluation of its usefulness. The work of Al-Adwan et al.[32] provides empirical evidence that EE positively influences PE in the context of online learning. Applied to historic districts, the ease of use of AR wayfinding systems can strengthen visitors' perception of their usefulness, which in turn enhances behavioural intention. This leads to the second hypothesis for EE:

H3: Effort expectancy has a positive effect on visitors' performance expectancy of AR wayfinding systems in historic districts.

Social influence (SI) refers to the extent to which individuals perceive that important members of their social circle believe they should adopt and use a given information system[23]. Numerous studies have identified SI as a significant determinant of behavioural intention towards new technologies[33,34]. In the context of historic district AR wayfinding, visitors' intention to use the system may be shaped by the opinions and recommendations of key influencers in their lives—such as family members or friends—who themselves adopt or endorse the technology. Notably, prior research has found that when important referents express positive attitudes towards a new technology, consumer trust functions as an antecedent to technology acceptance[35]. On this basis, the following hypotheses are proposed:

H4: Social influence has a positive effect on visitors' behavioural intention to use AR wayfinding systems in historic districts.

H5: Social influence has a positive effect on visitors' perceived trust in AR wayfinding systems in historic districts.

The UTAUT model has been extensively validated in diverse contexts of technology acceptance. For example, Andrews et al. examined librarians' attitudes and intentions regarding the adoption of AI technologies[36], while research on development organisations in India has employed UTAUT to investigate determinants of AI tool adoption[37]. During the COVID-19 pandemic, scholars explored how perceived advantages of technology shaped behavioural intention towards VR travel in the tourism sector, and how such intentions were influenced by different UTAUT constructs[38]. Similarly, Chao[39] found that satisfaction, trust, PE, and EE significantly and positively affected students' behavioural intention to engage in mobile learning. Collectively, these findings demonstrate UTAUT's strong explanatory power in predicting adoption behaviours for emerging digital technologies.

In recent years, scholars have extended UTAUT to cultural heritage digitalisation scenarios. Wen et al.[40] examined visitor acceptance of smart museum guides and found that PE and EE had significant positive effects on behavioural intention to adopt AR-guided tours. Furthermore, human–computer interaction and synergies between technology and organisational support were found to enhance the overall visitor experience and satisfaction[41], thereby contributing to the value of heritage exhibitions. Zhuang et al.[42] demonstrated that in virtual reality tourism, SI effectively increased acceptance and usage of AR tourism technology, with particularly strong effects among younger audiences. For the purpose of this study, the facilitating conditions (FC) construct of UTAUT is not included, given the high ubiquity and cross-platform compatibility of AR technologies, which can be readily used on everyday mobile devices[40].

Although UTAUT provides a robust explanatory framework, its application within the specific, experience-oriented context of open-air historic district AR wayfinding raises further questions. In particular, the operational mechanisms of its core constructs—and the potential need to introduce additional variables to enhance explanatory power—require deeper investigation. It is noteworthy that traditional definitions of PE often emphasise gains in efficiency and productivity, whereas historic district visitation frequently prioritises affective, immersive, and hedonic experiences. This shift in emphasis may challenge the explanatory strength of conventional PE in non-utilitarian contexts. Additionally, environmental complexities—such as unstable network connectivity, device heterogeneity, and diverse visitor behaviours—may elevate the salience of EE and, potentially, FC. Through empirical analysis, this study aims to both validate the applicability of UTAUT's core constructs in the historic district AR wayfinding context and extend the model to reflect the unique characteristics of this setting, thereby offering a more comprehensive and precise understanding of visitor adoption behaviour.

Extended variables and integration with the UTAUT model

Perceived risk theory posits that any act of purchase or adoption inherently involves the possibility that actual outcomes will differ from expected ones. Prior studies have shown that perceived risk is closely associated with uncertainty and unfamiliarity[43]. In this study, perceived risk refers to the extent to which users anticipate that the use of AR-based technologies may yield outcomes inconsistent with their expectations due to uncertain factors. Cabeza et al.[44] found that heightened perceived risk generates negative emotions, which in turn reduce users' behavioural intention.

Perceived trust constitutes a foundational element for the sustained use of AR technologies, as trust can stimulate users' agency and intentionality[45].

In novel technology contexts, trust and risk are interdependent: increased trust can alter how consumers perceive risk, and it may mediate the relationship between perceived risk and behavioural intention[46]. The inverse relationship between trust and perceived risk has been empirically validated in AI-assisted learning environments[47]. Based on these insights, the following hypotheses are proposed:

H6: Perceived risk negatively affects visitors' behavioural intention to use AR wayfinding systems in historic districts.

H7: Perceived risk negatively affects visitors' perceived trust in AR wayfinding systems in historic districts.

Perceived trust refers to users' belief in the competence, integrity, and benevolence of both the AR wayfinding system and its providers (e.g., the historic district management authority, technology developers). In contexts involving virtual interaction and information exchange, trust is a critical determinant of technology adoption. It has been recognised as a key factor in consumer decisions to adopt IoT solutions[48], digital technologies[49], and e-commerce platforms[50].

In cultural heritage contexts, visitors' trust in the historical content presented by AR wayfinding systems—particularly regarding its authority and authenticity—as well as the safeguarding of user privacy by managing bodies, are central to trust formation. This study posits that perceived trust plays a decisive role in influencing users' intention to adopt AR wayfinding systems in historic districts. Accordingly, the following hypothesis is proposed:

H8: Perceived trust positively affects visitors' behavioural intention to use AR wayfinding systems in historic districts.

The rapid development of intelligent and digital interaction technologies has expanded the paradigms of service engagement. According to cognitive experience theory, when users perceive system interactions to be simple and intuitive, they experience positive cognitive-affective states, which in turn enhance their behavioural intention[51].

In the context of AR wayfinding for historic districts, technologies such as real-time environmental tracking and multimodal feedback can foster richer and deeper content engagement[52], thereby reinforcing visitors' motivation to adopt the technology. Drawing on flow theory, when users establish a state of optimal interaction—where system complexity matches their skill level—they are more likely to become fully immersed, deriving pleasure and satisfaction from the experience[38]. This state can stimulate visitors' curiosity and cultural exploration[39].

Pleasure arising from high-quality interaction can act as a significant affective mediator in the technology acceptance process, functioning both as an outcome of positive interaction experiences and as a driver for sustained use. This leads to the following hypotheses:

H9: Perceived interactivity positively affects visitors' behavioural intention to use AR wayfinding systems in historic districts.

H10: Perceived interactivity positively affects visitors' perceived pleasure in using AR wayfinding systems in historic districts.

Self-efficacy refers to an individual's self-assessed ability to perform a specific behaviour and achieve desired outcomes[53]. In technology use contexts, AR-based guidance systems can enhance users' sense of personal achievement and capability. Guided by social cognitive theory, this study examines the role of self-efficacy in shaping visitors' adoption of AR technologies.

Prior research indicates that individuals with higher self-efficacy are more likely to perceive a technology as useful and to intend to use it[54]. Esawe[55] further noted that high self-efficacy individuals tend to develop more positive attitudes and emotional experiences during technology use. Specifically, confidence in one's ability to operate AR systems can both directly strengthen behavioural intention and indirectly promote adoption by increasing the enjoyment experienced during use[56]. Therefore, the following hypotheses are proposed:

H11: Self-efficacy positively affects visitors' behavioural intention to use AR wayfinding systems in historic districts.

H12: Self-efficacy positively affects visitors' perceived pleasure in using AR wayfinding systems in historic districts.

Perceived pleasure refers to the enjoyment, fun, and excitement experienced by users during the process of interacting with a technology. While the original UTAUT model primarily emphasises extrinsic, utilitarian motivations (e.g., performance gains), intrinsic, hedonic motivations warrant closer attention in experience-driven contexts such as historic district tourism.

Perceived pleasure has been shown to directly influence behavioural intention in entertainment, gaming, and social media environments[57] Additionally, research has revealed that the sense of enjoyment in VR/AR experiences can directly impact revisit intentions in tourism[58]. However, studies specifically examining perceived pleasure in AR wayfinding remain limited, and its unique role in non-utilitarian, immersive heritage contexts has not been fully articulated. Accordingly, the following hypothesis is proposed:

H13: Perceived pleasure positively affects visitors' behavioural intention to use AR wayfinding systems in historic districts.

The UTAUT model provides substantial explanatory power for adoption decisions concerning technology designed for efficiency and task completion. However, the essential nature of AR wayfinding in historic districts is more strongly aligned with experience-driven, non-utilitarian applications, in which visitor decisions are shaped by a broader range of psychological and situational factors.

To more accurately predict visitors' intention to use AR wayfinding systems in this context, this study extends the UTAUT core constructs by incorporating perceived pleasure, self-efficacy, perceived interactivity, perceived risk, and perceived trust as additional variables. These factors capture the emotional, cognitive, and socio-contextual dimensions of the AR visitor experience, while also uncovering their interactions with UTAUT's original constructs. The proposed hypotheses collectively aim to examine these relationships and provide a nuanced framework for understanding technology adoption in experience-oriented cultural heritage environments.

Questionnaire design

This study used a questionnaire survey to investigate the factors influencing tourists' adoption of AR technology. The instrument consisted of two sections: (a) demographic characteristics, and (b) research measurement scales.

The first section collected respondents' basic demographic information, including gender, age, educational attainment, number of previous trips, and level of familiarity with AR-based tourism services. The second section consisted of scale items developed on the basis of the UTAUT model and its extended variables. All measurement items were assessed using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

The questionnaire captured information on nine constructs—Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Perceived Risk (PR), Perceived Trust (PT), Perceived Interactivity (PI), Perceived Pleasure(PP), Self-Efficacy (SE), and Behavioral Intention (BI). The final instrument contained 30 validated items (see Table 1 for scale details).

To establish content validity, we conducted expert reviews ($n = 5$) and a pilot test with university students ($n = 50$). The questionnaire was subsequently refined based on pretest results, including item clarity analysis (Cronbach's $\alpha > 0.78$ for all constructs) and completion time optimization.

Data collection

The survey was primarily administered via an online questionnaire platform (Wenjuanxing) and disseminated through social media channels (WeChat, Rednote groups) and targeted e-mail invitations. A combination of snowball sampling and convenience sampling strategies was employed. The survey was initially promoted through the online platform to attract the first group of respondents. These initial participants were then invited to share the questionnaire with friends, family members, or other eligible contacts within their networks. While this approach facilitated a broader reach, it also carried the potential risk of sampling bias, as respondents might be more inclined to forward the survey to individuals with similar characteristics or interests.

Table 1 | Measurement Items and Sources of Variables

Construct	Code	Item	Reference
Performance Expectancy (PE)	PE1	The AR wayfinding system provides useful information for the tour.	Venkatesh et al.[70]
	PE2	AR wayfinding assists me in locating attractions more effectively.	
	PE3	AR wayfinding enhances my overall touring experience.	
	PE4	AR wayfinding meets my personalized touring needs.	
	PE5	AR wayfinding reduces difficulties in finding attractions.	
Effort Expectancy (EE)	EE1	Accessing the AR wayfinding system is straightforward.	Venkatesh et al.[70]
	EE2	The AR wayfinding process features intuitive operation and user-friendly procedures.	
	EE3	Learning to use the AR wayfinding system requires minimal time and effort investment.	
	EE4	I am fully aware of the available technical services at attractions and make selective use of AR wayfinding solutions.	
Social Influence (SI)	SI1	Some of my friends are currently using AR wayfinding services.	Venkatesh et al.[70]
	SI2	I would use the service if recommended by friends around me.	
	SI3	Promotional campaigns at attractions positively influence my adoption of AR wayfinding.	
	SI4	Using AR wayfinding has become a trend that I wish to follow.	
Perceived Trust (PT)	PT1	I trust that the attraction can provide high-quality AR wayfinding content.	Venkatesh et al.[70]
	PT2	I believe the information provided by the attraction's AR wayfinding system is authentic.	
	PT3	I feel comfortable using information provided by high-reputation users.	
	PT4	I am confident that AR wayfinding can effectively protect my privacy and security.	
	PT5	I trust that AR wayfinding services will honor their service commitments.	
Perceived Risk (PR)	PR1	I am concerned that using AR wayfinding may require excessive time and effort to learn.	Featherman[71]
	PR2	I worry that AR wayfinding might fail to deliver the expected outcomes.	
	PR3	I have concerns about potential personal information leakage when using AR wayfinding services.	
	PR4	I feel apprehensive that sharing travel information through AR wayfinding could pose safety risks.	
	PR5	I suspect that some users may share information in AR wayfinding with malicious intentions.	
Perceived Interactivity (PI)	PI1	The AR wayfinding interface features clear design, logical functional layout, and high operability.	Park M, Yoo J[72]
	PI2	AR wayfinding can accurately recommend resources based on my usage patterns.	
	PI3	My mobile device operates smoothly, with prompt response when loading and using AR wayfinding.	
	PI4	When encountering difficulties with AR wayfinding, I can promptly find support personnel to assist me.	
	PI5	During AR wayfinding usage, I can consciously edit the content as needed.	
Perceived Pleasure (PP)	PP1	I feel relaxed and enjoyable while using the AR wayfinding system.	Hsieh et al.[73]
	PP2	The AR wayfinding experience brings me considerable enjoyment.	
	PP3	Using AR wayfinding provides me with a sense of fulfillment.	
	PP4	I can obtain assistance from others when encountering difficulties with AR wayfinding.	
Self-Efficacy (SE)	SE1	I am confident in utilizing AR wayfinding effectively.	Ulfert-Blank et al.[74]
	SE2	I am proficient in operating AR wayfinding systems.	
	SE3	I possess strong curiosity about new platforms and technologies.	
	SE4	I enjoy continuously experimenting with and adopting innovations.	
	SE5	Successfully addressing my needs independently through AR wayfinding at attractions gives me a sense of accomplishment.	
Behavioral Intention (BI)	BI1	I am willing to learn how to use AR wayfinding services.	Venkatesh et al. [70]
	BI2	I intend to continue experimenting with AR wayfinding.	
	BI3	I have considered recommending AR wayfinding to others.	
	BI4	In the future, I would consider adopting AR wayfinding services more extensively.	

The formal data collection commenced in early November 2024 and continued for one month, yielding a total of 585 completed questionnaires. To ensure data quality, all submissions were subjected to a rigorous screening process. Invalid questionnaires—such as those with excessively short completion times, abnormally high answer repetition rates, or multiple submissions from the same respondent—were excluded. After removing 69 invalid responses, a total of 516 valid questionnaires were retained, resulting in an effective response rate of 88.21%. Within the valid sample set, 43.41% of respondents were male, and 56.59% were female. Regarding age distribution, 14.15% of respondents were under 18, 37.21% were aged 18–25, 17.05% were between 26 and 30, 13.18% fell within the 31–40 age range, and 18.41% were over 40 years old.

Results

Analysis of reliability and validity

To ensure the reliability and validity of the research scale, an initial analysis of each measurement item's reliability and validity was conducted, and low-reliability items or those negatively impacting model fit were removed. After

Table 2 | Reliability and Convergent Validity of Revised Measurement Indicators

Construct		Factor Loadings	CR	AVE	Alpha	SMC
Performance Expectancy	PE1	0.725	0.782	0.544	0.78	0.525
	PE4	0.774				0.599
	PE5	0.712				0.507
Effort Expectancy	EE1	0.759	0.849	0.585	0.85	0.575
	EE2	0.73				0.534
	EE3	0.789				0.622
	EE4	0.78				0.609
Social Influence	SI1	0.716	0.849	0.585	0.85	0.512
	SI2	0.803				0.645
	SI3	0.75				0.563
	SI4	0.788				0.62
Perceived Risk	PR2	0.773	0.865	0.617	0.866	0.597
	PR3	0.765				0.585
	PR4	0.821				0.673
	PR5	0.781				0.61
Perceived Trust	PT2	0.73	0.858	0.602	0.844	0.533
	PT3	0.728				0.53
	PT4	0.766				0.586
	PT5	0.809				0.654
Perceived Interactivity	PI1	0.717	0.85	0.531	0.85	0.514
	PI2	0.719				0.517
	PI3	0.755				0.57
	PI4	0.725				0.525
	PI5	0.727				0.528
Perceived Pleasure	PP1	0.788	0.849	0.585	0.849	0.62
	PP2	0.776				0.603
	PP3	0.758				0.574
	PP4	0.737				0.543
Self-Efficacy	SE1	0.798	0.848	0.583	0.849	0.637
	SE2	0.758				0.575
	SE3	0.776				0.601
	SE5	0.72				0.519
Behavioral Intention	BI1	0.729	0.838	0.564	0.848	0.532
	BI2	0.738				0.544
	BI3	0.79				0.624
	BI4	0.745				0.555

revision, the questionnaire's reliability was tested using Cronbach's Alpha. Results demonstrated an overall Cronbach's alpha of 0.869, with all latent variables' alpha values and composite reliability (CR) coefficients exceeding 0.7, confirming high reliability and internal consistency (Table 2).

Regarding the validity of the scale, factor loadings and average variance extracted (AVE) were used as evaluation indicators. As presented in Table 2, after revision all standardized factor loadings exceeded 0.6 with statistical significance ($p < 0.001$), the squared multiple correlation (SMC) values surpassed 0.5, and the AVE values were above 0.5, demonstrating strong internal consistency and convergent validity. The discriminant validity test results indicated that the square root of each latent variable's AVE was higher than its correlation coefficients with other latent variables (Table 3), confirming strong discriminant validity.

Empirical validation of the structural equation model

This study employed SPSS software and the lavaan package in R language for model validation and mediation analysis. Maximum likelihood estimation (MLE) was used for parameter estimation, while bootstrap sampling ($n = 5000$) generated 95% confidence intervals (CI) to test mediation effects. Model fit was evaluated using the comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). Following the assessment criteria proposed by Kline[59], a model is considered to fit well when CFI > 0.90, TLI > 0.90, RMSEA < 0.05, and SRMR < 0.08.

The structural equation model was estimated using the lavaan package, generating overall model fit indices as shown in Table 4. The results indicate that all fit indices measures meet the recommended thresholds for good to excellent fit, confirming strong model-data consistency.

Given the satisfactory overall model fit, path analysis examined the correspondence between the hypothesized model and sample data, yielding path coefficients and significance levels among latent variables (Table 5).

Hypotheses were tested using critical ratio (C.R.) values (parameter estimate/standard error) and associated p-values. Table 5 demonstrates that hypotheses H2, H3, H5, H6, H8, H9, H10, H11, H12, and H13 showed absolute C.R. values > 1.96 with $p < 0.05$, confirming statistically significant relationships and supporting these hypotheses. Conversely, hypotheses H1, H4, and H7 failed to reach statistical significance and were rejected.

According to the test results (Table 5), performance expectancy, social influence, and perceived risk did not exhibit significant positive effects on behavioural intention. When the model fit fails to meet the desired threshold or contains non-significant paths, adjustments should be made based on modification indices (M.I.) in conjunction with theoretical justification

First, a thorough theoretical review and data re-examination were conducted for the non-significant hypothesised paths identified in the initial tests. In the original model, three paths—H1, H4, and H7—did not reach statistical significance ($p > 0.05$).

Second, this study posits that in the open, experience-oriented, and non-utilitarian setting of historic districts, visitors' expectations of AR

Table 3 | Discriminant Validity Test

	SE	PI	PR	SI	EE	PP	PT	PE	BI
SE	0.916								
PI	0.151	0.676							
PR	−0.334	−0.172	0.956						
SI	0.362	0.18	−0.31	0.776					
EE	0.291	0.159	−0.371	0.306	0.89				
PP	0.358	0.166	−0.15	0.161	0.132	0.884			
PT	0.189	0.096	−0.341	0.297	0.184	0.085	0.79		
PE	0.116	0.063	−0.147	0.121	0.353	0.052	0.073	0.781	
BI	0.403	0.211	−0.35	0.326	0.384	0.282	0.351	0.223	0.845

Table 4 | Model Fit Indices

Fit Index	Threshold		Current Study	Interpretation
	Acceptable	Good		
CMIN	-		806.352	
DF	-		571	
X2 / df	<5	1.412	1.409	Excellent
GFI	0.7 ~ 0.9	0.923	0.923	Good
AGFI	0.7 ~ 0.9	0.910	0.910	Good
NFI	0.7 ~ 0.9	0.910	0.910	Good
CFI	0.7 ~ 0.9	0.972	0.972	Good
SRMR	<0.08	<0.05	0.075	Acceptable
RMSEA	<0.10	<0.05	0.028	Excellent

Table 5 | Path Analysis Results

Hypothesized Path	Estimate	S.E.	C.R.	*P*
H1: PE—BI	0.129	0.069	1.884	0.060
H2: EE—BI	0.252	0.090	2.803	***
H3: EE—PE	0.467	0.076	6.146	***
H4: SI—BI	0.077	0.080	0.953	0.340
H5: SI—PT	0.310	0.065	4.801	***
H6: PT—BI	0.308	0.078	3.965	***
H7: PR—BI	-0.073	0.092	−0.795	0.426
H8: PR—PT	-0.332	0.072	−4.635	***
H9: PI—BI	0.134	0.067	1.995	0.046
H10: PI—PP	0.159	0.056	2.857	0.004
H11: PP—BI	0.172	0.074	2.320	0.020
H12: SE—BI	0.271	0.087	3.100	***
H13: SE—PP	0.409	0.064	6.365	***

***$p < 0.001$, indicating a high level of statistical significance.

Table 6 | Revised model path coefficients

Hypothesized Path	Estimate	S.E.	C.R.	P
H2: EE—BI	0.342	0.080	4.297	***
H3: EE—PE	0.468	0.076	6.146	***
H5: SI—PT	0.313	0.065	4.828	***
H6: PT—BI	0.331	0.074	4.456	***
H8: PR—PT	−0.335	0.072	−4.668	***
H9: PI—BI	0.148	0.064	2.296	0.022
H10: PI—PP	0.159	0.056	2.856	0.004
H11: PP—BI	0.182	0.071	2.541	0.002
H12: SE—BI	0.301	0.080	3.756	***
H13: SE—PP	0.409	0.064	6.340	***

***$p < 0.001$, indicating a high level of statistical significance.

wayfinding systems are likely to prioritise enjoyment and immersion over purely "performance"-driven benefits. Although AR can deliver richer information, visitors may place greater value on novelty and emotional resonance. Accordingly, the direct path of H1 was removed.

In tourism contexts where personal autonomy is high—particularly with personalised, non-mandatory tools such as AR wayfinding—adoption decisions are more often driven by intrinsic interest and perceptions of the technology, rather than social pressure. Social influence may therefore operate indirectly by shaping perceived trust in the AR wayfinding system, rather than directly determining behavioural intention. Consequently, H4 was revised to incorporate perceived trust as a mediating variable, so as to better reflect the mechanism through which social influence operates in cultural heritage contexts.

Similarly, the statistical results indicated that perceived risk does not directly and negatively affect behavioural intention. For AR wayfinding systems, non-financial risks—such as concerns over data privacy, information accuracy, or operational errors—do not necessarily lead visitors to abandon their use. Instead, perceived risk appears to exert its effect indirectly by influencing perceived trust. Therefore, the direct negative path of H7 was removed from the model.

Throughout the model revision process, the study adhered to a combined principle of theoretical coherence and data-driven adjustment, ensuring that all modifications were grounded in established theory and that all retained paths demonstrated acceptable levels of model fit and explanatory power. The revised structural equation model and standardised path coefficients are presented in Table 6, and the final research model is shown in Fig. 1.

The mediation effect occurs when one or more mediating variables (Z) transmit the influence of an independent variable (X) to a dependent variable (Y). This study applied the bootstrapping mediation test method with 5000 resampling iterations at a 95% confidence interval to examine the mediating roles of performance expectancy, perceived trust, and perceived pleasure on behavioral intention (Table 7).

Analysis revealed three key mediation pathways: First, performance expectancy significantly mediated the relationship between effort expectancy and behavioral intention (H1-H4). Second, perceived trust served as a significant mediator in two distinct paths - between social influence and behavioral intention (H5-H6), and between perceived risk and behavioral intention (H7-H8). Third, perceived pleasure significantly mediated both the perceived interactivity to behavioral intention relationship (H10-H11) and the self-efficacy to behavioral intention relationship (H12-H13).

All mediation effects were statistically confirmed as the bias-corrected 95% confidence intervals excluded zero (all $p < 0.05$), demonstrating robust mediation across all specified paths.

Discussion

By constructing and validating an extended UTAUT model, this study has examined in depth the factors influencing visitors' intention to adopt augmented reality (AR) wayfinding systems in historic districts. The findings not only confirm the applicability of UTAUT in the cultural heritage domain but also reveal the limitations of traditional technology acceptance theories in experience-driven, non-utilitarian contexts, highlighting the complex interplay between emotional and socio-contextual factors.

First, the results demonstrate that effort expectancy exerts a significant and stronger positive influence on visitors' intention to use AR wayfinding systems than performance expectancy. This diverges from the traditional UTAUT assumption that performance expectancy typically functions as the strongest predictor. While this finding contrasts with studies in controlled, museum-based contexts, where performance expectancy predominates[49,50], it aligns with contemporary users' general "instant-use" preference for mobile applications. We argue that this inconsistency highlights the distinctive logic of technology acceptance in cultural heritage settings, where in open, dynamic tourist environments, visitors tend to prioritise ease of use over functional performance—consistent with Wang's[60] findings. In leisure tourism, individuals are unwilling to invest substantial effort in learning or overcoming technological barriers[61]; convenience and seamlessness become decisive adoption criteria. Even powerful AR systems lose appeal if perceived as operationally complex. This observation echoes prior research pointing to challenges of stability and interaction simplicity in outdoor AR applications[62–64], underlining the necessity of examining this technology in the specific context of historic districts.

Second, the results show that perceived interactivity influences behavioural intention through both a direct effect and an indirect effect mediated

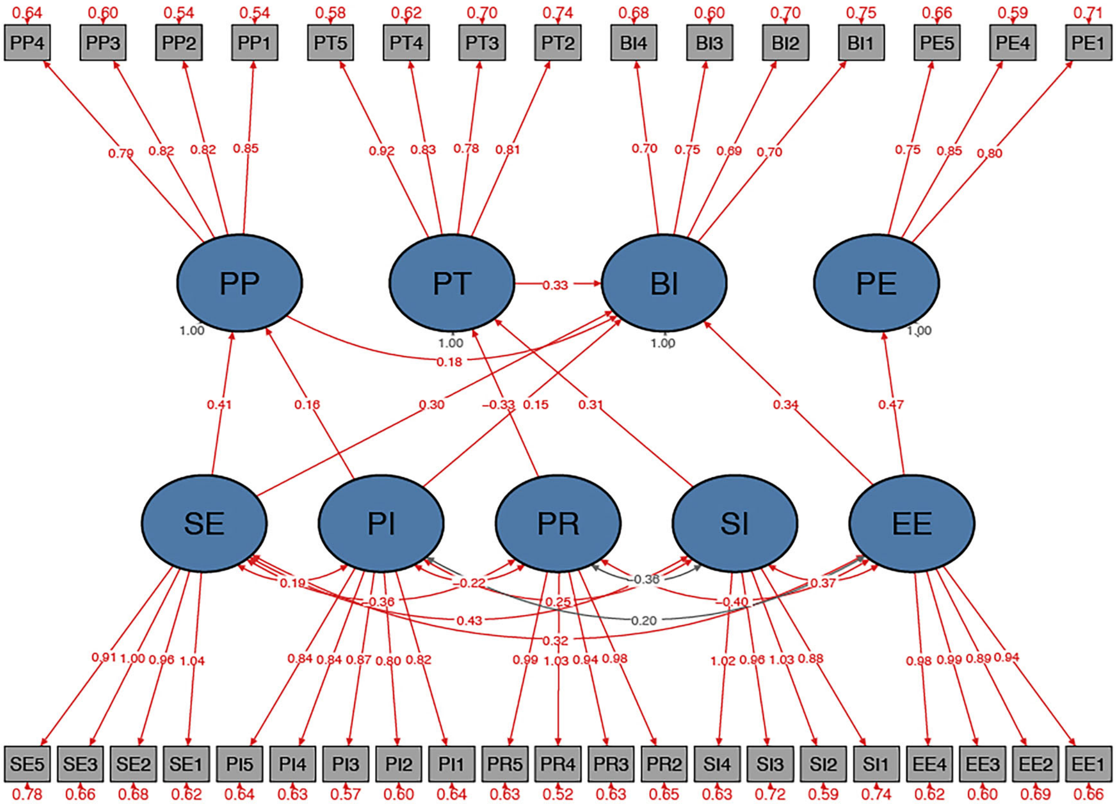

Fig. 1 | Path Diagram of the Revised Structural Equation Model.

Table 7 | Mediation Effect Analysis

Mediation Path	Effect Type	Estimate	Bias-Corrected95% CI		P	Mediation Result	Supported?
			Lower	Upper			
SI-PT-BI	d2	0.077	0.080	0.34	−0.080	Full mediation	Yes
	ind2	0.095	0.032	0.003	0.043		
	total2	0.171	0.082	0.037	0.013		
PR-PT-BI	d3	−0.073	0.092	0.426	−0.250	Full mediation	Yes
	ind3	−0.101	0.035	0.004	−0.182		
	total3	−0.174	0.092	0.059	−0.364		
PI-PP-BI	d4	0.134	0.067	0.046	0.006	Partial mediation	Yes
	ind4	0.027	0.016	0.094	0.004		
	total4	0.160	0.069	0.020	0.031		
SE-PP-BI	d5	0.271	0.087	0.002	0.112	Partial mediation	Yes
	ind5	0.070	0.031	0.027	0.015		
	total5	0.339	0.085	0	0.186		

by perceived pleasure. This underscores the centrality of interactivity in experience-oriented AR applications. Consistent with prior research in the cultural heritage and tourism fields[65,66], high-quality interaction not only facilitates greater satisfaction but also stimulates users' enjoyment, thereby strengthening adoption intentions. This mechanism can be understood as a form of "cultural flow": when AR interaction design reaches an optimal complexity, visitors can immerse themselves in historical narratives and derive deep enjoyment. In non-utilitarian, experience-driven cultural heritage tourism, this affective pathway is particularly important, expanding our understanding of intrinsic motivations in technology use.

Third, the study confirms that both social influence and perceived risk affect behavioural intention exclusively via perceived trust, revealing a complete mediation effect. This finding makes a notable theoretical contribution by refining the original UTAUT structure, in which these constructs are typically modelled as exerting direct effects on behavioural intention[25,26,46]. In the heritage context, where information authenticity and personal data security are critical concerns, perceived trust in the content (e.g., historical accuracy) and in the provider (e.g., site managers, developers) acts as a "gatekeeper" for adoption decisions. When social recommendations or authoritative endorsements increase trust, visitors are more willing to adopt AR wayfinding systems even in the presence of perceived risks. Conversely, perceived risk does not directly deter adoption unless it erodes trust. This insight suggests that in heritage contexts, where authority and authenticity are paramount, the credibility and transparency of managing institutions are essential for building user trust[67,68].

Finally, the results reveal that self-efficacy affects behavioural intention partly through perceived pleasure, implying that visitors' confidence in their ability to operate AR wayfinding systems can indirectly enhance adoption intentions by increasing enjoyment during use. This supports Bandura's[69] social cognitive theory, which posits that self-beliefs influence behavioural choices. When visitors trust their ability to fully utilise AR functions, they are more likely to become engaged and derive enjoyment, thereby encouraging continued use. Together with the findings on effort expectancy, this result emphasises the foundational role of perceived capability and ease of use in driving AR adoption in the historic district context.

This study extends the UTAUT framework to the distinctive cultural heritage tourism setting of open historic districts, making several contributions to existing scholarship.

First, it expands UTAUT's application boundary into non-utilitarian, experience-driven contexts. Whereas traditional UTAUT excels in predicting adoption for efficiency- or task-oriented technologies, our findings demonstrate that performance expectancy does not significantly predict intention in experience-oriented applications such as AR wayfinding in historic districts. This aligns with the argument advanced in the introduction and literature review—that historic district visits are primarily driven by experiential rather than utilitarian motivations—and addresses UTAUT's theoretical gap in such contexts. Conversely, the study identifies perceived pleasure and perceived interactivity as central determinants of behavioural intention, proposing an "experience–technology acceptance" model that emphasises emotional motivation in adoption decisions.

Second, it deepens understanding of UTAUT's core constructs in a specific cultural context. We show that social influence and perceived risk do not exert direct effects on intention but act entirely through perceived trust. This highlights that in the heritage domain, external informational cues (e.g., recommendations) and potential concerns (e.g., privacy risks) must first be converted into trust in the technology or provider before influencing adoption behaviour. This re-specification of UTAUT underscores the critical importance of "institutional trust" in non-mandatory, individually determined technology adoption.

Third, the study systematically explores the roles of perceived interactivity, perceived pleasure, and self-efficacy in AR adoption for historic districts. We find that perceived interactivity both directly influences intention and indirectly does so via perceived pleasure, forming a "perceived interactivity → perceived pleasure → behavioural intention" chain mediation pathway. This clarifies how high-quality interaction design can foster enjoyment, in turn enhancing adoption. Similarly, the partial mediation effect of perceived pleasure on the self-efficacy–intention link underscores that user confidence in operational skills can indirectly heighten enjoyment and facilitate adoption. Collectively, these findings refine our theoretical understanding of the interrelation between user experience and technology acceptance in the heritage tourism domain.

The results offer specific guidance for the design, promotion, and management of AR wayfinding systems in historic districts, with the aim of enhancing visitor acceptance and supporting the revitalisation and transmission of cultural heritage.

First, prioritise ease of use. Effort expectancy emerged as a stronger driver of behavioural intention than performance expectancy, signalling that visitors value straightforward operation above all. Developers should therefore place user interface (UI) and user experience (UX) simplicity at the forefront—by using intuitive iconography, streamlining steps, providing clear textual or audio navigation, and reducing the learning curve. "One-click start" or "foolproof" interaction modes, short tutorial animations, and context-sensitive prompts at key moments can ensure that even inexperienced AR users quickly become competent.

Second, employ content gamification to stimulate interest and pleasure. The strong effects of perceived interactivity and perceived pleasure indicate that AR wayfinding should be seen not merely as an information tool but as a medium for immersive experience. Integrating elements such as treasure hunts, historical puzzles, and virtual character interactions can transform historical narratives into engaging challenges. Examples include location-based AR tasks that "unlock" stories or characters at specific heritage sites, awarding virtual badges or achievements upon completion, or recreating historical scenes with interactive dialogues. Such gamified approaches can raise engagement, deepen immersion, and significantly increase sustained use.

Third, build trust in system management to mitigate concerns. Since social influence and perceived risk operate through perceived trust, fostering trust is paramount. Management authorities could:

1. Ensure authoritative, accurate AR content by partnering with cultural institutions and clearly citing sources (e.g., "Certified by the XX Historical Institute" or "Data from XX Gazetteer").
2. Implement transparent privacy policies and robust data security measures, informing users of data use and offering accessible privacy settings.
3. Collaborate with reputable tourism platforms or acquire official certification to leverage brand credibility.
4. Provide responsive feedback channels and technical support to address user issues promptly, strengthening post-use trust.

Finally, AR wayfinding implementation should go beyond mere technical deployment to become embedded in the overall management and marketing of cultural heritage sites. Although this study did not evaluate a specific AR application, its findings offer general design principles. AR should be positioned as a "cultural decoding tool" rather than a simple "information display screen". Optimising the triad of ease of use – gamified content – trust management can not only improve visitor experience but also promote the living heritage function of historic districts, achieving deeper integration between digital technologies and cultural heritage for sustainable tourism development.

Despite yielding several meaningful findings, this study has certain limitations that offer opportunities for improvement in future research.

First, in terms of research scope, this study focused on an open historic district in [specific city or region] as the context for data collection. The results may therefore not fully represent all types of historic districts or those situated in different cultural backgrounds, which may limit the generalisability of the conclusions.

Second, regarding research methodology, this study employed a cross-sectional questionnaire survey. Although structural equation modelling was used to examine the relationships among variables, this design does not allow for strict causal inference. Future studies could adopt longitudinal designs or experimental methods to more clearly establish causal chains.

Third, the data relied on self-reported measures provided by respondents, which may be subject to social desirability bias or common method variance. Subsequent research could incorporate behavioural data (e.g., actual system usage duration, feature click-through rates) to triangulate and validate self-reported findings.

Finally, while the extended UTAUT model demonstrated strong explanatory power, a portion of variance in behavioural intention remained unexplained. This suggests the presence of additional potential determinants not captured in this model. Examples may include visitors' cultural identity, specific AR content design attributes, and variations in experience arising from different AR hardware devices.

Augmented reality technology offers a novel means of enabling cross-temporal and cross-spatial "dialogue" with cultural heritage, facilitating broader dissemination and allowing the public to engage more closely with its historical and aesthetic dimensions. Future studies may further expand the theoretical framework by incorporating additional variables that could influence adoption intentions—such as cultural identity, dimensions of immersion in AR applications, and distinctive design features of AR content. Moreover, extending the investigation to a wider range of cultural heritage settings, such as museums or AI-enabled tour guides, and evaluating the universality and contextual specificity of AR adoption mechanisms across scenarios also represent promising research directions.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Received: 10 April 2025; Accepted: 22 September 2025;
Published online: 01 October 2025

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Acknowledgements

This work was supported by the following grants: [No. 25SJC-28] from the 2025 Special Topic on Social Education, Jiangsu Social Science Application Research Quality Project; [No. 2025JSETKT018] from the 2025 Research Project of Jiangsu Colleges and Universities Research Association for Educational Informationizion; [No. 202513573023Z] from the 2024 College Students' Innovation and Entrepreneurship Training Program; [No. 21] from the 2023 Science and Education Integration Program of Jinling Institute of Technology; and [No. jit-b-202230] from the Scientific Research Start-up Fund for High-end Talents of Jinling Institute of Technology. The funders played no role in the study design, data collection, analysis, interpretation of data, or the writing of this manuscript.

Author contributions

F.W.: Data curation, Conceptualization, Funding acquisition, Investigation, Methodology, Writing-original draft, Writing - review & editing. X.P.:

Investigation. Y.W: Resources, Methodology. W.F.: Writing - review. Y.D.: Writing - review. K.W.: Writing - review. All authors have read and agreed to the published version of the manuscript.

Competing interests
The authors declare no competing interests.

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