# A Study on the Design and Effect Evaluation of Immersive Heritage Tourism Experiences Empowered by Smart Technology—Taking World Heritage Sites as Examples

**Dongpo Yan[1,2], Azizan Marzuki[2], Jiejing Yang[1,3], Shuaizheng Zhao[2], Li Wang[1]**
[1]School of Business, Henan Kaifeng College of Science Technology and Communication, Kaifeng 475000, Henan, China
[2]School of Housing, Building and Planning, Universiti Sains Malaysia, George Town 11800, Penang, Malaysia
[3]School of Management, Universiti Sains Malaysia, George Town 11800, Penang, Malaysia

Corresponding author: Azizan Marzuki (e-mail: azizanmarzuki@163.com)

**ABSTRACT** Smart technologies have created new possibilities for enhancing cultural heritage tourism through immersive and interactive visitor experiences. This study investigates the design mechanisms and evaluation framework of technology-enabled immersive heritage tourism using three representative World Heritage sites in China as case studies. A three-dimensional evaluation framework encompassing technology integration, immersive experience, and cultural identity was established, and quantitative analyses were conducted to assess the effectiveness of intelligent technologies in heritage interpretation. Results indicate that technology interactivity, scene authenticity, and narrative coherence are the primary factors influencing immersive experience quality. Based on empirical findings, three optimization pathways—technology-adaptive design, multisensory collaborative interaction, and dynamic feedback enhancement—are proposed. The study provides practical guidance for the digital transformation of heritage tourism and offers methodological references for virtual–physical interaction systems, intelligent perception technologies, and immersive communication environments.

**INDEX TERMS** immersive heritage tourism, smart technology, cultural heritage, intelligent perception, interactive communication systems

## I. INTRODUCTION

CULTURAL heritage tourism, serving as a vital link between historical memory and contemporary experience, faces a transformative landscape defined by the structural evolution of technical craftsmanship and the rapid integration of intelligent material technologies. The industry must navigate the intersection of technological innovation, such as the digital modeling of complex fiber-reinforced heritage structures, and the rising demands of consumption upgrade to ensure the preservation of historical material logic in a modern context. World Heritage sites hold the profound memories of human civilisation but traditional models for display, mainly based on static display and text based explanation, do not meet the demands of modern tourists for in-depth cultural experiences. The development of smart technologies is a breakthrough solution to this dilemma. Through the integrated use of technology such as virtual reality technology, augmented reality technology, and artificial intelligence technology, heritage sites may create an experience scenario with immersive experiences, which can overcome time and space constraints and turn static cultural relics into perception ability and interactive space.

In the context of heritage tourism, immersive experiences are not only about the presentation of the technological effects, but they also entail the transmission of cultural meaning and the construction of value identification. How to design smart technologies to truly foster immersive experiences to the tourists as well as how to scientifically evaluate such experience have become core issues in the current heritage tourism research. Existing research is mainly based on the application effect of single technologies without a systematic discussion of technology design mechanisms and evaluation systems, especially without effect verification based on empirical data.

Based on this, this study takes three World Heritage sites in China—the Ming and Qing Imperial Palace (Beijing), the Mausoleum of the First Qin Emperor and the Terracotta Army, and the West Lake Cultural Landscape in Hangzhou—as case studies to explore the design logic and evaluation methods of immersive heritage tourism experiences empowered by intelligent technology. The research firstly reviews the current applying status and theory basis of smart technologies in heritage tourism, and then constructs the whole research framework including technical architecture, experience design and effect evaluating. Through a field research and data analysis, the research intends to uncover the mechanisms through which smart technologies impact immersive experiences and the aspects of design, which could be identified as major elements of design and the optimization paths. The research findings are expected to deliver actionable technical solutions and

evaluation instruments for the smart transformation of heritage sites by integrating high-performance technical structural logic into the digital restoration process. By utilizing intelligent fiber-sensing networks and advanced production simulations, the study supports a paradigm shift from "static protection" to a "living heritage transmission" that revitalizes the intricate material craftsmanship of historical artifacts.

## II. RELATED WORK

Cultural heritage tourism research presents a multi-dimensional theoretical perspective and methodological approach. Belhi et al. [1] analyzed tourist behavior data, preferences and feedback to construct a model that can personalize cultural content recommendations and enhance interactive experiences. Saydam et al. [2] found that Northern Cyprus has great potential for cultural heritage tourism, but it is constrained by factors such as political recognition issues, insufficient infrastructure and ineffective marketing. Kunze [3] found that "hometown flavor" food plays an emotional mediating role in heritage tourism . Ranwa [4] collected data from multiple perspectives, including community members, performers and tourism operators, to analyze the dynamic relationship between tourism activities and intangible cultural heritage practices. Mahadevan and Zhang [5] found that there are significant differences between domestic and foreign tourists in their experience dimensions, satisfaction drivers and future intentions regarding Lijiang.

Organized crime poses a serious threat to cultural heritage and sustainable tourism. Al-Ansi [6] analyzed the complex combination of multiple conditions leading to high crime rates, rather than the net effect of a single factor. Yücebaş and Toy [7] pointed out that different types of AR virtual guides perform differently in terms of user experience, information delivery efficiency, and emotional arousal. Ziółkowska-Weiss et al. [8] showed that connecting ancient Roman ruins in the Rhineland into themed routes is an effective way to revitalize heritage resources and develop cultural tourism. Salehipour et al. [9] proposed a sustainable interaction model, emphasizing that in developing cultural heritage tourism in Iran, it is necessary to properly handle the multiple balances between political goals and cultural protection, international image and local identity, and development needs and heritage authenticity. Sul and Chung [10] defined service landscape elements in smart tourism cities and analyzed how these elements affect tourists' perceptions, emotions, and satisfaction. This paper takes World Heritage sites as cases, focuses on the design mechanism and effect evaluation of smart technology empowering immersive experiences in heritage tourism, and responds to the following core questions: In the specific context of heritage sites, how should smart technology be designed to truly generate immersive experiences for tourists? How can this experience be evaluated? By incorporating technological design, user experience, and the cultural preservation needs of heritage sites into a unified analytical framework, this study aims to provide theoretical support and practical reference for the deep integration of smart technology and heritage tourism.

## III. METHODS

### A. RESEARCH DESIGN FRAMEWORK CONSTRUCTION

This research applies a hybrid research method using quantitative measuring and qualitative analyzing to build a design and evaluation mechanism for immersive experience of heritage tourism empowered by smart technology. The study first constructs three core 1 technological integration, 2 immersion, and cultural identity as a three-tiered evaluation framework of "technology-experience-value". To avoid conceptual overlap and potential multicollinearity, this study rigorously distinguishes and operationalizes each construct and its sub-dimensions. Technological integration focuses on the compatibility of smart technology with heritage scenarios, and its evaluation criteria include three measurement indicators: technological stability (reliability of system operation), interactive fluency (immediacy of user operation and system feedback), and content accuracy (consistency between virtual content and historical facts). Immersion refers to the degree of psychological engagement of tourists in a virtual environment, which is clearly divided into three levels in this study: sensory immersion (a sense of being present through sensory channels such as sight, hearing, and touch), narrative immersion (a state of being attracted by the storyline and emotionally involved), and challenging immersion (a flow experience brought about by interactive tasks). Cultural identity refers to the cultural cognition and emotional attitudes that tourists acquire in technological experiences, including three elements: knowledge acquisition, emotional resonance, and behavioral intention. [11-12]

This study selected three Chinese World Heritage sites as empirical research subjects: the Forbidden City in Beijing (representing historical architectural heritage), the Mausoleum of the First Qin Emperor and the Terracotta Army (representing archaeological site heritage), and the West Lake Cultural Landscape in Hangzhou (representing cultural landscape heritage) to ensure the universality of the research conclusions. Data collection methods used include questionnaire surveys, behavioral observation and physiological measurements.

The questionnaire survey was divided into four modules: basic information of visitors, experience of using technology, perception of immersion, and cultural identity attitude. 5 Likert scale was adopted for data collection. Behavioral observation was used to gather data on the distribution of visitor attention, frequency of visitor-interaction and expression of emotion during an experience using video recording and eye tracking.

Physiological measurements wore devices to document the physiological indicators like heart rate variability and skin conductance, reflecting the objective state of the visitors with regard to their level of arousal and emotional states.

Sample selection was done through stratified random sampling. At each heritage site, visitors using smart technology experiences were selected as the experimental group, while those receiving only traditional guided tours were selected as the control group. To eliminate the potential impact of cognitive differences due to professional background on the measurement of cultural identity, both groups were drawn from ordinary visitors, excluding professional museum staff working at the heritage sites. The sample size of each group was 200 people at minimum. A total of 720 questionnaires were distributed, and 684 copies of valid questionnaires were returned. 684 valid samples represent 95.0% valid response rate. The experimental group was made up of 412 participants while the control group was made up of 272 participants. To control for the potential impact of the "novelty effect" on the research results, this study added "perceived technological novelty" as a control variable to the questionnaire design and treated it as a covariate during the data analysis phase. Additionally, in the experimental group, we selected at least 30% of the tourists who had experience using similar smart technologies (such as VR/AR games) to partially offset the experience bias caused by first-time exposure to the technology. 272 participants represented a wide variety of touristic groups with different ages, education background and travel experiences.

### B. DESIGN AND IMPLEMENTATION OF TECHNOLOGY EXPERIENCE SCENARIOS

The design of the technology experience scenario abide by "cultural narrative as the main focus and technology serving the content", and builds a technical architecture containing the spatial layer, the interactive layer, and the narrative layer. The spatial layer applies 3D Modeling and Virtual Restoration Technology to restore the historical scene of the heritage site as accurately as possible, the modeling accuracy of 3D modeling is up to millimeters, and the standard of texture is 4K. Taking a historical building heritage as an example, the technical team used a combination of laser scanning and photogrammetry to complete the digital acquisition of the main building and its interior furnishings, and built a high-precision model, thereby realizing the true restoration of the building's structural details and material textures [13-14].

The interaction layer is designed with multimodal human computer interaction techniques such as gesture recognition, voice control and haptic feedback. The system uses an algorithm based on computer vision to track gestures with more than 95% accuracy and response time of 50 milliseconds. Voice interaction also integrates a natural language processing module, the visitor can ask natural language information about the historical information, and the system generates structured answer based on the knowledge graph technology. Haptic feedback enables the simulation of the texture of various materials via wearable devices, e.g. the wood feel of ancient buildings and the hardness of stone, to enhance the realism of the sensory experience. The principle used in the design of an interaction is "instant feedback", in order that all actions carried out by the visitor are responded to by the system in a timely manner, so as not to interrupt the feeling of being immersed in the experience.

The narrative layer is used to create a non-linear story line which enables visitors to head off in different ways according to their personal interests. The narrative content is based on careful archaeological research and historical documents, which ensures that the cultural information is accurate. Virtual guide characters are integrated into the scenes in order to navigate visitors through their explorations using emotional language and to trigger historical event re-enactments at key moments, e.g. during an ancient ritual and when building an architectural structure. The narrative pacing regulates the duration of experience at between 25 and 35 minutes, matching the best attention span based on cognitive load theory. The technology system also incorporates an adaptive recommendation algorithm which changes the content delivery in real-time based upon the interactions of visitors to the system in order to achieve a personalized experience.The technology system integrates a dynamic feedback optimization module. This module no longer simply adjusts based on a single emotional indicator, but instead performs contextualized attribution analysis by fusing multimodal data. The system not only collects users' physiological signals (heart rate variability, skin conductance) but also simultaneously analyzes their behavioral patterns (such as interaction frequency, path selection, and the duration of gaze on virtual content and hardware interfaces) and environmental interaction data (such as the trigger frequency and intensity of haptic feedback). Through a classifier based on a temporal convolutional network, the system can integrate these data streams to distinguish whether the user's arousal state stems from emotional engagement with heritage narrative content (e.g., elevated skin conductance and focused gaze when witnessing historical events) or from frustration with interaction with the technology hardware (e.g., elevated skin conductance accompanied by repeated gesture recognition errors and frequent gaze shifts to operational prompts). Based on this refined distinction, the system's adaptive recommendation algorithm can make more accurate responses: when identified as content-driven, the system will deepen the narrative, for example, by triggering richer historical details or emotional background music; when identified as hardware failure, the system will activate implicit guidance mechanisms, such as providing visual cues, simplifying the current interaction steps, or automatically calibrating sensors, rather than blindly changing the narrative rhythm.

The technology implementation uses a distributed architecture, in which various terminal devices including VR headsets, AR glasses and large touchscreens are distributed at the front end, and a cloud computing platform is used for data storage and computation at the back end. The system supports collaborative experiences for multiple users, up to 8 users online in the system at one time. Users can view one another's virtual avatars and facilitate voice communication and others. To ensure that the network environment at the heritage site is stable, a 5G private network and edge computing nodes are deployed to ensure that data transmission latency is lower than 20 milliseconds to prevent interruptions to the immersive experience due to screen stuttering.

### C. DATA ACQUISITION AND ANALYSIS METHODS

The data collection is broken down into three phases; pre-testing, in-experience monitoring, and post-testing. Pre-testing is undertaken before the tourists enter the experience environment and gathering baseline data such as demographic data, prior level of knowledge, and technology acceptance. In-experience monitoring is an automatic way to record the interaction of tourists, including the behavioral data of him or her, such as dwell time, operation frequency, path selection and gaze focus. At the same time, physiological signals are collected in real time with wearable devices at a sampling frequency of 100 times/s. Post-testing takes place directly at the conclusion of the experience, using a standardized scale to assess level of immersion and attitudes of cultural identity. The scale has 20 measurement items across four dimensions: sensory immersion, loss of time perception, emotional engagement and cognitive participation.

Qualitative data was obtained through semi-structured interviews, while on-site observation notes were taken. Interviewees included 36 people: tourists, technical designers and heritage site managers, with the average interview duration being 45 minutes per person. Interview content focused on topics like experiences with technology use, changes in cultural understanding, and suggestions for improvement. Qualitative data units have been analyzed using theoretical thematic analysis method by means of open-ended coding, axial coding, selective coding to extract out core concepts and relationship patterns in to interpret and complement the quantitative analysis results. All data analysis was conducted by using the software package of the Statistical analysis program (SPSS 26.0) and the non-parametric statistical analysis (AMOS 24.0) with a significance level of 0.05.

## IV. RESULTS AND DISCUSSION

### A. CURRENT STATUS OF SMART TECHNOLOGY APPLICATIONS AND CHARACTERISTICS OF TOURIST EXPERIENCE

Data analysis shows that application of smart technologies in World Heritage sites covers multiple aspects, depending on the purpose to be achieved: display, guidance, protection and management, but there are significant differences in terms of depth and effectiveness of application. Table 1 shows basic scenario of technology application, basic indicators of visitor experience for three case sites. Archaeological site heritage sites are implemented using AR with real scene technology, using tablets or AR glasses to display virtual real site scene to be restored on the site remains, with average time of experiencing 28.3 minutes. Cultural landscape heritage sites employ the combination of holographic projection and interactive screens to provide an immersive environment in the physical exhibition hall with a relatively lower experience time of 22.7 minutes.

As shown in Table 1, based on the match between the technology and the type of heritage, the experience is directly affected. VR large space technology has a best performance in historical building heritage sites with an immersive experience score of 4.42. This is attributed to the capacity of this technology to deliver a complete virtual environment that does not get disturbed by the real environment and enables the visitors of this environment to get immersed completely in the historical scene. When applied to archaeological site heritage sites, AR technology, despite its potential combination of virtual restoration and real remain, although the technical failure rate is relatively high (5.8%), mainly because of the effect of the change of outdoor ambient light on the accuracy of tracking, the immersive experience is relatively low (4.15). The holographic projection technology applied to cultural landscape heritage sites is constrained by the physical boundaries of the display space that in turn leads to a shorter duration of experience and rather less intense immersion (3.98). However, it still holds a high level in the cultural identity dimension (4.12), which suggests that the technology is not the only determining factor when it comes to the cultural effect.

### B. FACTORS INFLUENCING AND MECHANISMS OF IMMERSIVE EXPERIENCE

In order to uncover the mechanism behind the impact of smart technologies on the immersive experiences, this study built an SEM with independent variables of technological characteristics, mediating variable of immersive experience, and dependant variable of cultural identity. Table 2 shows the descriptive statistics and Correlation coefficient matrix of the variables. Technological characteristics possess three dimensions: interactivity, authenticity and coherence. Interactivity refers to the responsiveness and abundance of feedback of the technological system on user operations; authenticity refers to the degree of consistency between the virtual scene and the historical reality and the realism of sensory simulation; and coherence refers to the rigor of the narrative logic and the fluidity of scene transitions. Data shows that all the three dimensions of technological characteristics are also significantly positively correlated with immersive experience and the correlation values are 0.58, 0.64 and 0.61 respectively, with a moderate correlation

**TABLE 1.** Comparison of Technology Application and Visitor Experience Indicators at the Three Heritage Sites

| Types of heritage | Technical Form | Experience space ($m^2$) | Average experience duration (min) | Technical failure rate (%) | Immersive experience score | Cultural identity score |
|---|---|---|---|---|---|---|
| The Forbidden City of Ming and Qing Dynasties (Beijing) | VR large space | 800 | 32.5 | 3.2 | 4.42 | 4.35 |
| Qin Shi Huang Mausoleum and Terracotta Army Pit | AR overlay | 1200 | 28.3 | 5.8 | 4.15 | 4.28 |
| Hangzhou West Lake Cultural Landscape | Holographic projection + interactive screen | 450 | 22.7 | 2.1 | 3.98 | 4.12 |

with final cultural identity as well.

Structural equation modeling analysis showed a good overall model fit ($\chi^2/df = 2.14$, CFI=0.96, RMSEA=0.058). Path analysis revealed that technological features had a significant positive impact on immersive experiences ($\beta = 0.72$, $p < 0.001$), while immersive experiences also had a significant positive impact on cultural identity ($\beta = 0.81$, $p < 0.001$). The direct impact of technological features on cultural identity was not significant ($p > 0.05$, $\beta = 0.08$), indicating that immersive experiences play a fully mediating role between technological features and cultural identity. This result demonstrates that intelligent technology

does not directly enhance cultural identity, but rather transmits cultural values through the mediating role of immersive experiences..After incorporating "perceived technological novelty" as a control variable into the model, the path coefficients between each dimension of technological features and immersive experience decreased slightly, but the overall model and each major path remained significant ($p < 0.001$). This indicates that although the novelty effect does contribute to immersion, the technological features (interactivity, authenticity, and coherence) identified in this study remain robust in their explanatory power for immersive experience and are core elements for enhancing the experience.

### *C. TECHNICAL DESIGN OPTIMIZATION PATH AND EFFECT EVALUATION SYSTEM*

Based on empirical analysis, this study puts forward three optimization paths regarding ways of using the smart technologies to boost the immersive heritage tourism experience. First, the technology-adaptive design path focuses on the close matching of forms of technology with the types of heritage and characteristics of scene. For heritage sites that have complicated architectural constructions, VR large space technology is prioritized to form a complete virtual space; for archeology sites that have many physical remains, AR technology is used to realize the virtual real integration, but a light adaptive tracking system is needed to weaken environmental interference; for culture landscape that has strong narrative, holographic projection and combination with physical scenes are used to enhance dramatic expression. Cost-effectiveness is something that should be considered when investing in technology. Data shows that when the technology failure rate is controlled below 3%, there is significant improvement in the immersive experience score ($F = 15.32$, $p < 0.001$), hence system stability should be the first indicator for technology selection.

Second, the multi-sensory collaborative narrative path puts an emphasis on integrating visual, auditory, intramuscular, and proprioceptive channels. The study tested the impact of different sensory combinations of the immersive experience and Table 3 presents a comparison of the effects of three sensory configuration schemes. Scheme 1 is a pure visual presentation, with a 3D scene presented only with the help of a head-mounted display; Scheme 2 is a visual and auditory presentation, where spatial audio and historical environmental sound effects are presented with the visual experience; Scheme 3 is a multiple sense integration, where tactile feedback and environmental simulations such as wind, temperature, etc., are added to the visual and auditory experience. The results indicate that the more sensory channels there are, the higher the immersive experience score gets in a step-wise fashion. Scheme 3 achieved a 23.6% improvement compared to Scheme 1. Physiological data also supports this conclusion. The specific processing procedure is as follows: First, baseline correction was performed on the raw physiological signals (heart rate variability, skin conductivity, sampling frequency 100 Hz) collected from each participant, and the difference was calculated based on the resting state data of 2 minutes before entering the experience scene. Subsequently, feature extraction was performed on the corrected signals, and the average amplitude of skin conductivity response and the low-frequency/high-frequency ratio of heart rate variability were calculated as the core indicators of physiological arousal index. Finally, the multimodal physiological indicators were aggregated into a single physiological arousal index using the Z-score standardization method to ensure comparability between different individuals. Under the multi-sensory configuration, the physiological arousal index (standardized mean) of tourists reached 3.31, significantly higher than 2.45 in the pure visual configuration ($t = 4.27$, $p < 0.01$), indicating that tourists had a higher level of emotional arousal. However, cost-benefit analysis showed that Scheme 2 had the highest return on investment, with an experience improvement of only 18.4% and a cost increase of only 15%. Therefore, it is recommended to use it as the basic configuration scheme, while Scheme 3 is suitable for core experience nodes.

Third, the context-aware dynamic feedback optimization

**TABLE 2.** Descriptive statistics and correlation coefficient matrix of main variables

| Variable | Mean | Standard deviation | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| 1. Interactivity | 4.18 | 0.72 | 1.00 | | | | |
| 2. Authenticity | 4.05 | 0.68 | 0.62** | 1.00 | | | |
| 3. Continuity | 4.22 | 0.75 | 0.59** | 0.65** | 1.00 | | |
| 4. Immersive experience | 4.21 | 0.69 | 0.58** | 0.64** | 0.61** | 1.00 | |
| 5. Cultural Identity | 4.25 | 0.71 | 0.52** | 0.56** | 0.49** | 0.78** | 1.00 |

Note: ** indicates that $p < 0.01$ is significant.

**TABLE 3.** Comparison of the experience effects of different sensory configuration schemes

| Configuration Scheme | Technical components | Immersive experience score | Physiological arousal index | Cost Index | Input-output ratio |
|---|---|---|---|---|---|
| Option 1 | Pure visual | 3.65 | 2.45 | 100 | benchmark |
| Option 2 | Audiovisual combination | 4.32 | 3.12 | 115 | 1.26 |
| Option 3 | Multisensory Fusion | 4.51 | 3.31 | 158 | 0.89 |

path, at its core, distinguishes user feedback into "content-driven" and "hardware-driven" types, and adopts differentiated system response strategies accordingly. Based on the dynamic feedback optimization module described in Section 3.2, this path requires the technical system not only to monitor the user's real-time state but also to intelligently attribute that state. The system establishes a user intent understanding model by analyzing the coupling relationship between behavioral data (such as interaction success rate, and the distribution of gaze on virtual content and interface elements) and physiological data. When positive emotions evoked by content are detected (such as a steady increase in skin conductance accompanied by prolonged gazing and active exploration), the system will "deepen the content" by adding narrative branches and enriching scene details to enhance immersion and cultural resonance. Conversely, when negative emotions caused by technical frustration are detected (such

as a sudden increase in skin conductance accompanied by repetitive operations and frequent glances at the operation guide), the system will initiate "imperceptible intervention," such as automatically reducing the difficulty of interaction, displaying implicit guidance, or performing background sensor calibration to ensure the continuity of the experience.Furthermore, a closed loop visitor feedback mechanism should be created for collecting post experience evaluation information for content iteration to create a continuous improvement cycle of "design-implementation-evaluation-optimization".

With regard to the effective construction of the effectiveness evaluation system, this research suggests a comprehensive evaluation framework that consists of process indicators and outcome indicators. Process indicators are interested in the state of the experience (presence) on a moment-to-moment basis, such as physiological arousal level, frequency of interaction, dwell time, and variety of path selection. These indicators are gathered automatically by technological means that merit the degree of participation of the visitor in an objective manner. Outcome indicators are centered on post-experience changes in attitudes and behaviors, such as scores on immersion experience scales, cultural knowledge test scores, willingness to experience again, and movie recommendations, using standardized scores. The joint application of these two types of indicators is conducive to the comprehensive assessment of the technology application's effectiveness, and it avoids the one-sidedness of using a single indicator. The evaluation implementation should comply with the baseline comparison principle, and result separately measured before and after technology implementation, with the control of confounding variables and validity of the evaluation results.

## V. CONCLUSION

This research, situated within the context of World Heritage sites, systematically examines the design mechanisms and evaluation systems of smart technology-enabled immersive heritage experiences by integrating the structural logic of technical production and intelligent fiber-sensing technologies. By analyzing the interwoven material patterns of historical craftsmanship through digital simulations, the study establishes a multidimensional framework for the effective smart transformation of tangible cultural heritage. By developing a three-dimensional analytical structure "technology-experience-value," a hybrid research methodology was used to empirically analyze the application practices of technology at three heritage sites. The study found that smart technology has a significant effect into improve the heritage tourism experience, but this effect depends on scientific designing logic and strict evaluation standards. The theoretical contribution of this work results from the construction of an analytical framework for the integration of the smart technology and heritage tourism which reveals the mechanism of interactions between technological design elements and the experiential effects and also to expanding the application of the immersive experience theory into the area of cultural heritage. Its practical value is in fulfilling the need for operable tools and methods of technology selection, content designs and effectiveness evaluation at heritage sites, avoiding the blind and homogenized application of technology. The limitations of this study are that the sample only covers three heritage sites; future researches can be expended to more types of cultural heritage scenarios, to further prove the universality of the conclusions. Furthermore, the rapid pace of technological iteration necessitates a dynamic evaluation system that incorporates the structural logic of technical textile engineering to assess the application potential of emerging innovations. Future research should prioritize the integration of AI-generated content and brain-computer interfaces with intelligent fiber-sensing matrices to enhance the interactive depth and material resonance of heritage tourism experiences.

## AUTHOR CONTRIBUTIONS

Conceptualization –Dongpo Yan, Azizan Marzuki, Jiejing Yang, Shuaizheng Zhao and Li Wang; methodology – Dongpo Yan, Azizan Marzuki, Shuaizheng Zhao and Li Wang; investigation – Dongpo Yan, Azizan Marzuki, Jiejing Yang, Shuaizheng Zhao and Li Wang; writing-original draft preparation – Dongpo Yan, Azizan Marzuki, Jiejing Yang, Shuaizheng Zhao and Li Wang. All authors have read and agreed to the published version of the manuscript.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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