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Applied Study on Digital Technology in Empowering the Dissemination of Cultural Heritage Value in Museum

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Abstract: As China's cultural digitization strategy advances and museum functions expand, museums based on heritage sites face challenges, including an imbalance between cultural heritage specialism, public accessibility, and the risk of inadequate management in digital technology applications. This paper integrates international charters and guidelines to construct an original four-dimension-twelve-indicator theoretical framework. By applying two case studies from the Nanyue King Museum to the framework, a mixed-methods research approach is used to analyze the efficacy of digital technology applications. Findings reveal that both cases effectively enhanced public awareness and engagement with the sites and artifacts. However, the indicators show that issues such as inadequate service stratification still persist. The conclusions offer concrete pathways for optimizing compliance and efficiency in the digital practices of site-based museums, while also providing empirical support for the digital theoretical framework of cultural heritage value dissemination.

Keywords: digital technology; museum; cultural heritage value dissemination; cultural digitisation; Nanyue King Museum

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1. Introduction

1.1. Research Background

China's National Strategy for Cultural Digitisation (2022)[1] creates both opportunities and challenges for museums. As key institutions for safeguarding and exhibiting heritage, museums are moving beyond static displays toward multidimensional interpretation and public communication. The growing use of AI, VR/AR, big data, and cloud computing in public cultural services raises expectations: museums must not only protect authenticity and integrity but also convey heritage value through more inclusive, interactive, and educational approaches[2,3].

Archaeological-site museums face distinctive hurdles. Stratigraphy, structures, spatial contexts, and environmental details are highly specialized, posing comprehension barriers for general audiences. Digital tools offer remedies. Digital

displays increase access by overcoming temporal and spatial limits, broaden social inclusion—especially for youth and multicultural publics—and foster identification and belonging through interactive learning[4,5]. Yet risks persist: technologies can distort or misrepresent heritage; entertainment-driven approaches may eclipse meaning and education; and weak governance over copyright, data security, and content review undermines accuracy and compliance[6,7].

1.2. Significance of Study

A pressing question in China is how to employ digital tools to enhance interpretation without harming sites, integrate on-site and online experiences, and connect in-museum learning with community co-creation[1,8]. This study analyzes two representative cases to assess current practices and risks, and proposes practical guidance and an operational framework to build robust management for digital exhibitions, strengthen digital resource protection, and standardize review and release procedures, thus supporting compliance and sustainability[9,10].

2. Literature Review and Theoretical Framework

2.1. Principles for the Preservation and Presentation of Historical and Cultural Heritage

The Venice Charter (1964)[2] established authenticity and integrity as baseline values, advocating minimal intervention and reversibility so that adverse actions can be undone. In China, the Guidelines for the Conservation of Cultural Heritage (2015)[3] translate these values into procedures that prioritize research and planning: display and use must rest on thorough investigation and scientific assessment of historical, artistic, and scientific significance, as well as current conservation needs. This "value–procedure" dual structure provides an institutional basis for calibrating the relationship between digital tools and heritage sites, enabling appropriate digital presentation and interpretation[4,5].

2.2. Importance of Interpretation and Presentation

As public service functions expand, interpretation and presentation now stand alongside conservation. The ICOMOS Charter on the Presentation and Interpretation of Cultural Heritage (2008)[4] underscores narrative accuracy and verifiability, requiring reliance on credible historical sources and research capable of withstanding scholarly and public scrutiny. Exhibition planning must consider site impact: facilities and activities should not obscure visual integrity or circulation, ensuring the public's perception of the site's original character. Interpretation should accommodate diverse audiences through multilingual, multi-tiered pathways and varied media—text, audio, and multimedia—tailored to different ages, backgrounds, and education levels. Public participation through interactive programs, workshops, and lectures strengthens social memory, embedding heritage in everyday life[5,6].

Digitally, VR/AR broaden possibilities by creating immersive experiences, but spectacle-seeking can displace substantive interpretation. The key practical question is how to ensure technology serves understanding and education rather than substituting effects for meaning[7,8].

2.3. Digital Visualization Methodology

Methodological standards underpin credible digital heritage work. The London Charter (2009) requires clear differentiation among evidence-based reconstruction, reasoned inference, and artistic interpretation in computer-visualized projects, guarding against public misunderstanding. It also calls for preservation of para-data—process-generated records such as 3D scanning parameters, modeling revision logs, and virtual restoration quality checks—so that workflows, parameters, and decision paths are traceable. Such records enable verification, revision, and reuse, enhancing professionalism and credibility[6,9].

The Seville Principles (2011)[6] extend these norms to virtual archaeology, emphasizing transparency, traceability, and educational orientation. Methodological transparency thus becomes a prerequisite for professional quality and public trust, allowing digital technology to contribute more effectively to heritage preservation and dissemination[10].

2.4. Requirements on Publicness and Manageability

UNESCO (2015)[7] defines museums as public cultural institutions serving all of society, tasked with meeting public cultural needs and advancing social cultural development. For digitisation, it recommends institutional arrangements for copyright, metadata, long-term preservation, and migration to prevent loss through obsolescence or storage failure, ensuring durable digital assets[11].

Museums should also guarantee accessible, inclusive services by addressing differences in physical ability, language, and cultural background through multilingual offerings, captions, sign language, and audio description—ensuring equal access to cultural resources. Overall, digitisation is not a one-off project but a systemic, managerial commitment that must be integrated into institutional planning[12].

2.5. Four-Dimension-Twelve-Indicator Framework (Original)

Based on the international charters and guidelines above, this paper originate a four-dimension-twelve-indicator framework. The derivation process from international charters and local regulations to theoretical framework is elaborated in **Figure 1**.

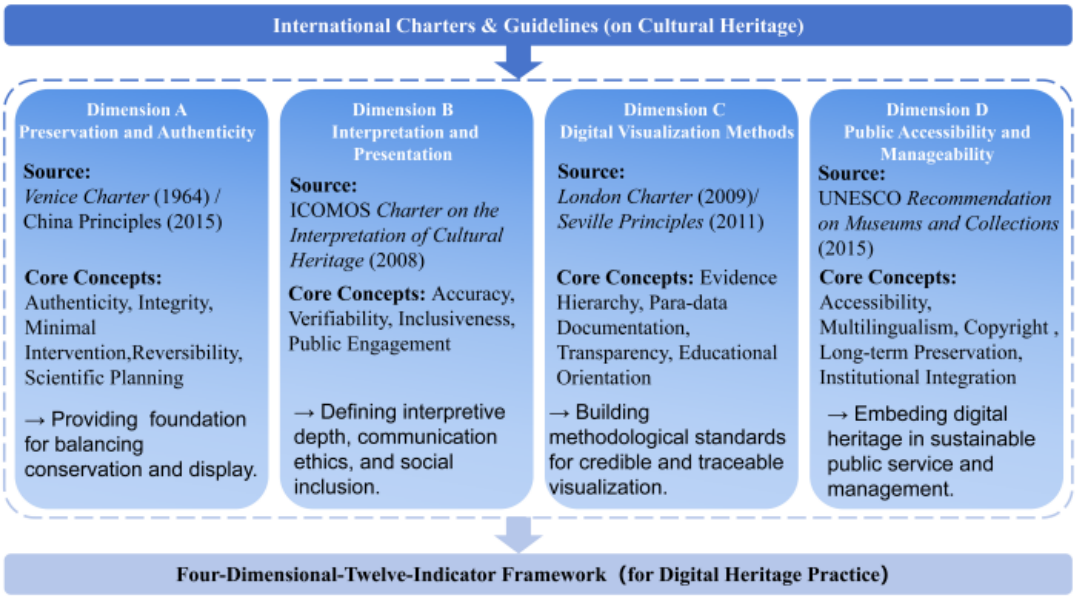

Figure 1. From international charters and regulations to the Four-Dimension-Twelve-Indicator Framework.

It helps evaluate and analyze the digital projects on cultural heritage value dissemination in museums (**Table 1**).

Table 1. Four-Dimension-Twelve-Indicator Framework

Dimension A	Preservation and Authenticity(Object Level)
Indicator 1	A1 Minimal Intervention: Avoid causing irreversible impacts on the site.
Indicator 2	A2 Reversibility: Digital or display installations should be removable or up-datable.
Indicator 3	A3 Authentic Representation: The authenticity of materials, craftsmanship, and context must be reflected in the presentation.
Dimension B	Interpretation and Presentation (Audience Level)
Indicator 1	B1 Presentation Friendliness: Do not obstruct the visual impact or circulation routes of the site itself.
Indicator 2	B2 Multi-level Interpretation and Engagement: Provide multilingual, multi-level interpretation and public participation channels.
Indicator 3	B3 Verifiable Narrative: Information must have clear sources and academic support.
Dimension C	Digital Visualization Methods
Indicator 1	C1 Classified Processing: Clearly distinguish virtual displays across the hierarchy of "evidence-inference-art"
Indicator 2	C2 Educational Functions: Digital outputs should serve public education and academic understanding.
Indicator 3	C3 Para-data Documentation: Modeling procedures and methodologies must be archived with para-data.
Dimension D	Public Accessibility and Manageability
Indicator 1	D1 Accessibility and Compatibility: Provide online accesses, barrier-free services, and multilingual versions.
Indicator 2	D2 Copyright and Para-data: Clarify copyrights, format standards, and metadata specifications for digital resources.
Indicator 3	D3 Preservation and Migration Mechanisms: Establish long-term preservation, backup, and migration plans, integrating them into management strategies.

This framework comprehensively encompasses the key elements and requirements for the digital projects of cultural heritage in museums, providing systematic guidance for evaluating and enhancing museum digital practices[12].

2.6. Relative Researches

Li, Zheng, Watanabe, and Ochiai review AI, VR/AR, cloud computing, and big data in museum exhibitions, proposing an integrated, closed-loop evidence chain from planning to assessment. Their model grounds this paper's C1 Classified Processing, C3 Process Data Recording, and D3 Long-Term Preservation and Migration (Li et al., 2024)[8,13].

Wang et al. use structural equation modeling to show how digitisation strengthens young audiences' connections to heritage via accessibility, interactivity, and identity/emotional bonds. This supports embedding audience experience and learning outcomes in B1 Presentation Friendliness and B2 Multi-level Interpretation and Participation (Wang et al., 2024)[14].

Shim et al. link the academic validity of digital narratives to public communication effectiveness, calling for verifiability, transparent evidentiary bases, and explicit uncertainty cues to avoid entertainment-driven meaning drift—aligning with B3 Verifiable Narratives and C1 Classified Processing (Shim et al., 2024)[15].

At the HCI level, Capece et al. survey advanced interfaces and advocate parallel, multidimensional, mixed-methods evaluation to reduce single-scale bias, informing D1 Accessibility and Compatibility and D3 Preservation and Migration governance (Capece et al., 2024)[16].

Yap et al. assess digitisation's effects at the tourism–museum nexus, identifying a dual mechanism: improved usability and access can raise engagement but, without strong narratives and information quality control, may dilute learning. This reinforces links among B3 Verifiable Narratives, C2 Educational Functions, and D2 Copyright and Para-data (Yap et al., 2024)[12,13].

3. Research Methodology

This study evaluates how digital technologies convey heritage value in site-based museums using a mixed-methods design that blends standardized quantitative measures with qualitative depth. The workflow follows three steps, from case selection to data collection and analysis/validation.

3.1. Case Selection Methodology

Cases were chosen for typicality, data availability, and practice completeness. Two long-running projects at the Nanyue King Museum were selected: (1) Audio-visual Restoration of the Crooked Stone Brook, representing an on-site experiential model; and (2) AR Smart Guide Glasses, representing an on-site augmented model. Together they cover mainstream digital scenarios focused on major archaeological contexts and artefacts. Publicly available project details, feedback, and metrics (official website, annual reports, local media) ensure reliable secondary data. Both projects have operated >1 year, providing sufficient longitudinal usage and experience data.

3.2. Data Collection Methods

3.2.1. Quantitative Data Collection

Two sources were used: museum extracts and an on-site survey. From museum records we captured session attendance and dwell time for the Meandering Stone Channel, plus AR usage counts and version shares (Adult/Child/English) for the AR tours—establishing baseline coverage and uptake. The on-site survey (Nanyue King Museum, 30 Sept 2025) employed stratified sampling by age (< 18, 18–30, 31–59, 60 +). 60 questionnaires were issued; 46 valid (76.7%). Items were closed-ended and organized around cognitive enhancement (site-function understanding), experience satisfaction (device usability), and project effectiveness (information delivery), using a 5-point Likert scale (1 = very dissatisfied, 5 = very satisfied).

3.2.2. Qualitative Data Collection

Qualitative data was gathered through on-site observation and in-depth interviews. On-site observation focused on user behaviour across both projects, recording audience dwell time at digital installations, interaction frequency (e.g., AR glasses usage count), and documenting equipment malfunctions or obstructed information via observation logs.

3.3. Data Analysis

Integrating questionnaire data with the Four-Dimension-Twelve-Indicators Framework, both quantitative and qualitative data were mapped to respective indicators. Through bidirectional validation between data and indicators, project compliance and areas for optimisation were assessed, ensuring the reproducibility to other studies throughout the analytical process.

4. Analysis on Major Cases

This section examines how digital technology disseminates cultural heritage value in museums through two case studies at the Nanyue King Museum. The museum was selected for its exemplary digital practice and accessible data, ensuring study feasibility. It has built a digital dissemination pathway around two key archaeological sites—the Tomb of the Nanyue King and the Palace Ruins—covering both on-site experiential and digitally enhanced exhibitions. These site-rooted immersive approaches reflect mainstream museum digitisation and provide a clear, traceable route.

4.1. Case Study 1: Audio-visual Restoration of the Crooked Stone Brook at the Palace of the Nanyue Kingdom

Archaeological site exhibitions face two main hurdles: (1) complex, overlapping stratigraphy—often worsened by later-

period damage—reduces display clarity; (2) predominantly static formats lack interactivity and visual appeal. The Nanyue Kingdom's Crooked Stone Brook showed these issues at its 2011 opening. A museum survey in late 2011 found only 36% of visitors could accurately identify the site; during self-guided tours, just 33% stopped to read plaques. Frequent complaints—"plaques too far," "font too small," "site lighting too dim"—made texts hard to read (Lan, 2011)[13,14]. Static displays thus transmitted information poorly and delivered weak experiences, prompting the museum to adopt audio-visual restoration and pursue digital upgrades.

The Audio-visual Restoration of the Crooked Stone Brook is a flagship response. Using 20 multimedia projectors, water-ripple lights, control consoles, and 3D modeling to reconstruct the brook's full form, it opened to the public in February 2021 with two daily one-hour shows (10:00 and 15:00). Visitors now see the site's static structure and simulated dynamic water, with sound-activated effects that evoke the Nanyue royal palace's Lingnan garden two millennia ago—flowing springs and birdsong included (Figures 1–4). In 2024, the project was named among the "Top Ten National Archaeological Site Conservation and Exhibition Cases" (Huang, 2021)[14,16].

Figure 2-3. A combination of media video projectors, water ripple lights, control consoles, and other equipment utilizes 3D modeling simulation and other technologies to outline the entire curved stone channel, simulating the dynamic water flow effects along its entire length.

Figure 4. High-brightness, high-lumen engineering projectors and holographic gauze screens simulate the restored scenery of the pavilion and water pavilion, bringing the narrative setting to life.

Figure 5. Using phantom imaging at key archaeological pillars on the site to popularize archaeological stratigraphy, presenting historical information and archaeological discoveries from each sedimentary layer.

When examining this case using the framework indicators of this study, the specific scores are shown in the scale (**Table 2**):

Table 2. Four-Dimension-Twelve-Indicator Framework (Audio-visual Restoration of the Crooked Stone Brook)

Dimension A	Preservation and Authenticity	
A1: Grade 5	A2： Grade 5	A3：Grade 4
Dimension B	Interpretation and Presentation	
A1: Grade 5	A2： Grade 2	A3：Grade 4
Dimension C	Digital Visualization Methods	

Dimension A	Preservation and Authenticity	
A1: Grade 1	A2： Grade 3	A3：Grade 5
Dimension D	Public Accessibility and Manageability	
A1: Grade 3	A2： Grade 5	A3：Grade 5

The project scored well across all four dimensions but showed two gaps: no multilingual/multi-level presentation, and unclear on-site differentiation in explanatory content.

On 30 Sept 2025, 46 valid questionnaires were collected; 89.13% were first-time visitors. After viewing the Audio-visual Restoration of the Crooked Stone Brook, 67.39% reported they "understood" the site. Field observation showed > 95% paused at the digital installations, extending overall viewing time, though younger visitors were less engaged by the light-and-sound displays. For C2 (educational functions), respondents noted the twice-daily schedule was insufficient: visits often did not align with screenings, preventing viewing; missing the initial projection segment also hindered understanding of the restored palace grounds, reducing completeness of information reception.

4.2. Case Study 2: AR Smart Guide Glasses

The AR Smart Guide Glasses, launched at the King's Tomb site in April 2023, overlay virtual information onto real scenes to deliver a richer, more interactive visit. The system provides adult and children versions tailored to different cognitive levels and interests: adult narration highlights historical context, cultural significance, and scholarly findings; the children's version uses vivid language and animation to introduce artifacts and spark interest in history and culture. (**Figures 6**–**15** are frames from museum-provided videos.).

Figure 6-7. Demonstration of usage and AR imaging effects of AR Smart Guide Glasses (Source: Official promotional video).

Figure 8. Example of AR glasses imaging, illustrating the overlay of a 3D-modeled relic with 3D animation.

Figure 9-11. Example of AR glasses imaging, showing experts recounting tomb exploration stories, using narrative storytelling, authentic footage , and 3D animation to present the process of the archaeological findings.

Figure 12-13. AR Glasses Imaging Comparison. Adult and Children's Versions of explanations on the Nanyue Kingdom Territory.

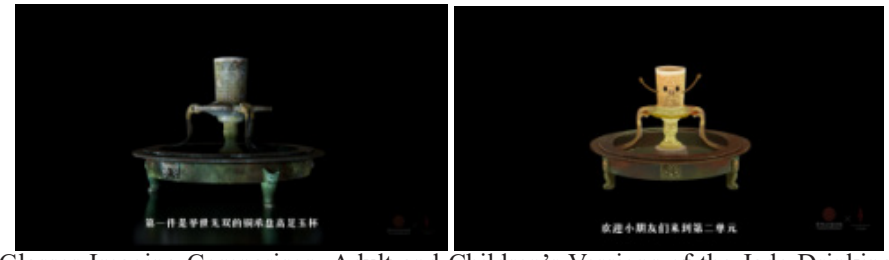

Figure 14-15. AR Glasses Imaging Comparison. Adult and Children's Versions of the Jade Drinking Cup for Collecting Sweet Dew.

Evaluating this case using the framework indicators of this study, the specific scores are shown in the scale (underlined in **Table 3**):

Table 3. Four-Dimension-Twelve-Indicator Framework (AR Smart Guide Glasses)

Dimension A	Preservation and Authenticity	
A1: Grade 5	A2： Grade 5	A3： Grade 5
Dimension B	Interpretation and Presentation	
A1: Grade 3	A2： Grade 5	A3： Grade 5
Dimension C	Digital Visualization Methods	
A1: Grade 5	A2： Grade 5	A3： Grade 5
Dimension D	Public Accessibility and Manageability	
A1: Grade 5	A2： Grade 5	A3： Grade 5

During the preparatory phase, the museum invited public participation via a global children's voice-over contest (Bu, 2022)[15]. This enriched content diversity and strengthened engagement with the museum, aligning with Indicator B2 on tiered interpretation and public participation within "Interpretation and Presentation." Additionally, official records note that on September 25, 2024, during International Deaf Awareness Week, the museum guided hearing-impaired visitors to use sign-language-enabled AR glasses, ensuring accessibility for special-needs audiences (Song, 2024)[16].

According to museum statistics, the system logged over 40,000 uses in 2024–2025, with version distribution as

follows: Adult 82.83%, Children 17.04%, English 0.13%. In a user survey (n = 40), 42.5% rated the experience "good"; 22.5% sought reduced visual obstruction, and 20% preferred lighter equipment—pointing to improvements needed in presentation friendliness (Indicator B1).

In summary, both cases meet standards across all four framework dimensions, with notable strengths. The framework effectively surfaces shortcomings and guides subsequent optimization.

By applying three-indicator scales across three of the four dimensions, composite radar charts were generated for each case (**Figure 16**). Comparison shows Case 2 outperforms Case 1, with Case 2 approaching 15/15 across dimensions, while Case 1 shows a marked shortfall in Dimension C (Digital Visualization Methods), consistent with on-site questionnaire feedback.

	Case 1	Case 2
Dimension A	14	15
Dimension B	12	13
Dimension C	9	15
Dimension D	13	15

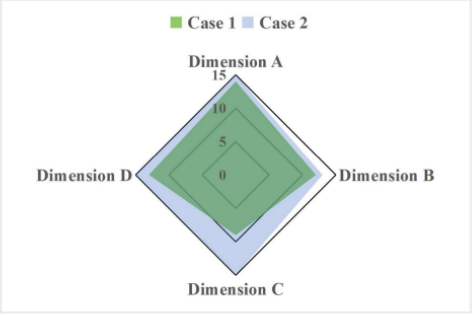

Figure 16. Radar chart comparing Case 1 and Case 2

5. Limitations and Future Research

5.1. Limitations of Study

This study has limitations in evaluation effectiveness and case coverage. Methodologically, although the questionnaire covered diverse groups, the sample was concentrated among participants who had already engaged with the projects, lacking long-term comparative data with audiences not exposed to digital initiatives. The research subjects are limited to two cases within a single museum, yielding insufficient feedback from children and professional researchers and restricting the representativeness of the qualitative analysis; the cross-museum applicability of the proposed framework remains unverified. In terms of evaluation dimensions, the analysis emphasizes short-term outcomes (e.g., on-site cognitive engagement and satisfaction) while lacking tracking of long-term outcomes (e.g., knowledge retention and cultural dissemination behaviors). Follow-up surveys could test whether cultural identification persists and whether audiences actively disseminate related content. The evaluation also excludes the cost–benefit ratio of technology—such as the alignment between AR glasses' investment, maintenance costs, and dissemination effectiveness—thus failing to offer decision-making references for resource allocation.

5.2. Possibilities for Future Research

To address these limitations, subsequent research can proceed in two directions to refine the framework. First, expand methodologies and data dimensions: design 6–12-month longitudinal follow-ups with knowledge tests and behavioral questionnaires to assess long-term effects (e.g., recall of the stone brook's functions and AR artifact details, voluntary sharing of cultural content, repeat visits). Introduce controlled experiments in which visitors are randomly assigned to digital-project or traditional-viewing groups, controlling other variables to quantify impacts on cognitive understanding and cultural identification. Broaden interview samples to include children, professional researchers, and accessibility groups, adopting demographic-specific methods such as children's drawing analysis and targeted group discussions. Second, at the project implementation level, formulate specific optimization recommendations for the Nanyue King Museum using

this study's framework—for example, in the stone brook restoration, add evidence-source QR codes that link to original archaeological reports, meeting Indicator C1 processing requirements.

6. Conclusion

This study examined the potential and efficiency of digital technology in disseminating the value of cultural heritage through specific case studies. Its original framework and practical findings provide valuable reference for similar digitisation projects at site-based museums, while also supplementing empirical evidence for relative researches in cultural heritage communications.

The original framework in this study serves as an effective evaluation tool for digitisation projects in site-based museums. The indicator system established across four dimensions not only identifies strengths of the project but also pinpoints areas for optimization, providing actionable assessment standards for digital practices.

Disclosure statement

The author declares no conflict of interest.

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