ISRG Journal of Arts, Humanities and Social Sciences (ISRGJAHSS)

ISRG PUBLISHERS
Abbreviated Key Title: ISRG J Arts Humanit Soc Sci
ISSN: 2583-7672 (Online)
Journal homepage: https://isrgpublishers.com/isrgjahss
Volume – III Issue –IV (July-August) 2025
Frequency: Bimonthly

Application of Digital Twin Technology in the Protection of Calligraphy Cultural Heritage

Pei Liu[1*], Ruxue Dou[2]

[1, 2] Sichuan Normal University, Shizishan Campus, Jinjiang District, Chengdu City, Sichuan Province, China

| **Received:** 06.08.2025 | **Accepted:** 12.08.2025 | **Published:** 14.08.2025

***Corresponding author:** Pei Liu

Sichuan Normal University, Shizishan Campus, Jinjiang District, Chengdu City, Sichuan Province, China

Abstract

This study focuses on the application of digital twin technology in the field of calligraphy cultural heritage conservation, constructing a 'physical-digital-intelligent' ternary interaction system and a five-dimensional digital twin model. The objective is to explore new strategies for preventive conservation, restoration decision-making support, and dynamic dissemination of calligraphy heritage. By integrating multi-source heterogeneous data acquisition, cross-scale modeling, and intelligent simulation technologies, this research addresses technical challenges in the conservation of calligraphy cultural relics. Through case studies, the feasibility and innovation of its practical application are validated, offering a novel research paradigm for the scientific conservation and inheritance of calligraphy cultural heritage. The results indicate that digital twin technology can effectively enhance the scientific rigor of calligraphy heritage conservation and foster innovation in cultural dissemination, holding significant implications for advancing the digital development of cultural heritage. Specifically, digital twin technology creates highly realistic digital models by accurately replicating the physical forms and intrinsic characteristics of calligraphy cultural relics, enabling conservators to conduct non-destructive analysis and research in virtual environments. The application of this technology not only avoids potential physical damage caused by traditional conservation methods but also significantly improves the efficiency and accuracy of conservation efforts. Furthermore, the digital twin model possesses dynamic updating and intelligent prediction capabilities, allowing for real-time assessment of the conservation status of cultural relics based on continuously monitored data, thereby providing a scientific basis for preventive conservation.

Keywords: *Digital Twin; Calligraphy Cultural Heritage; Cultural Relic Conservation; Revitalized Dissemination; Multi-source Data Fusion*

DOI: 10.5281/zenodo.16870679

1. Introduction

1.1 Research Background

Calligraphy art, as a cultural treasure of the Chinese nation, embodies millennia of civilizational memory and serves as a vital symbol of Chinese culture. However, extant authentic calligraphy works are confronting a severe preservation crisis. Taking *Eulogy on My Deceased Nephew* as an example, after millennia of erosion, the paper has undergone severe acidification and embrittlement, while the ink has gradually become blurred, posing immense challenges to its physical preservation. Meanwhile, the limitations of traditional display and dissemination methods have made it difficult for a broader audience to appreciate the unique charm of calligraphy art, thereby constraining the inheritance and development of calligraphic culture.On October 9, 2024, the Ministry of Education stated in its latest policy document, the *Notice from the General Office of the Ministry of Education on Further Strengthening Standardized Chinese Character Handwriting Education in Primary and Secondary Schools*[1] , that 'we should adhere to upholding fundamental principles while pursuing innovation and explore new pathways for digitally empowering standardized Chinese character handwriting.' This policy indicates that with the expansion of digital twin technology from the industrial sector to the humanities field, new opportunities have arisen for cultural heritage preservation.

1.2 Research Objectives

This study aims to construct a 'physical-digital-intelligent' ternary interaction system for calligraphic cultural relics and develop a five-dimensional digital twin model encompassing physical entities, virtual representations, data integration, service functionalities, and interconnected networks. The model is anticipated to facilitate preventive conservation of calligraphic heritage, provide decision support for scientifically informed restoration, and further explore effective pathways for the transmission of calligraphic culture driven by digital twin technology. Specifically, the research objectives are delineated into the following aspects:Firstly, by constructing a five-dimensional digital twin model, precise replication and simulation of the physical form and intrinsic characteristics of calligraphy cultural relics are achieved, laying a solid foundation for subsequent preventive conservation and restoration decision-making. Secondly, leveraging intelligent simulation technologies within the model, dynamic assessment and prediction of the preservation status of calligraphy cultural relics are conducted to promptly identify potential damage risks and implement corresponding intervention measures, thereby realizing effective preventive conservation of calligraphy heritage. Furthermore, through the collection and analysis of multi-source heterogeneous data, decision support for the scientific restoration of calligraphy cultural relics is provided, optimizing restoration plans, reducing the risk of physical damage during the restoration process, and enhancing restoration effectiveness and efficiency. Finally, the application potential of digital twin technology in the inheritance and revitalized dissemination of calligraphy culture is explored, innovating the display and dissemination methods of calligraphy culture, broadening the audience scope of calligraphy culture, and promoting the popularization and development of calligraphy culture.

2. Analysis of the Digital Twin Technology Paradigm

2.1 Technical Core

2.1.1 Multi-source Heterogeneous Data Fusion

This study integrates hyperspectral imaging technology, Li-DAR point cloud scanning technology, and macro photography technology to acquire multi-dimensional data on calligraphy cultural relics. Hyperspectral imaging technology can precisely capture the spectral characteristics of ink traces and paper, thereby revealing hidden information such as pigment composition and modification marks. Li-DAR point cloud scanning technology is employed to construct the three-dimensional spatial structure of cultural relics, enabling accurate restoration of their stereoscopic forms. Macro photography technology focuses on capturing detailed textures, obtaining high-resolution surface texture information (Figure 1). The integration of these three technologies provides comprehensive and precise foundational data for the digital twin. With the aid of hyperspectral imaging technology, we can delve into the microscopic world of ink traces and paper, analyzing the chemical composition of pigments, aging conditions, and potential restoration needs. Li-DAR point cloud scanning technology rapidly generates three-dimensional point cloud data of cultural relics through laser scanning; after meticulous processing, this data can be used to construct three-dimensional models of the relics, accurately reproducing their stereoscopic forms and spatial structures. Macro photography technology, leveraging its high-resolution advantage, meticulously records minute textures and features on the surface of cultural relics, providing authentic and reliable materials for texture mapping of digital models.

[1] On October 9, 2024, the Ministry of Education issued the *Notice from the General Office of the Ministry of Education on Further Strengthening Standardized Chinese Character Handwriting Education in Primary and Secondary Schools*, explicitly stating that 'we should adhere to upholding fundamental principles while pursuing innovation and explore new pathways for digitally empowering standardized Chinese character handwriting'.

DOI: 10.5281/zenodo.16870679

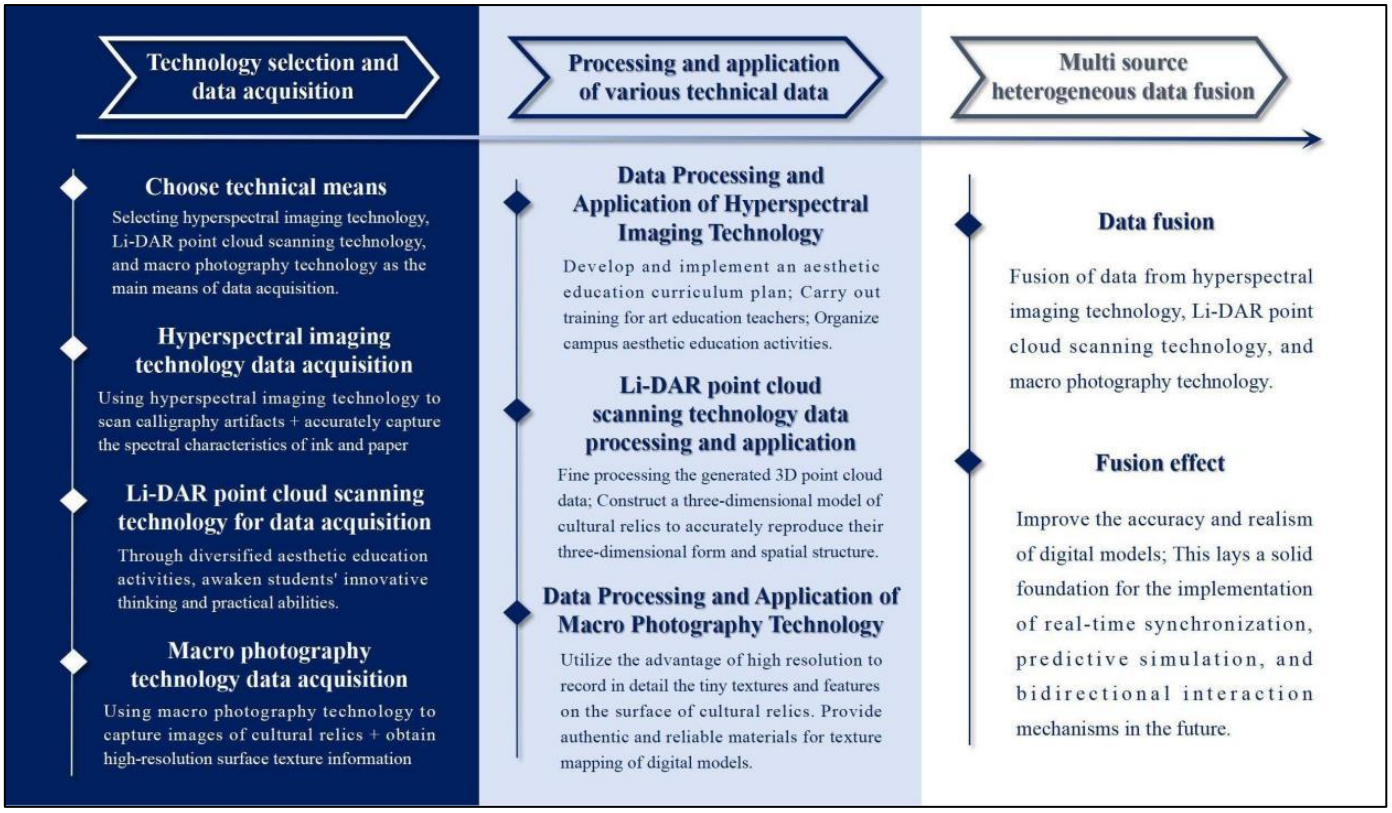

Figure 1 Flowchart of Multi source Heterogeneous Data Collection

(Source: self-made by the author)

2.1.2 Real-time Synchronization and Predictive Simulation

Utilizing a physics engine, we constructed models to simulate processes such as paper aging and ink fading. By continuously monitoring environmental data (including temperature, humidity, light intensity, pollutant concentration, etc.), the status of the digital twin is synchronously updated. Machine learning algorithms are then applied to predict the future degradation trends of cultural heritage, thereby providing a scientific basis for preventive conservation measures. For instance, by simulating the paper aging process under varying temperature and humidity conditions, corresponding environmental control strategies can be pre-formulated. Additionally, this predictive simulation model is capable of simulating the effects of various restoration techniques on cultural relics, assisting conservation experts in evaluating the merits and demerits of different restoration plans and facilitating the formulation of optimized restoration decisions. Through this series of real-time synchronization and predictive simulations, digital twin technology offers robust technical support for the conservation of calligraphy cultural heritage, rendering conservation efforts more scientific, precise, and efficient.

2.1.3 Bidirectional Interaction Mechanism

Digital twin technology not only enables real-time mapping of the current state of physical entities but also facilitates the feedback of improved restoration strategies, derived from restoration experiments conducted in virtual environments, into the decision-making process for physical conservation, thereby achieving interaction between the digital and physical worlds. Restoration experts can perform various restoration experiments on the digital twin, evaluate the effectiveness of different approaches, and effectively mitigate risks associated with restoring physical cultural relics. Furthermore, the bidirectional interaction mechanism fosters communication and collaboration among conservation personnel, researchers, and the public. By leveraging the digital twin platform, conservation personnel can share real-time updates on conservation progress and research findings, attracting greater participation from experts and scholars who collectively contribute their expertise to the conservation of calligraphy cultural heritage. This bidirectional interaction mechanism not only enhances participation and influence in the conservation of calligraphy cultural heritage but also opens up new avenues for the dynamic dissemination of cultural heritage.

2.2 Adaptive Innovation

2.2.1 Specific Parameter System for Calligraphy

By employing nano-scale resolution imaging technology, an accurate model is established for the penetration depth of ink into paper, enabling the restoration of the three-dimensional form and dynamic force variations of calligraphy brushstrokes. Through in-depth analysis of the distribution pattern of ink within paper fibers, it becomes possible to delve into the brushwork techniques employed in calligraphy creation, thereby opening up new perspectives for research in calligraphy art. Based on principles from materials science, the deformation process of paper under varying temperature and humidity conditions is simulated, analyzing how alterations in fiber structure impact the preservation state of calligraphy works.

2.2.2 Cross-Scale Modeling Technology

At the microscale, by simulating the diffusion and permeation processes of ink-tone particles, it becomes feasible to reproduce the unique artistic effects formed by ink on paper. Molecular dynamics simulation technology is employed to conduct in-depth research on the interactions between ink and paper fibers, thereby achieving precise reproduction of ink-tone effects. At the macroscale, mechanical analysis of mounting structures is carried out, and a mechanical model for the mounting of calligraphy works is constructed to evaluate the impact of different mounting methods

DOI: 10.5281/zenodo.16870679

on the long-term preservation of the works and optimize the mounting schemes.

3. Construction of Calligraphy Digital Twin

3.1 Data Acquisition Layer

3.1.1 Non-destructive Testing Technology

A multi-band spectrometer is employed to conduct fine scanning of calligraphy works to obtain image information across different spectral bands. By leveraging the disparities in spectral analysis, critical information such as modification traces, implicit stroke orders, and pigment compositions of the works can be unveiled. For instance, the application of infrared spectroscopy technology enables the detection of hidden draft lines beneath ink traces, providing valuable clues for calligraphy research. Phase-scanning X-ray diffraction is utilized to analyze the crystal structures and chemical compositions of mineral pigments, offering a scientific basis for cultural relic authentication and the selection of restoration materials. Through comparative analysis of the diffraction patterns of different pigments, the types and chronological periods of the pigments can be accurately identified (Figure 2).

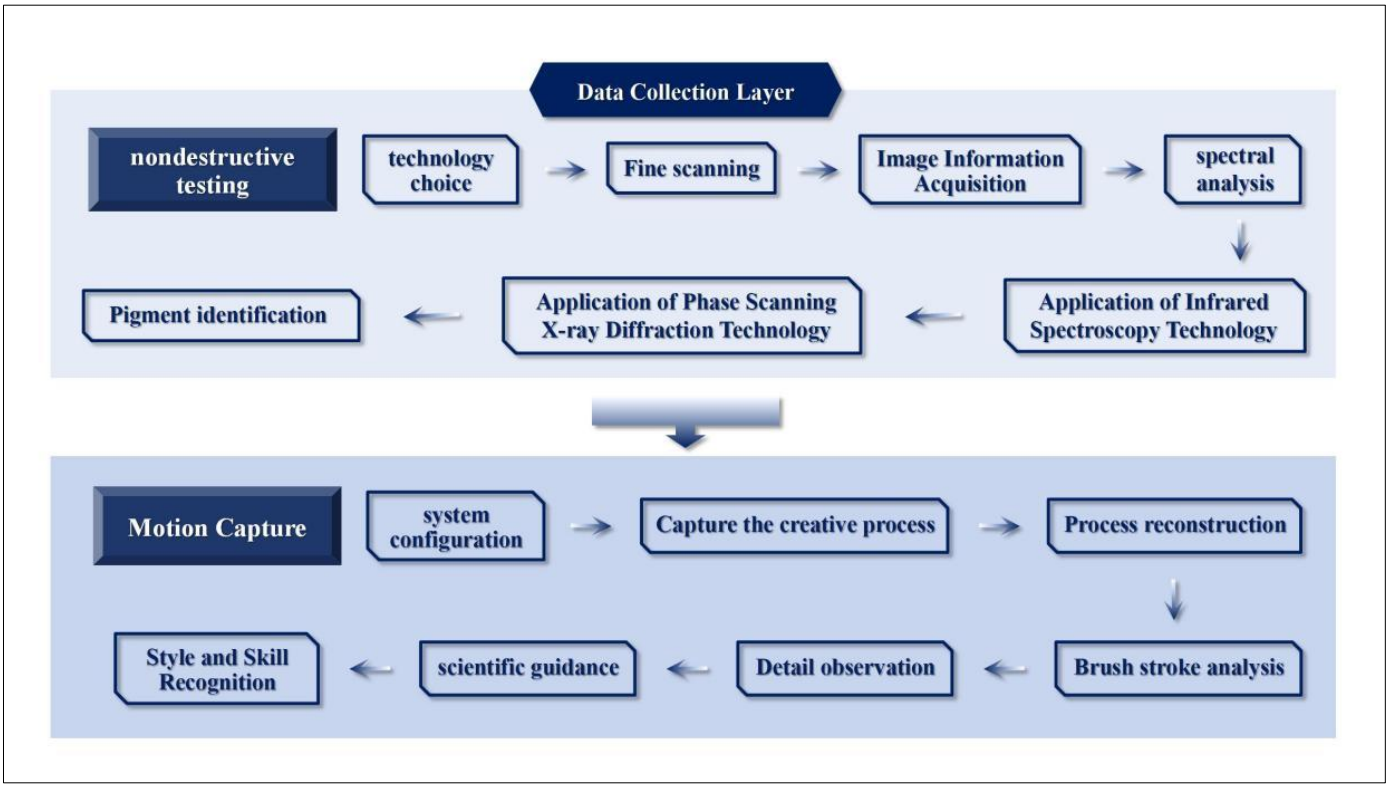

Figure 2 Architecture of Digital Twin Technology for Calligraphy Cultural Relics

(Source: self-made by the author)

3.1.2 Dynamic Capture System

During the process of calligraphy creation demonstration or copying, high-speed cameras and inertial sensors are employed to precisely capture key data such as the trajectory, speed, and force of the writer's brushstrokes, thereby reconstructing the entire calligraphy creation process. By integrating this data with the digital model of the calligraphy work, a digital reproduction of the dynamic aspects of calligraphy creation is achieved. This system not only records the calligrapher's creative process but also provides learners and researchers with detailed brushstroke analysis, aiding them in gaining an in-depth understanding of the essence of calligraphy art. Through the dynamic capture system, one can observe the subtle movements of calligraphers during creation with meticulous attention to detail. Additionally, the system can analyze the writer's brushstroke force, speed, and rhythm, offering scientific guidance for calligraphy education and training.

3.2 Model Construction Layer

3.2.1 Geometric Model

With the aid of 3D texture mapping technology, high-resolution image textures are precisely mapped onto 3D geometric models, enabling the true-to-life reproduction of the creases in Xuan paper and the three-dimensional forms of ink strokes, thereby significantly enhancing the visual realism of the digital twin. The application of this technology renders the appearance of the digital model nearly indistinguishable from that of the actual object. Meanwhile, by employing Generative Adversarial Networks (GANs) technology, virtual restoration of damaged areas in calligraphy works is conducted. Through training on a vast amount of historical restoration data, natural and reasonable restoration effects are generated, providing a scientific reference basis for restoration decision-making.

3.2.2 Behavioral Model

This study employs a material aging prediction algorithm integrated with Long Short-Term Memory networks (LSTMs) to achieve temporal simulation of the material aging process in calligraphy works. By inputting key information such as environmental data and the initial state of materials, the evolution trends of aging phenomena, including paper embrittlement and ink fading, are predicted. An environmental stress response model is constructed, which incorporates the interactive effects of various environmental factors such as temperature, humidity, light exposure, and pollutants. This model provides an in-depth analysis

DOI: 10.5281/zenodo.16870679

of the combined impact of these factors on calligraphy works, offering a scientific basis for environmental control.

3.3 Service Interaction Layer

3.3.1 Virtual Restoration Sandbox

A virtual restoration platform is developed to enable restoration experts to conduct various restoration experiments on the digital twin, including cleaning, reinforcement, and completion of damaged areas, without incurring the risks associated with restoring physical cultural relics, thereby reducing trial-and-error costs.Restoration Plan Optimization Based on Reinforcement Learning: By employing reinforcement learning algorithms, different restoration plans are evaluated and optimized according to restoration objectives and constraints, generating the optimal restoration strategy.Additionally, the platform supports multi-user collaboration, allowing restoration experts, researchers, and the public to work together in the same virtual environment, share insights, and facilitate knowledge exchange and innovation. The virtual restoration sandbox also features a detailed restoration history logging function, capable of tracking and recording the process and results of each restoration experiment, providing valuable references and insights for subsequent restoration efforts.

3.3.2 Augmented Reality Display

Leveraging holographic projection technology, the historical creative context of calligraphy works can be restored, such as recreating the environment, mindset, and creative process of Yan Zhenqing as he penned the *Eulogy on My Deceased Nephew*. This approach enhances the audience's immersive experience and cultural identity. Furthermore, augmented reality (AR) technology enables interactive displays and knowledge popularization of calligraphy cultural relics. By wearing AR glasses or using smartphones and other devices, audiences can interact with virtual calligraphy artifacts, such as zooming in on details, rotating for observation, and accessing annotations, thereby gaining a deeper understanding of the background information, artistic characteristics, and historical value of calligraphy works. Such interactive display methods not only enrich the audience's visiting experience but also significantly improve the dissemination efficiency of calligraphy culture. In the realm of dynamic dissemination of cultural heritage, AR technology also demonstrates immense potential. By constructing virtual calligraphy exhibition spaces, calligraphy artifacts can be displayed and disseminated in digital form, allowing more individuals to appreciate and learn about calligraphy art anytime and anywhere, transcending geographical and temporal limitations. Simultaneously, integrating with social media platforms can convey the charm of calligraphy culture to a broader audience, promoting its popularization and inheritance.

4. Validation of Core Application Scenarios

4.1 Preventive Conservation

Taking the intelligent display cases at Shanghai Museum as the research subject, a digital twin model of the exhibition hall's microenvironment was constructed. This model is capable of real-time monitoring and mapping of key environmental parameters, including temperature, humidity, light intensity, and concentrations of harmful gases. When any environmental parameter exceeds a preset threshold, the model promptly activates a risk warning mechanism. Additionally, the model can simulate the impact of different environmental control strategies on the preservation state of cultural relics, thereby formulating an optimized environmental control plan. For disaster scenarios such as fires and floods, this study employs digital twin technology to conduct emergency simulation modeling. By simulating potential damage to cultural relics during disasters, analyzing the effectiveness of different rescue plans, and determining the priority order for rescuing cultural relics and the optimal rescue routes, the efficiency of disaster emergency response is enhanced.

4.2 Restoration Decision Support

Prior to the actual restoration of physical calligraphy cultural relics, it is recommended to conduct a virtual restoration rehearsal using digital twin technology. By comparing the restoration plan based on digital twin technology with traditional decision-making plans grounded in expert experience, and employing quantitative metrics to evaluate restoration outcomes, scientific evidence is provided for the final restoration decision. Meanwhile, drawing on the technical experience of the China National Silk Museum, key data from the calligraphy relic restoration process (including restoration plans, operational records, material information, etc.) should be stored on the blockchain to ensure the authenticity, traceability, and immutability of the restoration process.

4.3 Innovations in Dynamic Cultural Dissemination

Drawing on the technological concept of the National Palace Museum, Taipei's ‘The Brush Endures Through Ages’ exhibition, a haptic feedback copying device has been developed. During the process of copying calligraphy works, this device simulates the resistance and elasticity of real brush writing through haptic feedback technology, thereby enhancing the user's interactive experience. Furthermore, artificial intelligence technology has been employed to revive virtual avatars of calligraphers, providing explanations of calligraphic styles and engaging in interactive exchanges with visitors during exhibitions, enabling cross-temporal dialogues with historical calligraphers. Within the metaverse context, an interactive experience featuring calligraphy digital twins has been created: a virtual study is constructed on a metaverse platform (such as Decentraland) to showcase calligraphy digital twins (Figure 3). Users can appreciate and copy calligraphy works in the virtual space, participate in calligraphy creation activities, which facilitates the dissemination and exchange of calligraphy culture.

DOI: 10.5281/zenodo.16870679

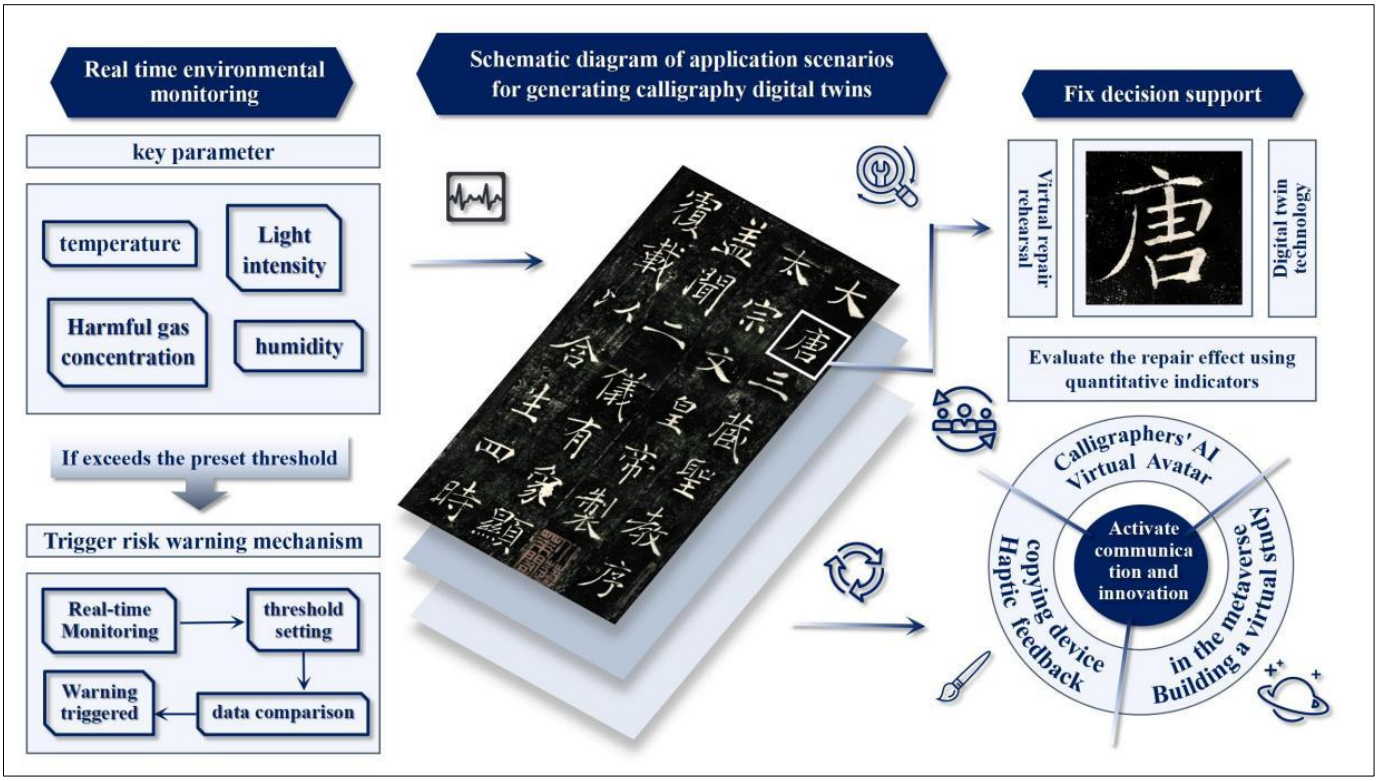

Figure 3 Schematic diagram of application scenarios for generating calligraphy digital twins

(Source: self-made by the author)

5. Key Technical Challenges and Breakthroughs

5.1 Data Dimension Challenges

Multimodal data, such as hyperspectral images and 3D point clouds, exhibit significant disparities in spatial and temporal dimensions, necessitating the research and development of efficient spatio-temporal registration algorithms to achieve precise fusion of data from different modalities and ensure the accuracy of digital twins. Currently, some studies have attempted to employ deep learning algorithms for cross-modal data alignment; however, further optimization is required when processing calligraphy cultural relic data. Given the limitations of non-contact acquisition technologies in terms of resolution and precision, exploring the application of quantum sensing technology in the data collection of calligraphy cultural relics could potentially overcome precision bottlenecks and obtain more refined artifact information. Due to its high sensitivity and precision, quantum sensing technology holds promise for bringing new breakthroughs in the data collection of calligraphy cultural relics.

5.2 Model Credibility Issues

A scientific verification and validation framework for digital twins should be established to evaluate the accuracy and reliability of the model by comparing the simulation results of digital twins with actual physical experimental data and historical monitoring data. Technical approaches such as error analysis and model comparison can be employed for comprehensive validation of digital twins. Given the unique aesthetic value of calligraphy art, an aesthetic evaluation function for calligraphy should be introduced during the modeling process to integrate physical laws with artistic principles, ensuring that digital twins not only reflect physical authenticity but also preserve the distinctive artistic features of calligraphy. Currently, some studies have attempted to quantify the aesthetic elements of calligraphy; however, further in-depth research is required to effectively incorporate these elements into digital twin models.

5.3 Ethical and Standardization Dilemmas

In accordance with the normative guidance on digitization outlined in the *Venice Charter*[2] and taking full account of the particularity of calligraphy cultural heritage, this study aims to explore the issue of copyright ownership of digital replicas, clarifying the rights and responsibilities of various stakeholders, including creators, collecting institutions, and technology developers. In the context of the digital age, copyright protection for digital replicas faces new challenges, necessitating the urgent formulation of corresponding laws, regulations, and industry standards. During virtual restoration, the 'principle of minimum intervention' should be adhered to, and research should be conducted to define the appropriate scope of intervention for virtual restoration to prevent excessive restoration from damaging the historical information and artistic value of cultural relics. Meanwhile, ethical boundaries for virtual restoration can be established through methods such as expert evaluation and public participation.

6. Practical Case Analysis

6.1 Digital Twin Project of Shiqu Baoji at the Palace Museum

The digital twin project of Shiqu Baoji at the Palace Museum has achieved real-time monitoring of the development of surface cracks on stone inscriptions and rubbings by constructing a predictive model for crack growth. It has also conducted an in-

[2] The International Charter for the Protection of Cultural Heritage Buildings and Historical Sites was adopted on May 31, 1964, at the second meeting of the International Conference of Architects and Technicians engaged in the work of historical heritage buildings in Venice. The Charter affirmed the important value and role of historical heritage buildings.

DOI: 10.5281/zenodo.16870679

depth analysis of the impact of carbon dioxide concentration generated by visitors' breath on the preservation of scrolls. Based on the simulation results from the digital twin model, the environmental control plan for the exhibition hall has been optimized, effectively slowing down the degradation process of the stone inscriptions and rubbings. This case fully demonstrates the remarkable effectiveness of digital twin technology in the field of preventive conservation for stone inscriptions and rubbings.

6.2 Intelligent Twin System at Xi'an Beilin Museum

The intelligent twin system at Xi'an Beilin Museum conducted a spatial heterogeneity analysis of the weathering rate on the surface of stone stelae, enabling precise localization of severely weathered areas. Leveraging digital twin technology, the system optimized the rubbing pressure parameters, ensuring high-quality rubbings while minimizing damage to the stelae surfaces. This study provides a scientific basis for the conservation of stone stelae and the improvement of rubbing techniques. This case underscores the pivotal role of digital twin technology in the conservation and utilization of stone stelae.

6.3 Digital Repatriation Initiative for Overseas Dispersed Cultural Relics

For precious overseas dispersed cultural relics such as the Sangluan Tie, cross-border aggregation research on discrete digital twins has been conducted. By integrating digital fragment information from different institutional collections and employing digital twin technology for virtual reassembly, efforts aim to restore the complete form of the cultural relics. Additionally, leveraging Non-Fungible Token (NFT) technology to establish rights ownership of digital twins serves to assert cultural sovereignty and facilitate the digital repatriation of overseas dispersed cultural relics. This initiative fully demonstrates the innovative application of digital twin technology in the conservation and repatriation of overseas dispersed cultural relics.

6.4 Comparative Analysis of Digital Twins between A Thousand Li of Rivers and Mountains and Calligraphy Works at the Palace Museum

The core research of the digital twin project for A Thousand Li of Rivers and Mountains at the Palace Museum focuses on the color degradation simulation of painting pigment layers and the image restoration techniques, whereas the digital twin research on calligraphy works delves deeper into the phenomena of ink penetration and the aging process of paper (Table 1). Through comparative studies in areas such as material property analysis, dynamic simulation methods, and restoration technique applications between the two, the universality and uniqueness of calligraphy conservation technology solutions are further validated, providing theoretical foundations and practical guidance for the development of digital twin technologies for cultural heritage.

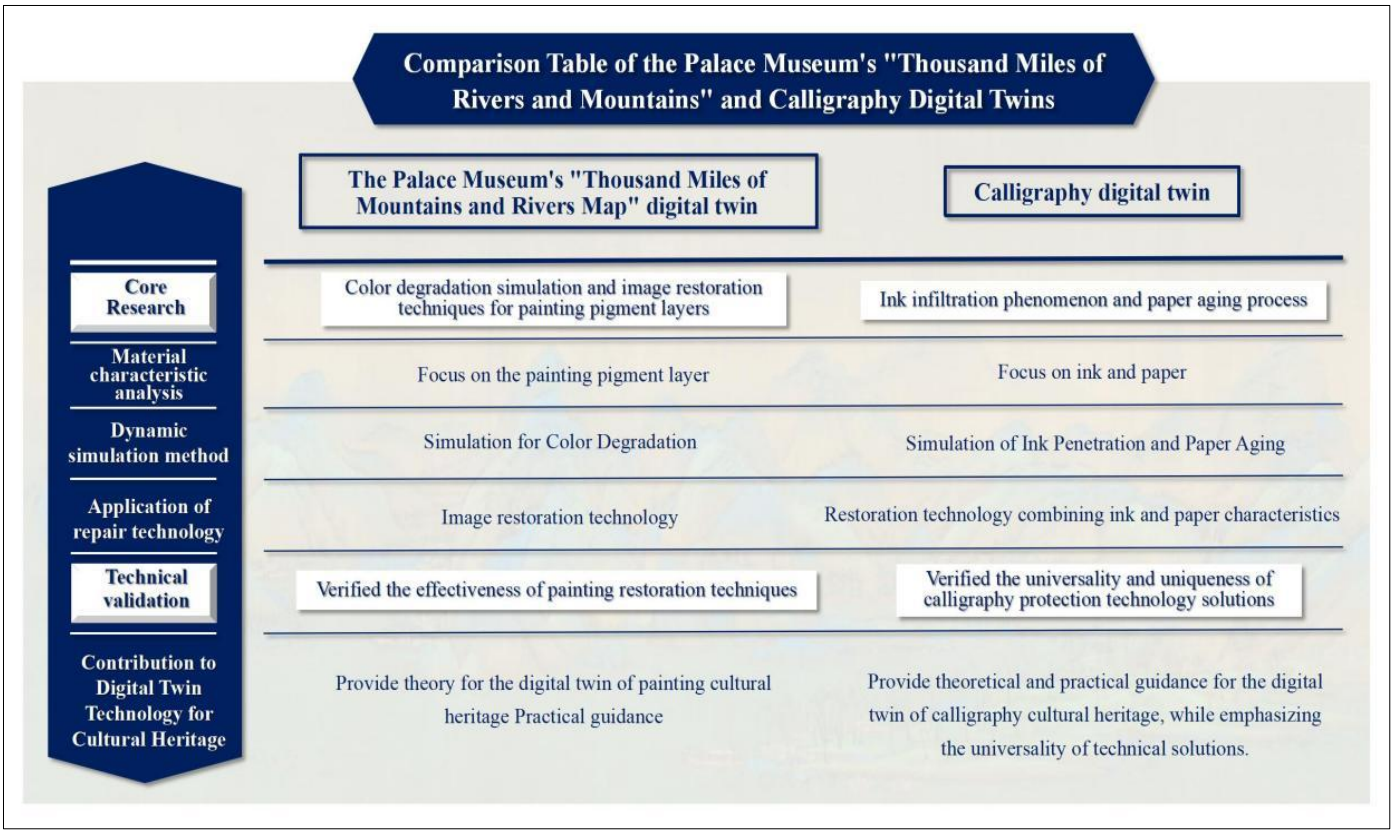

Table 1 Comparison Table of the Palace Museum's "Thousand Miles of Rivers and Mountains" and Calligraphy Digital Twins

(Source: self-made by the author)

6.5 Interview Analysis of Calligraphy Inheritors

Through interviews with inheritors of Qigong's calligraphy style and experts in intangible cultural heritage restoration, it can be observed that digital twin technology effectively supports traditional restoration techniques. For instance, by utilizing digital models, potential issues that may arise during the restoration process can be identified in advance, enabling the optimization of restoration plans accordingly. Furthermore, the invaluable information shared by inheritors, including historical contexts and experiences in calligraphy techniques, provides an indispensable humanistic dimension to the construction of digital models, endowing digital twins with richer cultural connotations. This process achieves a harmonious integration of technical precision and humanistic care.

DOI: 10.5281/zenodo.16870679

7. Pathways for Cultural Value Reconstruction

7.1 Memory Dimension

Construct a 'digital gene bank' for calligraphy techniques, enabling the digital and parametric preservation of calligraphic elements such as brushwork, composition, and ink application. By collecting extensive data on calligraphy works and the creative process, this approach analyzes and summarizes the underlying patterns of calligraphy art, thereby transmitting the core techniques and spiritual essence of calligraphy culture. The establishment of the digital gene bank provides a wealth of digital resources for the inheritance and research of calligraphy culture.

7.2 Dissemination Dimension

Through the interactive mechanisms of calligraphy twins in metaverse scenarios, temporal and spatial limitations are transcended, enabling global users to conveniently appreciate and learn calligraphy art. By employing diverse dissemination methods such as virtual exhibitions and online calligraphy courses, the aim is to expand the international reach of calligraphy art and enhance its global influence. Metaverse technology provides innovative platforms and methods for the international dissemination of calligraphy art, fostering intercultural exchange and integration.

7.3 Innovation Dimension

Based on digital twin technology, calligraphy re-creation algorithms are developed. By deeply exploring historical calligraphy data and integrating modern aesthetic trends with creative demands, these algorithms generate calligraphy works that embody both traditional charm and innovative styles, thereby promoting the innovative development of calligraphy art. Digital twin technology offers new research perspectives and methodologies for the field of calligraphy creation, significantly enhancing the innovative vitality of calligraphy art.

8. Conclusion and Prospects

This study has constructed a 'three-tier, five-dimensional' architectural model for digital twins of cultural heritage, providing a systematic framework for the digital conservation of cultural heritage. Simultaneously, a Delphi indicator system for evaluating the credibility of calligraphy digital twins has been established, offering scientific criteria for quality assessment of digital twins. These theoretical achievements have expanded the research scope within the field of cultural heritage conservation and provided a theoretical basis for subsequent studies. Digital twin technology has facilitated the transformation of cultural relic conservation strategies from 'emergency restoration' to 'predictive maintenance,' enhancing the scientific rigor and effectiveness of calligraphy heritage conservation. It has also reshaped a novel humanistic relationship of 'technology safeguarding civilization,' achieving profound integration between technology and culture. Its application in the conservation of calligraphy heritage has introduced new technological tools and methodologies to cultural relic conservation, carrying significant practical implications.Looking ahead, the application of quantum computing technology in the construction of ultra-fine digital twins holds substantial research value, as it can significantly enhance the precision and computational efficiency of digital twins. Meanwhile, the potential integration of brain-computer interface technology in the digital transmission of calligraphy techniques merits in-depth exploration, aiming to achieve more intuitive and efficient methods of calligraphy skill inheritance. With the continuous advancement of technology, the application prospects of digital twin technology in the conservation of calligraphy cultural heritage will become increasingly broad, anticipated to provide new development opportunities for the inheritance and innovation of calligraphy culture.

References

1. He Shuangzhe, Fu Ting. Research on the Innovative Path of Calligraphy Education in Colleges and Universities from the Perspective of Digital Media [J]. Beauty & Times (Middle), 2025, (04): 106-108.
2. Daniel. The Intersection of Chinese Calligraphy and Contemporary Art Forms [J]. Chinese Calligraphy, 2025, (03): 179-180.
3. Liu Yanze. Calligraphy Cognition and the Construction of Calligraphy Ecosystem in the Digital Intelligence Era [J]. Chinese Calligraphy, 2025, (03): 169-171.
4. Liu Xinting, Dong Yuanmei, Zhao Jianbo. Problems and Methods of Digital Aesthetic Education [J]. China University Teaching, 2024, (11): 10-16.
5. Xu Jiao. Research on the Digital Protection and Application of the Memorial Garden for Historical and Cultural Celebrities in Western Sichuan: Du Fu Thatched Cottage [D]. Sichuan Agricultural University, 2024.
6. Zhu Rui. Value Mining and Representation of Cultural Heritage in the Web3.0 Environment [D]. Shanghai University, 2024.
7. Zhu Zhiting, Dai Ling, Zhao Xiaowei, et al. Cultivating New-Quality Talents: The New Mission of Education in the Digital Intelligence Era [J]. E-Education Research, 2024, 45(01): 52-60.
8. Ministry of Education of the People's Republic of China. Notice from the General Office of the Ministry of Education on Further Strengthening Standardized Chinese Character Writing Education in Primary and Secondary Schools [S]. Ministry of Education of the People's Republic of China. 2024-10-09.
9. Jin Meng. Research on the International Communication Model of Chinese Calligraphy Culture [D]. China Academy of Art, 2022.
10. The Second International Congress of Architects and Technicians of Historic Monuments. International Charter for the Conservation and Restoration of Monuments and Sites [S]. The Second International Congress of Architects and Technicians of Historic Monuments. 1964-5-25.

DOI: 10.5281/zenodo.16870679