Digital Twin Empowering Intelligent Monitoring System Design for Preventive Conservation of Cultural Relics

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ABSTRACT
At present, China's cultural relics conservation is transforming from salvage-based conservation to preventive conservation. However, grassroots cultural and museum institutions are generally confronted with practical challenges such as high technical requirements, heavy reliance on manual labor, and inefficient data utilization. Meanwhile, the traditional conservation model can no longer meet the public's cultural needs, making it urgent to introduce new technologies to drive the transformation and upgrading of conservation work. This paper aims to explore the system construction of an intelligent monitoring system for the preventive conservation of cultural relics from the perspective of digital twin, so as to provide references and feasible approaches for the digital conservation practice and humanistic value interpretation of cultural heritage. By reviewing the current status of relevant research at home and abroad, and applying the theories of preventive conservation, interdisciplinary integration, and digital twin full life cycle management, this paper systematically analyzes the current situation of cultural relics conservation and the application demands of digital twin technology. On this basis, it summarizes the diverse practical values of digital twin technology in the digital conservation of cultural heritage, and completes the construction and design of an intelligent monitoring system for the preventive conservation of cultural relics, which consists of a physical perception layer, a data governance layer, a twin model layer, and an application service layer. This research promotes the digital transformation of cultural relics conservation and provides new ideas and perspectives for the cultural relics protection work of grassroots cultural and museum institutions.

Keywords: *Digital twin technology, Preventive conservation of cultural relics, Intelligent monitoring, Digital preservation.*

1. INTRODUCTION

1.1 Research Background

On the one hand, the Party and government attach great importance to the protection and development of cultural heritage. Since the 20th National Congress of the Communist Party of China, under the strong leadership of the CPC Central Committee with General Secretary Xi Jinping at its core, China's cultural undertakings have continued to prosper, and the protection and utilization of cultural heritage have been continuously elevated to new heights, with a series of supporting policies and measures successively introduced and implemented. The newly revised Law of the People's Republic of China on the Protection of Cultural Relics officially came into force on March 1, 2025, marking that China's cultural relics protection has entered a new stage of law-based governance. The General Office of the Communist Party of China Central Committee and the General Office of the State Council issued the Opinions on Further Strengthening the Protection of Intangible Cultural Heritage, which clarifies two major phased goals. This shows that cultural relics work has risen to the height of a national strategy. At the same time, how to protect, utilize and explore existing cultural heritage has become an important issue. The State Council Information Office of the People's Republic of China.

On the other hand, digital and smart development has been incorporated into the national strategic system and has become a key driver for innovating cultural relics protection models. In 2022, the General Office of the Communist Party of China Central Committee and the General Office of the State Council issued the “Opinions on Promoting the Implementation of the National Cultural Digitization Strategy”, which was also incorporated into the report to the 20th National Congress of the Communist Party of China. During the 17th group study session of the Political Bureau of the CPC Central Committee, General Secretary Xi Jinping emphasized the need to "explore effective mechanisms for the integration of culture and technology, realize digital empowerment and information technology transformation in cultural development, and turn cultural resource strengths into cultural development strengths". With the advent of the wave of digitalization and informatization, Digital Twin, as a cutting-edge technological means, boasts broad prospects in cultural relics protection and monitoring, and can inject strong impetus into the inheritance, innovation, protection and development of historical and cultural heritage.

1.2 Research Purpose and Significance

1.2.1 Research Purpose

Faced with the practical dilemmas in the protection and inheritance of cultural relics in China and the high attention paid by government departments, it is extremely necessary and urgent to integrate digital twin technology with the preventive protection of cultural relics and explore a scientific and reasonable mode for their protection and utilization. However, in existing research and practice, digital twin technology still suffers from problems such as insufficient adaptability and difficult implementation in the field of cultural relics protection, which cannot meet the current cultural needs of the public. Against this background, this paper conducts research on the application of digital twin technology in the preventive protection and intelligent monitoring of cultural relics for the following two purposes:

- First, it is to introduce digital twin technology into the field of cultural heritage conservation, explore the application paths of the technology, and build an adaptable technical framework, so as to improve the efficiency of digital conservation of cultural heritage.
- Second, by summarizing relevant research and practical cases both at home and abroad, this paper proposes application strategies of digital twins suitable for the current cultural relic protection in China, so as to address the pain points in the work of grassroots cultural and museum institutions.

1.2.2 Research Significance

1.2.2.1 Theoretical Significance

With the development of the economy and society, cultural relics protection is facing an increasingly severe situation. Traditional protection methods have been difficult to meet the practical needs of small and medium-sized cultural and museum institutions, and the emergence of digital twins has provided new possibilities for the preventive protection of cultural relics. Originating from the field of industrial manufacturing, digital twin technology features core values of "mirror mapping" and "real-time interaction". Its application in the preventive protection of cultural relics not only contributes to cultural relics protection but also enables digital twins to evolve from "technical twins" to "cultural twins", expanding and enriching their theoretical connotations.

1.2.2.2 Practical Significance

China boasts a large number of small and medium-sized museums, which are generally small in scale and commonly face problems such as insufficient funding, shortage of talents and backward technologies. Therefore, it is extremely urgent to shift the cultural relic conservation methods to digitalization. Adhering to the principle of authenticity in cultural heritage conservation, digital twin technology constructs high-precision geometric models through 3D scanning without touching the physical objects. Empowered by BIM technology, a full life cycle collaborative process is formed, thus completing the complete reproduction and interpretation of the physical entities of cultural heritage and their affiliated cultural values[3]. This system can open up a new feasible path for preventive conservation for cultural relic protection units and small and medium-sized museums, reduce the labor costs of traditional monitoring, and further improve the level of cultural relic protection.

1.3 Research Status and Review in China and Foreign Countries

1.3.1 Research Status in Foreign Countries

The application of digital twin technology in the field of cultural heritage protection began in the early 21st century. European and American countries started relatively early and have accumulated relatively rich research results. Notre-Dame de Paris in France is one of the early cases of systematically applying digital twin technology to cultural heritage protection. As early as before the fire in 2019, a high-precision 3D laser scan had been used to build its digital model; after the fire, the model was used for structural analysis and the formulation of restoration plans, becoming a model for the application of digital twins in heritage restoration [4].

Notably, foreign research has increasingly emphasized the humanistic dimension in the digitalization of cultural heritage. The Guidelines for the Digital Preservation of Cultural Heritage issued by UNESCO establishes the long-term accessibility of digital heritage as a basic principle, emphasizing digitalization and long-term preservation strategies. In recent years, a number of interdisciplinary research teams have been exploring paths for the in-depth integration of technology and humanities, and the digitalization of cultural heritage is moving towards a new stage where both technology and humanities are equally valued.

1.3.2 Research Status in China

Although research on the application of digital twin technology in China's cultural heritage sector started relatively late, it has developed rapidly. For instance, the Dunhuang Academy spent five years building "Digital Dunhuang", and by 2022, it had established the world's first blockchain-enabled cultural heritage open platform, which features partial characteristics of digital twins; the Palace Museum has built an immersive digital experience platform using digital twin technology, converting monitoring data into perceptible and in-depth cultural content for visitors, enabling a genuine "two-way interaction" between the public and cultural heritage [5].

Nevertheless, domestic research also has notable shortcomings. First, most studies focus on technical function realization, with relatively weak interpretation of humanistic values; second, system designs are mostly tailored for large cultural and museum institutions, with insufficient attention paid to small and medium-sized museums, and there is a shortage of low-cost, easy-to-operate intelligent monitoring systems suitable for primary-level institutions. Therefore, this study carries certain practical and realistic significance.

1.3.3 Research Review

In summary, relevant research both at home and abroad has laid the foundation for the application of digital twin technology in the field of cultural relics protection. The integration of digital twin technology and cultural heritage protection started earlier in foreign countries, with a relatively mature research system, yet the interpretation of humanistic values is weak; domestic research has kept pace with the trend and developed rapidly, but lacks theoretical originality. Taking the needs of grassroots cultural and museum institutions as the starting point, this study, based on relevant concepts of the new liberal arts, focuses on the application of digital twins in the preventive protection and intelligent monitoring of cultural relics. While solving the problem of disconnection between technology and humanities in foreign research, it also makes up for the shortcomings of grassroots applicability in domestic research, possessing both theoretical innovation and practical application value.

1.4 Research Methods

1.4.1 Case Analysis Method

By selecting typical cases of the application of digital twin technology in the field of cultural heritage protection at home and abroad, this study understands the current application status of digital twins in cultural heritage protection, verifies the effectiveness and feasibility of the research process, and integrates theory with practice. Through the disassembly and analysis of relevant cases, it summarizes experience that can be used for reference and problems to be avoided, so as to provide a reference for the design of this system.

1.4.2 Field Research Method

The researchers conduct field research in grassroots cultural and museum institutions of different scales. Through interviews, on-site observations and other methods, they summarize

the pain points in the monitoring work of grassroots cultural and museum institutions to ensure that the system design meets the actual needs of grassroots units. Meanwhile, through on-site visits to institutions such as the National Museum of China and the Museum of Archaeology and Art of Jilin University, they investigate the current application status of digital twin technology in cultural relics protection in large museums, so as to provide references for the application of digital twin technology in grassroots cultural and museum scenarios. (“Figure 1”)

Figure 1 Schematic diagram of the cultural relics exhibition hall environment (Image source: Author's photograph).

1.4.3 Literature Review Method

Through reviewing extensive literature on digital preservation of cultural heritage and digital twin technology applications, this study analyzes the current research landscape of digital twin technology both domestically and internationally. It systematically reviews existing research achievements and theoretical foundations, identifies key research entry points, and provides foundational support for constructing the research framework of this paper.

1.5 Research Contents

From the perspective of New Liberal Arts, this study thoroughly examines the feasibility and distinctive advantages of digital twin technology in cultural heritage preservation. It conducts an in-depth analysis of China's current cultural relic conservation status and designs a digital twin-based intelligent monitoring system for preventive conservation of cultural relics. The research comprises four key components:

- Part 1: Introduction. This section primarily elaborates on the research background, objectives, and significance, reviews the current research status both domestically and internationally, and provides a detailed description of the research methods employed.
- Part 2: Conceptual Definition and Theoretical Foundations. This section introduces fundamental concepts such as digital twin technology, preventive conservation of cultural relics, intelligent monitoring, and digital preservation of cultural heritage, while exploring relevant theoretical frameworks to provide theoretical support for subsequent research.
- Part 3: Analysis of Current Status of Cultural Heritage Conservation and Application Needs for Digital Twin Technology. By investigating the developmental status of preventive conservation of cultural heritage in China and analyzing pain points in monitoring practices at grassroots cultural heritage institutions, this study summarizes the current practical demands for digital twin technology applications at these institutions.
- Part 4: Design of an Intelligent Monitoring System for Preventive Conservation of Cultural Relics Based on Digital Twin Technology. In accordance with design principles, this study completes the design of an intelligent monitoring system for preventive conservation of cultural relics, covering the physical sensing layer, data governance layer, twin model layer, and application service layer, with detailed elaboration provided.

2. CONCEPTUAL DEFINITION AND THEORETICAL BASIS

2.1 Concept Definition

2.1.1 Digital Twin Technology

The concept of Digital Twin originated from NASA's Apollo program in the United States. In 2003, Professor Michael Grieves from the University of Michigan formally introduced this term during a product lifecycle management course. At its core, it involves creating a virtual digital model that is fully equivalent to physical products, forming a three-dimensional conceptual model comprising three modules: physical entities, virtual models, and virtual-real data interaction. This approach is also referred to as an information mirror model [6]. In the field of cultural heritage conservation, the application of Digital Twin technology models enables the preservation of artifacts' physical forms and intrinsic characteristics. The comprehensive virtual mapping of characteristics and evolutionary patterns provides robust support for preventive conservation of cultural relics.

2.1.2 Preventive Protection and Intelligent Monitoring of Cultural Relics

The core of preventive conservation of cultural relics lies in "early detection, early warning, and minimal intervention". It refers to a conservation mode that delays the aging or damage of cultural relics by controlling their surrounding environment and monitoring their conditions when no obvious diseases appear on the cultural relics themselves or they are only slightly damaged. Intelligent monitoring, on the other hand, utilizes technologies such as the Internet of Things and sensors to realize automatic collection and real-time transmission of data on the environment and status of cultural relics, conduct intelligent analysis based on big data, and issue risk warnings in a timely manner.

2.1.3 Digital Protection of Cultural Heritage

Digital preservation of cultural heritage utilizes digital technologies to achieve permanent conservation and sustainable utilization [7]. Its core objective is to establish high-fidelity, comprehensive digital assets that create "permanent archives" capable of resisting time erosion, adapting to natural changes, and preventing human-induced damage [8]. This approach encompasses multiple dimensions including physical digitization and value dissemination.

2.2 Theoretical Principle

2.2.1 Preventive Protection Theory

The concept of preventive conservation was introduced into the field of architectural conservation by Cesare Brandi in the 1950s. Over the past half-century, it has evolved both theoretically and practically, and is now recognized as one of the core theories in cultural heritage preservation. It emphasizes "prevention first, combined with prevention and treatment," advocating for interventions to mitigate potential risks through optimizing conservation environments and establishing monitoring systems.

2.2.2 Interdisciplinary Integration Theory

The concept of interdisciplinary integration can be traced back to the 1920s, when the Social Science Research Council of the United States first used the term "interdisciplinary" in its meeting minutes to describe comprehensive research activities involving two or more disciplines. It refers to the integration of knowledge from two or more disciplines to address complex problems that cannot be adequately tackled by a single discipline alone. From the perspective of the New Liberal Arts, this study integrates cutting-edge technologies such as digital twins from science and engineering fields to form an interdisciplinary integration system of "technology + humanities", which is more practical in the field of cultural relics conservation in the new era.

2.2.3 Digital Twin Full Life Cycle Management Theory

The Digital Twin Full Lifecycle Management Theory emphasizes building a digital mirror of physical entities through digital twin modeling, advocating for "virtual-real mapping and virtual control of physical systems." This approach enables dynamic closed-loop management spanning the entire lifecycle of cultural heritage—from construction and operation to maintenance and decommissioning. Its significance in cultural relic preservation lies in achieving intelligent lifecycle management, enabling real-time monitoring and timely response with early warnings. This methodology has made substantial contributions to

advancing the transformation and upgrading of cultural heritage conservation models.

3. ANALYSIS ON CURRENT STATUS OF CULTURAL RELICS CONSERVATION AND APPLICATION DEMAND OF DIGITAL TWIN

3.1 Current Situation Analysis of Cultural Relics Conservation

3.1.1 Current Development Status of Preventive Protection of Cultural Relics in China

At present, remarkable progress has been made in the development of China's cultural heritage conservation undertakings, which have entered a new stage. The concept of preventive conservation of cultural relics has gradually become the focus of cultural relics protection in small and medium-sized museums and cultural institutions. Since the 18th National Congress of the Communist Party of China, General Secretary Xi Jinping has issued dozens of important instructions on cultural relics protection, emphasizing that we should "effectively strengthen the protection of cultural relics, promote their rational and appropriate utilization, and ensure that the benefits of cultural relics protection are shared more by the people" [9]. The state has successively promulgated a number of policy documents related to cultural relics protection, reflecting China's growing emphasis on this cause and providing solid policy support for grassroots cultural and museum institutions to carry out preventive conservation of cultural relics. Nationwide, large museums above the provincial level have basically completed the construction of infrastructure such as high-precision environmental monitoring systems and intelligent control systems, forming a mature preventive conservation system. However, on the whole, China's preventive conservation of cultural relics is still in the developmental stage, and grassroots cultural and museum institutions still face many shortcomings: First, the protection model has not yet been transformed, still relying on manual inspection. This model is inefficient and unable to realize comprehensive, multi-layered real-time monitoring and management of cultural relics. Second, risk early warning is lagging behind, lacking intelligent analysis capabilities, making it difficult to predict the risk of cultural relics deterioration in advance. Third, the data system is incomplete, with a disconnect between data collection and decision-making.

3.1.2 Key Challenges in Monitoring Work for Grassroots Cultural Heritage Institutions

Through field research, we identified two major pain points in the monitoring work of grassroots cultural and museum institutions:

- Primary-level units have limited funding, making it difficult to procure high-end monitoring equipment, while the shortage of professional personnel further hinders the full utilization of existing technologies.
- Insufficient data utilization, with collected monitoring data primarily used for documentation rather than in-depth analysis.

3.2 Application Requirement Analysis of Digital Twin Technology

3.2.1 Real-time Data Acquisition and Visualization Requirements for Environmental Monitoring

At present, many grassroots cultural heritage institutions face disorderly and fragmented data sources, creating an urgent need for real-time collection of environmental data related to cultural relic preservation. Meanwhile, existing monitoring data are mostly displayed in numerical form and lack intuitive visual presentation, confining data interpretation to professional personnel only. Therefore, there is an urgent demand to build a complete system to collect and organize the monitored data and present them in an intuitive manner. Digital twin technology enables automatic data collection and real-time transmission through sensors and realizes the visual presentation of environmental data by means of digital twin models, thus meeting the needs of grassroots cultural heritage institutions for real-time collection and visualization of environmental monitoring data.

3.2.2 Dynamic Simulation of Cultural Relics Status and Risk Early Warning Requirements

Digital twin technology can dynamically simulate the evolution of cultural relics under different conditions based on historical data and

environmental patterns. Through algorithmic analysis, it enables intelligent early warning of deterioration risks, reminding relevant personnel to intervene in potential risks in advance, thus meeting the risk early warning requirements of grassroots cultural and museum institutions. Meanwhile, owing to its traceability, digital twin technology facilitates staff to quickly review the corresponding environmental conditions and records when risks occur, identify the main causes, and implement timely rectification. This paradigm has transformed cultural relics protection from traditional post-incident remediation to proactive prevention required by the current situation, significantly reducing the possibility of damage to cultural relics.

3.2.3 Digital Communication of Cultural Values and Public Education Needs

Traditional cultural values are often communicated in a single form, making it difficult to attract the attention of the contemporary public, especially the younger generation. The emergence of digital twin technology can effectively solve this problem. By using digital twin technology, realistic digital models of cultural relics can be created, and rich cultural resources can be disseminated to a wider audience through Internet platforms. Taking the Palace Museum as an example, by opening various digital applications, visitors can have a close encounter with the Palace Museum without leaving their homes. The communication of cultural values has gradually become digitalized and is no longer restricted by the opening hours and venues of museums. Some museums have combined interactive technologies such as VR and AR to create immersive and interactive exhibition scenes of cultural relics, enhancing audience engagement and visiting interest. This not only facilitates public education but also promotes the living inheritance of cultural heritage.

4. DESIGN OF INTELLIGENT MONITORING SYSTEM FOR PREVENTIVE CONSERVATION OF CULTURAL RELICS BASED ON DIGITAL TWIN

4.1 System Overall Architecture Design

4.1.1 Design Discipline

4.1.1.1 Principle of Preventive Conservation

Transitioning from "passive rescue" to "active prevention", the system establishes a dynamic early warning mechanism through continuous monitoring of environmental parameters such as temperature, humidity, light intensity, air pollutants, and vibration. This enables proactive intervention before cultural heritage deterioration occurs, achieving a closed-loop management process of "monitoring—prediction—control" to maximize the delay in cultural heritage aging.

4.1.1.2 Interdisciplinary Integration Principle

Cultural heritage conservation involves multidimensional knowledge and requires multi-source technical support. To address this challenge, the system integrates both the humanistic core of cultural heritage preservation and technological requirements, reflecting the philosophy of new liberal arts education.

4.1.1.3 The Principle of Full Life Cycle

This system emphasizes real-time mapping between physical entities and virtual models, as well as collaborative evolution throughout the entire lifecycle, forming a complete closed loop of "perception-analysis-decision-execution-feedback". It covers the entire process of cultural heritage monitoring, simulation, early warning, and prevention, achieving intelligent management of cultural heritage throughout its entire life cycle.

4.1.2 System Architecture

The system adopts a hierarchical and integrated architecture, which consists, from bottom to top, of the physical perception layer, data governance layer, digital twin model layer, and application service layer. All layers cooperate synergistically to ensure efficient system operation. The logic of the overall system architecture is as follows: The physical perception layer is responsible for environmental

data collection; the data governance layer performs data preprocessing and hybrid storage; the twin model layer runs models for environmental risk assessment, trend prediction, and other functions; the application service layer mainly provides users with services such as monitoring, early warning, and visualization. The four layers form a complete closed loop of "collection – governance – deduction – application".

4.2 Key Module Design

4.2.1 Physical Sensing Layer

The physical perception layer serves as the data foundation for system operation, with its core function being the real-time collection of environmental data for cultural relic preservation. The system mainly monitors the indicators listed in “Table 1”.

Table 1. Environmental parameter detection indicators

Parameter category	Specific indicators	Typical Impact on Cultural Relics
Climate Environment	Temperature, Relative Humidity	Thermal expansion and contraction, dry cracking, mold growth, salt precipitation
luminous environment	Illumination, ultraviolet radiation, color temperature	Pigment fading, cellulose photolysis, surface aging
Air environment	CO_2、SO_2、NOx、PM2.5/PM10、VOCs	Acid etching, corrosion, and dust accumulation contamination
mechanical environment	Vibration acceleration, tilt angle, microstrain	Structural fatigue, cracking, and collapse

4.2.2 Data Governance Layer

The data governance layer serves as the core hub of the system, responsible for receiving, storing, managing, and performing basic processing on aggregated multi-source data. It collects feedback data from the physical layer and provides data outputs to the model layer and application layer. Key functional modules include:

4.2.2.1 Data Preprocessing

The system unifies the format, imputes missing values and detects outliers for the accessed data. Linear interpolation or proximity filling is adopted for missing value imputation. The threshold method or 3σ principle is used for anomaly detection. The system marks and isolates obviously erroneous data to prevent them from affecting subsequent analysis.

4.2.2.2 Mixed Storage

The system database architecture is divided into four layers: a time-series database (InfluxDB or TDengine) is responsible for storing high-frequency environmental monitoring data and supports efficient querying and aggregation; a relational database (MySQL or PostgreSQL) manages cultural relic archives, user information and preservation records; and file storage (local NAS or MinIO) is used to save inspection photos and 3D models. Data services provide RESTful APIs to support real-time subscription, historical querying, statistical analysis and export, with TLS encryption and role-based access control implemented.

4.2.3 Twin Model Layer

The twin model layer serves as the core "brain" of the system, receiving multi-source time-series data from the data layer. Through mechanism-driven and data-driven models, it enables environmental simulation and risk prediction, with computational results dynamically mapped back to the data layer or pushed to the application layer. It primarily comprises the following three major models:

4.2.3.1 Environmental Risk Assessment Model

The model compares real-time temperature/humidity and light data with cultural relic safety thresholds. When detected values exceed the specified range, the system automatically calculates the duration of exceedance and deviation degree, then feeds the data back to administrators to determine whether intervention is required for the current environment.

4.2.3.2 Trend Forecasting Model

This model adopts the quadratic exponential smoothing method to process temperature and

humidity time series over the past 24 hours, and outputs the dynamic evolution curve and confidence interval for the next 6 to 12 hours. An early warning signal will be generated and marked if the predicted values reach the threshold, providing decision-making buffer for the control system.

4.2.3.3 Twin Visualization Model

Based on the simplified 3D floor plan of the exhibition hall and real-time sensor readings, the model can intuitively display the distribution of temperature, cold, humidity and dryness in different zones on the screen through color changes, allowing curators to monitor key areas in real time.

4.2.4 Application Service Layer

The application service layer serves as the user interface of the system, providing comprehensive functional services for users with different roles in the museum. Its main functional modules include:

4.2.4.1 Monitoring Visualization Module

Through virtual models and charts, the environmental conditions of cultural relics and their physical state data are visually presented, making monitoring results simple, intuitive, and immediately understandable.

4.2.4.2 Risk Warning Module

A tiered early warning mechanism is implemented with three levels—red, yellow, and green—to determine the frequency and sequence of message dissemination based on urgency, while providing risk intervention recommendations.

4.2.4.3 Immersive Display Module

Based on the digital twin model, an immersive exhibition scene is constructed, allowing users to view cultural relics in 360 degrees. Meanwhile, detailed interpretations of craftsmanship will pop up when users click on different parts of the relics, enhancing user engagement and promoting the communication and dissemination of cultural values.

5. CONCLUSION

With its creativity and forward-looking vision, digital twin technology has opened a new chapter for the preservation and utilization of cultural relics. It provides a brand-new cognitive perspective and builds a bridge across the constraints of time and space, enabling the "past and present" of cultural relics to be understood and appreciated by more people in the digital world, and enhancing cultural identity and confidence as audiences engage closely with historical and cultural heritage.

However, the application of digital twins in cultural relic conservation remains in the developmental stage, requiring collaborative efforts among museums and cultural institutions, research institutes, enterprises and other stakeholders. It is also necessary to increase investment in technological research and development and cultivate interdisciplinary talents. Looking ahead, digital twin technology holds great promise in the cultural sector, injecting more vitality into cultural heritage undertakings and contributing to building a culturally strong nation and strengthening national cultural confidence [10].

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