Long-Term Preservation Strategies for Cultural Heritage Digitization: A Case Study of the "Venice Time Machine" Project (Postprint)

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Abstract

[Purpose/Significance] To comprehensively review the current state of digital protection practices for cultural heritage and long-term preservation of digital resources, and propose relevant improvement strategies for specific issues in the practice of long-term digital preservation of cultural heritage, aiming to achieve broader inheritance and dissemination of cultural heritage resources and further enhance service quality.

[Method/Process] It identifies the necessity of achieving long-term digital preservation of cultural heritage resources oriented towards development and utilization, conducts an in-depth analysis of the international best-practice case for digital long-term preservation and development/utilization—the "Venice Time Machine" project, and accordingly proposes strategies for long-term digital preservation of cultural heritage in China.

[Result/Conclusion] Drawing on excellent foreign practical experience and guided by development and utilization, strategies for long-term digital preservation of cultural heritage in China are formulated from three aspects: resource coverage, technology integration, and service models.

Full Text

Preamble

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Research on Long-term Digital Preservation Strategies for Cultural Heritage: A Case Study of the "Venice Time Machine" Project

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Abstract

[**Purpose/Significance**] This paper comprehensively reviews the current state of digital preservation practices for cultural heritage and the status quo of long-term preservation of digital resources, and proposes relevant improvement strategies for specific problems existing in the practical work of long-term digital preservation of cultural heritage, aiming to achieve wider transmission and inheritance of cultural heritage resources and further improve service quality.

[**Method/Process**] The paper points out the necessity of achieving long-term digital preservation of cultural heritage resources with the goal of development and utilization, and conducts an in-depth analysis of the "Venice Time Machine" project as an international best practice case of digital long-term preservation and development/utilization. Based on this, it proposes strategies for long-term digital preservation of cultural heritage in China.

[**Result/Conclusion**] Drawing on excellent foreign practical experience and guided by development and utilization, this paper formulates China's cultural heritage digital long-term preservation strategy from three aspects: resource coverage, technology integration, and service model.

Keywords: cultural heritage; digital resources long-term preservation; Venice Time Machine; resource development and utilization
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Protecting historical and cultural heritage is an important cultural foundation for connecting national emotional bonds, enhancing national unity, maintaining national unity and social stability, as well as a prerequisite for maintaining world cultural diversity and creativity and promoting the common development of humanity. Since the 18th National Congress, Xi Jinping has made important instructions on the protection and utilization of cultural heritage [1], pointing out that cultural heritage is a non-renewable resource and that protection, construction, and utilization should be organically combined.

Digital humanities and cultural heritage digitization have become hot topics in China's philosophy and social science research in recent years. On the one hand, with the development of information technologies such as big data, Internet, and AR/VR, digitization has become a necessary method for protecting, developing, and utilizing cultural heritage. On the other hand, digitization is an important means of cultural heritage protection, not its ultimate goal. Cultural heritage protection begins with digitization, develops through inheritance and dissemination, and thrives through innovation and utilization. To fully realize the value of cultural heritage digital resources, it is essential to ensure

their long-term "ownability" and "accessibility." Therefore, attention must be paid to the long-term preservation of cultural heritage digital resources. Given the current situation of China's lack of goal-oriented long-term preservation of cultural heritage resources, this study analyzes excellent foreign cultural heritage digital long-term preservation practice projects, summarizes their basic operational and management characteristics, and promotes the practical work of long-term digital preservation of cultural heritage in China.

2 Related Research

2.1 Current Status of Cultural Heritage Digitization

The concept of cultural heritage was formally proposed by UNESCO in the 1972 "Convention Concerning the Protection of the World Cultural and Natural Heritage." Cultural heritage refers to cultural wealth created, left behind, and passed down by humanity, including both tangible and intangible cultural heritage [2]. Currently, in practical work on digital preservation of cultural heritage both domestically and internationally, various technical frameworks, key technologies, and typical system applications such as digital modeling, virtual restoration, digital management, digital resource display, digital simulation, VR/AR, and digital animation are primarily used to virtually preserve or reproduce cultural heritage through digital means [3-4]. Projects such as "American Memory," "Russian Memory," and "Gallica" demonstrate the effective application of digital technology in cultural heritage protection [5-6].

China started relatively late in cultural heritage digitization. In 1998, the Dunhuang Research Institute launched the "Digital Virtual Caves" project. In 2001, the Palace Museum established the Digital Palace Museum website. Since then, China has vigorously promoted research on implementation plans and technical strategies for digital protection of cultural heritage, and digital protection has become a consensus in academia and industry. Currently, research on the application of digital technology to cultural heritage in China mainly focuses on digital replication, restoration, 4D imaging experiences, and augmented reality for material cultural heritage such as ancient sites, ancient buildings, murals, and paintings, as well as intangible cultural heritage represented by traditional operas and ethnic customs [7].

2.2 Current Status of Digital Resource Long-term Preservation Research

Foreign countries started digital resource long-term preservation practices earlier, with numerous mature projects, mainly including Australia's PADI project, Germany's NESTOR project, Japan's WARP project, and the United States' NDIIPP program. Chinese libraries and documentation institutions also attach great importance to the local long-term preservation of digital resources and have conducted research and practice from multiple perspectives, such as the construction of a digital resource long-term preservation system and acquisition

of long-term preservation rights initiated by the Documentation and Information Center of the Chinese Academy of Sciences in 2009, and a series of operational procedures and standards formulated by the National Library in 2010, including "Long-term Preservation Digital Resource Handover Process" and "Collection Digital Resource Long-term Preservation Archival Inspection Standards" [8]. In October 2018, the National Science and Technology Library and Documentation Center hosted the "National Symposium on Long-term Preservation of Digital Resources" in Beijing, which conducted in-depth discussions on long-term preservation strategies and practices for various types of digital resources, including scientific data, digital humanities, digital archives, open education, and cultural heritage. Long-term preservation of digital information resources has become an important component of national information infrastructure.

Currently, research in the field of long-term digital resource preservation focuses on three aspects: Research on long-term preservation technical standards and their content, mainly including long-term preservation metadata, digital resource unique identifiers, file formats, information models, and storage space technical specifications [9-10]. Research on long-term preservation tools and storage methods. There are three main storage methods for long-term digital resource preservation: the first is archival classification storage of digital resources according to certain methods [11]; the second is database storage that uniformly inputs and stores digital resources as structured data [12]; the third is network storage that utilizes the advantages of the Internet and technical solutions such as cloud computing and Seagate storage to further establish online platforms like online libraries and digital museums [13-14]. Research on long-term preservation and cooperation strategies. Currently, scholars from various countries have reached a consensus on the development direction of adopting cooperative approaches for long-term digital resource preservation [15-16], and have proposed long-term preservation strategies under multi-institution, multi-subject, and multi-domain frameworks. Multiple international cultural heritage institutions have begun to adopt cooperative approaches for digital resource long-term preservation, with several digital preservation alliances and collaborative international cooperation projects emerging, such as the UK's Digital Preservation Coalition (DPC) and Europe's NEDLIB project.

3 Necessity Analysis of Long-term Digital Preservation of Cultural Heritage for Development and Utilization

Both long-term digital preservation of cultural heritage and its resource development and utilization involve collecting, restoring, and organizing images, photos, manuscripts, archives, and other materials related to important historical sites, major events, important figures, and ethnic skills and traditional memories. They aim to store, protect, disseminate, inherit, and develop and utilize cultural heritage resources in digital form, with the ultimate goal of preserving humanity's common culture and memory. The two are closely related, and achieving long-term digital preservation of cultural heritage with development

and utilization as the goal is scientific and necessary.

3.1 Long-term Digital Preservation and Resource Development/Utilization of Cultural Heritage as a Social Memory Need

On the one hand, both construction subjects involve cultural institutions and government departments such as archives, libraries, and museums. These cultural institutions and government departments possess rich cultural information resources, with both emphasis and overlap in resource preservation, and undertake different levels of tasks in cultural heritage protection. On the other hand, their target audiences can complement each other. Long-term digital preservation of cultural heritage focuses on the selection of preservation technologies, determination of preservation methods, formulation of preservation standards, and establishment of preservation systems, with its audience mainly being cultural heritage protection workers and groups with special needs or preferences for ethnic culture, resulting in a relatively narrow audience scope. In contrast, development and utilization of cultural heritage digital resources focus on cultural site restoration, urban landscape changes, grand scenes of ethnic festivals, and cultural activity experiences, with content more accessible to the public. They also support public co-construction, sharing, and joint use of cultural digital resources, thus having a broader audience. Long-term preservation of cultural heritage requires public recognition, and the best preservation method is for audiences to access cultural resources, promote their dissemination, and carry out further development and utilization.

3.2 Long-term Preservation Provides High-Quality Data Sources for Cultural Heritage Development and Utilization

Faced with users' increasingly generalized resource preservation needs, the construction of cultural heritage digital resources led by government departments and participated in by libraries, archives, museums, and other cultural institutions involves more extensive objects, with more complex types and manifestations. Resource types are gradually expanding from single image and text types to structured and unstructured data including audio, video, and network resources. Precise semantic description, multi-dimensional semantic association, and deep semantic aggregation of these massive, multi-source, and heterogeneous cultural heritage digital resources, along with their long-term preservation, can provide high-quality data sources for cultural heritage protection and development/utilization.

3.3 Development and Utilization as the Goal of Digital Cultural Heritage Long-term Preservation

Development and utilization are the ultimate goals of cultural heritage protection, while digital preservation is the prerequisite. Cultural heritage digital resources are important information resources, and their co-construction and

sharing for users has become a consensus. The long-term preservation of cultural heritage digital resources must also develop toward resource sharing.

4 Best Practices in International Long-term Digital Preservation of Cultural Heritage: A Case Study of the "Venice Time Machine" Project

4.1 Project Overview

The "Venice Time Machine" is a large-scale international research project launched in 2012 by the École Polytechnique Fédérale de Lausanne (EPFL) and Ca' Foscari University of Venice. It aims to establish an open digital archive covering over 1,000 years of Venice's historical and cultural heritage, using digital means to reproduce Venice's history and culture, as shown in Figure 1 [Figure 1: see original paper]. The project scans and digitizes a large number of documents and archives stored in the Venice State Archives, presenting Venice's millennium of historical changes in dynamic digital form. This not only provides the public with a new method for historical learning and research but also facilitates the long-term digital preservation of cultural heritage.

Figure 1 Scene display of the same location in different eras in the "Venice Time Machine" project (bringing back the prosperous clouds of 18th-century Venice (left) from today's St. Mark's Square (right))

4.2 Resources and Characteristics of the "Venice Time Machine" Project

The main implementation object of the "Venice Time Machine" project is the Venice State Archives, which, as one of the most complete national archives of historical materials in the world, houses a large collection of well-preserved and historically valuable archival documents. The massive collection of documents records various aspects of Venetian life over the past 1,000+ years, contains enormous research value, and demonstrates its unique resource advantages.

4.2.1 Complete and Rich Archival Resources The Venice State Archives preserves a vast amount of historical documents and archives spanning over 1,000 years of Venice's history, with a huge quantity of documentary materials. The content covered by the documents is extremely extensive, including personal birth and death records, will establishment, canal renovation, architectural design and urban planning, establishment of national conventions, and political development and changes, restoring the development and changes of Venice's millennium of history and culture from different perspectives.

4.2.2 Diverse Languages in Archival Records The Venice State Archives contains a large number of handwritten documents that directly reflect the

language culture and life scenes of the time. Throughout Venice's thousand-year history, much information was recorded in Tuscan, Latin, and Venetian dialect due to the continuous development and change of language.

4.2.3 Interconnected Documentary Resources The richness, diversity, and completeness of the documents owned by the Venice State Archives rank among the top archives worldwide. The complete and rich information resources provide an important foundation for reconstructing Venice's history and culture, and the intricate connections between documents are even more conducive to comprehensively sorting out and restoring history. As the director of the Venice State Archives, R. Santoro, said, "All the documents here are interconnected" [17].

4.3 Technologies and Technical Characteristics of the "Venice Time Machine" Project

The "Venice Time Machine" project is committed to converting all existing records into digital information and establishing a large open database for research and education. To achieve the digitization of such massive cultural heritage archives, not only powerful technical support is needed, but also many technical challenges must be faced. From the perspective of digital resource management processes, the technologies of the "Venice Time Machine" project can be divided into digitization technology (digital scanning technology), digital preprocessing technology (text recognition and automatic reading technology), digital resource organization technology (resource organization and association technology), and digital service technology (cloud service technology).

4.3.1 Digital Scanning Technology To achieve the digitization of collection documents, it is necessary to digitally scan a large number of documents collected in the Venice State Archives. However, due to the huge number of documents and the vulnerability of some files to damage, the "Venice Time Machine" project has accelerated the scanning process by cooperating with top industry enterprises and introducing semi-automated scanning robots. At the same time, to protect the integrity of ancient documents, the project has improved and refined scanning technology by drawing on CT scanning technology in medicine. The tomographic scanner can complete the scanning process without turning pages, reducing damage to ancient books during digitization and enabling faster scanning speeds.

4.3.2 Text Recognition and Automatic Reading Technology The digitization of the "Venice Time Machine" project is not limited to image scanning of collection archives; it also requires text recognition and automatic reading. However, due to the large number of manuscripts in the collection, conventional text recognition and automatic reading technologies cannot accurately identify and read the content. To solve this problem, project members chose to use machine learning technology to recognize the shape of entire words. By learning

from data samples, they continuously revised algorithms to improve algorithmic capabilities. Currently, the "Venice Time Machine" algorithm can analyze the structure of written text and establish associations between similar graphics. The system can find where the same text appears in other manuscripts. After achieving text recognition, project members combined methods from biotechnology for protein structure analysis and function prediction in text processing algorithms to combine text into complete sentences, ensuring maximum accuracy and reliability of content.

4.3.3 Resource Organization and Association Technology Creating associations between identified information is also the greatest value of the documents treasured in the Venice Archives. The project team uses keywords to establish links between different types of documents. This extensive cross-referencing of large amounts of data organizes information into a massive linked data resource repository. Information from different documents is organized in an interlinked semantic graph as part of a historical geographic information system, displaying resources from spatial and temporal dimensions. At the same time, matching and associating different documents enables researchers to reconstruct the social networks of Venice at that time. Associating and organizing massive historical information resources can discover new research clues. Scholars from various disciplines and fields such as linguistics, economics, and healthcare have collaborated with the "Venice Time Machine" to explore and research the data provided by the time machine.

4.3.4 Cloud Service Technology F. Kaplan pointed out in a TED report that the project is committed to using a "time machine" to travel through Venice from a thousand years ago, such as allowing people to see roads and buildings from ten or even a thousand years ago when checking routes in Google Maps [18]. The realization of this goal cannot be separated from cloud technology. The storage, development, and utilization of massive digital information resources rely on the support of cloud computing, and cloud technology can also make relatively accurate predictions about missing information to improve historical information.

4.4 Services and Operational Effects of the "Venice Time Machine" Project

Since its launch, the "Venice Time Machine" project has received widespread global attention and recognition. The project is considered a pioneer in the current field of big data humanities research. Although the project is still being implemented, it has already played an important role in scientific research, education, and historical cultural heritage protection.

4.4.1 Cultural Heritage Protection and Historical Traceability The "Venice Time Machine" project aims to reproduce Venice from the past 1,000

years for the public and present Venice's urban changes and development in visual form, restoring historical life scenes in Venice. The digitization and visualization of documents and materials from the Venice State Archives give the public a more comprehensive and three-dimensional understanding of history and are also conducive to the dissemination and long-term protection of Venice's and even Europe's millennium cultural heritage. In addition, through the interconnection and linking of documentary materials, the "Venice Time Machine" can sort out historical development and help solve historical puzzles. For example, it can provide record support for determining the development of ancient weights and measures; it can sort out the development process of the Venetian language; and it can supplement or demonstrate controversial content in current academic research due to vague or non-existent historical records through the traceability of documentary materials.

4.4.2 Cloud Data Access and Sharing The Venice State Archives has rich archival materials. An important goal of the "Venice Time Machine" project research is to store the archival resources of the Venice State Archives in virtual form on the Internet, establishing a large open database to achieve global network access to archival documents. Through the Internet, users can search for and read historical archival documents, which is not only conducive to the dissemination and protection of historical culture but also provides a brand-new research environment for experts and scholars in various fields. As the Venetian historian D. Raines said, "With the Venice Time Machine, we will be able to study topics that were almost impossible to research." The project provides new data for studying language evolution, population and economic dynamics, disease spread, art evolution, and architectural pattern migration. Currently, the open database of the Venice State Archives is still under construction, but some research applications have begun to be put into use. For example, the EPFL Digital Humanities Laboratory has developed a search engine specifically for images and architectural artworks, which is currently being applied in the field of Venetian cultural heritage [19].

4.4.3 Online Open Courses and Education The participants of the "Venice Time Machine" project come from top universities and research teams around the world, including researchers and students from multiple disciplines such as history, computer science, basic sciences, architecture, engineering, and art. The composition of project personnel from different disciplines provides certain advantages for the "Venice Time Machine" to layout services in the education field. To better combine new research methods with curriculum education, the project is currently building an education center that can provide students with on-site experiments, course teaching, and large-scale online open courses, enabling students to directly participate in research projects. In some universities in Venice, the research data generated by the project operation is combined and applied to some undergraduate and graduate teaching courses every year.

4.4.4 Enterprise Incubation and Support Relying on the "Venice Time Machine" project, Venice will establish a business incubator to strengthen the development of the cultural industry. The research or service content of future resident enterprises includes augmented reality applications for tourism and digital museums, restoration and protection of cultural heritage, machine learning technology, future urban planning, genealogy platforms, and epidemiological research based on past big data. Currently, the tourism industry has been widely influenced by the "Venice Time Machine" project. The project can provide virtual reality interactive technology support for the current tourism industry. The digital videos about Venice's urban history in the project results can provide the public with 4D simulation-based and even virtual reality-based historical retrospectives of Venice, which can drive the development of Venice's and even surrounding tourism industries. For example, Kaplan and others have produced a series of animated videos about Venice that span different spaces and times, showing Venice's historical culture and changes from multi-dimensional perspectives [20].

5 Implications of the "Venice Time Machine" Project for Long-term Digital Preservation of Cultural Heritage

Cultural heritage digitization construction is a focus of close attention from the government and all sectors of society. Since the Dunhuang Mogao Grottoes digitization construction project, China has gradually launched projects such as the digital Qin Shi Huang Terracotta Warriors Museum, Yuanmingyuan Ruins restoration, Wuling area cultural site reproduction, and Tibetan Buddhist Living Buddha query system construction, which have caused great repercussions globally. However, compared with the "Venice Time Machine" project, there is still room for breakthroughs, mainly manifested in three aspects: From the perspective of long-term preservation objects, most Chinese projects only involve the digital representation forms of information/resources, such as images, audio, and video resources, while the implicit knowledge content and its relationships within the resources have not been revealed; From the perspective of long-term preservation technology, current long-term preservation of cultural heritage mainly relies on mechanical replication models such as digital copying and digital storage, primarily aiming at data preservation and virtual reproduction, without forming a technical strategy system suitable for China's digital heritage project construction; From the perspective of long-term preservation models, many projects lack unique cultural characteristics, with "cloning" phenomena being common, low resource reuse rates, and traditional archival storage and database storage methods needing innovation.

Given the specific problems existing in China's digital cultural heritage project construction and the significant advantages demonstrated by the "Venice Time Machine" project in terms of resources, technology, and services, this study constructs China's cultural heritage digital long-term preservation strategy from three aspects: the depth and breadth of resource coverage, the construction of a

technical system framework, and the selection and integration of service models.

5.1 Achieving Full Coverage of Cultural Heritage Digital Resource Objects

From the perspective of the current status of China's cultural heritage digitization construction, the content covered is very extensive. In terms of preservation fields, it includes social science data, government electronic information, geographic spatial data, religion, history, art, and humanities. In terms of storage formats and forms of cultural heritage digital resources, there are both static texts and images, as well as dynamic audio, video, models, and various historical and cultural website information. In terms of processing depth of cultural heritage digital resources, there are structured, semi-structured, and unstructured resources. Currently, existing cultural heritage long-term preservation experiments and practices both domestically and internationally have not fully covered the resource objects involved in the cultural heritage field, or have not processed and processed them in sufficient depth.

To comprehensively cover the resource objects involved in the cultural heritage field, this paper classifies their types, mainly selecting digital resource categories, knowledge resource categories, institution categories, personnel categories, project categories, event categories, and database collection categories (see Figure 2 [Figure 2: see original paper]), and establishes a series of data attributes and object attributes to enable the objects of long-term digital preservation to cover all cultural heritage resources as completely as possible, and to prepare data for further establishing relationships between resources.

Among them, cultural heritage digital resources refer to all resources that have been digitized with the help of carriers such as text, images, video, audio, and three-dimensional models; knowledge resources refer to resource types other than those presented in specific carriers, such as some related tacit knowledge and knowledge organization resources (such as thesauri, Chinese Library Classification, and domain thesauri); institution and personnel categories refer to information about relevant cultural institutions or related personnel; project category information refers to resources involved in various cultural heritage projects; database collection category information refers to all special/comprehensive databases established based on cultural heritage projects; and event category information refers to the general term for all events related to a certain cultural heritage project, activity, or content, including both performance events, conference events, and interview events, as well as various physical resources derived from events.

Figure 2 Resource objects covered by cultural heritage

To achieve full coverage of multi-source heterogeneous resources of cultural heritage and further realize their multi-dimensional association, this study uses linked data technology, existing vocabularies, and linked datasets to describe the relationships between cultural heritage digital resources,

as shown in Figure 3 [Figure 3: see original paper]. Among them, the `dc:contributor` property establishes the relationship between cultural heritage database collections (`vivo:DataSet`) and related cultural heritage institutions (`foaf:Organization`), responsible parties (`foaf:Person`), and between digital resources (`ichresource:Resource`) and related cultural heritage institutions (`foaf:Organization`) and responsible parties (`foaf:Person`). At the same time, `dc:isPartOf` establishes the relationship between cultural heritage and related personnel and their belonging databases. The `vivo:currentMemberOf` property establishes the relationship between related personnel and their work units; the `swrc:carriesOut` and `swrc:worksAtProject` properties respectively associate the participation of cultural heritage-related institutions and personnel in cultural heritage projects; the `event:product` property reveals the relationship between cultural heritage projects (`vivo:Project`), related events (`event:Event`), and published digital resources (`ichresource:Resource`). In the event ontology, the defined `event:agent` associates events with institutions and individuals. In addition, it can be seen that this study associates as many cultural heritage database collections, institutions, personnel, projects, events, and digital resources as possible with knowledge resources in the cultural heritage field, aiming to reveal the implicit knowledge system structure in this field from various perspectives, which will provide rich semantic information for establishing thesauri and standardized ontologies in the cultural heritage field and offer a good semantic foundation for better integration and mining of the cultural heritage knowledge system.

Figure 3 Relationships between cultural heritage resource objects

5.2 Improving the Technical Strategy for Long-term Digital Preservation of Cultural Heritage

In the practical process of digital preservation and rational utilization of cultural heritage, many technical solutions have been well applied, while some remain only at the theoretical level. The success of the "Venice Time Machine" project is closely related to the formulation of technical strategies, involving multiple levels such as digital resource selection, precise description, semantic association, and shared services, providing an achievable technical path for long-term digital preservation of cultural heritage. Determining reasonable technical solutions and considering their feasibility, sustainability, practicality, and systematicity, and improving the existing digital long-term preservation technical strategy framework from multiple dimensions, is the focus of long-term digital preservation work for cultural heritage and a core element for achieving the utilization and secondary development of cultural heritage digital resources.

This study uses information space theory to construct a cultural heritage digital long-term preservation technical strategy framework from three dimensions: codification, abstraction, and diffusion (see Figure 4). The framework covers the technical processes of digital collection, organization, and dissemination/utilization in the cultural heritage digital technology system. Among them,

the codification space measures the degree to which information can be recognized by computers through the degree of codification, that is, what digital representation form cultural heritage resources need to present; the abstraction space measures whether the digitized information has undergone reasonable classification and comprehensive feature description, usually requiring analysis of digitized resources based on preservation goals and practices to determine the processing depth at the content level of preserved resources; the diffusion space mainly measures the dissemination speed, coverage area, and possibility of reuse of knowledge under visualized circumstances, that is, users' specific requirements for cultural heritage resources.

Figure 4 Technical strategy framework for long-term digital preservation of cultural heritage

5.2.1 Codification Space It is necessary to use various information technologies and presentation forms to collect, record, and extract cultural heritage resources and their knowledge characteristics, so as to understand and express information in the abstraction and diffusion dimensions. Specific digital forms such as text, images, video, three-dimensional models, and 4D simulation can be used for comprehensive, authentic recording and collection. This process only stores original digital objects and maintains their integrity and readability, without considering the content features and semantic relationships contained in the digital objects.

5.2.2 Abstraction Space Since the development and utilization of digital resources depend on the understanding of their formats and processing methods, simply achieving preliminary digital preservation cannot guarantee the reliability of long-term preservation. To further achieve cultural heritage digital resources for user use, while providing content data backup storage capabilities, it is also necessary to provide relevant metadata standards for storage, management, and use, and to establish regular upload, confirmation, use, and maintenance mechanisms for content data to ensure the integrity and usability of digital resources and their related functions. The abstraction space covers the entire process of cultural heritage resource digitization, resource description, resource association, resource aggregation, and resource services.

5.2.3 Diffusion Space Codification and abstraction spaces are prerequisites for cultural heritage to be accepted and recognized by users in a wider range. Therefore, the diffusion space is mainly used to measure the degree to which knowledge is contacted, learned, and accepted by the public after digital preservation. With the continuous change and improvement of user needs, the diffusion space can be divided into five different levels: preservable, presentable, understandable, shareable, and usable, which greatly influences the selection of technical strategies for cultural resource digital long-term preservation. This process involves the selection and combination of various technical strategies, such as relatively mature migration, emulation, UVC, data/program archiving

technologies, as well as emerging data reconstruction, cloud storage technology, and VR/AR technologies.

5.3 Constructing a Service Model for Long-term Digital Preservation of Cultural Heritage

To achieve long-term preservation of its digital resources and improve resource storage and service efficiency, cultural heritage needs not only to select appropriate technical strategies but also to establish service models suitable for its own development. This study uses distributed systems and cloud storage technology to distribute different types of digital resources to cloud nodes (see Figure 5 [Figure 5: see original paper]). Fundamentally, cloud storage combines network equipment, storage equipment, servers, application software, public access interfaces, access networks, and client programs. This storage model means knowledge as a service [21].

Figure 5 Service model for long-term digital preservation of cultural heritage

5.3.1 Application Service Layer This layer consists of user interfaces, Web browsers, data interfaces, etc., mainly providing users with services such as resource sharing, browsing, retrieval, and personalization, and achieving online interaction with users. This layer also includes Portal containers for receiving client information, which can aggregate and display multiple types of information as different resource forms according to user needs. After receiving user requests, the cloud storage system will also analyze the needs for cultural heritage digital resources and select suitable application software or access interfaces to provide personalized services for users.

5.3.2 Cloud Storage Layer The main function of this layer is to virtualize cultural heritage resources to form a resource pool, mainly including archival storage (such as storage system management, media management, storage mechanism management), repository management (such as database management, unique identifier management), and long-term preservation (such as preservation planning, environmental monitoring, strategy evaluation). Cloud storage functions, on the one hand, serve as the core service interface of the system, providing virtual resource integration, resource scheduling, system-driven services, and coordinating multiple devices to work in parallel to ensure the orderly management and scheduling of cultural and heritage resources; on the other hand, they face underlying resources to achieve resource management and various application services, and distribute digital resources to the “cloud” to achieve resource backup.

5.3.3 Basic Management Layer This layer mainly covers hardware such as servers, computer equipment, and storage equipment, as well as related technologies for interconnecting various resources, that is, after the semantic description

and association of digital resources, to achieve effective management of basic resources and facilities based on storage hardware equipment. On the one hand, this layer can achieve distributed processing of infrastructure, providing functional interfaces such as data computing and backup management for the cloud storage layer; on the other hand, it can integrate digital resources from different storage devices within regional institutions and integrate various hardware functions through cluster and virtualization processing of hardware facilities to form a regional cultural heritage resource cloud platform.

5.3.4 Cultural Heritage Resource Layer The cultural heritage domain data resource layer involves various data and resource collections in the cultural heritage field, including digital resources (audio, video, etc.), knowledge resources, cultural heritage institution-related resources, personnel resources, database resources, event resources, database collections, and cultural heritage project resources, covering a wide range, rich resource content, and complex resource types.

Digital technology provides new concepts and tools for the innovation and development of current cultural heritage protection, inheritance, dissemination, development, and utilization. Long-term digital preservation of cultural heritage is not only basic work for its development and utilization but also an important guarantee for achieving digital resource sharing and services in the face of diversified and ubiquitous user needs. Therefore, this study takes the successful experience of the "Venice Time Machine" project as an example, and based on summarizing its advantages in resources, technology, and services, proposes a development and utilization-oriented long-term digital preservation strategy for cultural heritage. From three aspects—resource coverage breadth and depth, technical strategy framework formulation, and service model selection—it systematically constructs a long-term digital preservation scheme suitable for China's cultural heritage.

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Note: Figure translations are in progress. See original paper for figures.