New Era for Dunhuang Culture Unleashed by Digital Technology

Shuxia Song

Department of Culture Promotion, Dunhuang Academy, Dunhuang 736200, China

Abstract

The development of information technology, particularly the rapid progress in big data, cloud computing, artificial intelligence, and other digital technologies, has emerged as a new driving force for the preservation, research, and promotion of Dunhuang culture. To achieve the goal of "Permanent Preservation and Sustainable Utilization "of Dunhuang caves, Dunhuang Academy takes protection as the breakthrough point, and progressively explores and promotes the profound digitization of Dunhuang culture's interpretation, display, and dissemination, so as to cater to the needs of the people and enhance cultural exchanges and mutual learning between China and foreign nations. This paper delves into the profound impact of digital technology on the preservation and dissemination of Dunhuang culture, in order to align with current trends of digital industrialization and the digitization of the cultural heritage and museum industry. Through these discussions, we hope that with the support of digital technology, the protection and dissemination of Dunhuang culture can be enhanced.

Keywords

Digital Technology; Culture; Promotion; Mogao Caves; Digital Dunhuang.

1. Value of Dunhuang Culture

As a traffic artery on the ancient Silk Road, Dunhuang stands out as an ideal region for the convergence of Eastern and Western cultures. Ji Xianlin once expressed, "The magnificence of Dunhuang culture lies in its integration of the essence of global cultures, serving as a model of the enduring assimilation of Chinese civilization with a long history of thousands of years." Since the inception by Emperor Wudi of the Han Dynasty in 111 BC, Dunhuang has been based on the excellent traditional Chinese culture, ceaselessly embracing and drawing lessons from, absorbing and integrating the achievements of other foreign civilizations, thus creating a brilliant Dunhuang culture. Dunhuang caves possess a wealth of cultural, historical, artistic, and scientific value. As significant repositories of ancient Chinese culture, they encompass various facets, including architectural art, painted sculpture art, mural art, Buddhist culture, and folk culture.

Built between the 4th and 14th centuries A.D., Dunhuang caves lasted for nearly two thousand uninterrupted years, profoundly reflecting the development and evolution of Chinese history. The murals, sculptures and documents in the caves show the face of ancient Chinese social life and provide valuable information for the study of Chinese history, society, religion, science and technology, culture and art. Moreover, they also reflect the cultural exchanges between ancient China and different regions such as ancient India, ancient Greece and ancient Persia.

Dunhuang caves are treasures of ancient Chinese painting and sculpture. The murals and sculptures fully display the style and characteristics of ancient Chinese art. These works of art are rich in subject matter and exquisite in craftsmanship, offering invaluable source material for the study of ancient Chinese art. The construction of the caves itself involves geology, architecture, engineering technology and other fields, which is the crystallization of the wisdom of the ancient Chinese people.

2. Background and Significance of Cultural Heritage Digitalization

2.1 The Framework for the Digitization of Cultural Heritage by National Policies

In August 2019, General Secretary Xi Jinping put forward in his speech at Dunhuang Academy, "It is imperative to employ advanced technologies such as digitalization and informatization to facilitate the return of cultural relics such as Dunhuang posthumous letters scattered overseas, and realize the digital sharing of Dunhuang cultural and artistic resources worldwide." Several Opinions on Strengthening the Reform of Cultural Relics Protection and Utilization clearly put forward that information technology such as the Internet, big data, cloud computing and artificial intelligence shall be used fully to promote the integration and innovation of cultural relics display and utilization. The Guiding Opinions on Promoting the Reform and Development of Museums put forward that it is significant to vigorously develop smart museums and gradually realize smart services, smart protection and smart management. The 14th Five-Year Plan for Cultural Relics Protection and Scientific and Technological Innovation also emphasizes the importance to expedite the establishment and advancement of the National Cultural Heritage Science and Technology Innovation Center and the key laboratories in the field of cultural relics protection. In May 2022, The Opinions on Promoting the Implementation of the National Cultural Digitalization Strategy promulgated by the General Office of the Chinese Communist Party and the General Office of the State Council of the PRC put forward that by the end of the 14th Five-Year Plan period, a comprehensive cultural service supply system will be established through the development of digital infrastructure, service platforms, and seamless integration of online and offline components. By 2035, a national cultural big data system with physical distribution, logical association, fast links, efficient search, comprehensive sharing and key integration will be built, and the panorama of Chinese culture will be presented and the digital achievements of Chinese culture will be shared by the general public.

The corresponding policies promulgated by the state can provide common standards and frameworks for various institutions to follow when digitizing cultural heritage, make the process of digitizing cultural heritage more systematic and standardized, help to promote the application and development of digital technology in the field of cultural heritage and museum, ensure the protection and rational utilization of cultural heritage, and increase the supply of quality public cultural products. It will add new momentum to the development of the cultural industry, encourage and promote the development and innovation of technology, and promote the development of the social economy.

2.2 The Development of Cultural Heritage Undertakings Keeping Pace with the Times and Integrating with the Development of Science and Technology

Culture's prosperity and strength are intertwined with the nation's. Culture is the bond of spiritual strength and the cornerstone of social development. The development of cultural undertakings is related to the well-being of people's livelihood and the all-round development of people. Since the Eighteenth National Congress of the Communist Party of China, remarkable achievements have been made in the development of cultural relics in China, and the work of the cultural relics census has been steadily promoted. According to statistics, there are 767,000 immovable cultural relics and 108 million movable cultural relics in China. The situation of cultural resources has been basically clarified. These huge numbers of folk cultural relics and lost cultural relics scattered overseas constitute a treasure house of Chinese cultural heritage resources to be further explored and utilized. The progress in cultural relics preservation is evident as museum construction flourishes, the utilization of cultural relics expands in both breadth and depth, and the development of cultural heritage continues to rise.

2.2.1 Infusing Culture with New Vitality through Science and Technology

The core of "Bringing Cultural Relics to Life" lies in enhancing the levels of protection, research, display, and inheritance of these invaluable treasures. Science and technology play an important driving role in the development of cultural undertakings. Traditional methods of cultural relics protection often rely on manual operation, making them susceptible to subjective and natural

disruptions. However, the application of science and technology can offer more precise and effective means of protection. For instance, high-resolution digital imaging technology can record the state of cultural relics non-invasively, obtain the internal structure and material information of cultural relics, and help to accurately assess the condition and damage degree of cultural relics. Furthermore, three-dimensional digital technology enables the creation of accurate digital models of cultural relics and provides a reference for the protection and restoration of cultural relics. In 2019, a fire hit the Notre Dame Cathedral in Paris, France, just as people mourned the loss of a symbol of European culture, the Notre Dame Cathedral in Paris, digital technology brought hope for its restoration. Using laboratory software, experts will employ digital technology to recreate a "virtual twin" of Notre Dame. It can map the location of each fallen stone within the virtual space to help understand the pre-fire condition of the cathedral. In addition, science and technology can also be applied to the environmental monitoring and control of cultural relics to ensure the stability and suitability of the preservation environment. Since its opening to tourists in 1979, Mogao Caves have always been under rational use, based on the premise of good protection, and have insisted on the importance of protection in its utilization. In order to reduce the occurrence of mural diseases caused by changes in the micro-environment of caves caused by visitors, sensors are installed in all open caves to monitor the temperature, relative humidity, carbon dioxide content and the number of visitors in real-time, and the monitoring data are transmitted to reception and management departments through the monitoring center, which provided a basis for the protection and rational opening of caves [1].

Science and technology provide more tools and methods for the study of cultural relics, and promote the deepening and innovation of research. The use of non-destructive scientific and technological means, such as infrared imaging, X-ray fluorescence spectroscopy, can reveal the internal structure and composition of cultural relics, and help researchers understand the history and production process of cultural relics. For example, the staff used an ultra-depth of field microscope, scanning electron microscope and other technologies to detect and analyze some bronzes unearthed from the No.2 sacrificial pit of the Sanxingdui site. The analysis results showed that there were textile residues of silk on the surface of bronzes, which provided a very important new basis for the relationship between Sanxingdui culture and the Southern Silk Road.[2] Coincidentally, murals from Dunhuang caves contain organic pigments, which gradually fade over time and can not be identified by the naked eye, but multi-spectral photography can assist in the visualization of faded murals. On the east side of the northern slope of cave 272 in Mogao Caves, the ribbon on the skirt of a flying apsaras is not visible under normal circumstances. However, multi-spectral photography can be utilized to study various cultural relics, including painted sculptures, murals, paper documents, silk paintings, and more.[3] Digital technology has enhanced the convenience of storing and managing information about cultural relics. Researchers can now access and analyze relevant data pertaining to cultural relics more easily. Meanwhile, science and technology also provide a platform for interdisciplinary research, enabling a large number of cultural relics information to be stored, shared and compared. Experts in different fields can explore multiple levels of cultural relics through sharing data and cooperative research, thus promoting interdisciplinary cooperation and in-depth development of research in cultural relics.

The application of science and technology has injected new vitality and innovation into the heritage of cultural relics. Virtual reality (VR) and augmented reality (AR) technology enable the audience to experience cultural relics and historical scenes, and stimulate their interest and participation in cultural heritage. At the beginning of 2022, Dunhuang Academy, in collaboration with Huawei, launched the "Feitian" special tour route in Mogao Caves. This route utilizes the latest Cyberverse technology, leveraging the extensive digital content from "Digital Dunhuang" to create highly immersive and visually stunning experiences. The virtual digital content produced by Dunhuang research results, digital Dunhuang high-precision mural images and three-dimensional model of caves is integrated with the real Mogao Caves scene in real-time through centimeter-level spatial recognition technology, creating a virtual twin world in Mogao Caves, enabling visitors to enjoy the complete mural content by using AR technology even if they do not enter the caves, thus achieving an effective balance between the protection of cultural relics and the opening of caves. The program

"2023 Chinese Poetry Congress" uses XR technology to restore "Flying Apsaras" from Dunhuang. The program recording utilizes a 360-degree immersion AR visual architecture to recreate the cave environment and capture the authentic artistic atmosphere. This immersive experience allows viewers to feel as if they are wandering through the mural caves, leaving a shocking impression on the audience. Digital exhibitions and online cultural relics databases have expanded and simplified the dissemination and sharing of cultural relics, and breaking the geographical and time constraints. Projects such as Immersive Digital Experience Exhibition in the Forbidden City by Tencent, Digital Axis, and Yunyou Great Wall help Chinese excellent traditional culture reach a broader boundary through artificial intelligence, cloud computing and other cultural and creative formats and cutting-edge technologies. Furthermore, the integration of science and technology with traditional handicraft techniques can facilitate the re-creation and repurposing of cultural relics. This not only extends the value of cultural relics to contemporary life but also fosters the development of cultural and creative industries.

2.2.2 Promoting the Development of Science and Technology, and Fostering an Interconnected and Mutually Beneficial Relationship through Cultural Activation and Utilization

Science and technology promote the inheritance and innovation of culture, and the cause of cultural activation and utilization also promotes the development of science and technology, while the integration of culture and science and technology enables them to gain each other and achieve coordinated development. The application of science and technology in the field of culture provides rich possibilities for cultural inheritance and innovation. Digital technology, VR, artificial intelligence and other scientific and technological means make the preservation, display and dissemination of cultural resources more convenient and extensive. Furthermore, the cause of cultural activation and utilization has also promoted the development of science and technology, with the continuous development of cultural activation and utilization, the demand for scientific and technological innovation and application is also increasing, and the cultural field has put forward new challenges to better attract audiences, enhance the experience and protect cultural heritage, which promotes the field of science and technology, and enable the development of more advanced technologies and tools that are culturally appropriate. For example, the cultural recommendation system based on artificial intelligence and the cultural experience platform based on VR are all technological innovations generated by the cause of cultural activation and utilization. The integration of culture and science and technology is communicated with and complemented each other The uniqueness and creativity of culture provide a new perspective and inspiration for the development of science and technology, and boost innovation and progress. In addition, the application of science and technology offers a broader platform and means for cultural activities and innovation, and expands the method of cultural expression and dissemination. Through mutual integration and innovation, culture and technology can jointly create more creative and innovative cultural products, activities and experiences, enrich the social application of cultural heritage digitization, fully release its value, and make more rapid progress in commercial development, so as to better serve the economic and social development.

2.3 Public Broad Demand for the Digitization of Cultural Heritage

Digitalization enables cultural heritage and museum resources to be accessed and obtained online through the Internet and digital platforms. The public can now access, learn and enjoy the content of cultural heritage and museums through mobile terminals such as computers and smartphones, without the limitation of time and region. This convenient access meets the needs of the public for cultural knowledge and art appreciation.

Digital technology provides more diversified ways of interactive experience. The public can interact with cultural heritage and museum resources through VR, AR and other technologies. Immersive experience enhances the sense of participation and interaction of visitors. This interactive experience fulfills the public's desire for close engagement with cultural and artistic works. Besides, digital technology also provides an effective means for the protection and inheritance of cultural heritage,

and the public typically exhibits a strong interest in and concern for the preservation and inheritance of cultural heritage, they are eager to understand and learn about cultural heritage through digital means, and join the team of protecting and inheriting cultural heritage. The public has a continuous demand for cultural knowledge learning and education. Digital cultural resources can be made available to the public in various forms such as teaching materials, online courses, and other resources, providing them with learning and research materials.

The public's demand for cultural consumption is increasingly diversified, and digital cultural heritage and museum resources offer a wider choice. The public can consume different types of digital cultural heritage and museum content according to their interests and needs, such as online purchases of works of art, digital museum visits, etc. Digital cultural and museum resources meet the needs of the public for diversified cultural consumption and enrich their cultural life.

3. Digital Technology for Activation and Utilization of Dunhuang Culture

Dunhuang caves are treasures in the cultural heritage of China and the world. However, the protection of the Dunhuang caves is under tremendous pressure due to natural weathering, man-made destruction and time erosion. In the new era of "Creative Transformation and Innovative Development", the advancement of digital technology is changing with each passing day, which provides new ideas for the protection, research and promotion of Dunhuang caves.

3.1 Digital Dunhuang

In order to realize the permanent preservation and sustainable utilization of Dunhuang caves, Dunhuang Academy has started the exploration and practice of digitalization since the late 1980s, namely the Digital Dunhuang Project. After more than 30 years of development, the digital Dunhuang project has established a set of key technical systems for the digital collection, processing, storage and display of cultural relics, and has formed huge amounts of digital resources such as digital photography collection, three-dimensional reconstruction of caves, and panoramic roaming of caves. In 2016, the Chinese and English versions of the "Digital Dunhuang" resource library were launched, realizing the global sharing of high-definition images and panoramic roaming programs of 30 caves. Currently, visitors from eight countries around the world, including China, Korea, Japan, the United States, Canada, the United Kingdom, France, Italy, Spain and Russia, have collectively visited more than 16.8 million times.

With digital technology as a basis, the digital Dunhuang project has left a valuable cultural heritage for future generations through the comprehensive digital recording, preservation and presentation of Dunhuang caves. Furthermore, by use of VR technology, the audience can experience Dunhuang caves art in an immersive way, which motivates the innovation of cultural heritage and art research. The digital Dunhuang project provides a new platform for cultural research and academic exchanges. Through the utilization of digital data, scholars at home and abroad can conduct comprehensive research and analysis of Dunhuang, thereby fostering academic cooperation and cultural exchanges. The promotion of this project has yielded remarkable results in the field of cultural relics. Furthermore, Dunhuang Academy has made relentless efforts to foster dialogue and cultural exchanges among civilizations in the new era. This initiative aims to enhance people-to-people communication, collaborate in building a community of destiny in cyberspace, and jointly create new cultural and civilizational achievements in the digital era.

3.2 Dunhuang Digital Exhibition

Based on the massive, pluralistic, heterogeneous and time-varying digital resources of digital Dunhuang, Dunhuang Academy has held digital Dunhuang exhibitions covering the display of duplicate caves, the thematic display of high-fidelity duplicate murals and the interactive experience of panoramic roaming through deep excavation, systematic refinement and thoughtful planning, enabling the audience to gain a brand-new Dunhuang cultural experience. The exhibition caters to the visual and sensory needs of the audience, and strongly supports cultural heritage, academic

research and education promotion, and advances the protection and dissemination of Dunhuang culture.

This method of displaying duplicate caves enables the audience to have an immersive experience, appreciate the details of the murals at close range, feel the artistic charm and historical value of Dunhuang murals, and understand the magnificence and uniqueness of Dunhuang caves more intuitively. Panoramic roaming interactive experience allows the audience to enjoy the mural art of Dunhuang caves through VR or AR equipment, which not only attracts more people to participate in the exhibition in depth, enhances the sense of engagement and interaction, but also allows them to feel the cultural tradition and modern in the appreciation, which promotes the inheritance and innovative development of Dunhuang culture.

At present, Dunhuang Academy has participated in more than 20 digital exhibitions at home and abroad. These exhibitions have drawn significant attention from diverse audiences and media outlets. They have sparked international interest in Dunhuang culture, bringing together people from different cultural backgrounds to appreciate and study Dunhuang culture collectively. Moreover, these exhibitions have facilitated the integration of cultural exchanges and dialogues, fostering new artistic and cultural creations. This kind of cultural blending and interaction enriches the connotation and diversity of Dunhuang culture, and further enhances the international influence of Dunhuang culture.

3.3 Mogao Caves Digital Display Center

In 1979, Mogao Caves were officially opened to the outside world. Initially, the site attracted a limited number of tourists. Since the reform and opening up, the social economy has developed rapidly. As people's living standards have improved over time, tourism interest has gradually increased, leading to a growing conflict between the protection of cultural relics and the rising demand for tourism. Due to the immovability and unalterable nature of the painted sculptures and murals in each cave of Mogao Caves, tourists can only enter the cave to have a view, akin to stepping into a "cultural relics storehouse". Monitoring data show that, an influx of visitors can lead to an increase in cave temperature, humidity, and carbon dioxide concentration, which can directly damage the murals. The seasonal pattern of tourism visits to Mogao Caves is quite evident, with the peak season occurring from July to September. During this time, a large influx of visitors poses a significant threat to the preservation of the caves, resulting in a less-than-optimal experience for visitors. Given the contradiction between the protection of Mogao Caves cultural relics and tourism, Dunhuang Academy, in cooperation with the Getty Conservation Institute of the United States, carried out a study on the carrying capacity of tourists, and finally determined that the best carrying capacity of Mogao Caves tourists is 3,000 people per day. In order to effectively alleviate the contradiction between the number of excess visitors and the protection of Mogao Caves cultural relics, Dunhuang Academy built and put into use the Mogao Caves Digital Display Center in 2014. The center utilizes state-of-the-art information technology and display methods to digitally collect, store, and transform murals and painted sculpture resources in Mogao caves into high-definition movies for presentation to the audience. Visitors can watch the 4K ultra-high definition wide-screen film "Millennium Mogao" and the 8K ultra-high definition ball screen film "Dream Buddha Palace", and experience the artistic charm of Mogao Caves through the omnidirectional and three-dimensional virtual cave scenes. After experiencing Dunhuang art at the center, visitors will gain a deeper understanding of Mogao Caves, allowing for a more focused and meaningful exploration of the physical caves during their visit.

After the completion of Mogao Caves Digital Display Center, Dunhuang Academy uses high-tech means to carry out scientific management, continuously optimize the network booking and ticketing system, and provide visitors with booking services through the visiting booking network. The online booking system allows for effective control of the number of tourists and enables accurate scheduling of visitors' visiting times, thus forming a new Mogao Caves tourism opening mode of "total amount control, online booking, digital display and on-the-spot cave viewing", which not only increases the daily carrying capacity of tourists to 6,000 people, but also greatly improves the visiting experience

and realizes the balanced development of Mogao Caves' cultural relics protection and tourism opening-up.

By far, Mogao Caves Digital Display Center has received more than 11.6 million visitors and played 44,000 movies. At the 34th Session of the World Heritage Committee held in Brazil in 2010, the experience in conservation management and tourism opening-up of Dunhuang and Mogao Caves was taken as a typical case to disseminate and share with world heritage sites around the world. "Mogao Caves have demonstrated an effective approach to manage heritage site tourism and protect the value of heritage sites with extraordinary vision, setting an exemplary image of great significance," put forward the attachment text of the conference document produced by the meeting [4].

3.4 Diversified Digital Innovation Dissemination Projects

The splendor of Dunhuang culture is widely known, but it also has complex and challenging aspects that make it difficult for most people to understand and engage with directly. In order to make cultural relics "live up" and truly enter the public's lives, Dunhuang Academy thoroughly explores the profound meanings embedded in Dunhuang caves while expanding its perspective and embracing innovation. It deeply analyzes the psychological traits, lifestyle patterns, and interests of the public, revolutionizing the way cultural communication is expressed. By leveraging digital technology, it transforms a wide array of existing digital resources related to Dunhuang caves into visually captivating digital achievements. This approach revitalizes traditional culture and successfully achieves the seamless integration of culture and digital technology. These digital communication projects break the limitations of traditional culture, make the cultural relics in caves "live up" and "go out". It helps integrate Dunhuang culture into people's daily life, and increase the perception and intimacy of culture.

At the end of 2017, Dunhuang Academy and Tencent jointly launched the Dunhuang "Digital Provider" program. "Provider" is a Buddhist term that refers to devout individuals who support the construction of Dunhuang caves. It is thanks to these "providers" that these caves have been continuously built for over a thousand years without interruption. Based on the concept of "Dunhuang Provider", "Digital Provider" continually encourages the public to participate in the digital protection of Dunhuang murals through the Internet, music, games, animation, literary creation and another digital creative approach, to become the "Digital Provider" of Dunhuang culture and inherit the culture from generation to generation. By use of digitalization, Dunhuang culture has been presented more richly and diversely, which also enables more people to contact and feel it. By far, more than 250 million people have participated in the online interaction of "Digital Provider", and 240,000 users have donated funds to the Dunhuang caves protection project on Tencent's public welfare platform.

At the end of 2018, the "Dunhuang Poetry Towel" project was launched. This project follows an interactive DIY approach. It selects eight representative theme elements and over 200 detailed elements from Dunhuang murals. Users have the freedom to choose their preferred mural elements and, through rotation, scaling, and combination, create unique scarves that reflect their imagination and aesthetic design. Additionally, users can opt to utilize professional design templates for inspiration. The project can not only guide the audience to think independently, but also maximize the display of individuality. After the completion of individual works, they will be included in the digital exhibition hall to be a part of Dunhuang's digital culture, which will be displayed publicly to all users, that is, to build a public art field online. It offers a space for self-discovery and understanding of others. The project utilizes modern artistic expression to inherit and interpret the story of traditional culture, conveying the distinctive cultural heritage and essence of Dunhuang and Mogao Caves, so that people can feel the charm of Dunhuang culture in daily life. Since the project went online three months ago, it has welcomed 2.5 million unique visitors.

Dunhuang Academy and Tencent reinterpret and create Dunhuang culture through digital means, and develop and create King of Glory's series of skin such as "Meet Flying Apsaras", "Meet Deer", "Meet Hu Xuan", Dunhuang animated drama, lighting Mogao Caves and other projects, so that the ancient Dunhuang culture releases new vitality, making it more in line with the aesthetic needs and cultural

background of contemporary people. These digital creative communication projects with rich forms and diverse contents make Dunhuang culture no longer just stay in the professional field, but be a part of people's cultural life. This enables people to appreciate the art and beauty of Dunhuang culture anytime and anywhere, becoming a driving force to enhance people's quality of life.

3.5 Yunyou Dunhuang Mini Program

During the COVID-19 epidemic in early 2020, in order to better meet the public's cultural consumption needs, Dunhuang Academy launched the first "Yunyou Dunhuang" mini program, which integrates exploration, sightseeing and protection of Dunhuang caves. Utilizing multimedia, networking and digital technology, "Yunyou Dunhuang" enables users to break the time and space constraints and explore Dunhuang caves from various angles without going outside, thus greatly expanding the promotion radius of Dunhuang culture. Users can not only explore murals from the dimensions of art type, dynasty and color, but also experience creative projects such as coloring murals to fund the restoration of cave murals. The mini program offers both an enjoyable audience experience and a variety of digital content formats, such as public welfare, animation, games, music, literature, etc. It promotes the innovation and revitalization of Dunhuang culture. Additionally, it popularizes and preserves China's traditional culture, integrating it into the younger generation, expanding the industry's prospects, and fostering cultural exchanges along the Silk Road. Since the launch of the "Yunyou Dunhuang" mini program, more than 200 million people have participated in online interaction, with a cumulative number of visits exceeding 60 million.

In order to further improve the transformation and application of the achievements of the "Yunyou Dunhuang" resource bank and expand the influence and radiation of Dunhuang culture, Dunhuang Academy and Tencent jointly created the first digital Dunhuang cultural ambassador, Jiayao, which attracted innumerable fans. Her prototype came from the Miaoyin Bird "Kalaviṅka" in Mogao Caves murals, and the character design referred to classical murals from Mogao Caves. It also adopts the real-time driving technology pipeline based on a game engine, combined with motion capture, full real-time driving and rendering, real hair and real-time cloth calculation, face driving underlying algorithm optimization and other technologies. Jiayao can not only make expressions in real-time, but also her hair, clothes and accessories can move with the wind as in reality.

In the future, Jiayao will learn and master rich knowledge grounded in the Dunhuang cultural knowledge map constructed by the "Yunyou Dunhuang" mini program, combined with AI technology, become the first digital commentator of Yunyou Dunhuang, exchange Dunhuang cultural knowledge with online tourists at any moment, and lead more people to appreciate the charm of Dunhuang culture.

3.6 Flying Apsaras Special Tour Route

Dunhuang Academy adheres to "integrity" and "innovation" unceasingly by means of "culture + technology", adopting more innovative ways to tell Dunhuang stories. For instance, in early 2022, Dunhuang Academy worked together with Huawei on launching the "Feitian" special tour route. This is an innovative measure based on the research results of digital Dunhuang and Dunhuang science, aiming at digging deeply into the artistic value and historical connotation of Dunhuang culture, and realizing the dissemination and experience of culture through the application of digital technology. By virtue of the massive digital resources of digital Dunhuang and the spatial positioning technology of Huawei Cyberverse, Dunhuang Academy has created a virtual twin world in Mogao Caves. Tourists can experience the unique glamour of Mogao Caves in a virtual environment, and it offers a fresh perspective by enabling viewing of cave cultural relics from outside. This kind of virtual and real integration brings unprecedented experience to tourists and enriches the content and form of the tour route. Feitian is a significant artistic image found in Dunhuang murals. In the special tour route of "Feitian", Dunhuang Academy presents Feitian art to tourists more intuitively and vividly, enabling a wider audience to comprehend and appreciate the distinctive cultural element of Dunhuang, thereby fostering the preservation and advancement of Dunhuang culture. In the "Feitian" special tour route, visitors can not only delight in the artistry of Feitian, but also engage with other iconic Mogao Caves images within the immersive setting of virtual and physical integration, and capture precious

moments through photography. This interactive experience increases the sense of participation and immersion, enabling tourists to experience the charm of Dunhuang culture more deeply. It also establishes a deep connection between Dunhuang culture and the people, achieving an organic integration of culture into people's lives. In addition, it demonstrates the strength of Dunhuang Academy in the application of digital technology, and provides useful experience and reference for the digital protection and dissemination of other cultural heritage.

3.7 Dunhuang Posthumous Papers Database, Digital Dunhuang Open Material Library and Digital Scripture Caves

In 2022, Dunhuang Academy continued to increase the application of digital technology to assist inheritance and promotion of cultural heritage. On August 19, the "Dunhuang Posthumous Papers Database" was launched. As a global Dunhuang literature resource-sharing platform, it includes basic information about Dunhuang literature, digital images, full-text documents and related research bibliographies. Furthermore, the database enables full-text retrieval of Chinese and Tibetan documents and allows users to browse through pictures and texts. It utilizes advanced digital technology to digitize Dunhuang posthumous papers, compiling and collecting information from various sources. This establishes a comprehensive information resource database of Dunhuang posthumous papers, providing valuable data to the global academic community. The project "cultural relics + science and technology" is a concrete measure taken by Dunhuang Academy to explore a new paradigm of cultural relics exhibition, which effectively promotes the creative transformation and innovative development of Dunhuang cultural resources, and constantly improves the dissemination, attraction and appeal of Chinese excellent traditional culture.

In the same year, under the guidance of the "Internet + Chinese Civilization" action plan by the National Cultural Heritage Administration, Dunhuang Academy and Tencent jointly created and launched the world's first blockchain-based open sharing platform for digital cultural heritage, "Digital Dunhuang Open Material Library". Based on the research results of Dunhuang science and the massive digital resources of caves, Tencent's advanced technology, the digital resources authorization and utilization system of cultural heritage has been innovatively constructed, and the "Digital Dunhuang Open Material Library" provides convenient, intelligent and personalized digital resources services to the public through the collaborative innovation of resources, technology, authorization and management mode. More than 6,500 high-definition digital resource archives from cave sites such as Mogao Caves in Dunhuang and documents from Dunhuang scripture caves are open to the world through the material library, creating a "one-stop" Dunhuang cultural sharing platform for scholars, cultural enthusiasts and artistic creators at home and abroad. The launch of "Digital Dunhuang Open Material Library" not only effectively realizes the safe and efficient flow of cultural resources, but also has profound practical significance in promoting the confirmation of digital resources, expanding the social openness of cultural resources, and enhancing the two-way interaction between Dunhuang Academy and the public.

In 2023, Dunhuang Academy launched the world's first participatory museum beyond time and space, "Digital Scripture Cave". The Dunhuang scripture cave is one of the most important archaeological discoveries of the 20th century, in which more than 60,000 ancient documents and works of art from the 4th to 11th centuries were unearthed, which is known as "the key to the medieval history of the world". At present, the cultural relics unearthed from the scripture caves are collected in dozens of institutions in China, Britain, France, Russia, Japan and other countries. Building upon a century of research results of Dunhuang science, years of digital Dunhuang accumulation, and leveraging game technology, Digital Scripture Cave introduces a groundbreaking concept and experiential approach as a "participatory museum beyond time and space." This innovative platform enables the public to virtually "travel" across various historical periods, such as the late Tang Dynasty, the Northern Song Dynasty and the late Qing Dynasty, offering a unique and immersive experience. In the "witnessing" and portrayal of key historical events, the platform offers an immersive experience to the public. It effectively conveys expert Dunhuang knowledge to the public through diverse perspectives and

engaging forms. By guiding the public to appreciate the silent value of cultural relics, perceive the wisdom of the ancients, and inherit traditional culture, it creates a new paradigm for the display and experience of cultural relics.

4. Practical Features of Digital Technology Enabling Dunhuang Culture Promotion

4.1 Continuous Exploration and Construction for the Whole Chain of Digital Development of Dunhuang Culture

With the help of digital technology, Dunhuang Academy has carried out in-depth protection, research and promotion of Dunhuang culture, boosted the convergence of technology and culture, and achieved the extension and expansion of deep digitalization in the links of protection and restoration, connotation excavation, wisdom management, activation and utilization. It also encourages the expansion of Dunhuang culture beyond its traditional confines and academic research, enabling a wider audience to appreciate and understand its unique artistic and cultural values. By constantly enriching the contemporary expression of Chinese traditional cultural elements, it addresses society's ongoing pursuit and longing for a richer cultural life. Furthermore, it actively empowers the entire cultural and museum industry, leveraging the power of science and technology across the entire industry, enabling the sustainable utilization and preservation of cultural resources through the application of technological advancements.

4.2 Technological Empowerment for Innovative Dissemination of Dunhuang Cultural Values

Dunhuang Academy has made a positive and effective practice in the digital dissemination of Dunhuang culture around "telling Dunhuang stories well". Digital technology enables the diverse presentation of Dunhuang culture in digital formats, and social media platforms with their wide reach have the power to attract attention and promote the dissemination of Dunhuang culture, engaging more people in its promotion. These digital media platforms offer the advantage of accessibility anytime and anywhere, breaking down geographical and temporal barriers. No matter where people are, they can remotely access and appreciate the essence of Dunhuang culture through the Internet and other channels, and they can experience the beauty and profound without visiting Dunhuang or Mogao Caves. Moreover, Dunhuang Academy refines and extracts the most representative cultural genes in Dunhuang culture, applies multi-dimensional digital technologies such as cloud and 3D printing of cultural relics based on virtual reality, and improves the readability and understandability of Dunhuang culture through the deduction of modern art forms such as film, television, music, animation, games and literary creation. These bring immersive and interactive digital communication projects to the public, and help cultural IP "go out of the circle". and create phenomenal products. In addition, it effectively stimulates public interest and awareness of cultural heritage, strengthens the connection between the contemporary value of cultural relics and public life, and builds an "online + offline" communication system, which integrates cultural heritage into contemporary life and provides the public with rich spiritual nourishment and cultural self-confidence.

4.3 Broaden Thinking and Integrating Resources from Various Angles to Foster New Development

Dunhuang Academy collaboratively integrates multiple resources, mobilizes collective efforts, establishes extensive channels for cooperation and communication, and collectively advances the digital research and preservation of Dunhuang culture. It also consolidates and manages the invaluable cultural resources of Dunhuang caves. By using digital technology, accurately recording cultural relics and combining them with relevant research data, a complete database of cultural relics is formed. The application of digital technology in the promotion of Dunhuang culture is jointly carried out, so as to convey the charm of Dunhuang culture to a wider audience, enhance global awareness and attention, and boost the international dissemination of Dunhuang culture. Furthermore,

deep integration of Dunhuang culture with tourism, cultural and creative industries and other fields will be achieved to inject new impetus into the development of cultural industries.

4.4 Utilizing Strengths for Global Dissemination of Dunhuang Culture

Mogao Caves hold diverse values and possesses an international presence. The application of digital technology not only brings new opportunities for the dissemination of Dunhuang culture in China, but also provides strong support for its international dissemination. By use of digital methods, Dunhuang culture can show its unique charm and profound connotation to the world in the form of multilingual and multimedia, break through the limitations of language and region, and enable more international audiences to understand and appreciate Dunhuang culture. Dunhuang collaborates with domestic and international scientific research institutes to advance the Dunhuang digitization project, facilitating the promotion and sharing of Dunhuang cultural and artistic resources. This ensures that Dunhuang culture resonates with the developmental needs of the new era. Furthermore, an international platform is established for sharing digital achievements, bringing together dispersed documents from Dunhuang scripture caves worldwide. This platform aims to facilitate the comprehensive collection and recording of documents and cultural relics in Dunhuang scripture caves, providing a convenient platform for global Dunhuang scholars and enthusiasts to share Dunhuang cave data and documents. It enables scholars, experts, and artists from different countries and regions to actively participate in the research, preservation, and dissemination of Dunhuang culture. This international cooperation and exchange help to absorb the wisdom and experience of different cultures and promote the development and influence of Dunhuang culture in the international arena.

5. Prospects for the Development of Dunhuang Culture Promotion with the Assistance of Digital Technology

Dunhuang Academy has fully implemented the cultural relics work policy of "protection first, rescue first, rational utilization, strengthening management", attached great importance to the leading and supporting role of science and technology in the cause of Dunhuang cultural relics, made great breakthroughs in the digital collection, processing, storage and display of cultural relics from caves, and realized the permanent preservation and sustainable utilization of cultural relics information. Moreover, leveraging scientific and technological capabilities, cultural heritage is revitalized, and concerted efforts are made to promote the digital dissemination of Dunhuang culture. This revitalization aims to harness the power of the digital age and maximize the influence and reach of Dunhuang culture. Dunhuang culture has made some achievements in digital dissemination, but it still faces a series of challenges and tasks to realize comprehensive digital dissemination. Therefore, the digital dissemination of Dunhuang culture still has a long way to go.

5.1 Expanding the Extension of Digital Technology to Foster the Activation and Utilization of Cultural Heritage

Currently, the main contradiction in China's cultural construction lies in the growing demand for cultural resources and the insufficient and imbalanced supply of such resources. The six caves in Gansu province managed by Dunhuang Academy are a significant part of China's excellent traditional culture, and the digitization work is of great importance for the protection, research and dissemination of the cultural value of these caves. However, in addition to the six caves under the jurisdiction of the Dunhuang Institute, many other cave temples along the Silk Road also possess rich cultural heritage. In the context of the "Belt and Road" initiative, expanding the scope of digital work and focusing on more cave temples will encourage us to comprehensively understand and protect these cultural heritages and incorporate them into the system of digital cultural heritage. Secondly, the implementation of digital engineering technology needs to be widely promoted, enabling more cave temples to benefit from the protection and dissemination of digitalization. Through the implementation and promotion of technology, the digital recording and preservation of the cultural heritage of cave temples can be realized, and the protection efficiency and research level can be improved. Moreover, the results of digitization can be widely disseminated through the Internet and

other digital platforms, allowing more people to access and appreciate these valuable cultural heritages.

The extension of digital technology in the activation and utilization of cultural heritage requires cross-institutional cooperation and collaboration. Dunhuang Academy will deepen the establishment of partnerships among other relevant research institutions, cultural institutions and research institutes to jointly boost the application and promotion of digital engineering technology in cave temples along the Silk Road. By means of resource sharing, experience exchange and technical cooperation, digital work can be implemented with a higher efficiency, and the scope of digital technology will be extended to a wider range of cultural heritage areas.

5.2 Deepening the Application of Digital Technology in Cultural Dissemination and Enhancing the Sustainable Development of Social and Economic Benefits

Digital technology digitalizes massive cultural heritage resources and transforms them into digital assets that can be stored, disseminated and utilized. Through digital methods, the cultural resources of Dunhuang caves can be accurately recorded, classified and sorted out, forming a huge cultural database. These digital cultural heritage assets have rich information and knowledge value, and can be widely used in academic research, education and training, cultural and creative industries and other fields, thus realizing the capitalization of cultural heritage.

In the past, cultural heritage resources were mainly circulated and disseminated within the cultural circle, and only be understood and appreciated by a few professionals and cultural enthusiasts. However, the application of digital technology has broken this restriction, enabling a large number of cultural heritage resources to cross the restrictions of regions and groups and enter a wider social circle. In the future, Dunhuang Academy will assist people in accessing and sharing the information and content of cultural heritage anytime and anywhere by means of digital exhibitions, virtual reality, social media and other channels, and participate in cultural heritage and communication, so as to enhance people's awareness and participation in cultural heritage, and improve cultural diversity and social cohesion.

The advancement of digital technology will also enable massive cultural heritage resources to achieve sustainable development in terms of social and economic benefits. In terms of social benefits, digital cultural heritage resources provide the public with rich cultural knowledge and aesthetic experience, encouraging cultural inheritance and innovation. In addition, the application of digital technology has also brought new development opportunities for education, tourism, cultural and creative industries, and boosted the prosperity of related industries and increased employment opportunities, achieving sustainable economic development. In the future, Dunhuang Academy will further enhance the development of digital technology to promote Dunhuang culture, actively cultivate the inheritance and promotion of cultural heritage, and contribute to the diversified development of society and economic prosperity.

5.3 Enhancing the Application and Innovation of Digital Technology in Cultural Heritage Education

The 21st Congress of the International Council of Museums (ICOM) held in Vienna in 2007 introduced a revised definition of the museum, firstly emphasizing "education" as the primary function of museums.[5] This shows that contemporary museums have been transformed from "collection centers" to "public centers". Currently, Mogao Caves of Dunhuang primarily conducts cooperative education activities between libraries and schools offline with more traditional methods. In addition, Dunhuang Academy will actively promote the integration of digital technology and digital achievements. This includes the development of online education platforms, allowing students and cultural enthusiasts to access Dunhuang culture courses, lectures, and resources through the network at their convenience and from anywhere. By using VR and AR technology, students can experience the details and atmosphere of murals in Dunhuang caves, and interact with virtual Dunhuang cultural elements in real scenes. It also greatly enriches the educational value and attraction

of Dunhuang culture. Moreover, the data on Dunhuang culture is visualized and displayed interactively, and the complex cultural heritage information is displayed in the form of charts, images and animations to help students and audiences better understand and analyze the characteristics and values of Dunhuang culture. Through the use of interactive display technology, students can actively engage in the learning process, enabling them to explore and discover the captivating aspects of Dunhuang culture on their own.

5.4 Establishment and Improvement of the Copyright Protection Mechanism for Digital Achievements

As a precious cultural heritage, the copyright protection of Dunhuang culture holds immense significance. However, the popularity and convenience of digital technology also pose the risk of copyright infringement. Digital dissemination projects of Dunhuang culture make it easy to replicate, disseminate, and modify content, which may lead to unauthorized use and piracy. Therefore, it is an important challenge to ensure the copyright protection of Dunhuang culture in the digital environment and safeguard the rights and interests of creators and stakeholders.

To address these challenges, a series of measures need to be taken. In the future, Dunhuang Academy will strengthen the formulation and implementation of copyright laws and regulations to ensure that the copyright of digital Dunhuang cultural works is fully protected. Secondly, efforts should be made to improve cultural popularization and education, enhance public awareness and attention to Dunhuang cultural copyright protection, strengthen international cooperation, collectively address the challenges of transnational digital copyright management, and promote the establishment of international cooperation and consensus. Moreover, the relationship between copyright protection and cultural dissemination should be balanced, ensuring that digital technology can be a strong support for the development of Dunhuang culture.

6. Conclusion

This paper mainly discusses the practice and exploration of the promotion of Dunhuang culture enabled by digital technology, and looks forward to future development. As a treasure of the Chinese nation, Dunhuang culture carries rich historical and cultural connotations, and the rapid development of digital technology provides new opportunities and challenges for its inheritance and promotion. After years of development, we can see that the application of digital technology in the field of Dunhuang culture has achieved certain results. Digital technology makes Dunhuang murals and documents permanently preserved, and offers valuable resources for future generations to study. Furthermore, unprecedented convenience in the dissemination and display of Dunhuang culture has been brought about by digital technology. It has also facilitated the innovation and integration of Dunhuang culture with other art forms, injecting new vitality and a contemporary sense into it.

However, there are some challenges in the process of empowering Dunhuang culture with digital technology. The first challenge lies in the technical aspects of digitization. Further research and exploration are required for high-precision digital restoration and image processing techniques. Secondly, the application of digital technology needs to be combined with the principles of cultural protection and inheritance to ensure that digital technology is not only a tool, but also provides beneficial support and promotion for the inheritance and development of Dunhuang culture.

Looking forward to the future, we will continue to promote the organic integration of digital technology and Dunhuang culture, and facilitate the in-depth application of digital technology in the field of Dunhuang culture. There will be a need to strengthen research and cooperation in related fields, train professionals with expertise in both digital technology and cultural and artistic backgrounds, and enhance the innovation capabilities and application levels of digital technology in the field of Dunhuang culture. In addition, attention will also be given to public participation and cultural popularization, with the aim of creating more interactive and diversified experiences through the utilization of digital technology. This will enable a greater number of people to understand, pay attention to, and actively participate in the inheritance and promotion of Dunhuang culture. In doing

so, Dunhuang culture will radiate with new vitality in modern society, injecting additional dynamism and vigor into the cultural treasures of the Chinese nation.

References

[1] Jinshi Fan: Adhering to the Mogao Caves Cultural Relics Management System, Dunhuang Research, No.4, (2015), p.2.

[2] Hongtao Ma : Insert the Wings of Science and Technology into the Protection and Utilization of Cultural Relics, How to Make Cultural Relics Live, p.37.

[3] Bolong Chai, Xiaowei Wang, Ailing Tang, Yuquan Fan: Preliminary Application of Multi-spectral Photography in the Investigation of the Current Situation of Mogao Caves Murals and the Study of Painting Techniques, Dunhuang Research, No.6, 2008.

[4] Jinshi Fan: Adhering to the Mogao Caves Cultural Relics Management System, Dunhuang Research, No.4, 2015, p.4.

[5] Yi Zheng: Research on Museum Education Activities, p.1.