Research on Advancing the Conservation and Heritage of the Kizil Cave-Temple Complex through Strategic Planning and Digital Exhibition

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Abstract

As the earliest existing large-scale grotto group in China, the Kizil Cave-Temple Complex faces new challenges under the influence of the new era's concept of preservation and heritage. Facing the current high-quality development of cultural tourism integration, digital technology is of great significance for the overall enhancement of the Kizil Cave-Temple Complex, including research, protection, and exhibition. This thesis establishes a holistic framework of digital technology, elucidates the development strategy for the Kucha Caves with the Kizil Cave-Temple Complex as a case study, and explores innovative digital technology and creative display ideas for the preservation and heritage of the Kizil Cave-Temple Complex through practical examples such as the digital research of the monumental image caves No. 47 and the upgrade of the Kizil Kucha Cave-Temple Museum.

Introduction

The Kizil Caves are the earliest surviving and longest-lasting large-scale cave temple complex in China. In 1961, they were designated as part of the first batch of Major Historical and Cultural Sites Protected at the National Level. In 2014, the site was inscribed on the World Heritage List as a component of the "Silk Roads: Routes Network of Chang'an – Tianshan Corridor." As important evidence of the Silk Road and the ancient civilization of Kucha, the Kizil Caves contain the largest number of caves and the most extensive cave complexes among all cave temple sites in Xinjiang.

Amid the flourishing research and exhibition development of cave temples in China, the Kizil Caves face multiple challenges, including a lack of interpretive content, a monotonous exhibition format, and insufficient supporting facilities within the park. Through comprehensive planning and digital research, the development of exhibition projects can enhance the recognition and dissemination of the site's value and research findings while ensuring the safety of the heritage itself. By conducting in-depth digital research on key caves and exploring innovative exhibition methods, This approach offers new perspectives and exemplary practices for the conservation and interpretation of cave temples.

1. New Context and Emerging Challenges

The General Office of the State Council issued the Guiding Opinions on Strengthening the Protection and Utilization of Cave Temples (Guobanfa [2020] No. 41), which outlines key tasks such as enhancing the digital protection and utilization of cave temples and improving their comprehensive exhibition standards. Both tasks require a foundation of digital research, employing digital acquisition technologies as a means and relying on standardized technical management processes for support. Furthermore, the 14th Five-Year Plan for the Protection and Utilization of Cave Temples by the National Cultural Heritage Administration emphasizes the need to fully leverage digital technologies and other modern scientific methods to innovate and expand the ways cave temples are presented and utilized.

As societal expectations evolve, people now seek higher-quality cultural and tourism experiences. Surveys indicate that visitors to the Kizil Caves primarily consist of local residents and out-of-town tourists. Local residents tend to favor short, high-quality cultural-themed travel routes, whereas non-local visitors are more interested in experiences that integrate cultural heritage with natural scenery. In particular, young students often participate in study tours to gain a deeper understanding of the rich values behind cultural heritage.

In 2023, the Kizil Caves received 280,000 visitors, with peak-season daily visits averaging around 1,500. The annual visitor volume and peak daily capacity have already exceeded the predicted carrying capacity by 87% and 39%, respectively. Currently, the main tourism activity in the park is on-site cave visits, with only six caves open to the public. Compared to the Mogao Caves in Dunhuang (see Table 1), the Kizil Caves offer fewer open caves, a more limited exhibition experience, and insufficient supporting facilities—failing to meet the growing demand for high-quality cultural tourism experiences.

Category	Kizil Caves	Mogao Caves in Dunhuang
Heritage Comparison	349 caves, of which 135 are relatively intact Over 10,000 square meters of murals 4 statues	735 caves, of which 492 are well-preserved Over 45,000 square meters of murals 2,415 painted sculptures Over 4,000 flying apsaras sculptures
Visitor Capacity	Daily average carrying capacity: 1,080 people Peak season capacity: 1,500 people	Daily average carrying capacity: 6,000 people Peak season limit: 12,000 people
Regular Visits	Access to 6 physical caves Total caves available for public access: 6	Digital exhibition center screenings (11,825㎡ + 8,205㎡) + access to 8 physical caves Total caves available for public access: 60

Emergency Access	Special caves not open to the public Total caves available for emergency access: 24	Access to 4 physical caves Total caves available for emergency access: 9
Visitor Numbers	280,000 visitors (2023)	2.1 million visitors (2019)

Table 1: Comparison of Heritage and Accessibility Between Kizil Caves and Mogao Caves in Dunhuang

Figure 1 shows the current status of facilities in the Kizil Caves Scenic Area (Source: Photographed by the author).

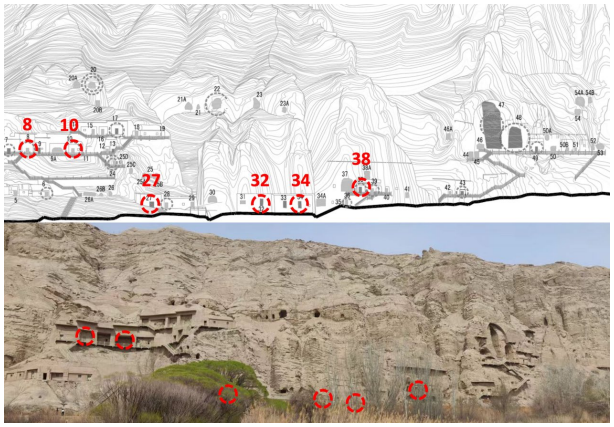

Figure 2 illustrates the locations of the currently open caves in the Kizil Caves (Source: Drawn by the author, with the base map provided by the Kizil Caves Research Institute).

Among the Kucha cave sites, in addition to the Kizil Caves, which are the earliest cave complex in China, there are eight other cave sites, including the Kumtura Caves, where Han, Kucha, and Uighur artistic styles coexist; the Kizilgaha Caves, which have historical ties to the royal family of the Kucha Kingdom; as well as the Senmusaimu Caves, Taitaier Caves, Wenbashi Caves, Aai Caves, Tuohulaike Aiken Caves, and Mazaboha Caves. Therefore, the future overall enhancement of the Kizil Caves must be based on the systematic planning of the entire Kucha cave complex.

2. The Digital Development Process and Challenges of the Kizil Caves

2.1 The Digitalization Development of the Kizil Caves Heritage

Since the 1980s, the Kizil Caves have undergone three major phases of surveying and data collection. The first phase (1980s) primarily involved traditional surveying, producing mapping results such as floor plans. The second phase (2006 – 2013) carried out systematic surveying, employing 3D digital acquisition technologies such as 3D laser scanning and oblique photogrammetry, resulting in CAD mapping drawings, orthophoto images of cave walls, mural photographs, and a limited number of low-resolution textured models of the caves. The third phase (2015 – 2019) focused on 22 caves with rich heritage remains, conducting digital imaging of murals and spatial model acquisition, producing high-definition mural images and detailed 3D models with high-resolution textures. The surveying results from this phase have been applied in restoration model production, VR virtual experiences, mural reconstruction research, and academic publications.

2.2 Challenges in Digitalization

The three phases of digital work have primarily served different objectives at various times. However, considering the diverse needs of research, conservation, and exhibition of the Kizil Caves, previous data collection efforts have also presented certain issues. For instance, the second-phase work focused on collecting spatial data of the caves, but the precision of mural texture and color information was insufficient, making it inadequate for subsequent studies on caves and murals. The third-phase results were highly detailed with accurate color reproduction, yet they did not systematically documentation physical spatial positions, leading to difficulties in locating data for archaeological research, cave conservation, and restoration studies, which in turn affected related work. Additionally, the data formats from both phases are non-standard and excessively large, making them inconvenient for daily use by cave researchers.

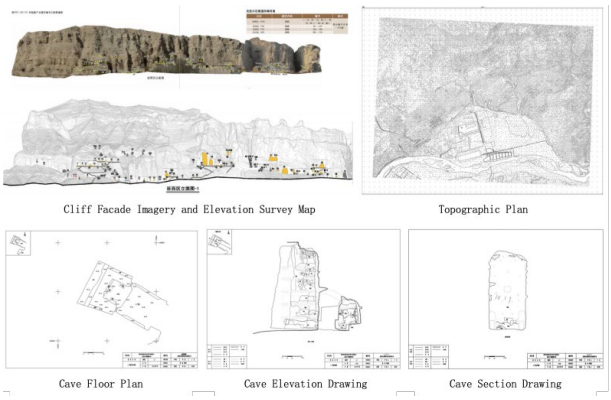

Figure 3: Forms of Digital Acquisition Results in the Second Phase (Source: Kizil Caves Research Institute)

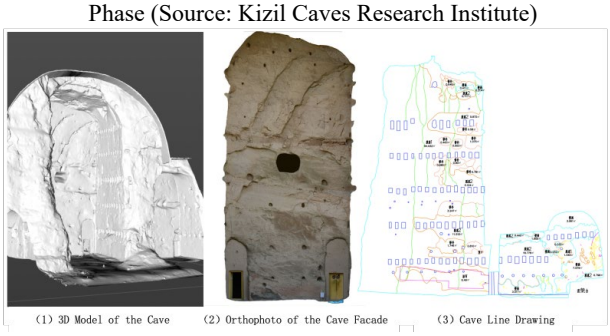

Figure 4: Mapping and Surveying Results in the Second Phase (Source: Kizil Caves Research Institute)

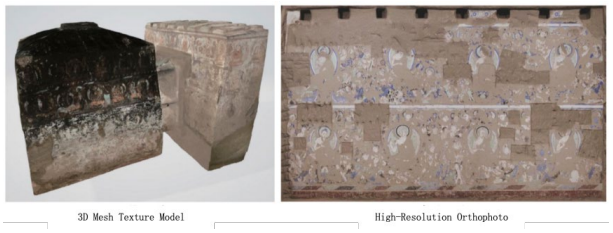

Figure 5: Forms of Digital Acquisition Results in the Third Phase (Source: Kizil Caves Research Institute)

Figure 6: Extended Applications of Digital Acquisition Results in the Third Phase (Source: Kizil Caves Research Institute)

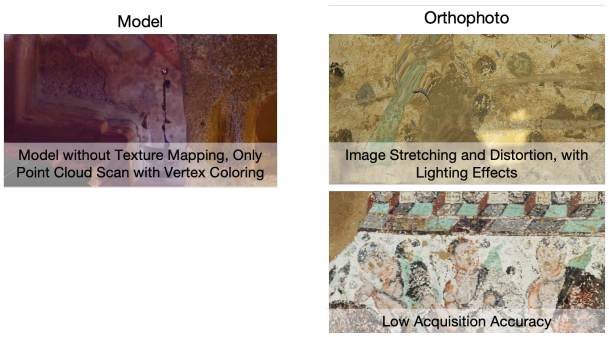

Figure 7: Example of Issues in Second-Phase Digital Acquisition Results (Source: Drawn by the author)

3. Strategies for Enhancing the Kizil Caves

3.1 Overall Concept for the Kucha Caves Planning

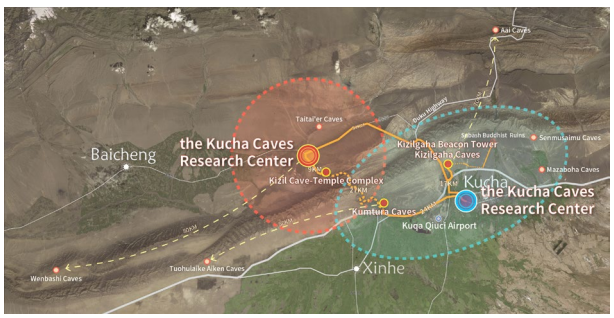

Figure 8: Overall Planning Concept for the Kucha Caves (Source: Kizil Caves Research Institute)

The planning focuses on a "2+3+6" open-utilization structure, establishing and operating two centers: the Kucha Caves Research Center and the Kucha Caves Digital Exhibition Center. It also aims to create three open visitor areas, namely the Kizil Caves, Kumtura Caves, and Kizilgaha Caves, and to enhance the protection and research areas for six caves: Senmusaimu Caves, Taitai'er Caves, Wenbashi Caves, Aai Caves, Tuohulaike Aiken Caves, and Mazaboha Caves(Miao, L.H., 2023).

By 2025, the goal is to deeply explore the heritage value of the Kucha Caves, strengthen technological innovation, improve talent development, and elevate protection and exhibition standards. The Kucha Caves will develop a preliminary system for research, conservation, exhibition, and utilization. A series of exemplary and innovative exhibition projects will be implemented, leading to a well-established cultural tourism product offering and the establishment of the Kucha Caves cultural brand, facilitating the integration of culture and tourism. By 2035, a comprehensive system for research, conservation, exhibition, and utilization will be fully established, and the national and international influence of the Kucha Caves cultural brand will be significantly enhanced.

3.2 Core Area Enhancement Strategy for the Kizil Caves

In response to the increasing number of visitors and growing cultural demands, the strategy for the Kizil Caves core area is to integrate and enhance the functionality of existing exhibition facilities, thereby improving the visitor experience.

First, appropriate visitor flow management will be implemented by increasing the number of caves available for public viewing, thus creating a better distribution of visitor traffic. Additionally, the cave access routes will be reorganized, and new experience pathways will be developed according to the caves that are open to the public.

Second, digital exhibition expansion will be introduced. Flexible digital experiences will be added to the park, including digital night tours of Cave 47 and augmented reality (AR) guided tours. This will enrich the display spaces during onsite visits and enhance the overall visitor experience. A dedicated digital exhibition center will be established, and the existing exhibition areas will be upgraded with digital displays, thus addressing the diverse demands for exhibition content.(He, Y., Ma, Y.H., 2016)

Third, educational activities will revitalize existing spaces. Research outcomes will serve as the foundation for educational programs. Open caves and newly established digital exhibition centers will be used as venues for educational activities, with AR restoration guides and digital exhibitions as the forms of presentation. This will provide comprehensive support for educational activities, offering complete learning experiences for students and professionals.(He, Y., Ma, Y.H., 2024)

3.3 The Importance of Cave 47

Cave 47 is located in the western valley area. It is a monumental image cave, with a main chamber, passage, and rear chamber. The main chamber has a height of 16.7 meters, and the cave’s surface area exceeds 800 square meters. The original large standing statue has been lost, but there are regularly spaced holes on the wall, and a base for a statue remains on the floor. The ceiling, passage, and rear chamber are adorned with several

layers of murals, covering an area of approximately 117 square meters, representing the early murals of the Kizil Caves.

Mr. Su Bai argued that the excavation of monumental image caves and the construction of large standing Buddha statues were defining characteristics of Kucha Buddhist art, and he proposed that this had an influence on regions west of the Pamirs as well as areas east of Xinjiang(Su, B., 1996).As the largest statue cave in the Kucha area and the site of a large standing Buddha statue, Cave 47 of the Kizil Caves is an outstanding example of large stone sculptures in the earliest known large cave temple groups in China. It serves as a witness to the long history of cultural exchange along the Silk Road, particularly between Central Asia and the East, and is the first station of the Sinicization of Buddhism.(China Architectural Design and Research Institute, Institute of Architectural History, Xinjiang Cultural Relics and Monuments Protection Center, Xinjiang Kucha Research Institute, 2013.) This cave holds significant value for the cultural identity of the Chinese nation and for promoting mutual learning between civilizations.

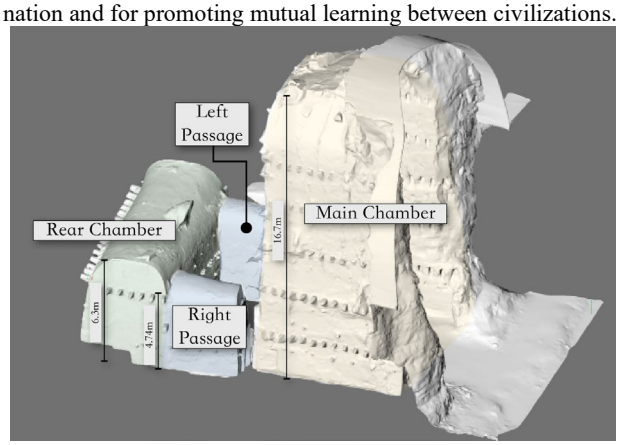

Figure 9: Spatial Layout Model of the Remains in Cave 47 (Source: Drawn by the author, base map from the Kizil Caves Research Institute)

4. Digital Exhibition Research Technology System for the monumental image caves

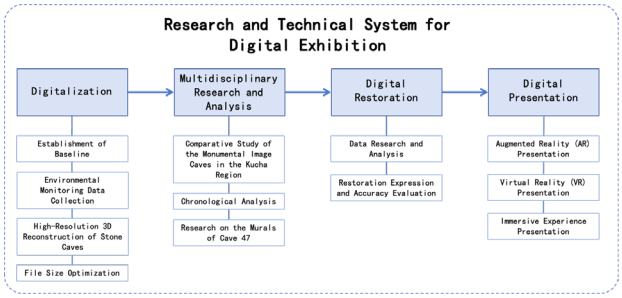

Figure 10: Digital Exhibition Research Technology System Diagram for Cave 47 (Source: Drawn by the author)

4.1 Optimization Strategies and Technical Workflow for Digital Data Collection

The current data acquisition plan has been specifically adjusted and optimized compared to previous technical approaches. The key optimization strategies are as follows:

① Establishment of Reference Points and Control Network Surveying: By integrating reference point establishment with control network surveying, we ensure seamless alignment of multi-level acquisition results.

② Layered data collection using multi-level scaffolding: Accurately designed safety scaffolding ensures the protection of the structure and enables precise image acquisition.

③ Precision Equipment Matching: Equipment is carefully selected based on the required accuracy to achieve optimal results.

④ Professional Software and Workflow: The use of specialized software and associated workflows ensures non-destructive data processing and high-precision acquisition outcomes.

⑤ Lightweight Data Processing: Optimized models are used to streamline data, making it adaptable to various scenarios and expanding application possibilities.

4.1.1 Establishment of Reference Points

As an integral part of the Kizil Cave complex, the digital 3D reconstruction of Cave 47 must be conducted within the same spatial-geographic coordinate system as the rest of the Kizil Caves to ensure data accuracy and consistency. For this purpose, four reference points were reviewed and measured, strategically positioned around Cave 47. These points were placed on stable ground to ensure long-term preservation of the markers, and the overall control network layout and surveys were conducted at these locations.

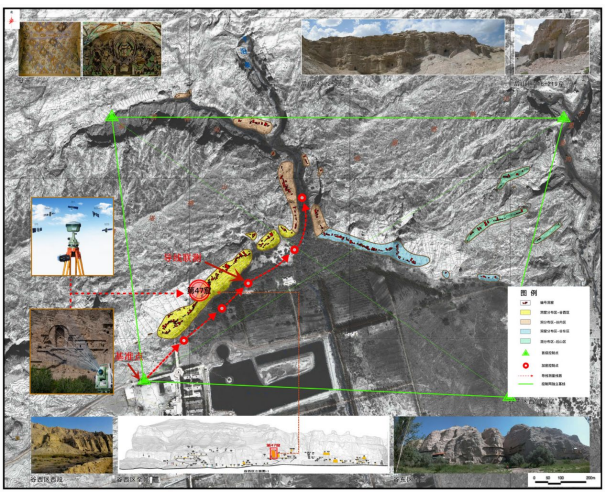

Figure 11 Overall Control Network Plan (Image Source: Author’s Own Illustration)

4.1.2 Surveying the Environmental Context of Cave 47

Aerial oblique photogrammetry using UAVs, combined with high-precision positioning sensors and supplementary ground-level photography with small drones, was employed to semi-automatically generate a 3D model. The resulting centimeter-level accuracy 3D model supports architectural restoration research and projection-based inverse calculations.

4.1.3 High-Precision 3D Reconstruction of Cave 47

The full-scale 3D digital reconstruction of Cave 47 is a crucial method for preserving accurate data on its existing appearance, form, design, materials, and spatial context. The high-precision 3D reconstruction of Cave 47 in the Kizil Caves adopts the CGCS2000 geodetic coordinate system and the 1985 National Elevation Datum as spatial references. Under a unified spatial reference framework, spatial and texture data were collected for both Cave 47 and the surrounding cliff face, ensuring a finely detailed 3D model of the cave and its geological surroundings. This process accurately records the architectural structure, murals, and other heritage elements of Cave 47.

Given the considerable height of the cave’s interior, an 8-tier working platform supported by scaffolding was used to conduct high-precision 3D spatial data acquisition. The cave, reaching a maximum height of 16.7 meters, features a complex structure with intricate details. High-resolution texture data (⩾300 dpi) were captured for approximately 800 square meters of cave wall surfaces. Through a systematic three-phase approach — surveying, data acquisition, and data processing — the high-precision 3D reconstruction of Kizil Cave 47 was successfully completed.

4.1.4 Lightweight Data Processing

Due to the large scale of Cave 47, the resulting data volume is immense, which restricts the display and utilization of the original 3D model data. The lightweight processing primarily includes geometric simplification and texture mapping methods for large-scale cave 3D models, adaptive multi-level detail models that preserve geometric structure and topological relationships, and the construction of a visualization framework for large-scale cave models. This workflow enables efficient data optimization and lightweight processing.

4.2 Multidisciplinary Research and Investigation

4.2.1 Comparative Study of the Monumental Image Caves

Among the more than twenty monumental image caves in the Kucha region, Kizil Cave 47 stands out as the most grand and complex. A systematic comparative study of the monumental image caves in the Kucha area provides academic support for the digital restoration of Cave 47. The comparative study focuses on three aspects: construction period, architectural form, statues, and murals.

① Comparative Study of Construction Periods:By sampling and analyzing the front and rear chambers of over twenty Monumental Image Caves in the Kucha region, this study examines the historical evolution of artistic forms within these caves.

② Comparative Study of Architectural Form:This study focuses on the spatial and temporal dimensions of the monumental Image Caves in the Kucha region, examining key aspects such as cave spatial layout, functional zoning, scale and structural composition, as well as architectural decorations.

③ Study on Sculptures:This research primarily explores three aspects: spatial arrangement, stylistic characteristics, and sculpting techniques. The study systematically examines the remaining traces of sculptures in the Monumental Image Caves of the Kucha region, including preserved statue platforms, relevant mural and relief remains, fixed sculpture chisel holes, and unearthed sculptural artifacts within the caves.

④ Comparative Study of Murals:This investigation focuses on the artistic characteristics of murals in Monumental Image Caves of the Kucha region, analyzing elements such as scene composition, mural narratives, and artistic techniques. The study aims to summarize the defining features and stylistic patterns of murals in these caves.(Zhao, L.Y., 2021)

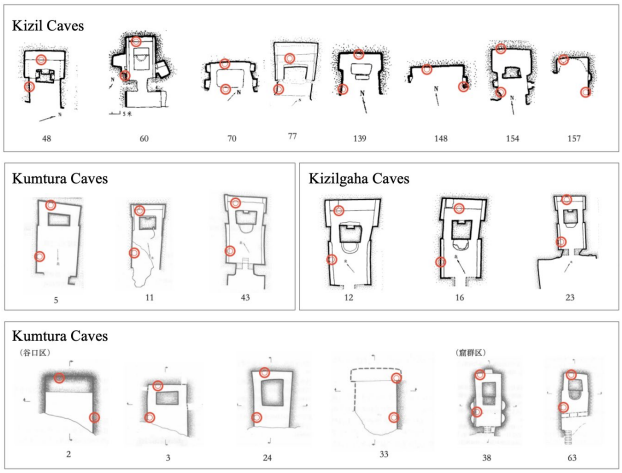

Figure 12: Proposed Sampling Points for Carbon-14 Testing in Monumental Image Caves of the Kucha Region (Image Source: Author’s Illustration)

4.2.2 Experimental Chronological Testing

In February 2023, an on-site investigation was conducted at Cave 47, including small-scale experimental AMS (Accelerator Mass Spectrometry) Carbon-14 testing. Five samples were collected from different locations within the main chamber, corridor, and rear chamber.The results for the main chamber samples predominantly ranged between 81 – 203 CE, approximately 200 years earlier than the results obtained in the last century from the rear chamber samples.(Huo, X.C., 2006)The rear chamber samples dated between 254 – 419 CE, aligning closely with previous testing results. Figure 13 illustrates the sample collection points, and further in-depth sampling and testing are planned to explore the cave’s evolutionary process.

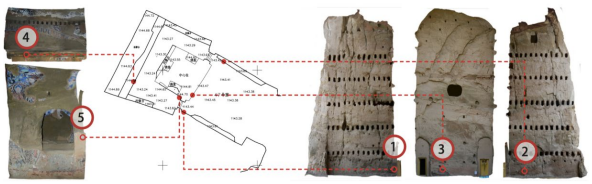

Figure 13: Experimental Carbon-14 Sampling Points at Cave 47, February 2023 (Image Source: Author’s Illustration, Base Map Courtesy of Kizil Cave Research Institute)

Sample Number	Material	Radiocarbon Age (BP)	Calibrated Calendar Age	
			1σ (68.3%)	2σ (95.4%)
1	Grass straw	670±20	1286AD (38.4%) 1303AD 1367AD (29.9%) 1380AD	1280AD (52.7%) 1316AD 1360AD (42.8%) 1388AD
2	Grass straw	1910±20	81AD (15.4%) 98AD 110AD (42.6%) 166AD 186AD (10.3%) 202AD	70AD (95.4%) 208AD
3	Grass straw	1895±25	122AD (68.3%) 203AD	76AD (95.4%) 218AD
4	Grass straw	1735±20	254AD (29.8%) 286AD 324AD (38.5%) 362AD	248AD (36.5%) 296AD 308AD (58.9%) 402AD
5	Grass straw	1670±20	375AD (68.3%) 419AD	262AD (6.1%) 276AD 346AD (89.4%) 425AD

Table 2: Report on Carbon-14 Testing Results at Cave 47, May 2023 (Source: Peking University Laboratory of Scientific Archaeology)

4.2.3 Mural Studies at Cave 47

A crucial aspect of the digital reconstruction project involves restoring the original appearance and colors of the murals. The study integrates:

- Multispectral and hyperspectral imaging
- Inorganic mineral pigment analysis
- Organic dye and binder analysis
- Mural production techniques and artistic studies

This comprehensive approach provides a scientific basis for the accurate color restoration of the murals in the complete digital reconstruction of Cave 47.

4.3 Technical Framework for Digital Restoration Research

With the application of digital technologies, it has become more convenient to reconstruct the different forms of caves across various historical periods. In the field, the architectural restoration research of the Yuanmingyuan Ruins adopted a multi-phase digital reconstruction approach, which led to substantial research outcomes and enabled more effective exhibition results.(Guo, D.H., He, Y., 2012)

Cave 47 bears rich traces of historical transformation; therefore, a restoration research model has been constructed to represent the cave’s major developmental stages — including its architecture, sculptures, and murals.(He, E.Z., Wei, Z.Z., 2017)This model aims to establish a comprehensive digital restoration resource library, which includes a repository of restoration documentation, technical drawings, and 3D models.The digital restoration research is divided into two main phases: research and analysis, and digital reconstruction and visualization, encompassing a total of four key steps.

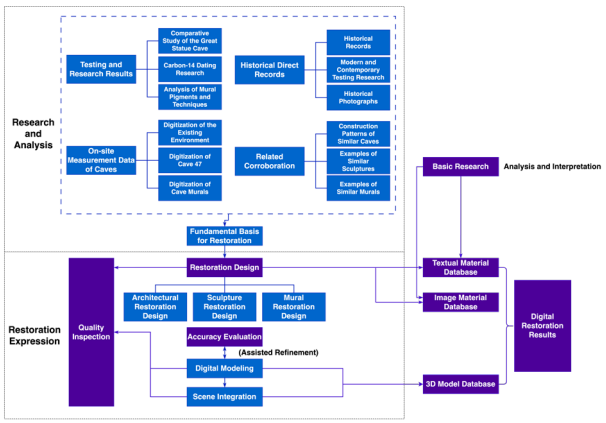

Figure 14. Workflow Diagram of Digital Restoration (Image source: Drawn by the author)

4.3.1 Phase One: Research and Analysis.

This phase focuses on diagnostic studies, on-site data measurement of the cave temple, collection of historical records, and investigation and compilation of supporting materials. Only on the solid foundation of thorough research and analysis can the reconstruction phase proceed.

Restoration and Visualization includes detailed restoration design (architecture, sculpture, and murals), precise digital modeling, and scene integration that reflects the accurate spatial relationships. The entire restoration process is accompanied by quality control, and all results undergo accuracy evaluation and documentation.

The final outputs of the reconstruction are compiled into a comprehensive database containing various types of data, including textual documentation, images, and 3D models.

The core of the research and analysis phase lies in organizing and interpreting the preliminary data according to the developmental stages of Cave 47. Comparative studies of large image caves in the Kucha region, along with findings from pigment and mural technique analyses, must be chronologically categorized based on the cave’s various historical phases. Direct historical records and other corroborating evidence should also be systematically examined to assess their accuracy, thus providing a reliable foundation for subsequent restoration design and precision evaluation.

4.3.2 Phase Two: Restoration Design Phase.

This phase focuses on the restoration of architectural elements, sculptures, and murals. The technical workflow includes:

① Restoration Design (covering architecture, sculptures, and murals);

② Model Creation;

③ Scene Integration and Accuracy Evaluation.

① Restoration Design:

Based on comprehensive collection and interpretation of prior materials, digital restoration design of Cave 47 is carried out. For each historical period, a set of restoration drawings is produced, forming the basis for subsequent model building and scene integration. At every stage of the process, accuracy assessments are conducted and documented.

② Model Production

a. Architectural Restoration Model Production: Based on the restoration design drawings of the cave, the architectural space is reconstructed through 3D modeling. Key construction details —such as the floor structure inside the cave—are meticulously recreated in accordance with relevant research findings. Texture maps required for the restoration model are created based on research results and integrated with the restored murals to produce a 3D reconstruction of the cave's architectural space.

b. Sculpture Restoration Model Production: Traditional techniques assist in the modeling process. For significant and representative sculptures, three levels of models are produced: a rough model, a refined model, and a high-resolution, colored model. Structural components inside the sculptures—such as wooden fixtures and the wooden armature used for support—are also modeled as schematic representations, providing a reference for future film or animation production.

c. Mural Restoration Model Production: Based on the restoration design drawings, murals are recreated with the assistance of fine arts professionals through hand-drawing techniques. Traditional artistic styles and painting methods are applied to ensure detailed and accurate mural restoration. Restored murals from various historical periods are then integrated with architectural models from the corresponding periods to produce complete models representing different stages in the cave’s development.

③ Scene Integration and Accuracy Evaluation:

Scene integration involves unifying all model components within a consistent coordinate system and aligning them precisely, with texture materials merged and harmonized. Based on subsequent research findings, complete models representing

each key historical phase are constructed. These models include comprehensive data on the cave's spatial structure, sculptures, and murals.

Since digital restoration cannot achieve a perfectly accurate historical reconstruction, the accuracy of restoration depends on the reliability of the underlying evidence. Therefore, throughout the entire restoration process, all results are assessed for their level of accuracy. Each model is rated according to a defined evaluation system. If future research provides updated information, the evaluation content will be iteratively revised using the established accuracy assessment framework, enabling long-term, sustainable development of restoration research.

Table of the Accuracy Evaluation System for Restoration Results

Accuracy	Restoration Reliability Assessment			Foundational Reference Materials			
	Architectural Space	Sculpture	Cave Murals	Diagnostic Research Results	On-site Survey Data	Direct Historical Records	Supporting Evidence
100%	Fully understood	Fully understood	Fully understood	Diagnostic results are rich and comprehensive; site remains are well-preserved; measured data aligns with direct historical records and mutually corroborates			
90%	Accurately understood	Accurately understood	Accurately understood	Diagnostic results are abundant; some remains are relatively complete; primary data is clear and detailed, consistent with historical records and supporting materials			
75%	Accurately understood	Basically understood	Basically understood	Primary data is clear and detailed, and aligns with historical records			
50%	Determinable	Hypothetical	Hypothetical	Moderate amount	Limited	Moderate amount	Present
15%	Hypothetical	Hypothetical	Hypothetical	Very little	None	Very little	Very little

Table 3. Accuracy Evaluation System for Restoration Results

4.4 Digital Exhibition Concept

The results of digital research are transformed into content that can be more conveniently applied to digital exhibition. Based on the restoration outcomes of Cave 47, and considering the varying distances between the audience and the actual heritage site, three exhibition approaches are envisioned: Augmented Reality (AR), Virtual Reality (VR), and Immersive Experience, enabling on-site digital display inside the cave, off-site exhibition near the cave, and remote exhibition far from the heritage location.

4.4.1 Augmented Reality Exhibition: While touring inside the cave, visitors can use AR to experience the alignment of the physical cave with the virtual restoration in the same dimension, angle, and visual perspective. By wearing AR glasses or similar display devices, the restoration content can be superimposed in real time over the physical environment, allowing for enriched presentation through interactive features.

4.4.2 Virtual Reality Exhibition: Within the Kizil-Kucha Caves Museum or other indoor environments, visitors can explore a fully immersive virtual environment. Whether through guided tours at specific points or interactive exploration, users can experience the grand spatial scale of the Mahāvīra Hall. VR headsets allow for historical immersion into the reconstructed cave environments.

4.4.3 Immersive Experience Exhibition: Designed for outdoor open-air spaces, immersive experiences stimulate all five senses to evoke emotional resonance. These exhibitions can serve as part of nighttime tours or special events, offering a full-scale, impactful presentation of the restored Cave 47 in its historical grandeur.

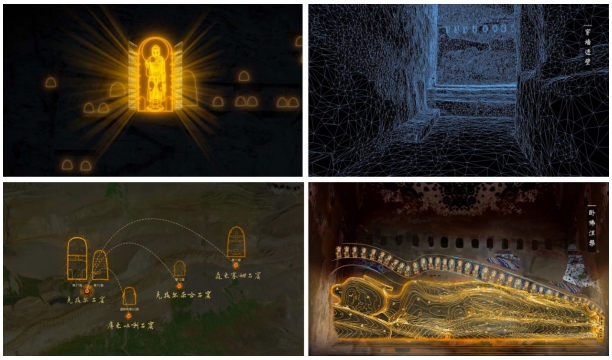

Figure 15 Nighttime Immersive Experience Rendering (Image Source: Author’s Rendering)

5. Digital Enhancement of the Kizil-Kucha Caves Museum

The digital enhancement of the Kizil-Kucha Caves Museum aims to establish it as the primary gateway for visitors exploring the Kizil Caves. It is designed to serve as both a historical exhibition space for tourists and an educational center for students and researchers focused on the art of Kucha murals. The goal is to integrate experiences of culture, art, and emotion, enabling visitors to embark on a magical journey through Kucha ’ s history — experiencing its aesthetics, learning about its artistic heritage, and gaining insight into the conservation and restoration of cultural relics.

In terms of exhibition content, emphasis is placed on accuracy, in-depth exploration of Silk Road heritage, and the visual appeal of Kucha art. The exhibition adopts contemporary formats that align with modern visitor habits, making effective use of immersive digital technologies. Modular designs, integrated smart equipment, and prefabricated installations allow rich experiences within compact spaces. Exhibition methods include time-and-space immersive transitions, virtual cave tours, interactive learning programs for young visitors, and artistic presentation of exhibits.

Entrance Hall: Incorporates keywords and historical texts associated with the Kizil Caves and Kucha art into the design elements, guiding visitors into the exhibition area. This creates a "Cultural Corridor of Kucha" with a strong atmospheric presence, setting an emotional foundation for experiencing Kucha culture.

Unit 1: The Silk Road – Origins: Introduces the geographic setting of Kucha and how the Silk Road facilitated the spread of Buddhism, leading to the creation of cave temples. This section explains the relationship between monasteries and caves, and introduces the main components of Kizil cave art, including architectural forms, sculptures, and murals, helping visitors grasp the historical background.

Unit 2: Digital Immersion in Kucha Murals: Showcases exquisite Kucha murals through digital reinterpretation. Visitors are immersed in the vibrant world of mural art, breaking through the limitations of traditional immovable heritage exhibitions. VR simulations offer interactive cave exploration experiences, enhancing engagement and immersion.

Unit 3: Treasures of the Caves: Features a central exhibit platform displaying unearthed relics related to the Kizil Caves, including sculptures, Kucha folk art, and religious objects. These artifacts reflect the diversity of life along the Silk Road

and highlight the cultural exchange and integration seen through the lens of the Kizil Caves.

Unit 4: Cave Conservation and Restoration: Presents the work of generations of restorers who have preserved Kizil murals, along with information on the overseas dispersal of Kucha art. This area fosters a sense of responsibility in visitors for the protection of cultural heritage. It also serves as an experiential learning zone for tourists and students, featuring displays on mural reproduction techniques, high-quality reproductions, and informative panels on conservation efforts.

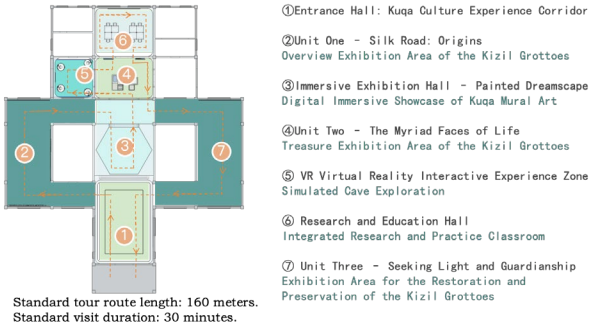

Figure 16 Spatial Circulation and Exhibition Content Design of the Kucha Caves Museum (Image Source: Illustrated by Zhou Shenghui)

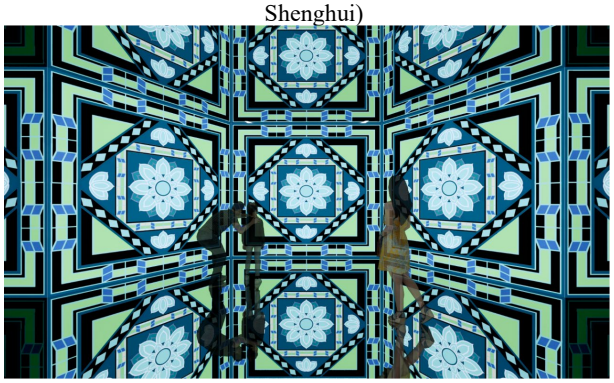

Figure 17 Exhibition Rendering of the Immersive Experience Hall (Image Source: Illustrated by Sang Erhao)

6. Conclusion

As the planning for the protection and transmission of the Kizil Caves and the research into their digital presentation deepen, our understanding of this ancient artistic treasure has significantly grown. We extend our heartfelt thanks to all individuals and institutions who have supported and contributed to this project.

We first express our highest respect to the colleagues at the Kizil Caves Research Institute for their expert guidance and invaluable advice throughout the planning, implementation, and research phases. Their passion and professionalism in cultural heritage preservation laid a solid foundation for the project’s success. Our gratitude also goes to the government of Kuqa City and the local residents for their tremendous support, which helped us better integrate into the local culture and facilitated on-site work.

Special thanks go to the surveying and mapping team, whose outstanding skills and dedication ensured high-precision and efficient digital work, providing essential technical support for the conservation and transmission of the caves. We are also grateful to Professor Cui Jianfeng and Professor Wu Xiaohong from the School of Archaeology and Museology at Peking University, whose academic insights and resources significantly enriched the depth and breadth of this project.

Finally, we extend our sincere appreciation to all colleagues and researchers involved in this work. Without their dedication and selfless contributions, the fruitful outcomes of this study would not have been possible.

Looking ahead, we aspire to make continued contributions to the field of digital heritage, advancing the preservation, research, and public understanding of cultural treasures such as the Kizil Caves.

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