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Research on Ancient Architecture at the Eastern Qing Tombs Based on the Theory of Full Life Cycle

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Abstract: As the largest and most complete surviving Qing dynasty imperial mausoleum complex in China, the Eastern Qing Tombs constitute a vital component of the World Cultural Heritage. This study examines the ancient architecture of the Eastern Qing Tombs, applying the full life cycle theory to divide its evolution—from planning and construction to contemporary conservation and utilization—into five distinct phases: origin, development, maturity, decline, and renewal. By examining the material characteristics and value evolution of ancient structures across each phase, this study constructs a full life cycle model using digital technology and explores its application pathways in heritage conservation, academic research, and cultural dissemination. Findings indicate that the full life cycle model enables systematic integration and dynamic management of Qing Eastern Tombs' architectural information, providing theoretical support and practical reference for the sustainable development of Ming and Qing imperial mausoleum cultural heritage.

Keywords: Full Life Cycle; Eastern Qing Tombs; Ancient Architectural Model; Cultural Heritage Conservation; Digital Modeling.

1. Introduction

Located in Zunhua City, Hebei Province, the Eastern Qing Tombs represent the pinnacle of ancient Chinese mausoleum architecture. Their architectural regulations, feng shui principles, and artistic value embody the political, religious, and aesthetic ideals of the Qing Dynasty's zenith, possessing historical, artistic, and scientific significance [1]. (As shown in Figure 1)

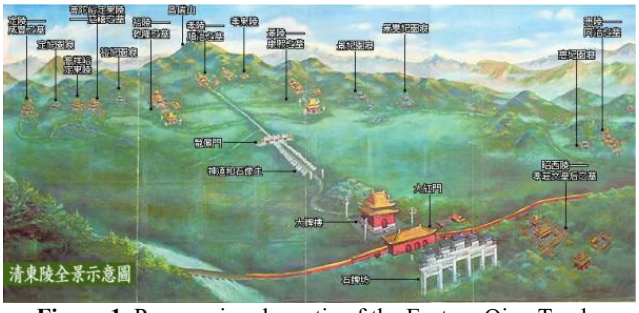


Figure 1. Panoramic schematic of the Eastern Qing Tombs

As a vital component of Ming and Qing imperial burial complexes, the Eastern Qing Tombs were inscribed on the World Heritage List in 2000, making their preservation and study of significant international importance. However, after centuries of weathering, these precious ancient structures face multiple threats including structural aging, material deterioration, and information loss. While traditional "emergency restoration" and "preventive conservation" approaches remain effective, they often lack comprehensive management of architectural information throughout the entire process.

Originating in engineering management, the Life-Cycle Theory emphasizes comprehensive tracking and systematic control of an object throughout its entire existence—from creation and development to eventual decommissioning. Applying this theory to the study of the Eastern Qing Tombs' ancient structures by constructing a life-cycle model not only enables comprehensive preservation and visualization of architectural information but also provides scientific foundations for preventive conservation, restoration decisions, and adaptive reuse. This approach holds significant theoretical innovation and practical guidance value for advancing the refined, scientific conservation of imperial mausoleum heritage.

International academia has applied the full life cycle theory to cultural heritage conservation earlier. For instance, Italy's "Full Cycle Monitoring and Restoration" research on ancient Roman architecture integrates historical transformation data through digital models. France's "Life Cycle Information Management System" established for the Palace of Versailles enables full traceability of conservation projects [2] . Domestic research has primarily focused on digital modeling of individual ancient structures, while systematic studies based on the full life cycle remain in their infancy. Research on the Eastern Qing Tombs has largely emphasized historical verification or single-structure restoration, lacking integrated analysis of the "entire process" of architectural preservation.

International academia has earlier applied the full life cycle concept to cultural heritage conservation. For instance, Italy implemented a "full-cycle monitoring and restoration" system for ancient Roman architecture, integrating historical transformation data through digital models to achieve sustainable conservation management [2]. France established the BIM-based "Life cycle Information Management System" (HBIM) for the Palace of Versailles, enabling comprehensive information traceability and project management throughout conservation works [3]. In recent years, driven by the emergence of IoT, AI, and Digital Twin technologies, the full life cycle management of cultural heritage is advancing toward intelligent and predictive approaches [4] .

Domestic research has made significant strides in the digital documentation and preservation of ancient architecture. Extensive studies focus on utilizing technologies such as 3D laser scanning and oblique photogrammetry for

high-precision information collection and modeling of individual buildings or architectural complexes [5]. BIM and its heritage-specific variant, HBIM technology, also provide new methodological support for ancient architectural information management [6]. However, overall, systematic, cross-stage research based on the full life cycle remains in its exploratory phase. Existing academic achievements concerning the Eastern Qing Tombs predominantly emphasize historical evolution verification, artistic feature analysis, or discussions on salvage restoration techniques for specific structures. There is a lack of an integrated "full-process" analytical framework that combines historical construction information, records of dynastic changes, current preservation status, and future monitoring and early warning systems. This study aims to fill this gap by constructing a dynamic life cycle management model applicable to the Eastern Qing Tombs and similar large-scale heritage sites.

2. Application of Full Life Cycle Theory to the Phases of Ancient Architecture at the Eastern Qing Tombs

The application of the full life cycle theory requires a clear deconstruction of the historical context of the research subject. By integrating the construction history, damage history, and conservation history of the Eastern Qing Tombs, their full life cycle can be divided into five distinct phases (Figure 2).

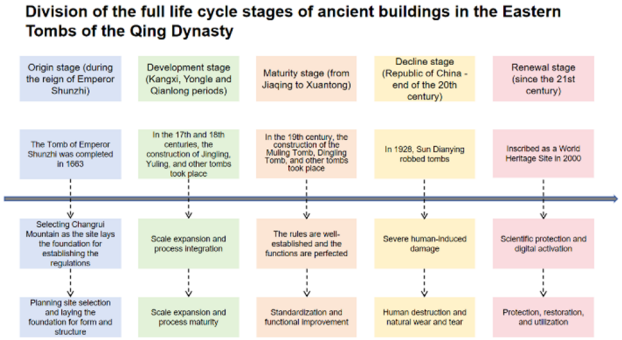


Figure 2. Schematic of the Life Cycle Stages of the Eastern Qing Tombs

2.1. Origin Phase: Planning, Site Selection, and Foundational Design (Shunzhi Era)

This phase marks the inception of the Eastern Qing Tombs' life cycle, centered on Emperor Shunzhi's selection of Changrui Mountain as the eternal auspicious site. The site selection process profoundly embodied ancient Chinese feng shui theory, pursuing the perfect integration of "dragon, cave, sand, water, and orientation" to achieve the ideal state of "unity between heaven and humanity" [7] . Guided by institutional codes such as the Da Qing Huidian, the overall layout, central axis relationships, and fundamental architectural standards for core structures were established.

Construction materials during this period primarily sourced local stone and premium timber from the Beijing metropolitan area, with craftsmanship largely inheriting Ming imperial architectural traditions. As the inaugural imperial mausoleum, Emperor Shunzhi's Xiaoling Tomb stands as direct testament to the planning philosophy and construction standards of this era through its monumental spirit way, exquisite stone figurines, and majestic Dragon-Phoenix Gate, laying the formal foundation for subsequent imperial tombs. (as shown in Figure 3)



Figure 3. Spirit Way and Stone Statues at Xiaoling Mausoleum, Eastern Qing Tombs

2.2. Development Phase: Expansion in Scale and Maturity in Craftsmanship (Kangxi, Yongzheng Periods)

The reigns of Kangxi, Yongzheng, and Qianlong marked the zenith of the Qing Dynasty and a period of rapid expansion for the Eastern Qing Tombs. The successive construction of Emperor Kangxi's Jingling and Emperor Qianlong's Yuling transformed the tomb complex from its initial "one tomb, one mausoleum" layout into a grand "cluster of multiple tombs." Architectural techniques reached new heights of sophistication during this period, incorporating diverse cultural elements. Examples include the Buddhist-themed stone carvings in the underground palace of Qianlong's Yuling and the "Stele Pavilion Commemorating Sacred Virtues and Divine Achievements" at Kangxi's Jingling (as shown in Figure 4). These works blended Tibetan Buddhist art with traditional Han Chinese carving techniques, showcasing the inclusiveness and creativity of Qing court art.

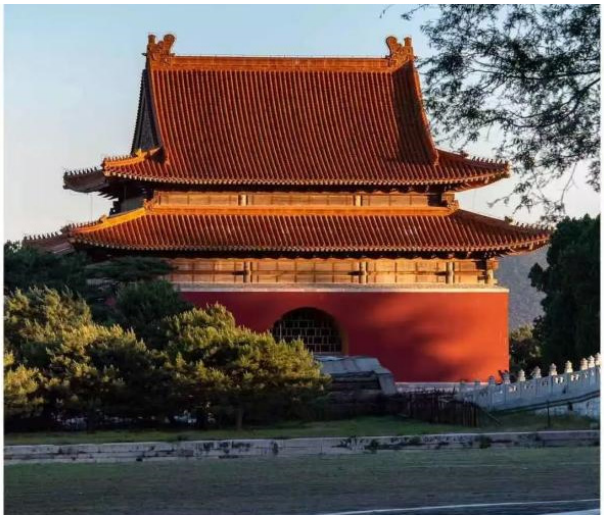


Figure 4. Stele Pavilion of Sacred Virtues and Divine Achievements

Material selection became more refined, extensively utilizing premium building materials such as Yunnan marble and pine wood from the deep forests of Northeast China. The level, complexity, and artistic quality of architectural

decoration significantly improved, marking the pinnacle of construction techniques at the Eastern Qing Tombs.

2.3. Maturity Phase: Standardization and Functional Refinement (Jiaqing to Xuantong Periods)

From the Jiaqing reign until the Qing dynasty's demise, the construction of the Eastern Qing Tombs entered a period of standardized regulation and consolidation. Tombs such as Emperor Daoguang's Muling, Emperor Xianfeng's Dingling, and Emperor Tongzhi's Huiling underwent minor adjustments in detail but strictly adhered to the layout principles of the "Zhaomu System," with architectural forms and spatial arrangements becoming increasingly standardized (as shown in Figure 5).

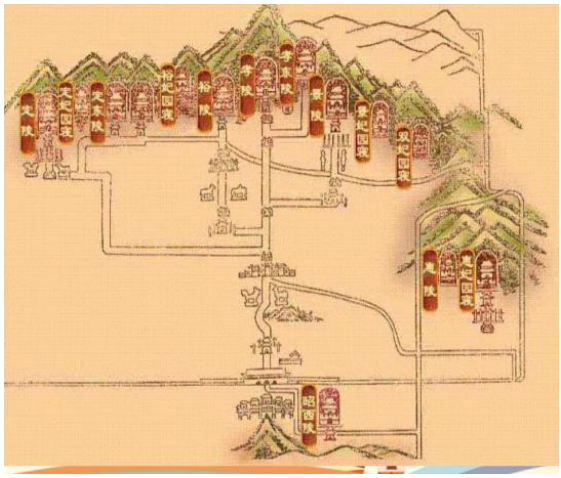


Figure 5. Schematic Diagram of the Zhaomu System in the Eastern Qing Tombs

Construction efforts during this phase focused on refining and optimizing tomb functions. Common enhancements included adding auxiliary structures like stele pavilions along the spirit path, sacrificial kitchens, and animal inspection pavilions, alongside improvements to drainage systems and security measures against fire and theft. Concurrently, influenced by the Qing Empire's declining national strength in its final years, some tombs saw simplified building materials and construction techniques. Nevertheless, overall efforts remained dedicated to preserving the regulatory integrity and solemn grandeur befitting imperial tombs.

2.4. Decline Phase: Human Destruction and Natural Deterioration (Republican Era to Late 20th Century)

The Republican era was a period of social upheaval, during which the Eastern Qing Tombs suffered severe, predominantly human-induced destruction. The most heartbreaking incident occurred in 1928 when warlord Sun Dianying's troops carried out a vicious plundering of the Qianlong Emperor's Yuling Mausoleum and Empress Dowager Cixi's Dingdongling Mausoleum. This resulted in the underground chambers being blown open, vast quantities of precious artifacts being looted, and severe damage to the architectural structures (as shown in Figure 6).

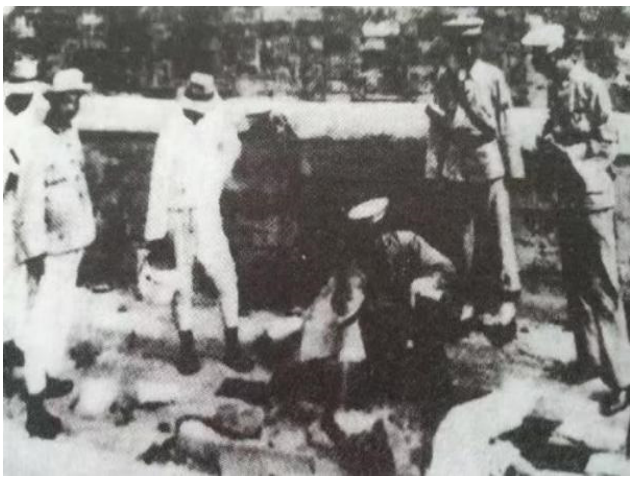


Figure 6. Scene at the Eastern Qing Tombs after the looting

Thereafter, until the founding of the People's Republic of China, management of the mausoleum complex remained lax, with theft and looting occurring intermittently. This exacerbated the loss of architectural components and accelerated natural deterioration. After the founding of the People's Republic of China, although the state began prioritizing cultural heritage preservation and initiated preliminary surveys and conservation efforts, many structures continued to deteriorate due to long-term exposure to natural elements like weathering, flooding, and biological damage. This was compounded by chronic under funding and a lack of advanced technical support. Consequently, vast amounts of historical information regarding original craftsmanship and repairs across dynasties were lost or incompletely documented, creating an "information gap."

2.5. Renewal Phase: Conservation, Restoration, and Revitalization (21st Century Onward)

With the widespread dissemination of international heritage conservation concepts and the enhancement of China's comprehensive national strength, the Eastern Qing Tombs entered a renewal phase centered on "scientific conservation, systematic restoration, and rational utilization." Conservation efforts during this period became increasingly systematic and technologically advanced: on one hand, a series of emergency reinforcement projects were undertaken; on the other, digital technologies were extensively employed for archival development, such as conducting 3D laser scanning of underground palaces and above-ground structures to create high-precision digital models. Simultaneously, active exploration of revitalization pathways unfolded, including the development of online virtual tour systems, the use of AR/VR technology to enhance visitor experiences, and the organization of thematic research and study activities. The goal of this phase was to achieve a strategic shift in ancient architecture conservation from "emergency preservation" to "preventive conservation" and "revitalization utilization," aiming to imbue this ancient heritage with new vitality and contemporary value.

3. Pathway for Constructing the Full Life cycle Model of Ancient Architectural Complexes at the Eastern Qing Tombs

A logical closed-loop process encompassing data collection, information processing, model construction, and application expansion, with the technical approach illustrated in Figure 7.

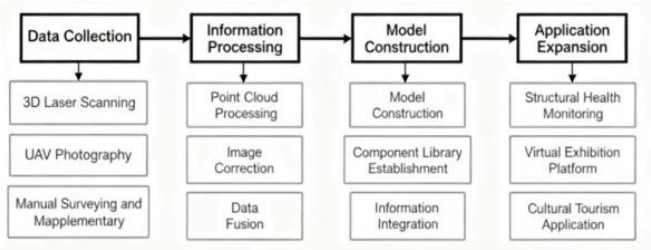


Figure 7. Technical Road map for Constructing the Qing Eastern Tombs Full Life cycle Model

3.1. Date Collection: Integration of Information Across All Phases

Historical Documentation Data: Compile archives such as the Qing Palace Engineering Regulations and Official Records to extract information on mausoleum construction timelines, material specifications, and craftsmanship processes; integrate looting records and restoration reports since the Republican era to form a "Historical Information Database."

Current Survey Data: Employ ground-based 3D laser scanning to obtain high-precision point cloud data of ancient structures (walls, roofs, components); utilize drone aerial photography to capture spatial layout data of the mausoleum complex; supplement details through manual surveying to form a "Current Geometric Database."

Monitoring and Sensing Data: Deploy sensors for temperature, humidity, crack displacement, and other parameters in key structures. Collect real-time environmental and structural change data to form a "dynamic monitoring database."

3.2. Model Construction: Multi-dimensional Hierarchical Design

Geometric Model: Based on 3D scanning data, construct a solid geometric model of the ancient architecture, precisely restoring the building's dimensions, form, and component connections, covering all structural details from foundation to roof.

Information Model: Historical documentation and current survey data are linked to the geometric model. Each component is assigned a "lifecycle tag" documenting its construction date, materials, and restoration history, achieving a "one-component-one-file" system.

Analysis Model: Integrates structural mechanics and materials science tools to build structural safety assessment models (simulating seismic and weathering impacts) and restoration decision models (proposing solutions based on historical techniques and modern technologies).

3.3. Model Optimization: Dynamic Updates and Iteration

Establish a "periodic updates + real-time adjustments" model optimization mechanism: Re-survey and update current data every 3-5 years; adjust structural safety assessment models in real time based on sensor monitoring data; supplement model content with newly discovered historical documents to ensure the model consistently reflects the actual state of ancient structures (as shown in Figure 8).

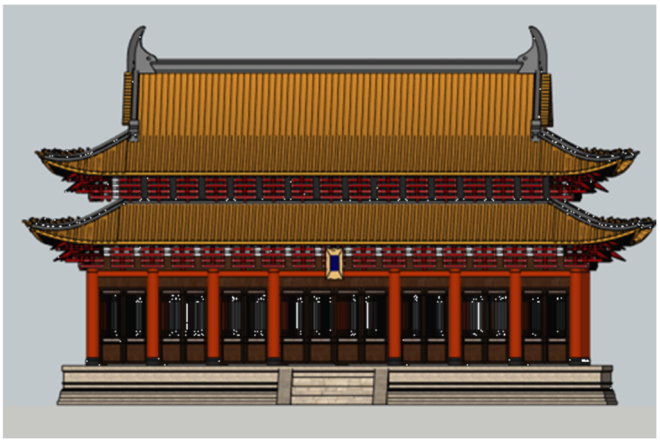


Figure 8. The model consistently reflects the actual state of ancient structures

4. Application Value of the Qing Eastern Tombs Ancient Architecture Life Cycle Model

4.1. Heritage Conservation: Transitioning from "Reactive Restoration" to "Proactive Prevention"

Preventive Conservation: Utilize structural safety assessment models to proactively identify potential risks in buildings, formulate targeted protective measures, and minimize irreversible damage [8]. For example, based on the model's prediction of weathering for the stone animal sculptures along the Sacred Way of Xiaoling, stone sealing treatments were implemented in advance.

Restoration Plan Optimization: Models simulate the effects of different restoration approaches. Combined with historical craftsmanship data from the "lifecycle tags," this ensures the authenticity and scientific rigor of restoration solutions. For instance, during the restoration of the dougong brackets at Long'en Hall of Yuling Mausoleum, the model provided craftsmen with precise component dimensions and mortise-and-tenon connection methods.

4.2. Academic Research: From "Fragmented" to "Systematic"

Architectural History Research: The model integrates information across all construction phases, providing a visual analytical tool for studying the evolution of Ming and Qing imperial mausoleum designs. This enables direct comparison of layout and structural component variations across different eras.

Craftsmanship Research: Through the deconstruction and analysis of architectural components via models, traditional craftsmanship details are reconstructed, providing data support for the preservation of traditional building techniques.

5. Conclusion

This paper systematically introduces the full life cycle

theory into the study of the ancient architecture of the Eastern Qing Tombs, constructing a comprehensive management framework covering planning and construction, historical evolution, current preservation, and future monitoring and early warning. By integrating historical documents, multi-source current surveying data, and real-time monitoring data, and relying on digital modeling technology (particularly HBIM), a full life cycle model of the ancient architecture of the Eastern Qing Tombs has been established, integrating geometric, informational, and analytical functions. This model provides robust technical support and decision-making tools for advancing the Eastern Qing Tombs from traditional "emergency, reactive conservation" to modern "preventive, scientific, and interactive conservation and utilization."

As an outstanding representative of China's ancient architectural complexes, the full-lifecycle conservation research of the Eastern Qing Tombs holds significant importance not only for the site itself but also offers a reference model for the preservation of similar cultural heritage. Future research should place greater emphasis on interdisciplinary integration, applying knowledge and methodologies from fields such as architecture, materials science, environmental science, and information technology to ancient building conservation. This will facilitate the development of a more comprehensive theoretical system and technical framework, contributing to the sustainable transmission of cultural heritage.

Acknowledgments

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