

Repair and Conservation Strategies for Cultural Heritage Sites on Mount Tai through the Integration of Modern Technology and Traditional Craftsmanship

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Abstract: Cultural heritage conservation benefits the present and generations to come. As a World Natural and Cultural Heritage Site, Mount Tai possesses a large number and wide variety of cultural heritage resources, carrying the millennia-old spiritual and cultural memory of the Chinese nation. Faced with the multiple challenges of natural weathering, tourism pressure, and the erosion of time, the repair and conservation of cultural heritage on Mount Tai still confronts many practical difficulties, and much remains to be done to advance this work. Taking the immovable cultural heritage sites, which account for the largest proportion of Mount Tai's cultural heritage resources, as the research subject, this paper explores repair and conservation strategies that integrate modern technology with traditional craftsmanship on the basis of hierarchical protection, with the aim of providing a reference for the scientific repair and preventive conservation of cultural heritage on Mount Tai in the new era.

Keywords: cultural heritage of Mount Tai; repair and conservation; modern technology; traditional craftsmanship; integration strategies

1. Introduction

Since ancient times, Mount Tai has been regarded as the “most revered of the Five Great Mountains.” Since the Pre-Qin period, it has been a sacred site where emperors conducted Fengshan ceremonies and sacrificial rites, as well as a culturally renowned mountain where Confucianism, Buddhism, and Taoism converged. In 1987, Mount Tai was inscribed on the UNESCO World Heritage List, becoming the world's first World Natural and Cultural Heritage Site. After thousands of years of accumulation, a large number of valuable cultural heritage resources have emerged in the Mount Tai region, most of which exist in the form of immovable cultural heritage sites. According to data from the Third National Cultural Relics Survey, there are more than 2,400 immovable cultural heritage sites in the Mount Tai region, covering multiple categories, including ancient buildings, grottoes, temples and stone inscriptions, ancient ruins, and ancient tombs. Cultural heritage sites such as Dai Temple, Bixia Temple, the Diamond Sutra at Jing Shiyu, and the Tang Cliff Inscription of the Ji Tai Shan Ming possess outstanding universal value.

The immovable cultural heritage sites on Mount Tai are widely distributed across complex mountainous terrain, with substantial differences in elevation, highly variable environmental conditions, and a high tourist carrying capacity, posing severe challenges to conservation efforts. For a long time, the conservation of cultural heritage on Mount Tai has primarily adopted hierarchical management based on administrative levels, while repair work has largely relied on the experiential judgment and manual skills of traditional craftsmen, with modern technologies still at the stage of comprehensive introduction. However, with the advancement of cultural heritage conservation concepts and scientific and technological progress, reliance solely on experiential judgment and traditional craftsmanship can no longer fully meet the requirements of precise diagnosis, preventive conservation, and long-term monitoring. How to effectively integrate modern technology with traditional craftsmanship while respecting the characteristics and historical authenticity of cultural heritage, thereby achieving complementary advantages, has become a key issue in the current repair and conservation of cultural heritage on Mount Tai.

2. Scientific Classification of Immovable Cultural Heritage Sites on Mount Tai

According to the criteria recognized by UNESCO, Mount Tai meets 7 of the 10 World Heritage assessment criteria, demonstrating extremely high natural and cultural value, including historical and cultural value, scientific research value, artistic value, and social value. Based on comprehensive analysis and evaluation, these sites are classified into three levels of protection:

2.1 Level I Protected Cultural Heritage Sites

Level I protected cultural heritage sites refer to immovable cultural heritage sites that possess outstanding universal value, occupy a core position in the World Heritage value system of Mount Tai, and exert influence throughout China and even internationally. They mainly include iconic cultural heritage sites of Mount Tai, such as Bixia Temple, the Tang Cliff Inscription, the Diamond Sutra at Jing Shiyu, and the Qin Cliff Inscription of Mount Tai; as well as cultural heritage sites that have been designated as National Key Cultural Heritage Sites under Protection and possess particularly outstanding value.

2.2 Level II Protected Cultural Heritage Sites

Level II protected cultural heritage sites refer to immovable cultural heritage sites that possess important historical and cultural value, occupy an important position in the regional cultural system, and play a key role in the study of local history and culture. They mainly include provincial-level cultural heritage sites under protection and some municipal-level cultural heritage sites under protection with relatively high value; important node buildings and groups of stone inscriptions along the main Mount Tai climbing route; and ancient ruins, ancient tombs, and other sites with relatively high historical and cultural value.

2.3 Level III Protected Cultural Heritage Sites

Level III protected cultural heritage sites refer to general immovable cultural heritage sites that possess certain historical and cultural value and constitute part of the cultural heritage system of Mount Tai. They mainly include municipal- and county-level cultural heritage sites under protection and unclassified immovable cultural heritage sites; ordinary stone inscriptions, small temples, ancient bridges, ancient road ruins, and other sites scattered throughout the mountains; as well as cultural heritage remains that possess certain value but are in relatively poor condition.

3. Application Scenarios and Integration Logic of Modern Technology and Traditional Craftsmanship

3.1 Applications and Advantages of Modern Technology in the Conservation of Cultural Heritage on Mount Tai

The application of modern technologies, such as modern surveying and mapping, environmental monitoring, scientific monitoring, and construction assistance, can effectively enhance the intelligent and refined level of repair and conservation of immovable cultural heritage sites on Mount Tai, providing technical support for the full life-cycle conservation of cultural heritage.

First, in terms of digital archiving, the Tai'an Surveying and Mapping Geographic Information Center has currently adopted 3D scanning equipment to conduct millimeter-level, non-contact data collection of representative stone inscriptions such as "Boundless Scenery in the Wind and Moon" and "High Mountains and Flowing Water," providing samples for the subsequent systematic digital archiving of groups of stone inscriptions. During the ongoing Fourth National Cultural Heritage Survey, drones, RTK surveying equipment, and handheld data collection systems are being used in combination to conduct high-precision surveying and aerial photography of archways, bridge and culvert structures, and pass ruins along ancient mountain-climbing routes. This has addressed the problems of poor accessibility to cultural heritage sites in mountainous areas and low efficiency of repeated verification in manual surveying, and has led to the discovery of a considerable number of new cultural heritage sites.

Second, in terms of BIM and digital management, third-party professional companies have taken Dai Temple's Hall of Heavenly Blessing as the core and the First Palace of Mount Tai as a key site, conducting three-dimensional surveying and mapping through 3D laser scanning and drone aerial surveying, establishing digital models, and developing a BIM cloud platform for real-time monitoring and early warning of ancient buildings, thereby promptly identifying and addressing potential safety hazards. The digitalization project for the murals in the Hall of Heavenly Blessing at Dai Temple has been completed, and an AR intelligent tour guide system has been launched, promoting the extension of cultural heritage from static preservation to digital presentation. This initiative will subsequently be extended to more areas.

Third, in terms of preventive conservation monitoring, the preventive conservation monitoring project for the Hall of Heavenly Blessing at Dai Temple is being comprehensively implemented, with systematic monitoring of environmental factors affecting mural safety, including temperature and humidity, carbon dioxide concentration, ultraviolet radiation, illumination, and visitor flow, and an all-weather monitoring and early-warning system is being established. In the next step, temperature and humidity sensors and illumination sensors will be gradually deployed inside more ancient buildings and around stone inscriptions in the Mount Tai Scenic Area to collect and monitor microenvironmental data in real time, with

comprehensive assessments conducted on a regular basis. In addition, modern technologies such as BeiDou positioning, stress-wave/infrared thermal imaging, ultrasonic testing, and VR/AR construction assistance can also be explored to comprehensively improve conservation effectiveness.

3.2 Techniques and Value of Traditional Craftsmanship in the Repair of Cultural Heritage on Mount Tai

The essence of cultural heritage conservation is an undertaking that combines both technical and humanistic attributes. Traditional craftsmanship is the foundation for ensuring the historical authenticity and cultural vitality of the cultural heritage of Mount Tai and possesses important value that cannot be replaced by modern technology.

First, in terms of material compatibility, traditional materials such as nanmu wood, pine wood, tung oil, glutinous rice paste, and gray bricks with black glazed tiles have been tested through centuries of practice and are compatible with the physical and chemical properties and aging patterns of the original materials of cultural heritage on Mount Tai, and can therefore be confidently adopted. In the repair of the timber structures at Dai Temple, locally sourced wood of the same species is used, and traditional techniques such as splicing and encasing are employed to repair components, which can effectively avoid structural stress caused by differences in the shrinkage rates and strength of new and old materials, thereby improving the overall repair effect. For the restoration of stone inscriptions, stone powder with a composition similar to that of the original stone is mixed with natural binding materials for filling, effectively ensuring consistency in weathering behavior.

Second, at the level of craftsmanship and techniques, the woodworking, tiling, stonework, and decorative painting techniques of the Mount Tai region embody the wisdom and dedication of craftsmen throughout successive generations, possess distinctive regional characteristics, and are difficult to completely replace with modern technology. Traditional techniques such as mortise-and-tenon repair, partial excavation and replacement, and component inlay repair are employed in accordance with the principle of “repairing the old as the old,” thereby preserving original components to the greatest extent and maintaining the original appearance of the cultural heritage. Techniques such as manual chiseling, joint cleaning, joint filling, and leveling are adopted so that the texture, color, and tactile quality of the stone are highly consistent with the original after repair, enabling the precise preservation of the inscriptions and decorative details of stone carvings while avoiding texture damage or edge chipping caused by mechanical construction.

Third, from the perspective of cultural transmission, traditional craftsmanship is also a carrier of cultural memory. The experienced craftsmen in the Mount Tai region who possess traditional woodworking, stonework, and decorative painting skills represent an invaluable repository of knowledge and experience. Cultivating young craftsmen through repair practices and achieving the living transmission of these skills is an inherent requirement for the sustainable development of cultural heritage conservation on Mount Tai.

3.3 Core Logic of the Deep Integration of Modern Technology and Traditional Craftsmanship

Modern technology and traditional craftsmanship are not in opposition to each other; rather, they constitute an integrative relationship characterized by complementarity and enhanced effectiveness. The core logic of their integration lies in relying on modern technology to address the problems of “being unable to see, measure accurately, and manage effectively,” while adhering to traditional craftsmanship to solve the problems of “being unable to repair properly, preserve authenticity, and maintain the original appearance.” The application of modern technology should follow the principle of “minimum intervention,” with boundaries strictly controlled. It is strictly prohibited to extensively cover the original fabric of cultural heritage with high-strength modern materials or to allow mechanical construction to damage the original texture of cultural heritage, so as to prevent irreversible damage to cultural heritage caused by modern techniques. Traditional craftsmanship should also keep pace with the times, preserving the spirit of craftsmanship while being empowered by technology, and jointly improving the level of conservation.

4. Establishing Repair and Conservation Strategies for Cultural Heritage through the Integration of Modern Technology and Traditional Craftsmanship

The repair and conservation of cultural heritage on Mount Tai should adhere to the basic principle of “technology empowerment and adherence to traditional craftsmanship.” Through “mechanism guidance and coordinated collaboration,” technology can provide traditional craftsmanship with scientific support, while traditional craftsmanship can set humanistic boundaries for the application of technology, thereby maximizing conservation effectiveness.

4.1 Establishing a Full-Chain Collaborative Repair System of “Diagnosis—Design—Construction—Evaluation”

First, at the diagnosis stage, non-destructive monitoring technologies such as 3D scanning, stress-wave testing, and environmental monitoring should be promoted to comprehensively collect geometric information, material composition, internal structure, distribution of deterioration, and environmental data of the cultural heritage itself, and to establish scientific records of deterioration, thereby providing a scientific basis for subsequent repair. At the same time, experienced senior craftsmen should be invited to participate in on-site surveys to verify and supplement the results of technical testing. Second, at the design stage, a complementary approach combining scientific analysis and traditional techniques should be adopted. For example, structural analysis software can be used to analyze the load-bearing conditions of ancient buildings, while traditional craftsmanship can be used to provide appropriate repair techniques. Third, at the construction stage, priority should be given to traditional craftsmanship, supplemented by modern technology. Before construction, laser rangefinders and electronic levels can be used to improve measurement accuracy, while power tools can be used for rough processing, followed by fine processing using traditional techniques. Key processes, including component processing, mortise-and-tenon fabrication, tile laying, and decorative painting restoration, should be carried out using traditional craftsmanship. Finally, at the evaluation and acceptance stage, modern technologies such as 3D scanning can be used to compare the condition of cultural heritage before and after repair and quantitatively evaluate the repair results. Craftsmen should also be organized to summarize the technical difficulties and innovations in craftsmanship encountered during the repair process.

4.2 Implementing Repair and Conservation Strategies under the Hierarchical Protection System

4.2.1 Strict Repair and Conservation Strategies for Level I Protected Cultural Heritage Sites

Level I protected cultural heritage sites should be subject to the strictest conservation measures. The principles of “systematic monitoring, maintaining the existing condition, and minimum intervention” should be followed for management and control. An overall conservation plan should be established, and modern technologies such as drone aerial photography and 3D laser scanning should be employed to establish digital archives and achieve remote monitoring. The scope and intensity of repair should be strictly controlled. During repair, priority should be given to traditional craftsmanship and original materials, so as to preserve the historical information and traces of time embodied in the cultural heritage to the greatest extent possible. For high-value ancient architectural heritage sites such as Dai Temple and Bixia Temple, regular structural safety inspections and anti-corrosion and pest-control treatments of timber components should be conducted to slow their deterioration. For various types of stone inscription heritage, conservation efforts should shift from passive restoration to active prevention. Comprehensive conservation measures, including protection against weathering, acid rain, and biological erosion, as well as surface cleaning and consolidation, should be adopted, together with environmental monitoring and regular assessment. At the same time, ecological environmental protection around cultural heritage sites should be strengthened, native vegetation and the original topography and landforms should be maintained, and soil erosion and geological disasters that may pose substantive threats to cultural heritage should be prevented.

Level I protected cultural heritage sites should also focus on the inheritance of their spiritual and cultural values. For example, the ritual functions of Dai Temple and the religious activities of Bixia Temple are themselves part of the value of these cultural heritage sites. Therefore, coordination with religious administration departments should be further strengthened, and relevant activities should be reasonably arranged on the premise of ensuring the safety of cultural heritage, so as to prevent excessive control or commercialization from severing the cultural value of cultural heritage from its contextual background. In the daily environment, the solemnity of the cultural heritage spaces and their cultural atmosphere should be maintained, and incongruous commercial advertisements and entertainment facilities should be prohibited.

4.2.2 Key Repair and Conservation Strategies for Level II Protected Cultural Heritage Sites

Level II protected cultural heritage sites are numerous and diverse in type, with varying states of preservation. The overall approach should be guided by “classified guidance, focused maintenance, and preventive protection”. Regular investigations of deterioration and risk assessments should be conducted, and risk lists should be established, with problems involving major potential hazards given priority. At the same time, well-planned daily maintenance programs should be formulated, and routine maintenance work should be strengthened to ensure that “minor problems are treated early and problems are prevented before they occur,” thereby preventing minor deterioration from developing into major problems. Traditional craftsmanship should be used as much as possible in repair projects, while modern technology should be appropriately incorporated to improve the overall repair effect.

Compared with the strict protection of Level I cultural heritage sites, Level II protected cultural heritage sites may be moderately opened and reasonably utilized on the premise of ensuring their safety. Qualified heritage buildings may be sup-

ported in being converted into small museums, memorial halls, or cultural exhibition spaces, where thematic exhibitions and cultural activities can be held. However, the impact of commercial activities on cultural heritage should be assessed regularly, and subsequent modes of utilization and the intensity of activities should be adjusted according to the assessment results.

4.2.3 General Conservation Strategies for Level III Protected Cultural Heritage Sites

Level III protected cultural heritage sites are numerous and widely distributed. The overall approach should adhere to the principle of “giving due attention, strengthening inspections, and ensuring basic maintenance,” while exploring a combination of government supervision and socialized conservation to strengthen daily inspection and protection. A cultural heritage site ranger system should be established, with local residents employed as cultural heritage site rangers responsible for daily care and regular inspections of cultural heritage sites and for promptly reporting any problems discovered. Relevant departments should regularly provide professional training and guidance to improve the professional capabilities of grass-roots conservation personnel. At the same time, cultural heritage surveys and registration should be further strengthened to ensure that every immovable cultural heritage site is incorporated into the scope of management. For cultural heritage sites where potential hazards or problems are identified during inspections, emergency conservation should be arranged according to the severity and urgency of the situation. Low-cost and highly efficient conservation techniques, such as vegetation clearance, drainage improvement, and simple structural support, should be encouraged to basically maintain the existing condition of the cultural heritage.

Level III protected cultural heritage sites are important nodes in the cultural heritage network of Mount Tai. Flexible and diverse approaches to adaptive utilization should therefore be explored. Ancient bridges, ancient roads, and ancient stone inscriptions scattered throughout rural areas should be incorporated into public cultural spaces in conjunction with rural revitalization and the development of beautiful villages, becoming cultural landmarks within local communities. Communities and villagers should be supported in participating in the conservation and utilization of cultural heritage, enhancing public awareness of cultural heritage conservation and ensuring that cultural heritage conservation benefits local livelihoods. Through adaptive utilization, a favorable situation in which the entire society participates in conservation can be fostered.

4.3 Integrating Ancient and Modern Approaches in Material Improvement and Talent Development

Materials are a key link connecting technology and craftsmanship. Scientific improvements should be made to traditional materials in light of the special environmental conditions of the Mount Tai region. Traditional glutinous rice mortar has good breathability but develops strength slowly. Composite improvements can be explored by adding appropriate amounts of low-alkali cement or water glass to enhance water resistance while maintaining the characteristics of traditional craftsmanship. Traditional tung oil dries slowly and is prone to accumulating dust. Natural drying agents or modern environmentally friendly wood wax oil can be explored for combined use to improve construction performance. At the same time, aging tests should be conducted under the environmental conditions of Mount Tai on modern stone consolidants and wood preservatives intended for use, and products with good compatibility with local materials should be selected to avoid the emergence of new deterioration caused by material incompatibility.

Building a talent team that possesses both modern scientific and technological literacy and a solid foundation in traditional craftsmanship is an important foundation for improving the quality and effectiveness of cultural heritage conservation. A joint training mechanism involving “engineers + craftsmen” should be explored. For major repair projects, a joint survey system should be implemented, with modern engineers and traditional craftsmen participating on site together and putting forward their respective opinions from their professional perspectives. Regular work exchange meetings between modern engineers and traditional craftsmen should be organized to facilitate mutual learning of basic knowledge of materials science and the principles of testing equipment, as well as traditional construction techniques and “repairing the old as the old” techniques. Local universities, vocational colleges, and other institutions should be encouraged to strengthen practical cooperation with cultural heritage conservation institutions in Mount Tai, systematically explore and organize traditional techniques and craftsmanship of Mount Tai, and establish specialized training programs to cultivate young professionals who understand modern technology while mastering traditional craftsmanship, thereby addressing the practical challenges of the aging traditional craftsman population and the shortage of successors.

5. Conclusion

The immovable cultural heritage sites of Mount Tai are the core carriers of the mountain spirit of Chinese civilization, and their repair and conservation constitute a cultural mission that transcends time and space. In the face of the dual challenges of natural erosion and changes of the times, only by organically integrating the precision and systematic nature of

modern technology with the adaptability and humanistic nature of traditional craftsmanship can a path of cultural heritage conservation suited to the actual conditions of Mount Tai be developed. Protecting Mount Tai means protecting the roots of the nation; repairing ancient sites means laying a solid foundation for the future. This work has no endpoint, but only the continued efforts of successive generations.

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