

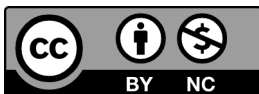
# Earth Architecture: A Symbiotic Path of Cultural Inheritance and Environmental Art Reconstruction

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**Abstract:** Currently, carbon emissions from the construction industry account for 39% of the global total, with building material production and transportation contributing the majority. Earth architecture, boasting prominent advantages such as utilization of local materials, low carbon footprint and environmental friendliness, has become a key solution to the above predicament. Firstly, sorts out the core concept of earth architecture and the basic properties of its materials, analyzes the development and evolution of its technology from a historical perspective, and explores the regional manifestation of its cultural value. Secondly, it focuses on important technological innovation directions, including material improvement and digital construction, and analyzes the approaches of cultural inheritance and environmental art reconstruction through practical cases. Finally, it puts forward practical strategies in line with China's national development conditions, contributing to the modern transformation of traditional architecture.

**Key words:** Earth architecture; Material improvement; Cultural inheritance; Environmental art; Sustainable development; Digital construction



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## 1 Introduction

Earth architecture runs through the development of human architectural civilization and embodies irreplaceable ecological wisdom and cultural genes. Archaeological excavations show that the remains of earthen cave dwellings at the Banpo Site of the Yangshao Culture in China (dating back about 6,000 to 7,000 years) are approximately 1,500 years older than similar earthen structures in Mesopotamia (Zhang Z P & Yan W M, 2014). After the Industrial Revolution, 30% of the global population still lived in various earth buildings for a long time. In the Loess Plateau in northwestern China, about 35 million traditional earthen cave dwellings are still preserved to this day (Akemjan T et al, 2011; Earth Architecture Professional Committee of China Architectural Society, 2021).

Since the 20th century, the global environmental crisis has promoted the revival of earth architecture. In 1998, UNESCO referred to earth architecture as “traditional wisdom for addressing climate change” (United Nations

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Educational, Scientific and Cultural Organization, 1998). China's "dual carbon" strategy and rural revitalization strategy have provided strong policy support for the modern development of earth architecture. Regarding the current research achievements in the field of earth architecture, existing studies still show obvious fragmentation. To improve this situation, this paper systematically sorts out and synthesizes relevant research at home and abroad over the past 20 years, and constructs a complete discussion framework covering concept, history, technology, practice and prospect. It is expected to provide a set of systematic theoretical guidance and experience for the modern transformation and sustainable development of earth architecture.

## 2 Concept Definition and Core Characteristics of Earth Architecture

### 2.1 Concept Definition and Classification System

The definition of earth architecture has evolved from "material-oriented" to "system-oriented": the early definition was "a building form using natural soil as the main building material" (Editorial Department of the Architectural Journal, 2002), while the current definition is "a building category that applies raw earth (including modified earth) to the main structure of buildings through techniques such as rammed earth" (Guo B Q, 2022), covering both traditional forms and modern modified types.

According to material processing methods and construction techniques, earth architecture can be divided into three categories: primary type, such as cliff-side cave dwellings on the Loess Plateau and earth flat-roofed houses in Yunnan; modified type, such as pressed earth blocks and lime-improved rammed earth walls; and composite type, such as fiber-reinforced earth architecture.

From the perspective of geographical distribution, earth architecture in China has formed five typical schools: the Loess Plateau Cave School (adapting to arid and less rainy climate with arch as the main structure), the Southeast Tulou School (taking defensive needs as the primary orientation with circular rammed earth structure), the Southwest Stilted Building School (adapting to hot and humid environment with earthen walls plus wooden stilted structures), the Northwest Gobi School (using Gobi soil mixed with sand to build walls with thick walls for heat insulation), and the Central Plains Sunken Courtyard School (underground earth architecture to avoid surface temperature difference). The fundamental reason for the differential characteristics of different regional schools lies in the adaptive integration between earth materials and the local environment.

### 2.2 Dual Characteristics of Material Properties

The core advantages of earth materials are concentrated in two main aspects: ecological environmental protection and thermal performance. The life-cycle carbon emission is only 9% of that of concrete. Taking a 100<sup>2</sup> rural houses with earth structure as an example, their life-cycle carbon emission is about 0.8 tons, which is 6.3 times lower than that of brick-concrete buildings (Li B F et al., 2016; Department of Architecture, Henan University, 2020). Rammed-earth walls also have excellent humidity regulation capacity. In western Henan, the indoor temperature difference between winter and summer in cave dwellings can be maintained within the human comfort range (Yang S Z et al., 2019). By absorbing and releasing water vapor, the indoor humidity is controlled between 45% and 60%, reducing

dehumidification energy consumption by 30% in plum rain seasons and humidification demand by 25% in arid areas(Liu J P et al., 2016). Its thermal conductivity is 1/3 to 1/2 of that of concrete walls.

However, its inherent defects are also obvious: the compressive strength of unmodified earth is 0.5-1.5MPa, and the strength decreases by more than 70% when exposed to water (Zhang X F et al., 2015); the seismic fortification intensity of traditional earth buildings is below 6 degrees. During the Wenchuan earthquake, the collapse rate of traditional earth buildings was 85%, while that of modified ones was only 12% (Mu J et al., 2010). The shortcomings in strength, water resistance and seismic performance, coupled with the limitations on bay width and storey height (Wang Z et al., 2019), constitute key challenges to be overcome in its modernization process.

## 3 Historical Evolution and Cultural Value Carrying of Earth Architecture

### 3.1 Historical Context of Technological Evolution

The development of earth construction technology in China has a clear context, which can be divided into four stages: germination, development, prosperity and transformation. The Neolithic Age to the Xia and Shang Dynasties was the germination period, with primitive cave dwellings and wood-frame mud wall techniques emerging. The Western Zhou to Qin and Han Dynasties were the development period, when formwork ramming technology matured, and the rammed earth strength of the Qin Great Wall reached 1.2MPa (Liang S C, 2011). The Sui and Tang to Ming and Qing Dynasties were the prosperity period, forming a standardized system, and the strength of the lime-soil foundation of the Forbidden City was as high as 3.5MPa . The modern and contemporary period is the transformation period, integrating modern technologies and witnessing the emergence of new techniques such as pressed blocks(Zhang F H, 2017) .

Breakthroughs in technology are the core driving force for the phased development of China's earth architecture. The wedge-shaped rammer in the Qin and Han Dynasties increased construction efficiency by 40%, the corner reinforcement technology in the Sui and Tang Dynasties solved wall cracking problems, and the mortar plastering technique in the Ming and Qing Dynasties improved water resistance by 50% (Pan G X, 2015).

### 3.2 Material Carrier of Regional Culture

Earth architecture serves as the material carrier of regional culture and its specific manifestation. Its architectural form, structural techniques, and spatial layout all embody the cultural genes and survival wisdom of specific regions. The earthen dwellings in Mazha Village, Tuyugou, Xinjiang, have built a self-sufficient micro-ecological system relying on thick earthen walls, salt-alkali mud waterproofing technology, and yard water storage ponds, adapting to the extremely arid environment (Wang X D, 2015).

Jiang's Manor in Shaanxi is built against the mountain, with three nested cave groups inside. The maximum span of the arch reaches 4.2 meters. The hierarchical drainage not only contains the principles of engineering science but also demonstrates the philosophical thought of "the unity of man and nature". Its indoor spatial layout also strictly conforms to the traditional ethical order (Zhao B, 2018).

The example of Fujian Tulou is quite typical, which maximizes the defensive performance of earth architecture. By adopting the method of "rammed earth plus cobblestones", the wall thickness of the Chengqi Building ranges from

1.5 meters to 2.1 meters. Combined with the circular layered ramming process, it has the ability to resist typhoons of magnitude 12, creating a unique spatial form of “external defense and internal cohesion”. It is not only a physical barrier for clan settlements but also condenses a profound sense of cultural belonging (Huang H M, 2016).

## 4 Contemporary Technological Innovation and Evolution Path of Earth Architecture

### 4.1 Material Improvement: Core Breakthrough in Performance Enhancement

The modern architectural technology system provides systematic solutions to the performance shortcomings of traditional earth materials. Compressed Stabilized Earth Blocks (CSEB), through improving aggregate gradation and adding stabilizers, can increase the compressive strength to 3.5-5.0MPa, which is 3-5 times that of traditional adobe [8]. The nano-silane modification technology developed by Tsinghua University has improved the water resistance of walls by 60%. In terms of toughness enhancement, adding fibers has obvious effects: wheat straw fibers can improve crack resistance by 45%, glass fibers can increase flexural strength by 38%, and the strength retention rate of bamboo fiber modified materials after freeze-thaw cycles is still 85%. These technologies were integrated into the poverty alleviation project in Dingxi, Gansu, successfully increasing the seismic fortification intensity of buildings to 8 degrees [17]. Cutting-edge technologies have propelled earth architecture into the intelligent era. The self-healing earth material developed by the University of Bath in the UK has a strength recovery rate of 90%, and the temperature-sensitive adaptive material developed in China can reduce the comprehensive energy consumption of buildings by 20%, pointing out a new development path for earth architecture [28].

### 4.2 Construction Technology: Dual Improvement in Efficiency and Quality

The technological innovation of the formwork support system for earth architecture has provided key support for the overall improvement of rammed earth construction efficiency. The team led by Mu Jun from Xi'an University of Architecture and Technology independently developed a new type of “bamboo plywood-screw” composite formwork. The measured bearing strength can reach 2.5MPa, which meets the actual needs of mechanized ramming construction and overcomes the technical difficulty of weak structural corners of traditional formwork (Mu J, 2017).

The combination of digital construction technology and prefabricated construction technology has effectively promoted the industrialization process of earth architecture. The Earth 3D printing equipment developed by Tsinghua University has a printing accuracy of  $\pm 5\text{mm}$ , and the construction efficiency is 4 times that of traditional manual ramming technology (School of Civil Engineering, Tsinghua University, 2020). The Netherlands used digital construction technology to print earth residential projects, reducing the construction period by 2/3 compared with traditional construction techniques. Building Information Modeling (BIM) technology can accurately perform numerical simulation and optimization analysis on the thermal performance of earth architecture (College of Architecture and Urban Planning, Tongji University, 2021).

The new prefabricated earth wall panel assembly technology developed by Hunan University adopts the construction method of factory-standardized prefabrication and on-site rapid assembly. The prefabricated wall panels

are composite structures of CSEB modified earth blocks plus steel mesh, with a weight of 60% that of concrete wall panels of the same specification. The measured installation efficiency is 10m<sup>2</sup> per person per day. This technology has significantly improved the construction efficiency and quality control level of earth architecture. In the poverty alleviation relocation project in Xiangxi, Hunan, 120 sets of standardized earth houses were built. The construction period was 40% shorter than that of traditional ramming technology, and the construction waste emission was 85% less than that of traditional construction methods (College of Civil Engineering, Hunan University, 2020).

### 4.3 International Exchange: Two-way Integration of Technology and Culture

International academic exchanges and technological cooperation in the field of earth architecture are increasingly developing, and a global technological cooperation network is taking shape. The “Standard for Performance Testing of Earth Building Materials” led by the International Center for Earthen Architecture and Sustainable Construction (CRAterre) defines 12 key performance testing indicators, and this standard has been adopted by the European Union and many other regions and international organizations. The joint Earth residential project in the Sahara region, carried out by China and Morocco, has deeply integrated the core technical resources of both sides, well adapted to the extremely harsh climatic environment of the Sahara Desert, and has achieved large-scale promotion and application, providing an international cooperation model for the practical exploration of earth architecture in arid regions (China Academy of Building Research, 2019).

In addition, the cultural carrying characteristics of earth architecture itself make it a medium for cross-cultural communication and mutual learning of civilizations. The Dali Earth Art Center project, jointly designed by China and France, not only achieved a large span structure of 12 meters but also integrated local traditional techniques with modern structural mechanics. The China Earth Architecture Exhibition at the Venice Architecture Biennale told the story of Eastern construction wisdom to the international academic community (Organizing Committee of Venice Architecture Biennale, 2021). These practices have distinct local characteristics, which indicates that the innovation path of contemporary earth architecture is a development path of absorbing diverse elements in open cooperation and seeking universal values while respecting regional characteristics.

## 5 Practical Paths of Cultural Inheritance and Environmental Art Reconstruction

### 5.1 Cultural Inheritance: From Technique Protection to Dynamic Inheritance

The focus of cultural inheritance is to realize the transformation from static technique protection to dynamic inheritance. At present, China has established a three-in-one protection mechanism based on technical recording, talent training and policy support. The Ministry of Housing and Urban-Rural Development has completed a national survey of techniques, and many related techniques, such as Fujian Tulou, have been successfully included in the national intangible cultural heritage list. Talent training adopts a combined model of universities, workshops and projects. Xi’an University of Architecture and Technology offers relevant special courses, and Weiyuan, Gansu, has trained more than 1,000 grass-roots construction craftsmen (Department of Housing and Urban-Rural Development of Gansu Province, 2021). Shaanxi, Fujian and other places have also introduced corresponding subsidy support and protection policies

(Department of Housing and Urban-Rural Development of Shaanxi Province, 2019).

However, the true cultural inheritance lies in the organic unity of cultural value and modern functions. The cave homestay renovation project in Pingyao, Shanxi, on the basis of retaining the traditional arch structure and earthen kang structure, added modern bathroom facilities and heating systems. After renovation, the unit price is 800 yuan per night, and the annual passenger flow has increased by more than 3 times, finally achieving a win-win situation of cultural inheritance and economic benefits (Shanxi Institute of Ancient Architecture Protection, 2018). Songyang, Zhejiang, transformed the abandoned earth granary into a rural public library, maintaining the original style of the building and carrying out internal reinforcement, turning it into a public cultural space that activates rural vitality (Zhejiang Provincial Institute of Architectural Design and Research, 2019).

## 5.2 Environmental Art Reconstruction: Case Analysis and Strategy Extraction

The Yucun 1932 Cultural and Creative Park project in Moganshan retained 80% of the original rammed earth walls. For damaged parts, supplementary repair methods were adopted. At the same time, it innovated diversified formats such as art exhibitions, characteristic catering and theme homestays, integrating cultural inheritance with industrial development, and receiving 800,000 tourists annually (Wang S & Lu W Y, 2018; Administrative Committee of Moganshan Yucun Cultural and Creative Park, 2023).

The project has formed three main integration approaches in environmental art reconstruction. Firstly, the integration of function and art: the project divided the original factory space into different functional areas such as art exhibition area, characteristic catering area and theme homestay area. On the basis of retaining the original texture of rammed earth walls, modern exhibition board facilities were added, adopting the design concept of the coexistence of industrial style and local style. In the bicycle-themed restaurant, metal components and rammed earth walls echo and collide in material, forming a visual effect with a sense of the times and regional characteristics. Secondly, the harmonious coexistence between architecture and nature: the design team fully explored and utilized the natural relics and historical sites in the site, such as ancient wells and native mulberry trees, and created core landscape nodes such as the mulberry cocoon garden and the ancient well square, making the rammed earth architecture and the surrounding natural landscapes such as bamboo forests and tea gardens form a layered ecological landscape pattern. Thirdly, the orderly transition between public space and private space: the project plans a 2,000-square-meter central square and 12 courtyard spaces. The enclosed layout of earth architecture forms a gradient spatial sequence of open, semi-open and private spaces. Relying on perfect spatial design and format combination, it has become a demonstration project for rural revitalization.

The Carthage Ancient City in Tunisia takes the symbiosis of historical heritage and modern landscape as its main development direction, creating an international typical model for the protection and utilization of earthen heritage sites. The earthen buildings left over from the Roman Empire period were destroyed in many wars, leaving behind relics such as city walls and palaces. The project adopted the protection principle of minimal intervention and carried out refined restoration projects. For collapsed rammed-earth walls, anchor fixing and modified earth grouting were used for reinforcement. The grouting material was prepared by mixing local soil, lime and nano-silane in a ratio of 8 : 1 : 1, which not only enhanced the wall strength but also maintained the original appearance. The exposed earth surface was sprayed with microcrystalline stone protective agent, improving weathering resistance by 50% (Liu L A & Zhang Y F, 2020).

Its environmental art reconstruction focuses on the core concept of “heritage narration”, forming a display and communication system composed of historical corridors, landscape nodes and interpretation systems. Wooden sightseeing planks were laid along the city wall relics, and a glass viewing platform was set up in the center of the palace relics, which not only effectively protected the relics themselves but also provided tourists with an immersive viewing experience. The newly built visitor center adopted modern rammed earth construction technology, with walls made of CSEB blocks. The appearance reproduced the texture and color of the ancient city’s rammed earth walls through process replication, forming an organic echo with the heritage style. The landscape design integrated the regional cultural elements of Carthage, applying the mosaic patterns unearthed from the relics to the ground pavement project, combined with the planting of native plants, turning the entire heritage park into an “experiential history textbook”, receiving more than 1.2 million tourists annually.

In summary, successful practices show that only by balancing authenticity and adaptability in culture, integrating traditional techniques with modern technology, realizing the symbiosis between architecture and nature in landscape, and constructing a value system of diversified format integration in function, can the unity of cultural value, ecological value and economic value be achieved.

## 6 Development Dilemmas and Future Prospects of Earth Architecture

### 6.1 Practical Dilemmas: Triple Constraints of Technology, Market and Cognition

In terms of technology, there are problems a lack of a standard system and weak supply chain support. There are a few suppliers of special ramming equipment and modified materials, resulting in a long construction period and high construction cost(Rural Construction Promotion Association, 2022). In terms of the market, there is a cost paradox: the initial cost of modified earth architecture is 10% to 15% higher than that of brick-concrete structures, but the 50-year life-cycle cost is only 60% of the latter. However, investors pay more attention to short-term economic benefits (China Building Energy Conservation Association, 2020). According to relevant research surveys, only 35% of rural developers are willing to choose earth architecture, while the remaining 65% still adhere to the concept that earth architecture is of inferior quality. The “dual misunderstanding” in cognition further increases the resistance to promotion: some decision-makers regard it as an outdated architectural form, while some protectionists strongly oppose it, worrying that its modernization reform will destroy authenticity. These multiple constraints have pushed earth architecture to the edge of urban construction.

### 6.2 Development Path: Synergetic Promotion of Technology, Policy and Culture

Looking forward to the future, the development path of earth architecture relies on the innovation driven by technological innovation, policy innovation and cultural innovation. In terms of technology, it is urgent to establish a technical support system based on “standardization + intelligence”, formulate special technical standards, promote the application of 3D printing and intelligent materials, and form a mechanism for continuous performance monitoring(Institute of Standardization and Quota et al., 2023). In terms of policy, it is necessary to strengthen the dual-track support mechanism of “incentive + guarantee”, incorporate earth architecture into the green building evaluation

system and provide special subsidies, provide loan interest discount support for rural revitalization-related projects, establish a special fund for the protection of earth architecture techniques, provide financial support for inheritors and training institutions, and designate “earth architecture pilot areas” in the urban renewal process of cities such as Xi’an and Lanzhou to integrate earth architecture into the urban texture organically(Xi’an Municipal Bureau of Natural Resources and Planning, 2021). In terms of culture, it is necessary to establish a multi-dimensional promotion matrix of “communication + experience”, demonstrate its modern value through international exhibitions and theme museums, develop related experience projects, and promote universities to offer courses related to earth architecture to cultivate compound professional talents.

## 7 Conclusion

The ecological construction wisdom and in-depth regional cultural genes carried by earth architecture still maintain vigorous practical vitality in contemporary society. Its main development logic lies in the in-depth integration of traditional construction forms and modern engineering technology. Against the background of the country’s proposal of dual carbon goals, rural revitalization strategy and sustainable design concept, earth architecture has entered an important development stage. Relying on the collaborative development roadmap of establishing technical standards, improving policy support systems and forming social consensus in the future, earth architecture will realize the development transformation from the edge to the mainstream.

Earth architecture is not only a key building type for implementing the concept of sustainable development, but also a primary material medium for carrying the regional cultural context. In the future, it will become an important link connecting historical context and development trends, and coordinating the symbiotic relationship between man and nature, thereby adding a Chinese solution with ecological low-carbon characteristics, cultural inheritance significance and technological innovation attributes to the field of global sustainable architecture.

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