



Study on Preventive Protection Countermeasures of Wood Structure of Residential Buildings in Shade Town, Kangding City

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Abstract

As a natural organic material, wood has been widely used in traditional residential buildings since ancient times because of its advantages of easy resource regeneration, environmental protection and good thermal insulation. However, in the wood structure of residential buildings at high altitude in Ganzi Tibetan Autonomous Prefecture, Sichuan Province, due to the influence of climate, humanities, biology, physics, chemistry and other factors, the wood properties have changed, resulting in the cracking, decay, insect-eating, mildew and other problems that threaten the structural safety of residential buildings, thus affecting the durability of the wood structure. This study takes Muya residential building in Shade Town, Kangding City as the research object, and through on-the-spot investigation of the present situation of local residential buildings, finds out the problems existing in the wood structure during its long-term use. At last, the influence of local climate, hydrology, geology and other characteristics of Shade Town on wood structure in residential buildings is summarized, and preventive protection strategies such as moisture-proof, moth-proof and fire-proof in existing wood structure of residential buildings are preliminarily put forward, which provides scientific basis for preventive protection of traditional wood structure buildings and even new wood structure buildings.

Subject Areas

Architecture

Keywords

Residential Architecture, Timber Structure, Preventive Protection

1. Introduction

This study takes Shade Town, Kangding City as the research object, and through the investigation and on-the-spot investigation of the wood structure of Muya Tibetan residential buildings in this area, puts forward preventive repair and treatment measures for the phenomena of local corrosion of wood structure caused by biological diseases and insect pests, fire caused by low fire resistance grade of wood, wood decay, mildew or cracks caused by too high or too low moisture content of wood, so as to improve the durability and use safety of wood structure in Tibetan stone-wood residential buildings in western China, and make protection and renewal of Tibetan residential buildings in western Sichuan.

Most of the buildings in western minority areas such as Ganzi Tibetan Autonomous Prefecture are stone-wood structures. The analysis of wood structure damage in residential buildings mainly includes local corrosion of wood structures caused by biological diseases and insect pests, fire caused by low fire resistance grade of wood, wood decay, mildew or cracks caused by too high or too low moisture content of wood, etc. The above damage and damage of wood structures not only affects the architectural beauty, but also poses a safety hazard to the use of buildings to a great extent. Therefore, it is necessary to improve the wood treatment technology and technology on the basis of existing wood structure problems so as to improve the durability of wood structures in this area. On the maintenance cost, through the investigation of local houses, it is not difficult to see that many wooden structures of houses have some problems such as corrosion, cracks, aging, etc. Many residents don't treat their damaged structures in order to save the repair cost, which will surely lead to greater security risks, but actually further increase the later maintenance cost. Therefore, in order to avoid the deterioration of the situation and the increase of the later cost, it is necessary to improve the wood properties from the source through technology or other means, and apply the perfect wood treatment technology to the improvement of existing houses and new houses. The results of the new wood treatment technology will provide a useful reference for the repair and preventive protection of wood structures of residential buildings in other plateau areas. Therefore, it is necessary to focus on the research of wood treatment technology in plateau areas.

2. Research Status at Home and Abroad

2.1. Domestic Research Status

2.1.1. Research Status of Wooden Architecture

The protection and restoration of wooden buildings in China started late, but developed rapidly. In recent years, a large number of excellent research results have appeared. For example, Zhao Hongtie, *et al.* discussed the details of construction and structural mechanics reinforcement of ancient buildings in China in 2012's Review of Structural Performance Research of Ancient Timber Struc-

tures. Shao Jinsong, *et al.* introduced the application of FRP strengthening technology in the restoration of ancient buildings in detail in the Summary of Research and Application of FRP Strengthening Wood Structures in 2015. In 2019, Kong Jian's "Research on Preventive Protection and Maintenance Technology of Ancient Timber Buildings Taking Qufu Confucius Temple as an Example" deeply discussed the preventive protection and maintenance scheme of wooden structures, and put forward corresponding reinforcement and repair methods for common damage forms of wooden structures, with a view to providing guidance for future preventive protection and maintenance of ancient wooden structures in Qufu Confucius Temple. In 2015, Cao Ying's master's thesis, "Research on Protection of Traditional Dwellings with Wood Structure in Anhua", discussed the wooden dwellings in Anhua from the aspects of material properties, architectural shapes, structural characteristics and protection techniques. In 2017, Ma Deyun *et al.* upgraded the inspection and appraisal methods of ancient buildings in the Summary of Safety Inspection and Appraisal Methods of Ancient Timber Structures, which provided ideas for the inspection and restoration of wooden structures (**Table 1**). At present, the domestic units mainly engaged in the research of wooden cultural relics protection include Timber Institute, Palace Museum, Chinese heritage Research Institute, Beijing Institute of Ancient Architecture, Beijing Institute of Cultural Relics Protection and Design, etc.

Established in 1957, the Institute of Wood Industry of the Chinese Academy of Forestry (CAS) is a comprehensive national research institution in the field of wood science and technology, providing technical support for the protection of China's cultural heritage. Xu Jiahe, Wang Chao *et al.* described the work status of the Institute over the years and its contribution to the protection of wooden structures (November 2020). The Institute first participated in the repair of wooden components of ancient buildings in 1968, when it undertook the tasks of drying, identification, corrosion prevention and physical and mechanical tests of wood used for the maintenance of Tian'an Gate. In October 1989, the expert group of wood science of the Institute went to Lhasa, Tibet to undertake the pest control and anticorrosion project of wood components in Potala Palace maintenance. In 2001, the Institute focused on the study of wood decay law in the typical environment of western China, and carried out the research of anti-corrosion and flame retardant surface treatment technology of ancient building wood components based on the Ta'er Temple in Qinghai Province, and formulated the national standard "GB/T 33041-20160 Regional Division of Land wood decay and termite Hazard Grade". In July 2002, the Ministry of Housing and Urban-Rural Development and the state Administration of Quality Supervision, Inspection and Inspection jointly issued the "Code for Acceptance of construction quality of wood structure engineering", delimit the standard for the use of anticorrosive wood. In January 2017, the Development Plan of China's Timber Protection Industry (2016-2020) (hereinafter referred to as the Plan),

Table 1. Domestic research status of timber architecture.

Serial number	Time	Author	Paper topics	Main content
1	2012	Hongtie Zhao [1]	Survey on Structural Properties of Ancient Wooden Structures	The paper discusses the reinforcement of ancient buildings and structural mechanics.
2	2020	Jian Kong [2]	Study on preventive protection and maintenance technology of ancient wooden buildings—Taking Confucius Temple in Qufu as an example	Based on the characteristics of ancient wooden structures of Confucius Temple in Qufu, this paper discusses the preventive protection and maintenance scheme of wooden structures, and puts forward reinforcement and repair methods for common damaged forms of wooden structures, so as to provide guidance for future preventive protection and maintenance of ancient wooden structures of Confucius Temple in Qufu.
3	2015	Jinsong Shao [3]	Review on research and application of FRP strengthening wood structure	The application of FRP reinforcement technology in the restoration of ancient buildings is introduced in detail.
4	2015	Ying Cao [4]	Study on the Protection of Traditional Dwellings in Anmugou	This paper discusses the wooden houses in Anhua area from the aspects of material properties, architectural modeling, structural characteristics and protection technology.
5	2020	Haiyan Zhang [5]	Overview of current standards for wood structure buildings in China	This paper expounds that in recent years, China has revised a series of codes and standards related to wooden structures, and has gradually formed a relatively complete system. The revision of these standards has laid a foundation for the innovative development of wooden structures.

organized by China Timber Protection Industry Association, was officially issued. “Planning” put forward in the future innovation and development of wood construction focus on encouraging wood anti-corrosion, insect control (ant), mildew, drying, flame retardant, modification and other protection treatment research.

After more than 50 years of accumulation and development, established the ancient bearing evaluation exploration, construction, wood identification, wood chemistry, wood protection, dry wood, wood mechanics, and other associated with the ancient wood and wood preservation research direction, and ancient buildings, wooden parts and wooden longitudinal topic more than 20 items, the protection of cultural relics related to the protection of historical and cultural heritage in our country, Outstanding contributions have been made to ensuring the quality of key cultural relic protection projects (**Table 2**).

Table 2. Research status of wood building treatment technology in China.

Serial number	Time	Author	Paper topics	Main content
1	2020	Lin Chen [6]	Preventive protection of wooden columns in traditional wooden structures-preliminary analysis based on real simulation results	In this paper, the real simulation method (quantitative analysis) of existing traditional wooden structures is adopted to analyze the influence of different factors on the durability of wooden columns, which provides a scientific basis for the preventive protection of traditional wooden structures and even new wooden structures.
2	1997	Xiangbin He	Present situation and development of wood anticorrosion	This paper focuses on the analysis of the history and methods of wood preservation research at home and abroad in recent decades. Wood corrosion, including animal and plant damage, climate influence and other threats caused by various environmental factors, is an important factor limiting the service life of wood.
3	2020	Minjuan He	Comprehensive study on seismic performance and design methods of multi-storey wood structures	In this paper, the development of multi-storey and high-rise timber structures in recent years is reviewed, and a series of experimental and theoretical studies are carried out on multi-storey and high-rise timber structures, revealing the seismic mechanism of some structural systems. Finally, the seismic design method of multi-storey wood structure building is summarized.
4	2017	Lili Yu [7]	Research progress on weatherability of embalming wood	In this paper, the weatherability of wood materials is studied, in order to provide reference for the healthy development of anticorrosive materials.

2.1.2. Protection and Repair of Traditional Wooden Structure

As a natural and organic building material, wood has been favored by the architectural field since ancient times. However, in the long-term use of wood structure, due to the long-term climate change, biological hazards and human factors, the wood structure is easy to produce cracking, decay, moth, mold and other problems. In order to prolong the service life of wooden structure, the traditional protection and repair technology of wooden structure came into being and developed.

Our traditional building wood component protection technology development has a long history, with the context of historical development analysis, as early as one thousand years ago, in the book “Baopuzi” of Jin dynasty Ge Hong contains “copper green coated wood, into water not rot”, that is to use copper oxide as wood preservative method. In the early stage of the development of the protection of traditional wooden structures (early 20th century), a group of architects represented by Liang Sicheng and Liu Dunzhen began to visit all over the country to conduct detailed investigation and research on the existing ancient

buildings at that time, which opened the way for the research and protection of ancient buildings. In Liang Sicheng's *History of Chinese Architecture*, he introduced in detail the development of Chinese traditional wooden architecture in various periods. In China, the protection and renovation of traditional building timber structure started in 1950s and the research work focused on universities and research institutes. In 2018, the CPC Central Committee plans to submit to the First Session of the 13th National Committee of the Chinese People's Political Consultative Conference a Proposal on Protecting Cultural Relics and Building Features in Ancient Capitals and Inheriting Traditional building Construction Skills (the Proposal). According to the Proposal, the techniques of ancient building construction and repair (hereinafter referred to as "ancient building skills") are the summary and refinement of rich technical and technological experience accumulated by Chinese craftsmen in the process of building and repairing buildings for thousands of years. In traditional wooden architecture protection and restoration in field development successively formulated a series of relevant construction technical data and engineering standards, such as: "the ancient building workers technical level standard CJJ21-89", "ancient buildings renovation project construction regulations", "ancient buildings renovation project construction regulations", "ancient timberwork maintenance and strengthening technical specifications" and so on.

In the subsequent research on traditional wood processing technology, valuable articles have emerged. Zhao Zhen (2017) explored the problems of damp diseases, types of damp exposure, formation factors of damp diseases and damage mechanism of common traditional dwellings with brick and wood structure in Suzhou, and proposed corresponding moisture-proof methods. Yu Lili *et al.* (2017) analyzed and prospected the current situation and research trend of the weatherability of wood anticorrosive treatment materials from the research of weatherability of wood materials, in order to provide reference for the development of anti-corrosion treatment technology. Masson's pine is a native tree species in southern China, which is used as raw materials in the construction industry, but its growth is vulnerable to various diseases and pests. Shi Longbiao (2019) proposed four overall control measures and three specific control measures for diseases and pests of Masson's pine. Xiaoning Zhao (2019) outlined the basic principles of wood quarantine treatment and introduced in detail the wood inspection and quarantine treatment methods such as fumigation treatment, water-immersion pest control treatment and heat treatment, in order to provide reference for reducing the risk of invasive foreign pests.

2.2. Foreign Research Status

At present, Britain, France, and Italy, represented by European countries, have established a relatively perfect system of historical building protection law and historical heritage building repair technology is relying on the perfect historical building protection system to achieve the traditional construction process and

save finishing, repair technology selection, etc.; all have strict rules. At present, there are few systematic discussions on the inheritance system of traditional architectural restoration technology in various countries. However, with the accumulation of practical experience, many works on restoration technology have been published. A representative example is: “Guide to Techniques and Materials” (Architectural Conservation: A Technical Guide), which analyzes the properties of different building Materials in the past and proposes protective Techniques. In addition, there are some works on the protection and repair technology of different building structure types, which are highly targeted and have strong guidance for the specific protection and restoration practice. For example: Conservation of Historic Brick Structures: Case Studies and Reports of Research (Conservation of Historic Brick Structures: Case Studies and Investigation reports), Conservation of “Historic Timber Structures: An Ecological Approach” (Conservation of Historic Timber Structures: An Ecological Approach)\ Stone Conservation: Principles and “Practice” (stone protection: Principles and practice), etc.

The protection and restoration of wooden buildings in foreign countries first began in Japan, and the attempt to restore Horyuji Temple began as early as the 10th to the 15th century. After continuous development, the protection system and technology have been improved intermittently in modern times. For example: the Ancient Capital Preservation Act 1966 protects historic buildings and their surroundings. The 1994 Nara Authenticity Document pointed out that the particularity of values in different cultural backgrounds should be fully recognized, and heritage protection should be combined with cultural context rather than universal application. The Guidelines for the Protection of Wooden Built Heritage issued in 2017 provide detailed explanations and regulations on the inspection, investigation, analysis and evaluation, intervention measures, monitoring and maintenance of wooden buildings. In addition, European and American countries have also carried out a lot of research on wooden structures. For example, in *Deutsche Fachwerkbauten* published by Hermann Phelps in 1954, German half-wood structures were briefly classified and introduced through a large number of physical photos. In the 1990s, Manfred Gerner published *Fachwerk: Entwicklung, Gefüge, Instandsetzung* (1994) and *Fachwerk: Entwicklung, Instandsetzung, Neubau* (1999) introduced in detail the construction techniques, culture and art, and protection measures of German half-wood structures. Heinrich Stiewe’s *Fachwerkhäuser in Deutschland*, published in 2007, describes the historical value, cultural and artistic value of half-timber-framed houses in Germany, as well as the basic content of conservation and restoration. *Timber frame construction*, edited by Sobon Jaek, introduces early American wood-frame architecture; and *Woodhouse*, edited by Blaser Weme, introduces rural wood-frame architecture in the Alpine region.

To sum up, in the past, people would protect and repair wooden components according to traditional experience. In the decades after the founding of the

People's Republic of China, a large number of new methods for the protection and repair of architectural wooden components emerged. At present, the research on the protection of wooden components involving physics, chemistry and biology at home and abroad is increasingly mature and has remarkable results. Summarizing the current research results at home and abroad, it can be seen that the academic field focuses more on the innovation and development of wood structure protection and repair technology, while relatively weakening the research on the protection strategies and protection subjects of related technologies. These factors lead to the risk of losing the protection and repair technology of traditional building wooden components. The innovation and development of wood structure protection and repair technology are inevitable, but the traditional technology is the wisdom crystallization of ancestors, with a strong national character, so the protection and development of the traditional wood structure protection technology are equal.

In addition, the study of wood protection in building is more focused in terms of architectural heritage, but also has small wooden local-style dwelling houses building research, but the study of high altitude southwest minority residence, more concentrated in the village and building on the whole, the Tibetan folk buildings in wood and wooden parts detailed comparative study of the whole is relatively small. There are a lot of studies on the investigation, repair and protection of wood in building structures at home and abroad, but most of them are concentrated in places with good geographical location and traffic conditions, mainly pure wood structure. There are few special studies on the pathology of wood structure in Tibetan buildings in high altitude areas in southwest China. Therefore, this project takes Shade Town in the high altitude area of Southwest China as the research object, conducts investigation and experiment on the wood structure in the local residential buildings, finds out the factors affecting the durability of the wood structure, and puts forward corresponding solutions, so as to provide some technical improvements for the construction of residential buildings in southwest China. Therefore, it is very important to study the wood structure of the residential buildings in the high altitude area of southwest China.

3. Existing Problems of Wooden Structure of Residential Buildings in Shade Town, Kangding City

Several residential buildings with typical wood structure in Shade Town, Kangding City were selected as the research objects, and the damage problems of the wood structure of the houses were investigated on site and the factors leading to the damage of the wood structure and affecting the wood performance were summarized. The types and disease types of traditional building wooden components in Shade Town, Kangding City were summarized, and the factors affecting the generation of diseases were analyzed. In the process of investigation, the interview information of craftsmen was obtained and the appearance investigation of wooden components was adopted to scientifically judge the types and charac-

teristics of common diseases, insect pests and wood damage defects of traditional building wooden components (**Figure 1**).

The research found that during the long-term use of residential wooden structures in Shade Town, Kangding City, due to the influence of climate change, biological pests and human factors, the wooden structures are prone to deformation, cracking, decay, microbial insect infestation, fire and other problems that threaten the security, stability and durability of the wooden structures (as shown in **Figure 2**). Therefore, the whole life cycle of wood-framed buildings is inseparable from daily protection and maintenance. In the past, people would protect wood-framed buildings according to the traditional experience. With the rise and development of modern technology such as construction and protection of wood-framed buildings, new methods related to the construction and protection of wood-framed buildings are constantly emerging. The innovation and development of wood frame protection technology are inevitable, but at the same time in the subtle weakening of the value of the traditional craft, and the traditional wood architecture to the modern society has brought two aspects of value heritage, one is the existing preserved.

The traditional wooden construction object is the construction technology passed down from generation to generation by craftsmen. The traditional building technology is the wisdom crystallization of our ancestors. But starting in the 1980 s, with the old craftsmen of the traditional wooden construction process



Figure 1. Photos of the investigation and interview (Photo source: taken by the author).



Figure 2. Damage condition of wooden structure of residential houses (Photo source: taken by the author).

begin to retire, in inherited master less and less, local artisans in basic research of wooden construction techniques are insufficient, make them to the traditional art history, art origin, cultural value, art inheritance and innovation, All these factors lead to the possibility that the construction technology of traditional wooden structure may be lost. Compared with the wood construction object, the traditional wood construction technology is also in urgent need of protection.

4. Discussion on Preventive Protection Countermeasure of Wooden Structure of Residential Buildings in Shade Town, Kangding City

4.1. Preventative Reinforcement of Wood

For wood subjected to fungi and pests, chemical treatments can be used to enhance wood stability and pest resistance. For wood decay, anti-decay agent should be coated to enhance anti-decay ability, and ensure dry ventilation. For the crack of the member, regardless of the size of the crack, the first thing is to remove the deposit in the crack, and when the crack width is very large (greater than 30 mm) impact FRP fiber cloth or iron hoop should be used to strengthen the cracked member in order to recover or improve the stiffness and strength of the member. When the damage degree of structural members is very serious, the member is not enough to provide the bearing capacity required by the structure, the original can be replaced by the newly made member, but certain measures should be taken (such as applying prestress, etc.) to ensure the deformation coordination of the old and new wood. For the decayed component, when only the surface wood is decayed, and the internal material is intact and can still meet the requirements of the bearing capacity, and the decayed part is removed clean, and after the surface is clean and anti-corrosion treatment, according to the original and original size, the use of dry wood and water-resistant adhesive repair neatly, when the wood decay is serious, especially the wood decay at the root of the column has a great influence on the structure performance. Generally, the pier reinforcement method is used to bond the new and old materials together, and the iron hoop or FRP fiber cloth is used to add the hoop to the pier joint to strengthen the cooperative working performance of the new and old materials.

4.2. Building Structure Inspection

The detection and inspection of the existing contents and current working conditions of the maintenance and reinforcement measures of wooden structures in the past dynasties should focus on the stress state of the reinforcement members. The new deformation or displacement, the re-emergence of the decayed parts after the original decayed parts are dug up, and the adverse effects on other parts of the buildings caused by improper maintenance and reinforcement. Non-destructive testing technology can be used in the problem detection of wood structure of residential buildings in Shade Town, Kangding City. This technology is mature

and reliable, and has been widely used in the preventive detection of wood component buildings. Wood non-destructive testing technology is a non-destructive testing technology that gradually emerged in 1950s to detect the physical properties, growth characteristics, mechanical properties, damage and defects of wood. It was first applied to the detection of standing trees, and then gradually it was widely used in wooden building components.

There are five kinds of nondestructive testing commonly used: vibration wave testing, ray testing, magnetic powder testing, penetration testing, eddy current testing. From the perspective of relevant research status, the nondestructive testing technology applied to the wood structure of residential buildings in Shade Town, Kangding City is mostly carried out based on the vibration wave principle and ray principle, such as ultrasonic detection, stress wave detection, microwave detection and so on. It is mainly used to survey the material properties of wood, wood damage defects, wood growth characteristics and other information. Different detection techniques are applicable. By means of these nondestructive testing techniques, the internal damage of wood structures can be effectively detected, which provides a scientific reference for later maintenance of wood structures.

4.3. Wood Drying

Wood drying is an indispensable measure in the maintenance of wooden residential buildings and an important guarantee of engineering quality. Without drying treatment or drying up to the standard of the component, it is prone to cracking, deformation, decay, moth and discoloration and other defects. The moisture content control of wood before anticorrosive treatment is an important measure to ensure the penetration of anticorrosive agents and reach the standard of wood anticorrosive treatment. The water content control of wood components after anticorrosion treatment is the key to preventing wood decay, moth decay, cracking and ensuring its service life. During the investigation, it was found that local villagers mainly use traditional experience to dry wood. No specific drying steps are required. Under normal circumstances, the best time to dry wood is summer and autumn. The standard to judge whether the wood is well aired is through empirical judgment and naked eye observation. There is a certain error. Therefore, it is very important to arrange a set of conditions that meet the local wood drying standards.

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Conflicts of Interest

The author declares no conflicts of interest.

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