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Chapter 10

Traditional Wooden Buildings in China

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Abstract

Chinese ancient architecture, with its long history, unique systematic features and wide-spread employment as well as its abundant heritages, is a valuable legacy of the whole world. Due to the particularity of the material and structure of Chinese ancient architecture, relatively research results are mostly published in Chinese, which limits international communication. On account of the studies carried out in Nanjing Forestry University and many other universities and teams, this chapter emphatically introduces the development, structural evolution and preservation of traditional Chinese wooden structure; research status focuses on material properties, decay pattern, anti-seismic performance and corresponding conservation and reinforcement technologies of the main load-bearing members in traditional Chinese wooden structure.

Keywords: traditional Chinese wooden structure, materials and properties, anti-seismic performance, reinforcement techniques

1. Introduction

Being one of the world’s three major architecture systems, Chinese ancient architecture plays an important role in the global history of architecture. With its long history, unique systematic features and wide-spread employment as well as its abundant heritages, Chinese ancient architecture keeps growing and developing. Emerging from a system using earth and wood to one using bricks and wood, it held on its tradition of taking wooden structure as the main structure and carpentry as the main technology. After over 2000 years of progression and evolution, it has formed a complete system of structure and construction, which includes regulations and standards inherited both from Song Dynasty (1103 AD) and from Qing Dynasty (1734 AD). Compared to Western ancient buildings constructed with stones, bricks and natural concrete, Chinese traditional wooden buildings lack durability and need frequent main-
tenance and renovation, and properties of the wood in use have a fairly big influence on the joints and the performance of the whole structure. However, under the influence of traditional Chinese philosophy, buildings have been more of an exhibition of social status and the materials and structures involved have not been taken seriously as a technology for a long time.

The study with significance to the modern world in the field of Chinese traditional wooden buildings started in the 1920s and 1930s. Historic and artistic fields of the architecture attracted most attention and were often selected as main research directions over a long period of time. Up to now, limited number of fundamental studies on the structural behaviour of Chinese traditional timber structure and its typical joint connections can be found; hence there is an urgency to study and evaluate the seismic performance and structural behaviour of the existing historical timber buildings so as to prevent as much earthquake-inflicted damages as possible from occurring in the near future.

Taking Dou-gong brackets and mortise and tenon joints of Chinese traditional timber structure as objects, the ongoing research project of our team includes structure performance and anti-seismic mechanism of different joint connections between columns and beams, reinforcement technology of the weak parts, along with the utilization and analysis of modern engineering wood products as alternative materials in the repair and new construction of Chinese traditional timber constructions.

Material performance and structure behaviour researches of Chinese traditional wooden buildings are often based on specific emergency repairment and strengthening projects of historical buildings, which somewhat limits the systematicness and universality of the researches. On the other hand, taking convenience of cultural awareness and characteristic of oriental structural system into consideration, the results of relevant studies tend to be published domestically, which also increases the difficulty of international academic exchange and interaction. In consequence, the intention of this chapter is to collect and introduce relevant research status as well as phased achievements of my team systematically. And the publication of this book will be certain to generate a trend to study traditional wooden structure and encourage worldwide academic exchange and cooperation.

2. The structure and preservation of traditional Chinese wooden architecture

Represented by traditional Chinese wooden architecture, oriental wooden structure stands out in the architecture world, and after a long course of development and accretion, it has reached a high level of standard theoretically and practically. Take the example of the Yingxian Wooden Pagoda, the highest wooden tower existing worldwide. Besides the fact of being 67.1-m high, it has also survived several major earthquakes and therefore embodied the perfect combination of techniques and aesthetics of wooden structures as well as the intelligence of ancient Chinese people. Consulting two significant building standards from Song Dynasty and Qing Dynasty, this chapter introduces the development and structural
evolution of traditional Chinese wooden structure, focusing on three classic structures and via the examples of well-known wooden structures such as the Yingxian Wooden Pagoda, and presents the condition of study and preservation of historic buildings in modern China.

2.1. A brief guide to the evolution of traditional oriental wooden structures

Due to different cultural backgrounds, ancient architecture used to have seven independent systems, of which some are extinct or never widely spread and thus had limited achievements and influences. That left Chinese architecture, European architecture and Islamic architecture to be considered the world’s three main architectural systems. And among them, Chinese architecture and European architecture are the most long-lasting, widely spread and successful ones. Ancient Chinese architecture had undergone primitive society, slave society and feudal society, among which the last one was the time when Chinese classic architecture developed the most.

1. **Primitive society (7000 years ago to twenty-first century BC)**. The building types vary due to different climates, geographical features and materials. Among them, there are two typical types: wooden frame and mud wall buildings that emerged from cave houses in the Yellow River basin and the Ganlan-style buildings (wooden buildings that built on stilts) from nest houses in the Yangtze River basin. In the late stage of the primitive society, building sites already had trace of privatization and the walls and roofs of buildings were mostly interwoven branches or twigs with mud coating (see Ref. [1]).

2. **Slave society (2070–476 BC)**. In the twenty-first century BC, the wooden frame and rammed earth construction and regular enclosed courtyard building groups came along, which showed great improvement in timber frame technology. The sixteenth century BC was the prime time for the development of the Chinese slave society and a time when documentary trace began. Based on the size of the rammed earth foundation of the palaces and temples, buildings at this point of the history had larger scale and stricter hierarchy and scale of cities, height of city walls, width of streets and other buildings of significance were required to be built according to their rank. In the Spring and Autumn periods (770–476 BC), the popularization of tiles and appearance of high-platform buildings for imperial and ducal palaces were the most important improvements. High-platform building means building a platform of tamped earth underneath the palace. As the leuds sought more magnificent palaces, the decoration and painting of ancient architecture were taken a step further (see Ref. [1]).

3. **Feudal society (475 BC to 1911 AD)**. With the collapse of slavery, agriculture and handicraft rapidly grew and the utilization of ironware accelerated the improvement of structure technology and wooden structure's construction quality. Fireplaces, heated brick beds and cellars can be seen at this period of time. The Han Dynasty was a thriving time for classic Chinese architecture when the nowadays commonly seen beam-lifted frame and through-type frame wooden structures were formed. And at the same time, the traditional roof of Chinese buildings also flourished. Since then, the introduction of Buddhism greatly boosted the development of Buddhist architecture, one of the most
important types of classic Chinese architecture. The Tang Dynasty was a time when the techniques and artistic qualities of classic architect were developing the fastest. Tang-style architecture demonstrates the extremity of size and regulations, extremity in architectural complex layout and features of large expansion and large volume. And the construction form and material requirements of wooden structures especially Dou-gong brackets were standardized. Tang-style architecture also produced a far-reaching influence on countries such as Japan. Later in the Song Dynasty, modular system was adopted and the book building standards were officially published which set standard rule for buildings' measurements and basic moduli so that the size of wooden components could be properly defined.

In the late stage of feudal society, building forms were becoming more and more simplified and the entirety of the beam-column frame was enhanced. The buildings presented a serious and rigorous image with more ingrained decoration and painting. In Qing Dynasty, the ethnic diversity contributed to the blossoming of various residential building types. And the monomer building form of official architecture was set and therefore improved the standard of architectural complex design. The promulgated book construction practices enumerated 27 practices of monomer building and formulated new construction moduli, which contributed much to accelerate the design and construction process and controlling material consumption (see Ref. [2]).

2.2. The structural system and characteristics of traditional Chinese wooden structure

Based on different construction frames and geographic features, the traditional Chinese wooden structure frame system can be divided into three types: through-type frame, beam-lifted frame and log-cabin-type frame (see Refs. [3, 4]), as seen in Figure 1.

1. **Through-type frame.** The through-type frame is constructed of vertical connection with separated frame and mostly used in rural housing. There is no reference to this type in the official building standards. The common practice of this type is to connect the columns with square crossbeams along the length of the house, forming a truss and then use square crossbeams to connect every two trusses, forming the frame of the house. The characteristics of this type include using materials with small cross section that are easy to obtain, using multiple square crossbeams along the length of the house that can be assembled beforehand, enhancing the entirety and stability of the structure and ren-

![Figure 1. Three types of traditional Chinese wooden structure.](image-url)
dering the installation of walls convenient and saving manpower and materials with its simple practice, direct force transmission and ever-evolving and adaptable nature.

2. **Beam-lifted frame.** This frame type formed in the Spring and Autumn period kept evolving and then became a settled practice. This frame type varies in material size and frame combination according to different social ranks, which was strictly set in regulations such as building standards in Song Dynasty and construction practices in Qing Dynasty. Beam-lifted frame is usually composed of the frame layer, the Dou-gong brackets layer and the roof layer. Usually, it is constructed by placing a beam head on top of a column and then on top of that, using a shorter column to hold a shorter beam and another beam head and another column and so forth. And eventually, the short column on the short beam holds the weight of the purlin. This type was widely used in large-scale buildings such as palaces and temples in northern China. The characteristics of beam-lifted frame are long distance between columns along the length of the house, enclosing larger interior space and aesthetically pleasing structural features.

3. **Log-cabin type.** Log-cabin type is an ancient structural type that dates back to the primitive society. In China, it was found to be used in building the outer coffin in Shang Dynasty tombs from over 3000 years ago and in the caved patterns on Han Dynasty relics found in Yunnan province in south-western China. It is referred as ‘Mukeden’ in north-eastern China, meaning to pile up caved logs (often cut into semi-cylinders) to build houses. This type of structures is often seen in areas such as Inner Mongolia, forests in north-eastern China and mountain areas in Sichuan province and Yunnan province in south-western China. Its characteristics are as follows: it can regulate the room temperature to fit the fickle climate in mountain areas and can withstand earthquakes to some extent; it requires only simple materials and minimum manpower but possesses great diversity and mobility; however, to build this type of houses, a great amount of wood is required and the size and location of doors and windows are greatly limited so it is not as widely spread as the other two types.

2.3. The preservation and research status of two typical remaining historic wooden buildings in China

(I) **Yingxian Wooden Pagoda.** Yingxian Wooden Pagoda, originally known as the Yingxian Wooden Pagoda of Fogong Temple, was built in 1056 AD, Liao Dynasty, and is the largest and oldest high-rise wooden building in existence in the world (as seen in Figure 2). It is a 67.31-m tall pagoda of a multi-storied pavilion type with an octagonal cross section and nine floors that disguised as five. It has a diameter of 30.27 m, weighs 7400 tons and altogether consumed 3700 m$^3$ of timber. With 54 types of Dou-gong brackets of different functions, shapes and sizes installed, it is often referred as a museum of Dou-gong bracket. However, as a consequence of multiple earthquakes during the recent thousand years, wars and unfit repair in modern times, the pagoda suffers from all kinds of problems such as a severe tilt of the main body and the twist of the column frame of the second and third floors. Based on the observation data of 2010, the overall slope was 1.25% and counting, especially of the second floor which accounted for 60–70% of the slope.
Since 1933, Liang et al. began to conduct detailed researches and measurement on Yingxian Wooden Pagoda. In 1966, the book Yingxian Wooden Pagoda was published, and in 1973 (see Ref. [5]), architectural experts such as Yang Tingbao began their 10 years of restoration of this architectural treasure after discussing the issue of its partial tilt and setting basic rules and solutions regarding the repair and reinforcement of the pagoda. The Committee of Yingxian Wooden Pagoda Restoration and Preservation Construction Management was found in the 1990s, and after the early-stage study, it started monitoring the structural soundness of the pagoda in 2008 and continued till this day. Since the 1990s, many scholars and their teams have studied the structural state (e.g. Ref. [6]), damage dispersion, seismic reaction analysis (e.g. Ref. [7]) and material deformation (e.g. Ref. [8]) features under external forces. Refined finite element (FE) models were established, respectively, based on the Dou-gong bracket joints and the whole structural system and load-bearing quality analyses were conducted under lateral load (e.g. Ref. [9]). And the ideal restoration model of the pagoda was established through computer-aided design (CAD) drawings and three-dimensional (3D) models (see Ref. [10]). Yet, there are still issues to address in terms of repair and preservation. In recent years, scholars came up with plans such as major repair of the framework, total support of the pagoda and raised support of the upper section. But because of the significance, structural complexity and uniqueness of the pagoda, the present plan is to reinforce and repair the tilted parts and damaged components on the second and third floors (see Ref. [11]).

(2) East palace of Foguang Temple. The palace is located in Wutai county, Shanxi province, in northern China and originally built in Northern Wei Dynasty (386–534 AD, one of the
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References


