The zaojing: review of a unique wooden construction typology

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Abstract

The zaojing is an ancient Chinese construction system consisting of a dome-shaped assembly of interlocked wooden pieces. These structures are placed above live performance spaces to enhance sound diffusion while creating background scenery. Existing zaojings in China display a diverse range of geometric expressions, construction details, and structural behaviours. Despite their uniqueness and historical interest, very little literature about the zaojing is known to exist, and what does is not comprehensive. Building on recent field investigations in rural China, this paper sheds new light on zaojings. Following a summary of ancient Chinese construction practice, a comprehensive list of publications on zaojings is first reviewed. The paper then identifies differences between various zaojings and suggests a typological classification. Construction details and repair practices are eventually described. In conclusion, the study brings forward the typological diversity of the zaojing, a unique wooden ceiling system whose significance in the history of wood joinery construction has not yet been fully appreciated.

Keywords
Zaojing, shallow wooden domes, China, 10th—19th centuries, wood construction, wood-to-wood joints, repair.
Introduction

The zaojing (Chinese: 藻井; pinyin: zǎojǐng) is a Chinese construction system for dome-shaped ceilings that combines small wooden pieces with interlocking connections. It is set in temples, pagodas, palaces, colleges, and theatres, usually in the most distinguished position of the building, e.g. directly above a religious statue, main throne, podium, or opera stage. Usually richly decorated, its uncommon technical refinement was proportional to the value sought and authority of the space that it was intended to cover.

In ancient China, the zaojing was also known as qijing (绮井), huanjing (圜井), fangjing (方井), longjing (龙井), dousi (斗四) and douba (斗八). 'Zaojing' is the designation that is regularly used today in China. Its literal meaning is 'algae well'. Indeed, the zaojing traditionally symbolizes a steady flow of water and is believed in geomancy to suppress the trouble caused by the fire-devil and to protect wooden buildings from fire.

As this type of shallow wooden dome has no direct western equivalent, the term zaojing is used in this paper.

Ancient secular activities, like festivals, gatherings, and celebrations, were always closely related to religious worship. Accordingly, an opera stage was usually arranged within a temple complex and eventually represented the most important public place in the village. However, opera stages were the venues for all stories, involving both human characters and divinities (Figure 1). As such, the construction of zaojings, placed on top of opera stages for structural, aesthetic, and acoustic reasons, was therefore not bound by ancient rigid feudal and religious regulations. This particular historical feature gave rise to a large diversity of developments. Today, most existing zaojings are present in opera theatres, on account of their secular and entertainment use, away from political or religious influence. For all these reasons, this paper mainly focuses on zaojings that cover opera stages.

Figure 1. A performance on the opera stage in Hu’shi Ancestral Temple, Auhu Village, Ninghai County, Zhejiang Province (see Figure 13-k). Built in the 1920s. Photo credits: Peiliang Xu.
After a brief overview of construction practice in ancient China, this paper presents an extensive review of literature on zaojings in China, combining ancient sources with recent publications. The section that follows reports a field investigation carried out recently in both South and North China. This investigation led to the development of an original classification of zaojings. The last section focuses on construction details in zaojings and their repair by contemporary master builders.

**Construction practice in ancient China**

Timber is the predominant material for primary load-bearing systems in ancient Chinese construction. Although China has been influenced by foreign culture many times in history, traditional building construction still retains its essential and basic construction principles⁵.

**Craftsmanship**

According to the Rites of Zhou (周禮)⁶ and Zuo Zhan (左傳)⁷, the ruling class appointed a special officer Si Kong (司空) to design, construct, and manage palaces, defensive walls and hydraulic engineering⁸,⁹. This system has existed since the 10th century BC and has survived the successive dynasties since then. Different titles were given at different times, e.g. Jiang Zuo Jian (将作監) in the Song Dynasty (960-1279). Jie Li (李诫), the author of Yingzao Fashi, was the Chief Jiang Zuo Jian at that time. In the Qing Dynasty (1636-1912), the profession was divided into a ‘sample house’ (樣房, yàng fáng) and a ‘calculation house’ (算房, suàn fáng)⁸. The former was responsible for designing, sketching, and modeling (繪圖, huì tú); the latter was responsible for construction hudge⁸. For instance, the Lei (雷) and Liu (柳) families were known as famous ‘sample’ and ‘calculation’ houses, respectively.

Before the Ming Dynasty (1368-1644), rulers classified craftsmen as artisan households, a lower social class⁸. They were not allowed to be employed in other industries, and instead, had to serve in the imperial engineering corps for free for several years over a lifetime⁸. The so-called artisan-input-policy (輸役) can also be considered as an opportunity for artisans to exchange with, and learn from, each other. Although this feudal policy no longer exists, its legacy is still found in the current carpenter community of rural areas: construction as a skill for subsistence usually stays within the same family.

In the Song Dynasty (960-1297) or before, explicit specialization for construction has been already established. The earliest Chinese construction literature Yingzao Fashi has catalogued ten specialties⁹,¹⁰: hydraulic engineering (堰塞), masonry (石作), large woodwork (大木作), small woodwork (小木作), carving (齏作), forging (鍛作), cutting (錘作), bamboo (竹作), tile (瓦作), and clay (土作). The classification in the Qing Dynasty (1316-1912) added four other specialties¹¹: scaffolding (搭材), lacquer (油漆作), painting (畫作) and window-paper pasting (裱糊作). For each specialty, technical norms and empirical principles were inherited through apprenticeship⁸,⁹,¹⁵.

‘Large woodwork’ refers to the manufacturing and assembly of the main load-bearing elements in buildings: columns, beams, purlins, rafters, etc. It is considered as the most prominent specialty and it plays a dominant role in housing construction. ‘Small woodwork’ commonly refers to the production and installation of non-load-bearing parts. Although zaojings are catalogued as small woodwork in the Yingzao Fashi¹², owing to the refinement of their manufacturing, they were completed by carpenters of large woodwork⁴. This distinction is still true today, as confirmed in our field investigation.

**Faithful structural expression**

The terminology Che Shang Ming Zao (徹上明造), as used in the Yingzao Fashi¹⁰, or Che Shang Lu Ming Zao (徹上露明造), as used by Sicheng Liang¹³, constitutes a strong principle of ancient Chinese construction. It means that roof frames are exposed directly, without any covering. Broadly speaking, it also signifies that all structural components are delicately manufactured and accurate. Carpentry is visible and creates the shape. The zaojing is a perfect representative of this typical feature. The system not only allows a larger span and height but also creates the dome-like shape by employing standard joints.

In March 1932, Huiyin Lin (林徽因, 1904-55), the first female architect in modern Chinese times published her first paper about ancient Chinese Architecture⁵ and stated that:

« the beauty of Chinese architecture lies in its faithful expression of the structure [...] The shape of the building is the straight result of the structure and construction [...] Although the building system has slightly changed from the Ming to the Qing dynasties, e.g. several details became non-structural, the spirit of the visible and expressive load-bearing remained consistent. »
Literature review on zaojings in China

The zaojing in ancient documents

Although China has a long history, very few monographs on its construction history subsist. One reason is that the dissemination of construction skills in ancient China essentially relies on personal communication.

The first known mention of a zaojing in specialized literature lies in Yingzao Fashi (营造法式)\(^{10}\), literally translated as Treatise on Architectural Methods, published in 1103 and authored by Jie Li. The treatise is the oldest existing publication about construction with a systemic introduction in Chinese history. It formulates a unified set of principles and specifications for construction, material consumption, and workloads for official supervisors, builders, and artisans. They were mainly presented in written tables of dimensions, sometimes accompanied by hand-drawn illustrations. The treatise served less as a non-binding technical manual than as a mandatory governmental prescription used to control financial expenses of construction projects\(^{14,15}\). As far as zaojings are concerned, only the douba and small-douba types are recorded in the treatise\(^{12}\), in a written form (Figure 2).

The douba type was mainly applied in official temples. Two remarkable existing wooden examples are the zaojings in the Pagoda of Fogong Temple (应县木塔, 1056)\(^{16}\) and in the Main Hall of Baoguo Temple (保国寺大殿, 1013, Figure 9 top)\(^{17}\).

In another official specialized literature, Gongcheng Zuofa (工程做法)\(^{11}\), published under the Qing Dynasty (1636-1912) and literally translated as Municipal Engineering Practice Rules, the term ‘Dragon Well’ (longjing) is merely mentioned\(^{1}\), without further written or graphical detail.

Some scholar regarded the zaojing in the Taihe Hall (太和殿, 1695) in the forbidden-city as the representative of the longjing-type\(^{1}\). The name already hints that the shape was only allowed within the ruling class.

In other two available non-official monographs, Luban Yingzao Zhengshi (鲁般营造正式, 1465-1505)\(^{19}\) and Yingzao Fayuan (营造法原, completed in 1929)\(^{20}\), there is no mention of zaojing at all.

Since the Tang Dynasty (618-907), it is stipulated that the zaojing could not be used in ordinary secular residences\(^{1,21}\) because it was considered as one of the noblest architectural elements. This fact may explain why few descriptions of zaojing constructions are found in ancient literature.

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The zaojing in modern documents

The first formal study of (ancient) Chinese architecture dates back to the 1930s shortly after the ‘Society for the Study of Chinese Architecture’ was set up.22 A large number of field investigations on existing ancient buildings have been conducted. Sicheng Liang, founding member of the society, not only completed a large number of field surveys, recording and mapping ancient construction work, he also interpreted two historic treatises (Yingzao Fashi and Gongcheng Zuofa), comparing their text with real examples and interviews with artisans. He published the earliest known description of the origin of zaojings in May 1937, based on a dictation of the scholar Zhiping Liu (刘致平, 1909-95):

« The zaojing originated from the Zhongliu (中樞) structure in central Asia [Figure 3 left]. It is a kind of reciprocal frame. On a square or polygonal plane, linear wood or stone members are stacked layer by layer, resulting in a conical frame without vertical support [...]. This construction enables a wider span and larger height. The sky-light or the chimney was placed on the top [...].

In China, in the Han Dynasty (202 B.C-220 A.D), the zaojing has already become a common and mature building part in Chinese architecture, which could be observed in the poems and literature of that time [...]. The image on the portrait of the stone tomb in Yinan (沂南) Shandong Province (山东) is the zaojing in dousi form [...]. The painted ceiling of zaojing form in the Mogao Caves [Figure 3 right] and the Yungang Grottoes are the best surviving specimens in the Sui and Tang dynasties (581-907) [... or the origin of the later form of small zaojing [...]. »

There is currently no agreement on what is the earliest wooden zaojing in China. However, it is known that the existing wooden zaojings in China were all built after the Late Tang Dynasty (618-907), since the earliest existing Chinese wooden construction, the Nanchan Temple, was constructed in 845.

The Volume VII of the Complete Works of Liang Sicheng also provides a translation23 of the original description of douba zaojings in Yingzao Fashi, Figure 4 left. Later on, the book Interpretation of Yingzao Fashi by Guxi Pan (潘桂西, 1928-) offered some further interpretation of the douba.24 When scholar Shen Lu (盧鎮, 1918-77) published the investigation of Xuanluo Pavilion in the Journal of Society for the Study of Chinese Architecture in 1944,25 the construction of a zaojing with the triangular network was briefly discussed (Figure 11 bottom), but without giving any proper name.

More recent mentions of zaojings appear in an analysis of ceilings in the Taishun area (泰順), South Zhejiang (浙江)4, and in a study on the ‘Gao-chi’ technique in Fujian (福建)26 and Taiwan (台灣)27. The latter studies focus on spider-web-shaped zaojings, also brought to attention in the biographical study28 of a critical carpenter master, Yishun Wang (王益順, 1868-1929) from Fujian, who built and guided some significant wooden edifices in Taiwan in the 1920s. Zaojings are also documented in detail in some unpublished reports of conservation works.

In 2015, Hanquan Guo (过汉泉, 1945-), carpenter master from the Jiangsu province (江苏) briefly introduced the construction of zaojings in his handbook on The Techniques of Wooden Construction in Southeast China.29 The discussion is limited to douba and spiral zaojings. Still, the zaojing construction did not circulate in the Jiangsu province, and local carpenters learned the practice and skills from Anhui and Zhejiang provinces.30

The zaojing is also referred to in more studies on opera stages, addressing aspects related to architecture and construction30,31,32,33,34,46,49,50, opera culture34,35,36,37,38,40,43,44, cultural heritage3,31,41, or acoustic performance42. The first description of opera stages was published in 1931.33 Between 1932 and 1933, pictures of twenty-seven opera buildings were published in the Pictorial Drama (国剧画报) (Figure 4 right)44, as a follow-up of Lanfang Mei’s visit to America in 1929.45

Table 1 organizes all references on zaojings and opera stages collected by the authors. It highlights the absence of a comprehensive classification of zaojings. Their geometries, construction techniques, and structural behaviours have not been studied scientifically and systematically. Despite numerous exquisite realizations, no comprehensive research on zaojings has been formed in the architectural academy yet.

Table 1. Existing references on zaojings, arranged by topics.

<table>
<thead>
<tr>
<th></th>
<th>Architectural history</th>
<th>Construction</th>
<th>Geometry</th>
<th>Acoustics</th>
<th>Opera Culture</th>
<th>Cultural Relics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opera stage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zaojings without a specific type</td>
<td>23,30,31,32,33,46</td>
<td>30,49,50</td>
<td></td>
<td>2,3,34,35,36,37,38,40,43,44</td>
<td></td>
<td>2,3,41</td>
</tr>
<tr>
<td>Douba type (official)</td>
<td>1,33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reciprocal type (North)</td>
<td>1,24</td>
<td>1,12,24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spiral type (South)</td>
<td>30,49,50</td>
<td>30,48,49,50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Octagonal type (South)</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spider-web type (South)</td>
<td>26,27,28</td>
<td>26,27,28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sichuan type (South-west)</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Field Investigation of Subsisting Opera Zaojings in China

In order to complete the current knowledge on zaojings, the authors have carried several field investigations in North and South China between 2017 and 2018 (Figure 13).

Opera zaojings in North China

The Shanxi province is home of the largest ancient building heritage in China, including opera-stages. Juxian Wei (卫聚贤, 1899-1989) proposed in 1931 three main reasons contributing to this good preservation:

1. The dry climate in Shanxi is conducive to the preservation of wooden structures.
2. All discovered stages from the Song to the Ming Dynasties used high-quality timber, such as pines and cypresses.
3. People in Shanxi are more conservative and preferred to keep these buildings as ‘original’ as possible when restoring them.

The prevalence of opera stages is closely related to the prosperity of the local opera culture, especially in the Yuan Dynasty (1217-1368). These opera stages were mainly built inside official temple complexes and stood independently from other building structures (Figure 5 top). Figure 5 and Figure 6 display three existing opera stages in North China, all built more than 650 years ago. They are located in the same area, with a unified style and scale. Some scholars assume that they were constructed by the same carpenter faction. These three opera zaojings have more complex geometries and construction processes than the douba zaojings mentioned earlier during the Song Dynasty (960-1279) in the Yingzao Fashi.

In North China, the zaojing essentially functions as the main roof framework. It is composed of wooden sticks that cantilever radially, reaching balance thanks to the lever principle (Figure 7). Generally, it is divided into three levels (Figure 5 and Figure 6): three main progressively smaller square frames with regular 90-degree rotations are positioned at different heights. The height and size of each square frame are critical to the overall assembly since they determine the geometries of the ridgelines and roof slope, as well as structural performance. The dou-gong, which is a typical structural element joining columns and beams, and diagonal-corner elements were employed for load transfer between these squares. This feature is particularly useful to increase the rigidity of the framework during ground movements, which is frequent in the area.
In the above three references, different wood material, member sizes, and composition principles were adopted, resulting in diverse geometrical expressions and spatial arrangements. Since they have no proper name in literature, this paper qualifies them as 'northern zaojings'.

From the Jin (1115-1234) and Yuan dynasties to the Ming Dynasty, the opera stage changed from being open to three sides to one single side, resulting in new stages being reshaped from square to flat rectangle. Consequently, a beam frame with simpler arrangement replaced the roof framework with central symmetry. On the contrary, in south China, the construction of opera stages and zaojings began to prosper from the Ming Dynasty.

**Opera zaojings in south China**

The Ninghai county in Zhejiang Province (浙江) is known as the birthplace of ancient opera stages in South China. Opera stages in Zhejiang were initially built during the Song and Yuan dynasties. During the Ming dynasty, a rapid economic development and relaxed imperial rules
allowed non-dignitary people to construct temples on their own. The tradition of building an opera stage within the temple started simultaneously. The opera stage became the most central public setting in the village as it was used for sacrificial ceremony, clan meetings, and opera performance. Troupes of comedians were invited to perform for several days, particularly during fishing and harvest seasons, important festivals and events, weddings and funerals, as well as during the revision of the genealogical table of a clan. This custom has mostly been preserved today.

The ancestral temple complex was donated by a clan to the community and usually required several years of fine construction. Its refinement and grandeur sought to demonstrate the wealth and prestige of the clan in the area, and it is, therefore, one of the most complex and exquisite architectural elements.

In Ninghai, the opera stage was not a separate unit but positioned centrally and jointly connected to the other buildings of the temple complex (Figure 8 bottom left). Moreover, opera stages in the area frequently combine two or three zaojings in a row: the first one covers the stage, the other two protect the crowd. That is a unique feature among ancient Chinese opera stages. The layout of the temple complex materialises habits related to the watching of plays (Figure 8). The central space under the wooden domes was reserved for guests and local men. In the buildings on both sides, the first floor and its balconies were arranged for women and the ground floor for children. A courtyard impluvium, typical during the Ming dynasty, fills the space in between buildings.

A particular construction policy, translated as ‘split construction’, has been carried out for hundreds of years in the Ninghai county. The traditional Chinese buildings are usually symmetrical. Along the axis, the first portion of the project was divided into two equal parts by the client, who asked two different construction teams to build one half each, including the construction of the structure, the carving, and the painting. Their work would eventually be combined and tightly merged. However, in the meantime, the differences in construction and crafts between two sides were easily distinguished – as seen in the section on top of Figure 8: the two extreme buildings present a different roof structure. The ‘split construction’ process consequently allowed the client to pick the best carpenter master out of the two candidates, who would eventually make up for differences or mistakes in the other half of the building.

The southern zaojings are structurally independent of the roof and do not carry other loads than their self-weight (Figure 12 and Figure 14). An additional self-supported roof covers those zaojings and protects them from rain and wind. Most efforts, when designing these zaojings,
were directed towards increasing acoustic performance. Thanks to this functional separation unlike its northern counterparts, a large diversity of zaojing types could develop in south China.

In the Ninghai county only, there are more than 120 surviving zaojings within ancestral temples. Five main types populate the area: douba, octagonal, round-cap, and spiral. The douba zaojing in Baoguo Temple (Figure 9 top), was built in 1013 and is the earliest known wooden construction in South China. Octagonal (Figure 9 bottom) and round-cap (Figure 10 top) zaojings are direct descendants of douba zaojings. Octagonal and round-cap zaojings are composed of smaller components that are more delicately manufactured. Both types are of similar sizes, with an average height of 1.5m, and width and depth of 3.5m. Round-cap zaojings are named after their resemblance to ancient soldiers’ round cap. Spiral zaojings (Figure 8, Figure 10 bottom, and Figure 11 top) are recognized as the most elaborated type of zaojings, obtained after a counter-clockwise twist of a round-cap zaojing. The choice of one type over another is also given by rules. For example, the octagonal shape is traditionally regarded as a Taoist sign and could not be used randomly.

In addition to the Zhejiang province, the Jiangxi province (江西), Fujian province (福建) are other main distribution areas of surviving zaojings with similar form and size in South China. Spider-web-shaped zaojings (name used by local carpenters, Figure 12) look similar to the octagonal type in Zhejiang but are different in structure. They are specific to...

Figure 12. Spider-web-shaped zaojing in the opera stage of Longshan Temple, Zhanghua County, Taiwan (see Figure 13-z). Rebuilt in 1831. Width: 5.5m; Depth: 5.5m; Height: 5.5m. Photo credits: Longshan Temple. Bottom: Behind structure of the spider-web-shaped zaojing in Dacheng hall of Kong Temple, Taipei, Taiwan (see Figure 13-y). Built in 1925. Carpenter master: Yishun Wang. Width: 4.7m; Depth: 4.7m. Photo credits: Huiyu Huang.

Figure 13. Distribution map of zaojings visited during the field investigations.
the Fujian and Taiwan (台灣) provinces. The zaojing in Xuanluo Pavilion25 (Figure 11 bottom), Sichuan province (四川), is a unique stack of small pieces in an ordered triangle-based grid. Similar types have been found in Jiangxi and Taiwan as well, but with a smaller span, e.g. the zaojing with a span of 3.84m in Sanchuan Hall of Taipei Longshan Temple by master Yishun Wang in the 1920s. Examples of mixed forms also exist, combining web and spiral layouts, for instance.

Spiral zaojings mainly consist of three elements (A, B, and C, Figure 14). Element A is a piece that cantilevers inside to the dome. Element B is a piece whose curve defines the perimeter of the dome. Although element C locks the assembly, it is believed by local contemporary carpenters to be a purely decorative member with no structural function.

Classification of Chinese zaojings

Regional variations in construction techniques and styles have contributed to a diverse range of geometric features (Table 2). Figure 15 compiles all types of zaojings found in Shanxi (North China) and Zhejiang (South China) provinces.

Seven types of zaojings emerge from our investigation, according to their geometry and geographic distribution (Figure 15). The douba, the oldest and official type, is implemented very cautiously and with rare development. The northern zaojing is the only one working as the roof frame. Its geometric pattern is never fixed. Compared to the round-cap type, the spiral zaojing has a greater span and is generally applied in more exquisite opera stages. Although octagonal and spider-web types are geometrically similar, the latter is apparently constructed at a larger scale, and the structure behind is more massive. The triangular network in the xuanluo zaojing could also be adapted to the round-profile geometry. Currently, the example in the Xuanluo Pavilion in Sichuan province is the biggest and oldest example of this type.

Table 2. Comparison of opera stage zaojings in North and South China.

<table>
<thead>
<tr>
<th></th>
<th>North China</th>
<th>South China</th>
</tr>
</thead>
<tbody>
<tr>
<td>climate</td>
<td>dry</td>
<td>high annual rainfall</td>
</tr>
<tr>
<td>geography</td>
<td>plain</td>
<td>mountain area</td>
</tr>
<tr>
<td>seismic zone</td>
<td>yes</td>
<td>now</td>
</tr>
<tr>
<td>prevailing period</td>
<td>from the Yuan to mid-Ming dynasties (approx. from 1300 to 1600)</td>
<td>from the mid-Ming Dynasty (approx. from 1600 to 1920)</td>
</tr>
<tr>
<td>main types</td>
<td>northern</td>
<td>spiral/octagonal/round-cap/spider-web</td>
</tr>
<tr>
<td>dimension of opera stage</td>
<td>width: between 7.3 and 8.0 meters, depth: between 6.8 and 7.9 meters</td>
<td>width: between 4.5 and 6 meters, depth: between 4.5 and 6 meters</td>
</tr>
<tr>
<td>dimension of zaojing</td>
<td>width: between 7.3 and 8.0 meters, depth: between 6.8 and 7.9 meters, height: between 3.7 and 4.4 meters</td>
<td>span: between 3 and 5 meters, height: between 1.2 and 2.3 meters</td>
</tr>
<tr>
<td>column supports</td>
<td>often wood, sometimes stone</td>
<td>often wood, sometimes steel or brass</td>
</tr>
<tr>
<td>structure</td>
<td>some openings on the roof</td>
<td>fully enclosed roof</td>
</tr>
<tr>
<td></td>
<td>The zaojing works as the roof structure</td>
<td>The zaojing is under the roof structure</td>
</tr>
<tr>
<td>components</td>
<td>in large size, barely carved, without painting</td>
<td>in small size, finely carved, with omnipresent colourful painting</td>
</tr>
<tr>
<td>acoustic effects</td>
<td>without acoustic function</td>
<td>obvious acoustic quality</td>
</tr>
</tbody>
</table>
Figure 15. Types of zaojings with dougong assembly. From top to bottom: douba, northern, spiral, round-cap, octagonal, spider-web, xuanluo. Drawing credits: Jingxian Ye.
Current conservation practice of zaojings in North- and South China

Opera Stage in Niuwang Temple,
Wei Village, Linfen County, Shanxi province

The opera stage inside the Niuwang Temple was built in 1283 and is the oldest existing wooden opera stage in China. Its plane is nearly square and is opened toward the North. Two stone columns are set up in the north corners, with the well-preserved inscriptions of the construction year: the north-west column was set up initially, in 1283; and the north-east column was a replacement from the first repair in 1321. This information is consistent with the inscription in the opposite temple of the whole complex. The repair in 1321 followed a very high-magnitude earthquake in 1303 and its three to four year-long aftermath. Two round wooden columns are set up in the south corners. The stage base is 1.15 meters lifted above the ground and is covered by a hip-and-gable roof. The temple complex has been occupied by a machinery factory since 1970.

In Shanxi, the repair of ancient buildings is generally taken upon by the local official cultural heritage protection department. The latest significant repair of the Niuwang Temple complex started in August 1977 and lasted one year. According to two reports documenting the process, the repair strategy was determined by the following conditions:

1. The main framework is original from 1321. Only the roof surface, tiles, and edges of the foundation were replaced or repaired during the Ming or Qing dynasties. Most rafters have been shortened over time.
2. Due to the sunken road on the south of the stage, the drainage channel has long eroded the stage foundation. The south stage base, therefore, appeared cracking and squeezing and both wooden columns sunk from being continuously soaked in water. The stage base is 1.15 meters lifted above the ground and is covered by a hip-and-gable roof. The temple complex has been occupied by a machinery factory since 1970.
3. Though the opera stage has been severely tilted to the south, the zaojing maintained its stability, and no cracking or loose dislocation between joineries could be found. Therefore, it was unnecessary to dismantle and repair this part piece by piece. However, most dougong members under the eaves had to be replaced because they reached a strength limit in tension, and were plastically deformed. They were made of local poplar timber.

Consequently, the repair sequence consisted in: unloading the roof structure, i.e. removing roof tiles, boards, and rafters; lifting as one block the part of the zaojing that is above the second square frame; fixing it on a temporary scaffolding; dismantling the lower components; reinforcing the foundation; levelling the columns and the bottom square frame (tie); replacing the damaged components of the bottom layer with eucalyptus in order to increase their tensile strength; dropping and installing the lifted upper frame; and eventually protecting the wooden pieces from water using tung oil. The process prevented the dismantling and hence the damaging of most of the zaojing while reducing operational costs and construction time.

Figure 16. Opera stage in Niuwang Temple, Wei Village, Linfen County, Shanxi Province (see Figure 13-c). Built in 1283, rebuilt in 1321. Top: Section view, excerpt from Kaiying Wu. Bottom: Zaojing above the second frame. Photo credits: Jingxian Ye.

Opera Stage in Family Ye’s Ancestral Temple,
Yi Shi Village, Ninghai County, Zhejiang Province

The other traditional approach to repair is called luojia (落架, Luò Jià) and consists in dismantling every single piece before repairing and replacing it at the same location. The repair of the spiral zaojing in the opera stage of family Ye’s ancestral temple (Figure 17) recently provided a perfect illustration of the approach. The process provided a rare opportunity to observe the inner structure, construction, and wooden-joints of the chicken-cage spiral type. Four main steps can be identified and are illustrated in Figure 17: preparation; disassembly; repair and manufacture; reassembly.

The preparation traditionally starts with a sacrificial ceremony in honour of the local ancestors. The topmost components of the roof structure are first removed. Tiles and beams are divided into two groups depending on whether they present good properties, in which case they will be reclaimed at the end of the process. Carpenters tend to keep a large number of wooden beams in place in order to use them as a stand during the next steps (Figure 17 first row).
The disassembly of the zaojing starts with the removal of the top plates, generally fixed with handmade nails. The rest of the assembly uses purely interlocking and is made loose thanks to the upward tap of a wooden hammer or stick. From the top layers to the bottom ones, tangential curved slats are removed before radial cantilever elements. Components of a same layer are numbered clockwise and temporarily tied up together (Figure 17 second row).

During the repair and re-manufacture steps, component are first visually checked and cleaned with a brush. Newly manufactured components replace original ones if more than a third of the whole length is damaged, or if the critical joint is seriously destroyed without a possibility of repair. When the newly manufactured component is small enough, it is made from previously discarded components (Figure 17 third row).

The reassembly follows the inversed sequence. A trial assembly is performed beforehand in order to ensure the fitting of all elements. Small cracks are filled with tiny slivers of timber in order to ensure that every node works effectively in a tight construction (Figure 17 fourth row).

Figure 17. Renovation of the spiral zaojing in Family Ye’s ancestral temple, Yi Shi Village, Ninghai County, Zhejiang Province (see Figure 13-a). Started from 16th February 2016. From top to bottom and from left to right: disassembly of roof, removal of top plates, hammering of caisson; dismount of 18th layer, tie-up of same-layer components, clean-up of components; carving of new cantilever component, carved component, manufacturing of new tenon tongue; reassembly, hammering of reassembled caisson, close to completion. Photo credits: Xiaodong Chai.
Conclusions

To draw parallels between Chinese and Western cultures is not common in construction history. In 1923, Huiyin Lin used western gothic architecture to characterise, for the first time, the ‘faithful structural expression’ of ancient Chinese frame construction5: both share a common attitude in displaying their ‘true’ form, i.e. the one needed to guarantee their stability. For most construction systems, the comparison stops here since gothic architecture mainly builds on masonry and the transfer of axial compression forces, while Chinese architecture mainly builds on timber and the transfer of bending moments.

However, when considering domes, gothic cupolas and southern zaojings, share further peculiarities: both can only support their own weight and are meant to enclose a major space with a continuous and decorated ceiling surface. In both cases, an invisible timber framework carries the roof weight and withstands wind or seismic loads. In both cases, the span is achieved with proportionally smaller pieces. In both cases, the circular base of the dome evolves from four quadrangular points of supports.

What distinguishes the southern zaojing however, and the spiral zaojing in particular, is its mixed use of stack and cantilever principles when assembling the small wooden pieces. Not only this mixed use would mechanically not make sense with stone elements, it also decreases acoustic reverberation by creating a rougher ceiling surface than masonry domes.

Opera zaojings have rare equivalent in China and abroad. Unlike large religious or political landmarks, surviving specimen are located in rural areas and have not benefitted from continuous care and restoration. Nevertheless, they are the pride of each village and some are maintained thanks to skilled local master builders who perpetuate an age-old empirical construction knowledge. The genesis of that knowledge has yet to deliver all its secrets.

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6. Dongqian Zhou (周公干). Rites of Zhou (周礼) [M]. Appr. The middle of the 2nd century BC.

7. Quanzuo Zuo (左丘明). Zuo Zuan (左传) [M]. 403-386 BC. (Narrative range 722 - 468 BC.)


10. Jie Li (李诫). Yingzao Fashi (营造法式) [M]. 1103. After the establishment of the North Song Dynasty (960-1127), palaces, regional administrative offices, temples, and gardens with luxurious and exquisite styles were extensively constructed. Officials in charge of the project riddled with corruption. The state treasury could not cope with the huge expenses. Therefore, design standards, specifications, materials, construction quotas, and building grades were urgently formulated to prevent corruption. In the first edition of Yingzao Fashi in 1091, an appropriate modular system and precise material regulations is lacking. Therefore, fraudulent practice could not be prevented. In 1097, Jie Li was appointed to re-edit the regulations. He consulted a large number of old rules, and empirical techniques from various experienced artisans. The new Yingzao Fashi was completed and published in 1103, with a total of 34 volumes.

11. - Ministry of Works (工部). Qing Gongcheng Zuofa (清工部工程做法) [M]. Abbreviation. Gongcheng Zuofa (工程做法). 1734. It is a monograph on building technology in the Qing Dynasty, with a total of 71 volumes. The first 27 volumes list twenty-seven kinds of building-frames. The last 24 volumes are focused on the quotas of materials and workloads. The remaining amounts are about other specialties or works.


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