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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 exist 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.

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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 position¹ 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* (綺井), *huanjing* (圓井), *fangjing* (方井), *longjing* (龍井), *dousi* (斗四) and *douba* (斗八)¹. '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^{2,3}. However, opera stages were the venues for all stories⁴, 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* (周礼)⁶ and *Zuo Zhuan* (左传)⁷, the ruling class appointed a special officer *Si Kong* (司空) to design, construct, and manage palaces, defensive walls and hydraulic engineering^{8,9}. 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* (将作监) in the Song Dynasty (960-1279). Jie Li (李诫)¹⁰, 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' (样房, yàng fáng) and a 'calculation house' (算房, suàn fáng)⁸. The former was responsible for designing, sketching, and modeling (烫样, tàng yàng); the latter was responsible for construction budget⁸. For instance, the Lei (样房雷) and Liu (算房刘) 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 (输役) 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 *Yinzhao Fashi* has catalogued ten specialties^{9,10}: hydraulic engineering (壕寨), masonry (石作), large woodwork (大木作), small woodwork (小木作), carving (雕作), forging (旋作), cutting (锯作), bamboo (竹作), tile (瓦作), and clay (土作). The classification in the Qing Dynasty (1316-1912) added four other specialties¹¹: scaffolding (搭材作), lacquer (油漆作), painting (画作) and window-paper pasting (裱糊作). For each specialty, technical norms and empirical principles were inherited through apprenticeship^{8,9,15}.

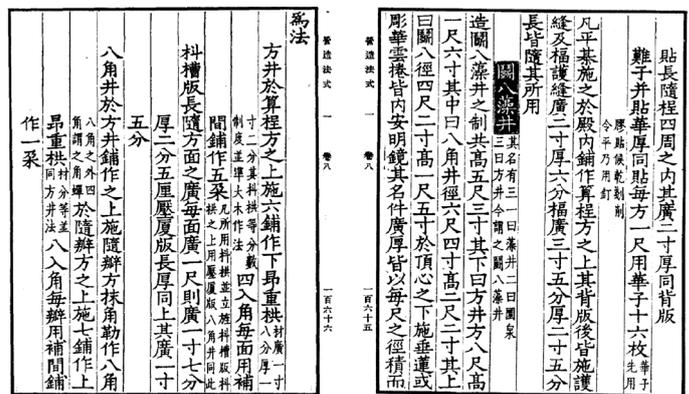


Figure 2. Description of Douba zaojing, pages extracted from the Principles of Small Woodwork III, Volume VIII of *Yingzao Fashi*¹², published in 1103.

'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 *Yinzhao Fashi*¹², 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* (彻上明造), as used in the *Yingzao Fashi*¹⁰, or *Che Shang Lu Ming Zao* (彻上露明造), 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 treatise¹², 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 mentioned¹, without further written or graphical detail.

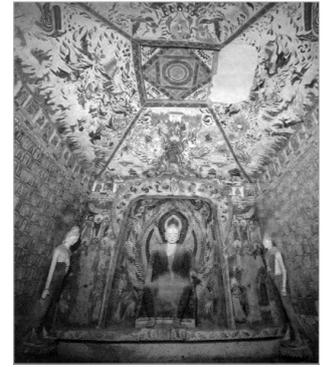
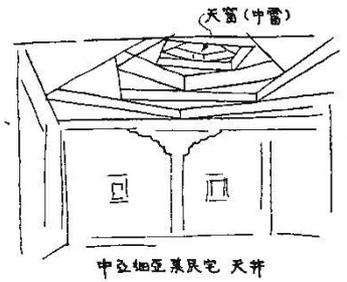


Figure 3. Left: sketch from the Zhongliu (中雷) structure in central Asia, excerpt from *Sicheng Liang*¹. Right: the painted *zaojing* in the Mogao Grottoes Cave No.249, Dunhuang, Gansu Province (甘肃). Built under the Western Wei Dynasty(A.D.535-556). Photo credits: Dunhuang Academy.

Some scholar regarded the *zaojing* in the Taihe Hall (太和殿, 1695) in the forbidden-city as the representative of the *longjing*-type¹. 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.

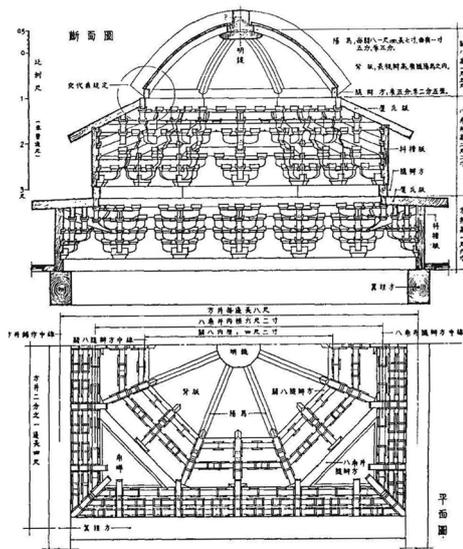


Figure 4. Left: Section and plan of a *douba*, an excerpt from *Liang Sicheng*²³. Right: The opera stage in Sichuan Province, as published in 1932. Photo credits: Rushan Qi.

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 up²². A large number of field investigations on existing ancient buildings have been conducted. Sicheng Liang (梁思成, 1901-1972), 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 1937¹, based on a dictation of the scholar Zhiping Liu (刘致平, 1909-95):

« The *zaojing* originated from the Zhongliu (中雷) 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 skylight 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 Yinzaofashi* by Guxi Pan (潘谷西, 1928-) offered some further interpretation of the *douba*²⁴. When scholar Shen Lu (卢绳, 1918-77) published the investigation of Xuanluo Pavilion in the *Journal of Society for the Study of Chinese Architecture* in 1944²⁵, 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 (泰顺), South Zhejiang (浙江)⁴, and in a study on the ‘Gao-chi’ technique in Fujian (福建)²⁶ and Taiwan (台湾)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 (王益顺, 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 provinces⁴.

The *zaojing* is also referred to in more studies on opera stages, addressing aspects related to architecture and restoration^{23,30,31,32,33,46,49,50}, opera culture^{2,34,35,36,37,38,40,43,44}, cultural heritage^{2,3,41}, or acoustic performance⁴². The first description of opera stages was published in 1931⁴³. 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 1929⁴⁵.

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.

	Architectural history	Construction	Geometry	Acoustics	Opera Culture	Cultural Relics
Opera stage	23,30,31,32,33,46	30,49,50			2,34,35,36,37,38,40,43,44	2,3,41
<i>Zaojings</i> without a specific type	1,33			42		
<i>Douba</i> type (official)	1,24	1,12,24				
Reciprocal type (North)	30,49,50	30,48,49,50				
Spiral type (South)		29	29			
Octagonal type (South)	4	4				
Spider-web type (South)	26,27,28	26,27,28				
Sichuan type (South-west)	25	25				

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 (山西) 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 preservation⁴⁷:

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)^{2,30,32}. 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^{2,30,31}. They are located in the

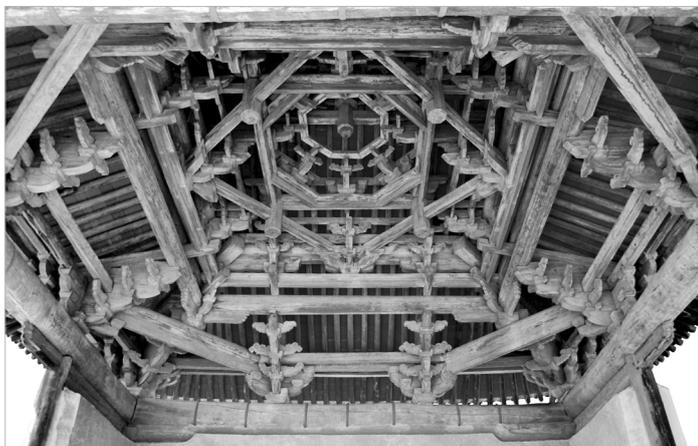


Figure 5. Opera stage in Niuwang Temple, Wei Village, Linfen County, Shanxi Province (see Figure 13-c). Built in 1283, rebuilt in 1321. Width: 7.45m; Depth: 7.42m; Height: 3.79m. Photo credits: Jingxian Ye.

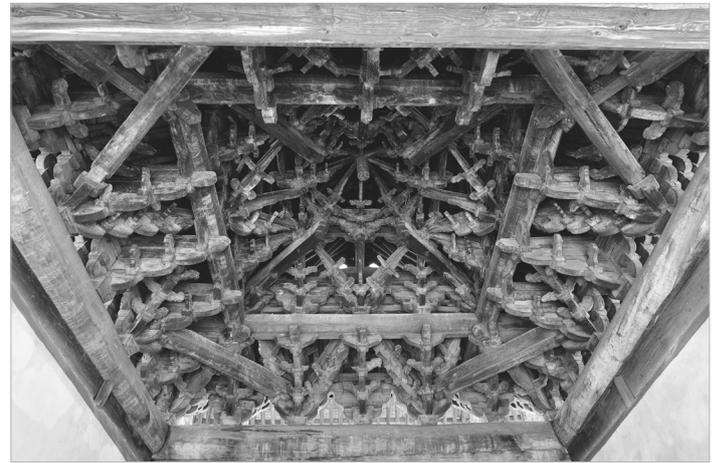


Figure 6. Top: Opera zaojing in Dongyang Temple, Dongyang Village, Linfen County, Shanxi Province (see Figure 13-d). Built in 1345. Width: 8.04m; Depth: 7.90m; Height: 4.43m. Bottom: Opera zaojing in Dongyue Temple, Wangqu Village, Linfen County, Shanxi Province (see Figure 13-e). Built in 1350 (est.). Width: 7.37m; Depth: 6.83m; Height: 4.14m. Photos credits: Peiliang Xu.

same area, with a unified style and scale³¹. Some scholars assume that they were constructed by the same carpenter faction³⁰. 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-angle 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.

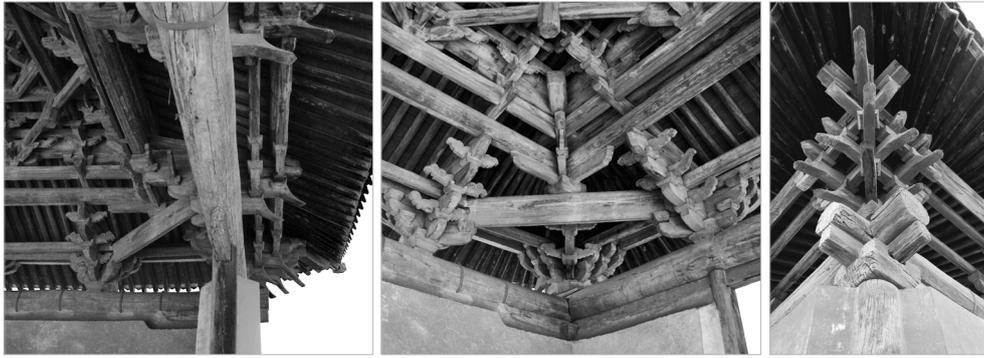


Figure 7. Details of opera zaojing in Niuwang Temple, Wei Village, Linfen County, Shanxi Province (see Figure 13-c). Built in 1283, rebuilt in 1321. Width: 7.45m; Depth: 7.42m; Height: 3.79m. Photo credits: Jingxian Ye.

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 symmetry³⁰. On the contrary, in south Chi-

na, 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 dynasties³. During the Ming dynasty, a rapid economic development and relaxed imperial rules

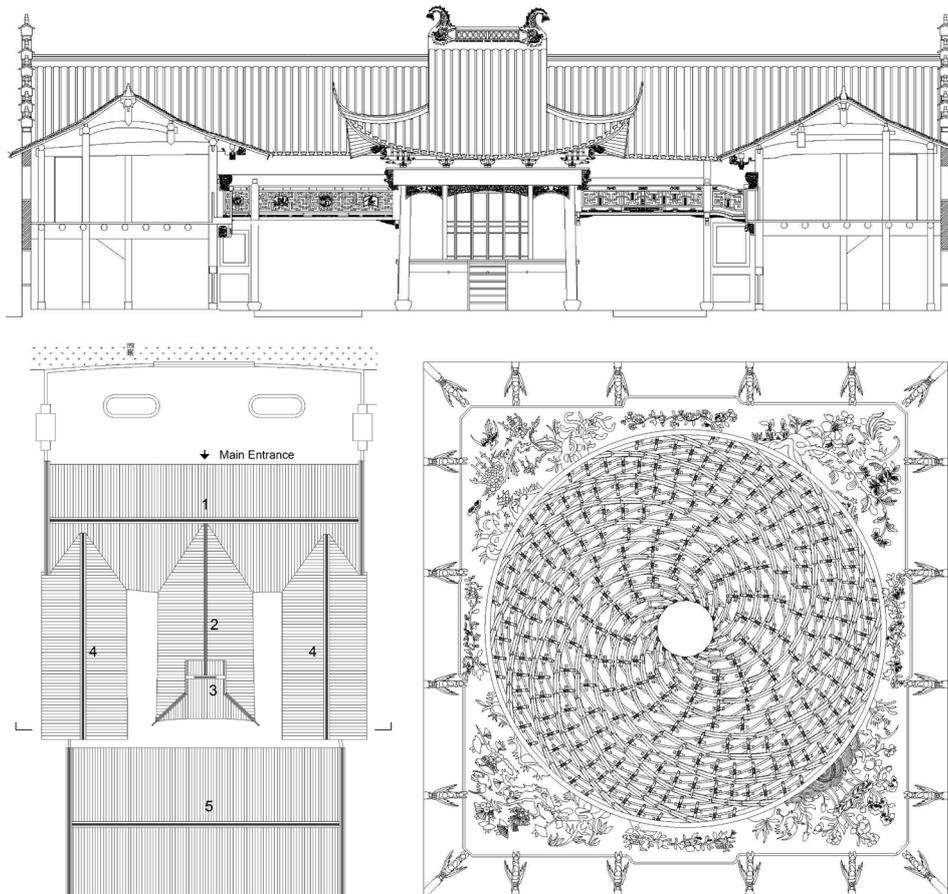


Figure 8. Wei'shi Ancestral Temple, Xiapu Village, Ninghai County, Zhejiang Province (see Figure 13-l). Built in 1890. Height: 1.15m; Diameter: 3.3m. Top: section view through the temple, the opera stage is in the middle. Bottom left: top view of the temple: 1. backstage; 2. opera stage under the zaojing; 3. seats under the other zaojings; 4. wing buildings; 5. temple hall. Bottom right: plan view of the spiral zaojing above the opera stage. Drawing credits: Ninghai Government.

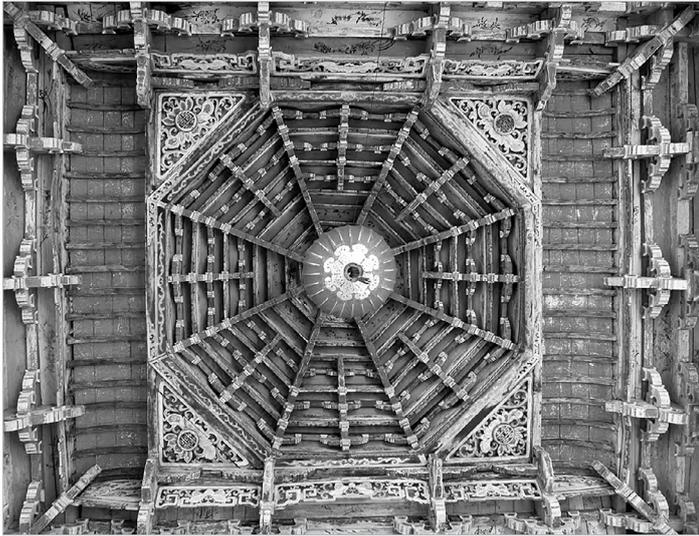
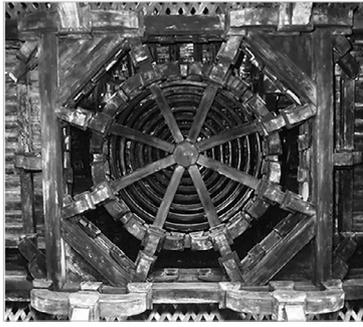


Figure 9. Top: Small *douba zaojing* in the main hall of Baoguo Temple, Ningbo County, Zhejiang Province (see Figure 13-r). Built ca. 1013. Height: 0.9m; Diameter: 1.85m. Bottom: Octagonal *zaojing* in the opera stage of Chongxing Temple, Xidian Village, Ninghai County, Zhejiang Province (see Figure 13-m). Built in 1841. Height: 1.38m; Diameter: 2.74m. Photo credits: Peiliang Xu.

allowed non-dignitary people to construct temples on their own³. The tradition of building an opera stage within the temple started simultaneously³. 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 construction³. 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

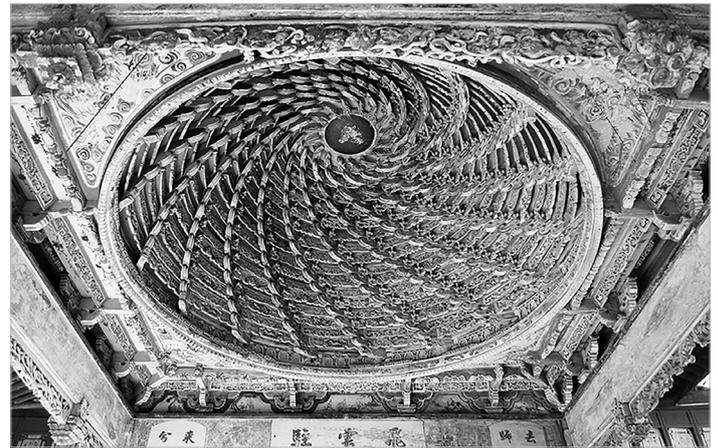
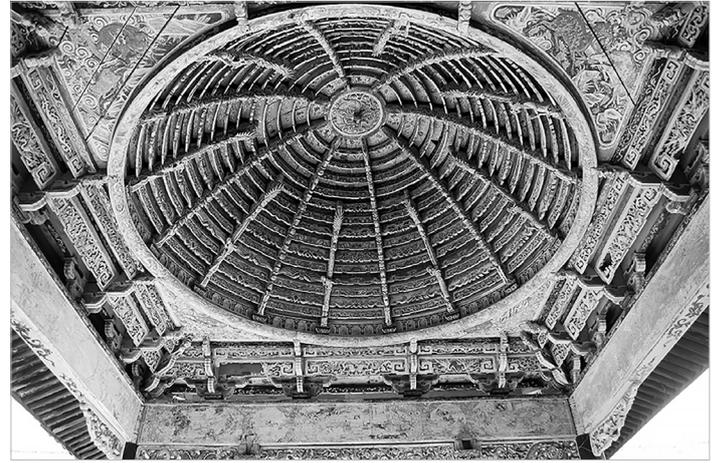


Figure 10. Opera stage of Hu'shi Temple, Au Hu Village, Ninghai County, Zhejiang Province (see Figure 13-k). Built in the 1920s. Height: 1.38m; Diameter: 3.45m. Top: Round-cap *zaojing*. Bottom: Spiral *zaojing*. Photo credits: Jingxian Ye.

under the wooden domes was reserved for guests and local men³. In the buildings on both sides, the first floor and its balconies were arranged for women and the ground floor for children³. A courtyard *impluvium*, typical during the Ming dynasty⁵¹, fills the space in between buildings.

A particular construction policy, translated as 'split construction' (劈作做), 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 painting³. 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*,

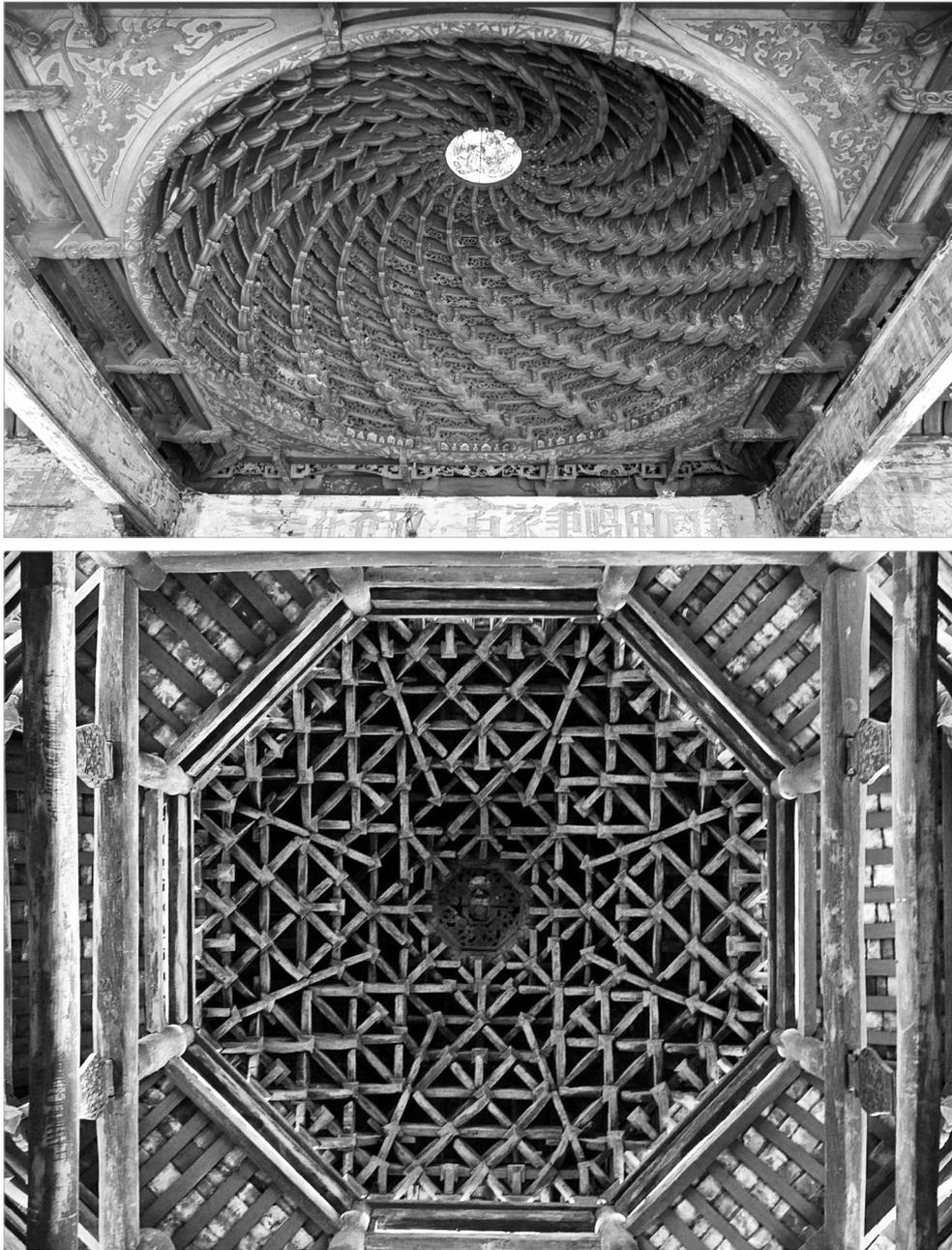


Figure 11. Top: Spiral *zaojing* in opera stage of Yu'shi Temple, Ma Au Village, Ninghai County, Zhejiang Province (see Figure 13-n). Rebuilt in 1911. Height: 1.46m; Diameter: 3.8m. Photo credits: Peiliang Xu. Bottom: Xuanluo *zaojing*, in the Xuanluo Pavilion, Li Zhuang Village, Yibin County, Sichuan Province (see Figure 13-s). Built in 1596. Width: approx.4m; Depth: approx.4m. Photo credits: Sichuan Tourism Information.

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 China¹⁷. 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 randomly⁴.

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

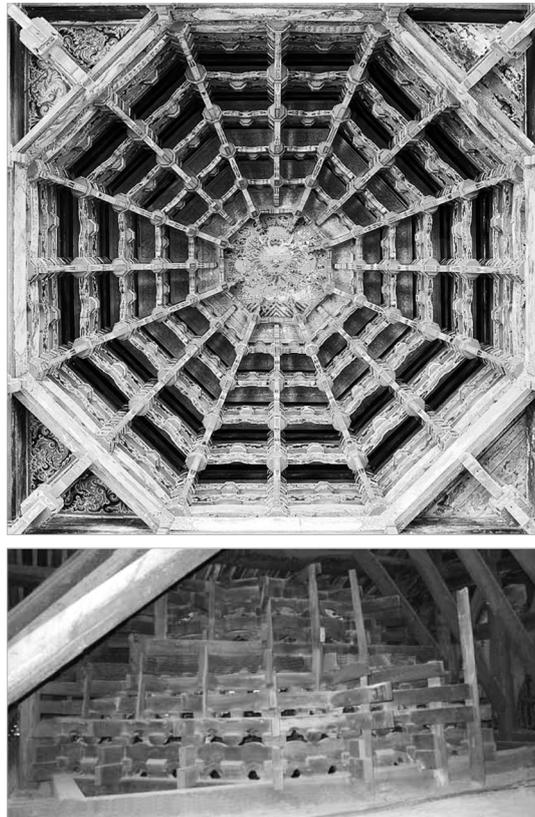


Figure 12. Spider-web-shaped zaojing in the opera stage of Longshan Temple, Zhanghua County, Taiwan (see Figure 13-z). Rebuilt in 1831. Width:5.5m; Depth:5.5m; Height: Photo credits: Longshan Temple. Bottom: Behind structure of the spider-web-shaped zaojing in Dacheng hall of Kong Temple, Taipei, Taiwan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



- | | | | |
|------------------------------|------------------------------|-------------------------------|-------------------------------------|
| a. Dou Dafu Temple, Taiyuan | h. Yuhuang Guan, Changzhi | o. Ye'shi Temple, Ninghai | v. Hua Bridge, Pinnan |
| b. Zishou Temple, Jinzhong | i. Dai Temple, Zezhou | p. Chenghuang Temple, Ninghai | w. Sanguan Temple, Zhangzhou |
| c. Niuwang Temple, Linfen | j. Sanshan Huiguan, Shangai | q. Qin'shi Temple, Ningbo | x. Yu'shi Ancestral Temple, Lantian |
| d. Dongyang Temple, Linfen | k. Hu'shi Temple, Ninghai | r. Baoguo Temple, Ningbo | y. Kong Temple, Taipei |
| e. Dongyue Temple, Linfen | l. Wei'shi Temple, Ninghai | s. Xuanluo Pavillion, Yibin | z. Longshan Temple, Zhanghua |
| f. Feiyun Building, Linfen | m. Chongxing Temple, Ninghai | t. Tianbao Village, Yichun | |
| g. Wufeng Building, Changzhi | n. Yu'shi Temple, Ninghai | u. Huyan Temple, Jindezhen | |

Figure 13. Distribution map of zaojings visited during the field investigations.

the Fujian and Taiwan (台湾) 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.

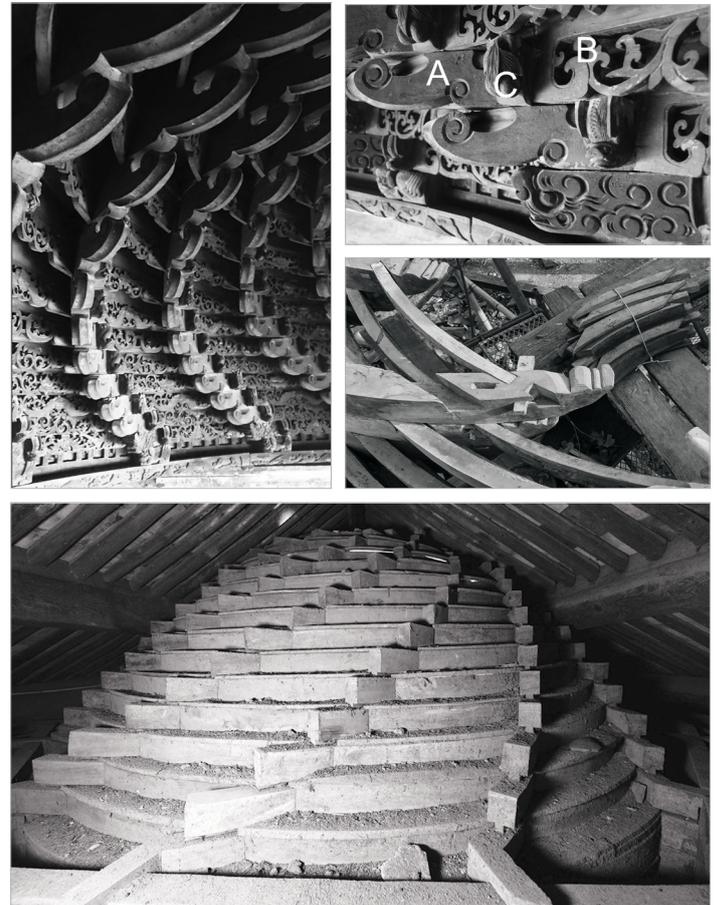
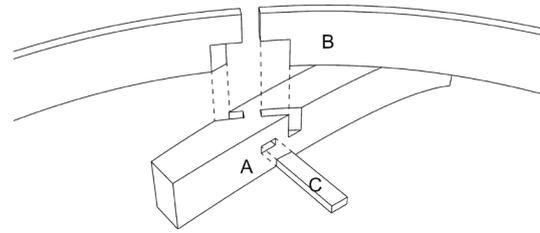


Figure 14. Construction details of spiral *zaojings*. Credits: Jingxian Ye.

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

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

		<p><i>Douba type</i></p> <ul style="list-style-type: none"> - closed roof - not the roof structure - in North & South China
		<p><i>Northern type</i></p> <ul style="list-style-type: none"> - open roof - supports the roof structure - in North China
		<p><i>Spiral type</i></p> <ul style="list-style-type: none"> - closed roof - not the roof structure - in South China
		<p><i>Round-cap type</i></p> <ul style="list-style-type: none"> - closed roof - not the roof structure - in South China
		<p><i>Octagonal type</i></p> <ul style="list-style-type: none"> - closed roof - not the roof structure - in South China
		<p><i>Spider-web type</i></p> <ul style="list-style-type: none"> - closed roof - not the roof structure - in South China
		<p><i>Xuanluo type</i></p> <ul style="list-style-type: none"> - closed roof - not the roof structure - in South-West China

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^{2,31,32,49,50}. 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 complex⁴⁹. The repair in 1321 followed a very high-magnitude earthquake in 1303 and its three to four year-long aftershock⁴⁹. 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 1970⁴⁸.

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^{48,49}. According to two reports documenting the process^{48,49}, 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 dynasties⁴⁹. Most rafters have been shortened^{48,49} over time.
2. Due to the sunken road on the south of the stage, the drainage channel has long eroded the stage foundation⁴⁸. The south stage base, therefore, appeared cracking and squeezing and both wooden columns sunk from being continuously soaked in water^{48,49}.
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 piece⁴⁸. However, most *dougong* members under the eaves had to be replaced because they reached a strength limit in tension, and were plastically deformed⁴⁸. 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 (桐油)^{48,49}. The process prevented the dismantling and hence the damaging of most of the *zaojing* while reducing operational costs and construction time⁴⁸.

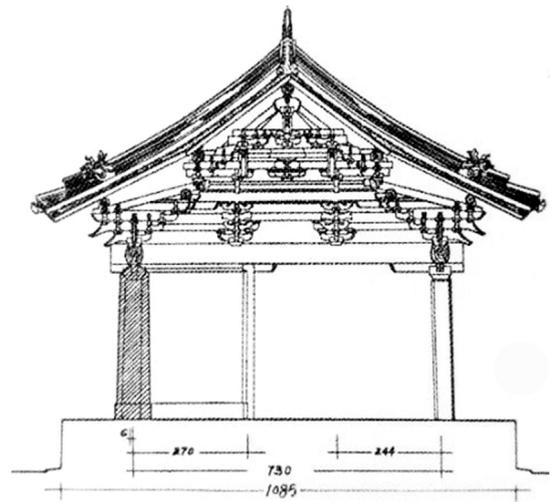


Figure 16. *Opera stage in Niuwang Temple, Wei Village, Linfen County, Shanxi Province* (see Figure 13-c). Built in 1283, rebuilt in 1321. Top: Section view, excerpt from Kaiying Wu². Bottom: *Zaojing* above the second frame. Photo credits: Jingxian Ye.

*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)⁸ 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).

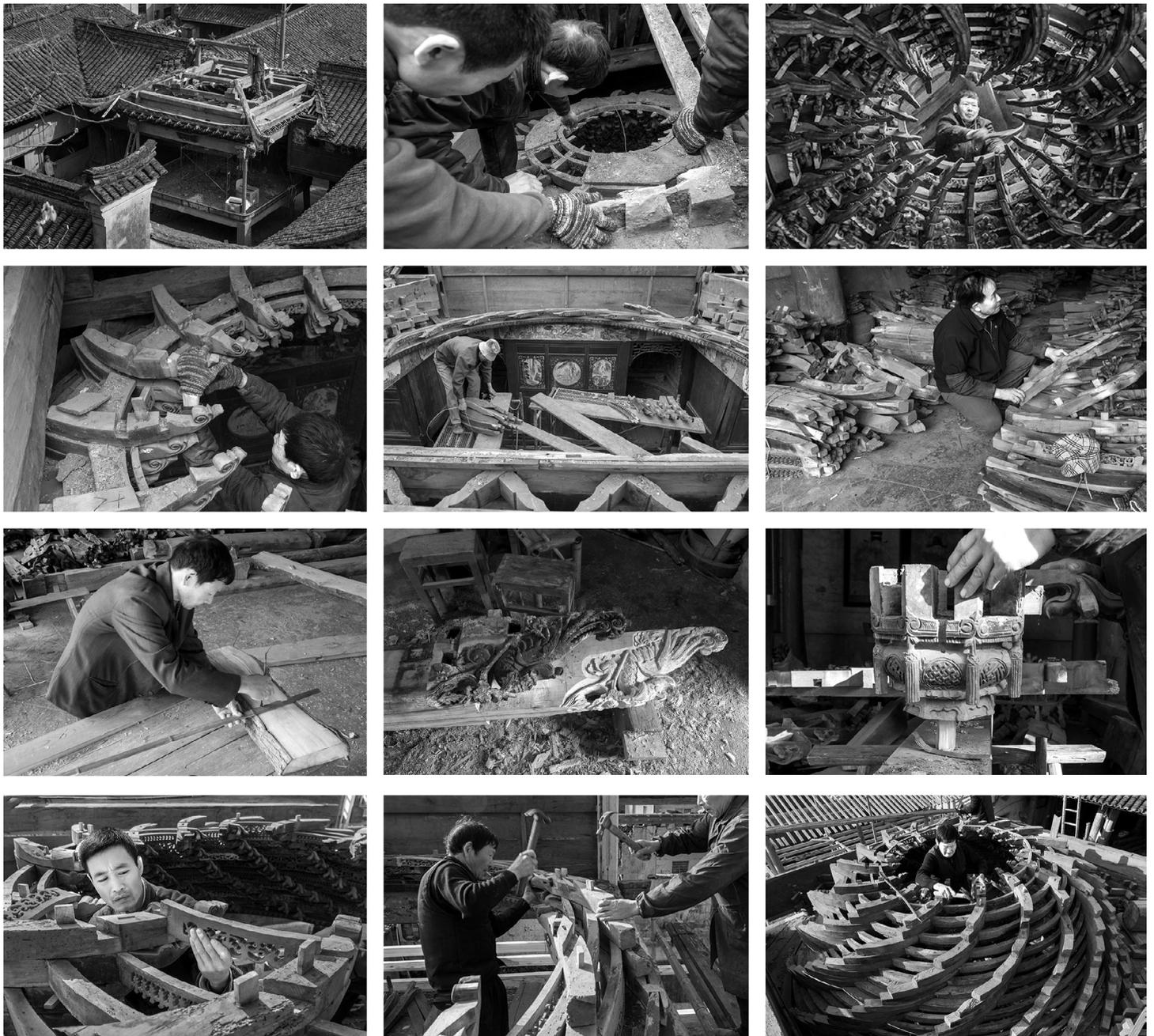


Figure 17. Renovation of the spiral *zaojing* in Family Ye's ancestral temple, Yi Shi Village, Ninghai County, Zhejiang Province (see Figure 13-o). Started from 16th February 2016. From top to bottom and from left to right: disassembly of roof, removal of top plates, hammering of caisson; dismantling 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.

Acknowledgment

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