

# The ancient Chinese opera spiral wooden domes

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## Introduction

### *The zaojing \_ shallow wooden dome*

The *zaojing* is an ancient architectural element that is widely found in various public buildings, such as temples, pagodas, palaces, and theatres. It is a richly decorated sunken ‘dome’ with a round top and a square bottom set into the ceiling and assembled from a large set of pieces using purely interlocking wood connections. The domes were usually used in the centre of buildings, directly above a religious statue, main throne or opera stage.

The literal meaning of the *zaojing* (Chinese: 藻井; pinyin: zǎojǐng) in Chinese is ‘algae well’. Therefore, the *zaojing* is traditionally the symbol of a steady flow of water, and believed in geomancy to suppress the trouble caused by the fire-devil and to protect wooden buildings from fire. As this form has no Western equivalent, the term *zaojing* will be used in this paper to refer to this kind of shallow wooden dome.

### *Opera zaojing*

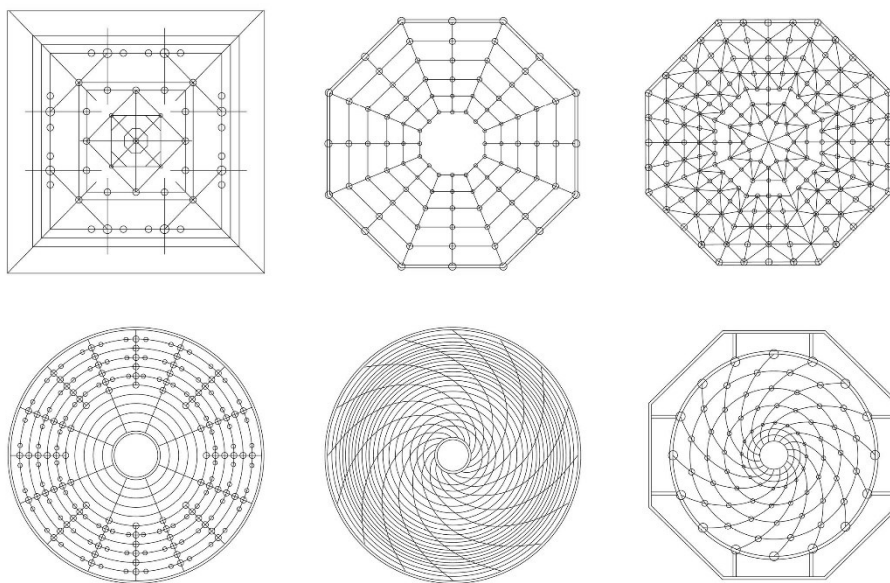
In ancient times, the secular activities, like festivals, gatherings and celebrations, were always closely related to religious worship. Accordingly, an opera stage was usually arranged within a temple complex. They consequently formed the most important public place in the area. In these ancient opera stages, *zaojings* were frequently employed for their structural, aesthetic and acoustic properties.

In South China, ancient opera stages with *zaojings* are found mostly in ancestral temples where sacrificial ceremony, gatherings and clan meetings took place. The complete edifice was donated and supported by one clan and its refinement and grandeur sought to demonstrate the wealth and prestige of the clan in the local and it is, therefore, one of the most complex and exquisite architectural elements [1]. An opera performance (Fig.1) generally lasted for several days and was staged whenever important festivals and events took place — particularly those marking the opening of the fishing season or harvest, as well as weddings and funerals [2]. This custom has largely been preserved today.

Regional variations in construction techniques and styles contributed to a diverse range of geometric expressions, delicate manufacturing and structural behaviours. This paper is based on the field research into existing opera wooden domes in Shanxi province (north) and Zhejiang province (south), which has revealed at least six types (Fig.2). This paper concentrates on the spiral wooden dome, which is a unique local type.



*Figure 1. An opera performance at the opera stage of Hu'shi Ancestral Temple, Auhu Village, in Ninghai. Built in the 1920s. Ref. ZJ-01. Photo: Xiao Wang Shushu.*



*Figure 2. Six kinds of zaojing types collected during a field research. Above: Reciprocal, Spider's-web, Ru-yi gong; below: Round-cap, Spiral, Mix of Octagonal and Spiral.*

This paper focuses on the spiral *zaojing* in the Ningbo area, Zhejiang province (South China). The field practice of surviving traditional wooden construction in rural China is discussed by looking at surviving examples (Figs 1-3), examining a newly-built example (Fig.8), its renovation process (Fig.9), the involved construction technology (Fig.7) and its evolution (Fig.8).

## Spiral Opera Wooden Domes in South China

### *The spiral type and its variations*

The spiral *zaojing* is constructed in the form of a counter-clockwise spiral, embedded in the centre of the ceiling. In the area surveyed, more than 20 surviving ancient spiral wooden domes have been recorded. They were constructed or reconstructed from the Mid-Qing Dynasty (approx.1750) to the early modern period (early 20th century). The existing spiral types are of similar sizes, with an average span of 3.5-4 meters, a depth of 2 meters. Among them, the ancient opera spiral dome in Qin'shi Ancestral Temple (Fig.3 left, ZJ-02), completed in 1925, reaches a remarkable span of more than 5 meters.

Two spiral variations have been catalogued in the region. The first, is named *chicken-cage-spiral* type (Fig.3 left) after its resemblance to the local bamboo chicken cage [2]. The second, named *ox-hair-spiral* type (Fig.3 right), provides a more expressive and dynamic perception because of the intense movement in the spiral geometry, but it certainly is more complex in terms of geometric generation and construction.

During the investigation, carpenters with the ability to construct new chicken-cage-spiral wooden *zaojings* have been interviewed. A representative example of a new spiral chicken-cage type has been documented precisely. It is located in the main hall of Baoguang Temple (Fig.8), just completed in 2017 by carpenter Master Liquan Zhang in Yinzhou of Ningbo area Zhejiang province.

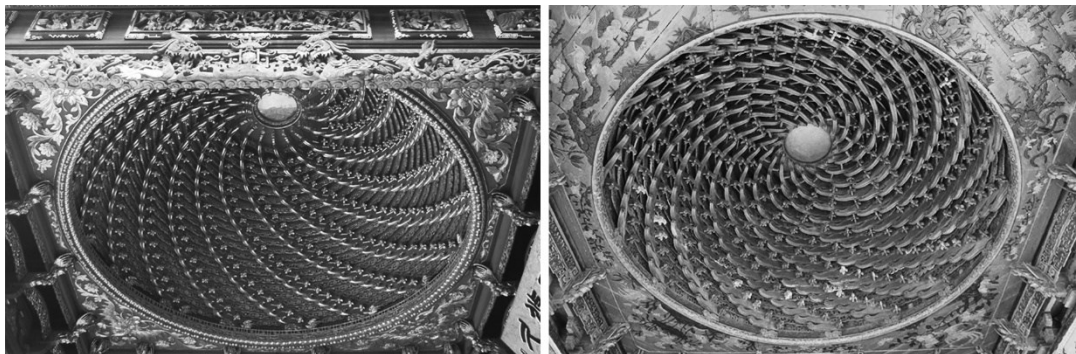


Figure 3. left: *chicken-cage-spiral* type in the opera stage of Qin'shi Ancestral Temple, in Ningbo. Built in 1925. Height: approx. 2.25m; Diameter: approx.5m. Ref. ZJ-02; right: *ox-hair-spiral* type in the opera stage of Wei'shi Ancestral Temple, Xiapu Village, in Ninghai, built in 1890. Height: 1.15m; Diameter: 3.3m. Ref. ZJ-03. Photo: Peiliang Xu.

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### *Geometry of the spiral type*

Sketching is the first step for a new spiral *zaojing* construction. It should be noted that the sketching graph is conducted from the view of the producer, i.e. above the dome. It is opposite to the rotation direction of the pattern from the perspective of a viewer. The sketching tools are usually leftover pieces of timber on site: one wood board, one wooden strip with a steel nail passed through it and one pencil. The geometric data for all the circles and curves are engraved on the wooden strip (Fig.4 left).

#### Circle and Division.

The spiral wooden dome is regularly divided by the spiral lines, called “Yangma” (阳马) locally. In most cases, it is evenly divided into 16 parts by 16 spiral lines (Fig.5), sometimes 20. The corresponding points of division are well distributed on the inner- and outer- circle, basically positioned at midpoint. As opposed to the European history of geometry, no concept of angle existed in ancient China [3]. Consequently, the adoption of the midpoint principle contributed to the distinctive characteristic of even division and symmetry in traditional Chinese construction.

#### Spiral Line.

The spiral wrap line is the curve connecting the points of division on the inner- and outer- circles, which determines the visual expression of a spiral wooden dome. The curvature of the spiral line is controlled by carpenters themselves. For Master Zhang, a spiral line is composed of three arcs; the first and second outer arcs have both a radius similar to the outer circle, and the position of the centre of the second arc is moved outward compared to the first one – note that this geometric construction process does not guarantee that both circles are precisely tangent –; the last arc is hand-painted to connect the inner circle (Fig.5 left). The closer to the centre of the dome, the greater the curvature.

#### Layer.

A spiral wooden dome is evenly divided into 16 to 24 layers by a series of concentric circles, with an average thickness of 8 to 9 centimetres. Constructions with 20 layers are the most common.

In general, the actual dimensions and radii of each component could be obtained from the sketch on a scale of 1:10 (Fig.4 left). Therefore, Master Zhang strongly emphasizes the precision of the sketch and empirical adjustment in construction. Sometimes, other local carpenters from different factions used to sketch a scale of 1:1 directly on the floor below the proposed wooden dome (Fig.4 right).



Figure 4. left: Master Liqun Zhang demonstrated the sketch of a new-built spiral zaojing on site, the scale of 1:10. Ref. ZJ-04; right: Master Shichun Wang demonstrated the sketch of a new-built spiral zaojing on the floor on site, the scale of 1:1. Photo: Lijia Wang.

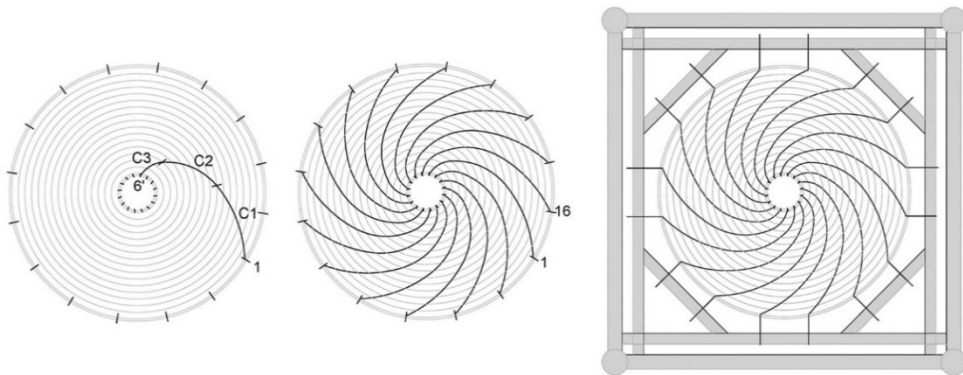


Figure 5. Form-finding principle for the spiral-line and distribution of its weight over the edge beams.



Figure 6. Space between the upper roof structure and the spiral zaojing. Ref. ZJ-01, built in the 1920s, in Ninghai.

### *Structure of the spiral type*

Symmetry plays an important role in the structural stability of the ancient wooden domes. The outer square beam frame and the four diagonal beams develop into an inner octagonal frame. Every two ridges are positioned on one beam-member through wood-only joinery. The weight of the *zaojing* is evenly distributed through 16 ridges, each representing a spiral warp line (Fig.5 right). Accordingly, the spiral form was placed carefully to be able to match the position of the supporting beams on the bottom. We have not yet had the opportunity to examine the spiral type with 20 spiral lines from behind.

Our investigation showed that *zaojings* in South China are completely detached from the roof structure of the opera stage (Fig.6). Conversely, in North China, the *zaojing* is the roof framework itself, which plays a crucial role in the roof shape generation and structural construction. This is the fundamental difference between the ancient opera wooden domes in Northern and Southern China.

### *Assembly of the spiral type*

The spiral type is made up of three main components (A, B, and C; Fig.7). Component A, the longitudinal cantilever member, and component B, the peripheral curved slat, are assembled to generate the shape of a hemisphere. Component C is a purely decorative member, according to local contemporary carpenters.

Components A are cantilevered layer by layer, and they are jointed by the ‘Go-Through Tenon’ (通榫), which can be seen in Fig.9 (middle) from the renovation process of the spiral opera *zaojing* in Family Ye’s Ancestral Temple. In this renovation this part has been purposely improved by Master Zhang. He adds a ‘Dovetail Joint’ between every two cantilevered components A to increase the tensile capacity (Fig.8 right). To allow future disassembly or component replacement, the socket part of this dovetail joint is made penetrable as well.

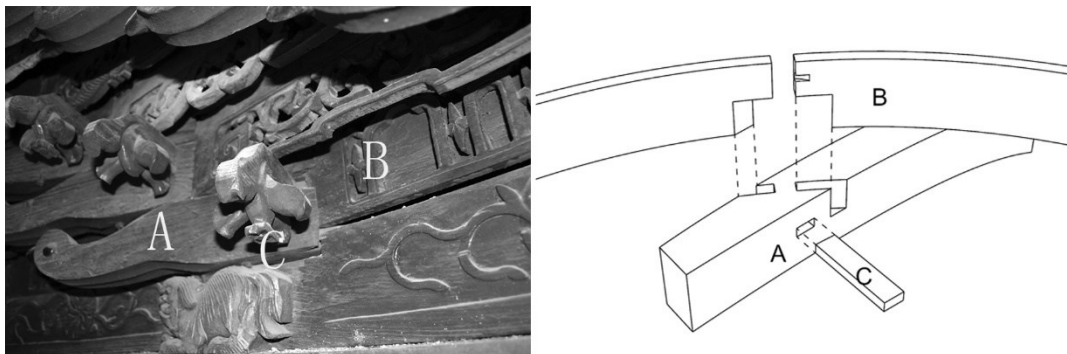


Figure 7. Components A, B, and C. The spiral *zaojing* in opera stage of Wei’shi Ancestral Temple, Xiapu Village, Ninghai, built in 1890. Ref. ZJ-03.

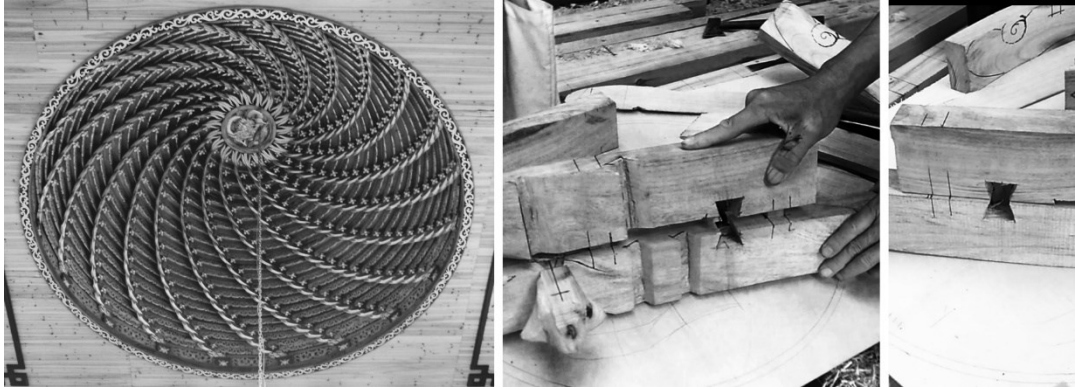


Figure 8. Master Liqun Zhang demonstrated the joints between every two components A of the spiral *zaojing* in the main hall of Baoguang Temple, Zhanqi Village, in Yinzhou, built in 2017. Height: 2.25m; Diameter: 5.2m. Ref. ZJ-04.

In most cases, the ‘Straight Tenon’ (直榫) is applied to connect Components A and B. For Master Zhang, in some finer projects, a ‘Sliding Dovetail’ has been adopted for this position.

The curvature of the spiral line is changing from the edge to the centre. The closer to the centre, the larger the curvature of component A. At the same time, the width of components A gradually decreases from the bottom to the top. In the example of Baoguang Temple (ZJ-04), built by Master Zhang, the components A slowly changes from 5 centimetres at the bottom to 3.5 centimetres at the top in width, in consideration of both aesthetics and structural performance. The width of the components B in different layers is basically the same, only their length and curvature are changed layer by layer.

Our research, has shown that component C works mainly as the decorative part and has no structural or constructional significance (in contradiction with [4]). When the component C is attached to component A, the ‘Straight Tenon’ is usually applied in between, where the sliding dovetail is applied by Master Zhang. This implies a different construction sequence.

It is worth noting that the newly constructed wooden spiral dome in Baohuang Temple (ZJ-04) in 2017 by Master Zhang also reaches the remarkable span of more than 5 meters. Whether such performance is related to his extensive use of the dovetail joint needs further analysis and confirmation. In the late 1980s, Master Zhang participated in the renovation project of the ancient opera spiral wooden dome in Qin’shi Ancestral Temple (ZJ-02), which has the largest span of all the known ancient spiral examples.

In summary, the interview with Master Zhang reveals that carpenters’ knowledge and judgment of size, shape and weight are still relatively empirical.

### *Renovation of the spiral type*

The restoration of ancient spiral wooden domes mainly consists in replacing damaged elements. The renovation of the spiral *zaojing* in the opera stage of family Ye’s ancestral temple (Fig.9) is a unique case. It was a thorough

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process involving the complete disassembly, repair, and reassembly, which provides a rare opportunity to observe the inner structure, construction, and wooden-joints of the chicken-cage spiral type.

### Preparation

According to local convention, a sacrificial ceremony is required before the operation, to pray for the blessing of the ancestors. Part of the roof structure over the *zaojing* is first disassembled. Components such as tiles and wooden beams with good properties are reserved for future reassembly. Several wooden beams are left to be used as a stand for the carpenters during the operation.

### Disassembly

It appeared that the top plates of the *zaojing* are fixed with ancient handmade nails, and the rest is constructed with wood-only connections. Layer after layer, the tangential curved slats are removed first, followed by the radial cantilever elements. Each element is numbered clockwise before it is dismantled. A wooden hammer or stick is used to tap upward to make the wooden construction loose and avoid damage caused by locally concentrated forces during disassembly. The dismantled components of the same layer are tied up together to prevent future confusion (Fig.9 left).

### Repair and remanufacture

At this stage, each component is checked and cleaned with a brush. If the damaged area is longer than a third of the whole length, or if the critical joint is seriously destroyed without a possibility of repair, a new component is manufactured and replaces the original one. The remaining part is kept as source material for the manufacturing of other small elements (Fig.9 middle).

### Reassembly

The assembly sequence is simply the reverse of the disassembly sequence, from bottom to top. In order to ensure the fitting of all elements, a trial assembly is performed beforehand. After all members are installed in place, the gap between each joint is immediately checked. Small cracks are filled with tiny slivers of timber, in order to ensure that every node works effectively in a tight construction. The repair or new construction is generally scheduled for autumn to avoid the rainy season in South China. (Fig.9 right)



*Figure 9. Renovation of the spiral zaojing in Family Ye's ancestral temple, 2016. Left, dismant of the 18th layer. Middle, hammering of the reassembled zaojing. Right, close to completion. Photo: Xiaodong Chai.*



## Material selection

As the saying goes “North Pine and South Fir”, wooden construction in North China commonly used pine wood, while in South China carpenters preferred Chinese fir.

Zhejiang, the surveyed area, is located in southeast China. Most of the region is rich in pine wood. Still, Chinese fir is preferred everywhere in Zhejiang. It is indeed related to the local wet and rainy climate, which favours termites. Pine is easily infested, but Chinese fir is more resistant to insects. Other advantages [5] of Chinese fir are listed as follows: the grain of Chinese fir is very straight; not easily deformed; lightweight but with high intensity; tough but easy to process. Furthermore, compared to other wood materials, Chinese fir can undertake the fluctuations of temperature and humidity more frequently.

Meanwhile, materials were locally sourced in ancient Chinese wooden construction. Yew, camphorwood and mulberry were local commonly used building materials in Zhejiang as well. Interestingly, the choice of timber varies according to the position of the component in the construction, clearly related to expected and available structural performance. Based on the interview with Master Zhaolong Ge, an empirical chart of material selection is summarized in Table 1.

In general, before the construction, three years is needed to deal with the timber, such as drying, disinsectisation and baking with charcoal. Wood nails are boiled or roasted to increase their hardness. The boiling is as follows; put the wood nail into the pot and boil; once the pot boils dry, add water to continue, repeat, probably for 16 or 17 hours until the surface of the wood becomes black and with the sound similar to metal when knocked [5]. In the case of fire-baking, the wood material is placed on the fire, roasted and rotated. Regarding the bamboo nail, frying in tung oil is a favoured method to manufacture a more solid one without corrosion and insects.

Table 1. A principle of wood material application according to the position of components.

Components	Wood type	Principle
Beam	Pine, Camphor	Good performance in tension for horizontal members
Pillar	Chinese fir, Chinaberry	Straight log for vertical members
Wood nails	Solid beech, Elm, Chinese Mahogany, or Bamboo	Solid wood
Rafter	Pine	Easily processed and replaced
Window frame/ Furniture	Phoebe	Durable in frequent movements
Elements for carving	Camphor, Pine	Easily processed

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In particular, the principle mentioned above should be considered as empirical knowledge rather than norm or standard. It is greatly influenced by factors beyond construction technology, e.g. economy, transportation, climate and culture.

Today camphor is usually used as the primary material by Master Zhang, since camphor is fragrant and insect-resistant, as well as suitably hard to be processed.

One typical feature of the spiral wooden domes is the curved members. It is obviously a material-consuming process if all members need to come from straight logs. For this problem, Master Zhang indicated that he chose naturally curved logs purposely instead of artificially bending them. The approach gives additional value to irregular trees that otherwise have little value in timber structures.

This approach is similar to the recorded Medieval European shipbuilding [6] technology, which took the advantage of irregular tree trunk geometry. Interestingly, the surveyed district, where spiral wooden domes prevail extensively, is in the coastal area and used to be a centre for China's shipping hundreds of years ago. However, whether the processing of curved members in architecture is related to traditional shipbuilding still needs to be verified.

### **Typical Construction Policy**

#### *'Split construction'*

A typical construction policy translated as 'split construction', has been carried out for hundreds of years in Ninghai district. The traditional Chinese buildings are usually symmetrical. Along the axis, the first portion of the project that was to be constructed 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 [2]. 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. The 'split construction' process consequently allowed the client to pick the best carpenter master out of the two candidates.

#### *'Zhaomian-Arts'*

The field survey showed that the circles in existing spiral examples were frequently imperfect in geometry. However, local carpenters actually do not care about this defect. In Chinese traditional wooden construction, there existed no mapping system with exact dimensions like those in the West. Under such conditions, when the Chinese carpenters constructed the form of a circle or a hemisphere, proportions and relationships of the components were valued over accuracy. This can be seen in several rare surviving sketches by a local carpenter master for the web-type *zaojing* [7] (Fig.10).

However, in the traditional timber practice some typical tools for measuring and recording have been developed and applied for thousands of years. The geometrical and dimensional information of all the components were marked in one or several strips, and their positional relations are expressed by unique symbols [8]. In other words, there exists a modulus relationship between all the components in construction. If one kind of component is sized, the dimensions of other components are determined immediately [9].

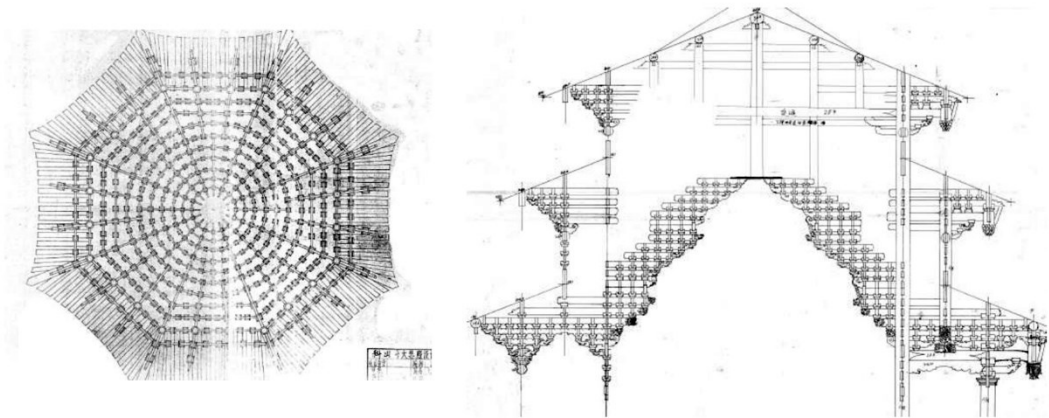


Figure 10 left. Original sketches of web-type zaojing in the main hall of Keshan Temple, Xidi faction, Fujian province. Drawing: Master Shimeng Wang.

This approach is called ‘Zhaomian’ (罩篾) in Zhejiang province and ‘Zhangchi’ (杖尺) or ‘Gaochi’ (篙尺) in other Chinese areas, and as ‘Kiku’ (规矩) in Japan. Normally, it is considered as the essential knowledge of carpenter works, and only the carpenter master in a team has the right and ability to define dimensions [8]. Therefore, the ‘Zhaomian’ tools were usually only mastered by the carpenter master, who held the strip and directed the workers to produce different components at the same time and to assemble them into a whole structure. As such, the approach represented a reasonable workflow and management system.

The way of measuring and symbolizing changed greatly in different regions and carpenter factions. The knowledge of dimensions is passed to the apprentice through oral traditions, and the set of ‘Zhaomian’ tools is carefully preserved by the carpenter master over his lifetime.

## Conclusion

The authors initially used the term *caisson* to refer to such domes [4], following erroneous translations published earlier. After discussion with local experts, it is believed that the Chinese *pinyin* pronunciation *zaojing* (Chinese: 藻井) should be adopted instead.

Following a field survey and an extensive literature review, this paper brought to light a unique wooden construction typology in China. *Zaojings* are unique masterpieces of wood joinery. Much more have to be understood about them today in order to ensure their long-term preservation.

## Acknowledgements

We would like to thank the protectors of these ancient wooden domes, for their efforts and persistence for decades. We would like to thank Mr Xiaodong Chai who generously provided us with the pictures. We are sincerely grateful to the carpenter masters Mr Liqun Zhang and Mr Zhaolong Ge who provided the component samples and explained their carpentry knowledge without reservation. We are particularly grateful to Mr Gangxiang Zhao, for his endless supports, inputs and encouragements in this research.

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