
MEASUREMENT AND ANALYSIS OF THE ANCIENT CHINESE TIMBER-FRAME BUILDING

Chuang SUN

Beijing Tsinghua Urban Planning & Design Institute

E1822A, Building Jia 1, East Qinghe Jiayuan, Middle Qinghe Street, Haidian District,
Beijing 100085, China, chuangsun@126.com

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Abstract: The documentation of ancient Chinese timber architecture is the precondition to analyze and explain the traditional design and construction technology. In the past, most of the drafts and drawings used in research of Chinese architectural history were based on traditional manual measurement methods. Nowadays, the introduction of modern measurement technologies leads a development in traditional architecture documentation. With the application of three-dimensional laser scanning, total station and other modern measurement methods, the sample quantity and accuracy of measured data is greatly enhanced. The size comparison and module of timber components is easy to analyze based on the classification and analysis of the measured data. However, because of the imperfect conditions of measurement site, the inaccuracy in construction, and the deformation in the endurance period of the timber structure, recovering the original design dimension is very complicated. Therefore, the method of documentation should be explored and perfected to provide more ideas and methods on the analysis and explanation in the field of Chinese architectural history and heritage conservation.

1. QUESTIONS

Study of Chinese ancient architecture by modern architecture perspective and approach began with the born of "Society for Research in Chinese Architecture" in 1930s. The history documents test and architecture site research became two essential methods of architecture history survey. The research method, combining the theory and practice, is different from the ancient Chinese history research which relies on pure documents. It is particularly concerned about the investigation and measurement of the existing construction. With the records of the morphology, size, and variety of remains and information and the organization of related files of the construction, it concludes the period of the architecture and then outlines the historical development of ancient Chinese architectural context by sample accumulation. Surveying and Mapping in the modern sense originated from the West. The early researchers of ancient Chinese architecture took it into the system of Chinese architecture history research system and developed the theoretical mapping system based on modern architecture such as plans, elevations, sections and other drawings for standard, thus brought the recording measurement of Chinese ancient building into modern architecture fields. The

measuring map records the image, size, and the relationship of the building components faithfully, and it plays a crucial role of recognition and study of ancient architecture. (Figure 1)

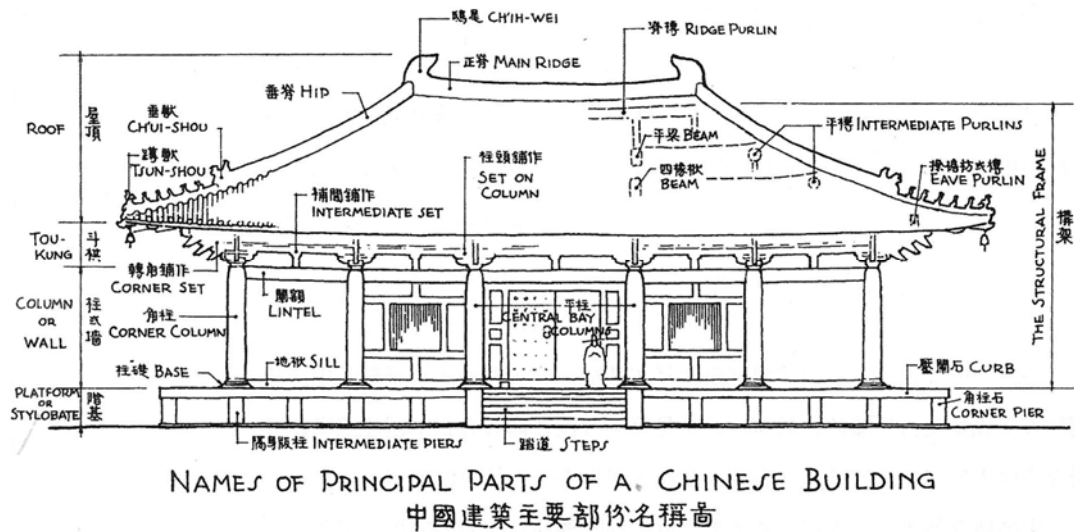


Figure 1: Principal parts of a Chinese timber-frame building. (Drawn by “Society for Research in Chinese Architecture”)

As is known to all, the Chinese ancient building takes the timber frame for main system. A building is composed by hundreds of thousands of timber pieces based on geometry and logic organization. The timber bites each other by tenon-and-mortise under a certain acceptable error. To facilitate the rapid of construction and form a certain building paradigm the Chinese ancient building turned to the development of modeling and modular, and engendered “Cai-Fen(the standard timber module for all construction)” , “Dou-Kou(the width of a Cai)” and other modular control systems. Most beginners or laymen would marvel at the numerous sophisticated timber elements of a building. But the construction has its rigorous combination of logic for experts. The logical relationship of the organization must be the original design and method of calculation for the timber frame construction. Generally, the design is mainly related to the design of modulus, Dou-Gong (bracket set) construction, plan of the column, control method of roof, standard scale of construction ruler and so on.

Unfortunately, there is no enough written record to memorize the the intelligent design by the ancient builders. For the communication of design information relies on words and experience in ancient China, the intelligence and handicraft are passed by oral teaching for the most common transmission way. As the time passed by, those “design” methods has gradually disappeared into oblivion. Although we can objectively record the morphology and size of the building by mapping, to explain its construction ideas further is another problem. It is not all known for people to realize the implied ratio behind the timber construction. Now we must mention two books as the grammar of ancient Chinese architecture—<YingZaoFaShi(Building Standard)> in Song Dynasty and <GongChengZuoFa(Structural Regulations)> in Qing Dynasty. These two books are the most important theoretical basis to explain the ancient architecture, and they have introduced and summarized the materials and employment in ancient time. However, they did not emphasize the design methods as also. In fact, it didn’t deliberately obscure for secret, the original intention for the compilation of the two books are about “money” and “grain” and to comprise construction specifications for project budget and work acceptance. In <YingZaoFaShi>, the craftsmen’s building design methods were mentioned only between the lines unintentionally.

2. MEASUREMENT

“The ancients imply the design methods while they left the buildings.^①” The only way to restore the original design is to “ask” the ancient building itself. The logical relations are concealed under the real sizes of the building. Based on the measurement, combining with the documents and theories must be an inevitable way for the timber structure research. There are lots of achievements on this topic. In addition to the theory of module controlling for tradition^②, there are other standpoints which hold enough evidence from theory to practice. Some standpoints insist that some constant proportion must play the role in adjusting the whole scale of the profile design and section design. And the most straight forward proportional controlling method turns to the integral number and simple ratio to seek the source of the design. There are kinds of discussion about the design methods of timber construction, but the acceptable results are mainly based on the enough convincing measured data.

Here, the author emphasizes the accuracy of measured data and sample quantity. The ancient buildings are of modularization to some extent, and the same components should have the same design size, but taking the measurement of individual samples is also a rough road to conceal the true size which is closed to the original one. There are some small acceptable errors during the process of timber construction, and the timber components are tended to turn to deformation and to be repaired during the thousands of years of natural invasion and human disturbance. All of these objective factors confuse the measurement and make the standardized components become less uniform. Enhancing the measurement accuracy and sample number, identifying the confounding factor and paying more attention to details are be put into effect to treat the historical information overlaid. It should be more objective and rigorous to observe the ancient building measurement by archaeological perspective than ignoring the detail for general.

In the era of surveying and measuring mainly by hand, the measurement is more common by taking individual samples instead of other similar components. But to interpret the design of timber structures should comprehensively study the huge mass information of timber components. Nowadays, with the continuous development of modern mapping technology, surveying and mapping work become more dependent on scientific and technological methods. The commonly use of Total Station, Three-dimensional laser scanner, close range photogrammetry and other mapping tools has brought new prospects for mapping work. Usually , the morden mapping tools have the advantage of data precision and sample quantity and they can get data without touching architect, and finally transfer the data to the computer. Thanks to the development of the mapping tools, obtaining the high-precision and high quantity of data mapping must be more easier, thus it can provide a more broad perspective on studying wooden design methods.

3. ANALYSIS

For the purpose of exploring the structural design method of ancient Chinese timber-frame building, School of architecture, Tsinghua University has conducted several site investigation including more than ten buildings of different years and located in different regions in China recent years. ^③Arranging and analyzing the first hand information by measuring the buildings, we put forward other researching to explain the wooden structure design.

① Liu Chang. *Beijing Forbidden City*. Beijing: Tsinghua University Press, 2008. Page 105

② Chen Mingda. *Research on Timber Construction in the Song Manual Building Standards*. Beijing: Cultural Relics Publishing House, 1981

③ The related achievement refers to the research by Liu Chang, Tsinghua University , for example: Liu Chang, ZhengLiang. *Finding Arithmetic in the Design of Chinese Historic Timber Structures*. Architectural History(24). Beijing: Tsinghua University Press, 2009. 23-36

3.1 Measurement points

On the content of the measurement, we insist a comprehensive work and also give considerations to some key point. Firstly, we should analyze which part is closed related to the whole design, such as the construction components or some proportion. As mentioned above, the Chinese ancient buildings have a certain pattern of the image for similar appearance. The construction of the general ideas can be divided into three parts: the platform, the housing body and the roof. The core of the design is the interior structure of the roof—the most complex and sophisticated part. We follow this route: The curvature of the roof is determined by the location of purlins; the work of the complex construction of the beam and lintel is just to lift the purlins frame to the right height and right step locations; the Dou-Gong(bracket set) in the early time often has closed relationship with the roof construction; the locations of Dou-Gong corresponds with the plane of the top of column; the space between the axis of the column forms the bay of the housing body. Therefore, we outline several major structural nodes:

- 1, Truss design (method of determining the pitch and curvature of a roof)
- 2, Dou-Gong design (structure and size, standard materials)
- 3, plane of column top (bay)

Furthermore, we follow these priorities to analyze the logical structure of ancient buildings and form the frame of our focus in measurement. (Figure 2^④)

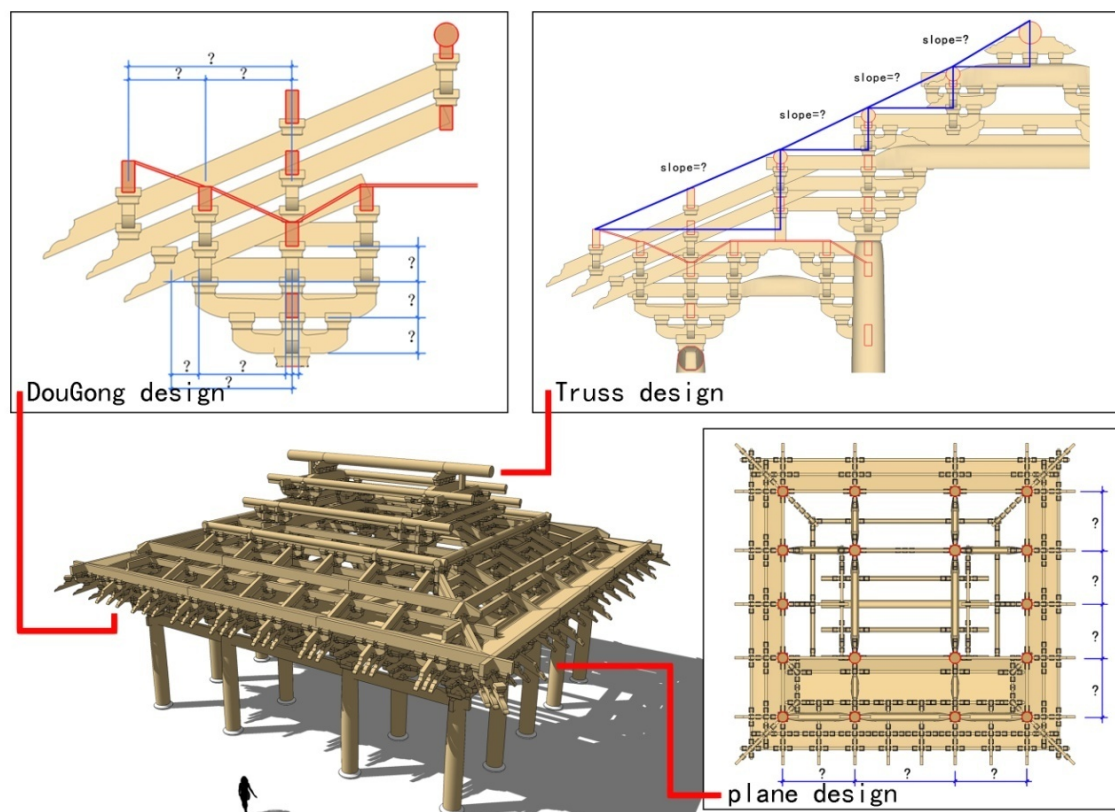


Figure 2: Three major structural nodes

④ from here to the end, the author takes the timber structure of the main hall of Hualin Temple for example. Having been built in A.D. 964 the main hall is the oldest timber building in the south of China. It has been measured by School of architecture, Tsinghua University before it was relocated in 1986. See "Yang Binglun, Wang Guixiang, Zhong Xiaoqing. *The Main Hall of Hualin Temple in Fuzhou*. 1981. The remeasurement was carried out in 2007 by Liu Chang, Liu Zongxin. See Sun Chuang, Liu Chang, Wang Xueying. *Survey and Explanation of the Measurements of Timber Structure of the Main Hall of Hualin Temple in Fuzhou*. 2010.

The content of measurements should involve each component on the key structure. We measured each component of the same type and the same “design” size with patience. Especially for two sides of a component we have to measure them respectively so as to remove the measurement error. Because we cannot dismantle the building to take the component down and measure it on flat desk, we should pay more attention to the tenon-and-mortise to attach the component’s original image. Meanwhile, we concern about the concept of distance between the timber components. The ideas come from the construction features of Chinese ancient architecture by “axis” principle. Usually, the distance between the axis plays more important role than the sizes of the components themselves.

3.2 Measurement tools

While adopting the manual measurement method, we take the three-dimensional laser scanner and total station for both powerful auxiliary. Here, I need to clarify that the use of modern instruments has never denied the role of manual measurement. It is not only to respect for the senior research but also based on reality practice. The manual measurement has great flexibility and convenience. The measurement process by hand is a communication between the ancient buildings and researchers, and any study without site investigation has no convincing. Our measurements have never been separated from climbing on the roof and taking the data by hand. The use of laser scanner is to improve the capabilities of large-scale data collection and strengthen the accuracy of collecting data. Taking the data of the component size into computer for measuring and observation by scanning can eliminate the manual error. All researchers using tape measurement understand that the manual error could not be controlled efficiently. Additionally, the documents stored down by scanning make the reviewing and examining more convenient. We can trace the origin and provenance of the measured data, even the measured method, which cannot be achieved by manual measurement. The introduction of modern instrument can promote the measurement more rigorous and improve the capability of the measurement significantly. (Figure 3)

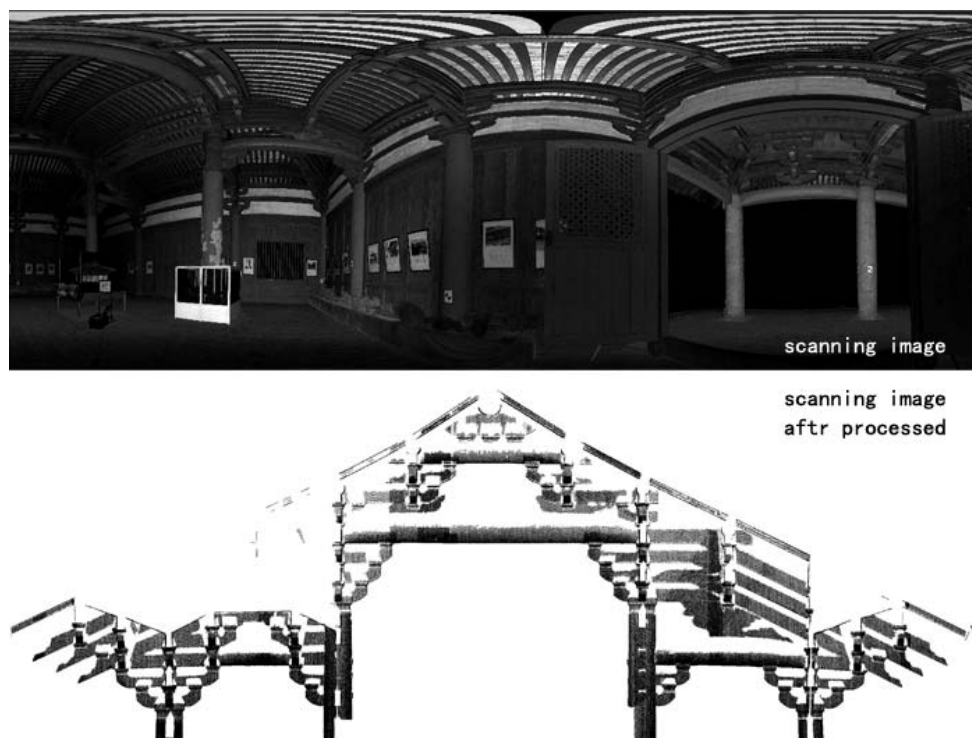


Figure 3: The 3D laser scanning image for measurement.

3.3 Data measuring and processing

Measurement by instruments can save outside work time, but it brings up more indoor work instead, such as data processing. The three-dimensional scanning file is called “point cloud”, which is comprised of millions of points. More and more details will be found during the boring work of point cloud processing. And some tiny distortion can be noticed clearly on computer screen. Because the general situation of distortion makes the measurement more complicated, it urged us to pay more attention to the position selection so as to make the measured data more accurate. (Figure 4)

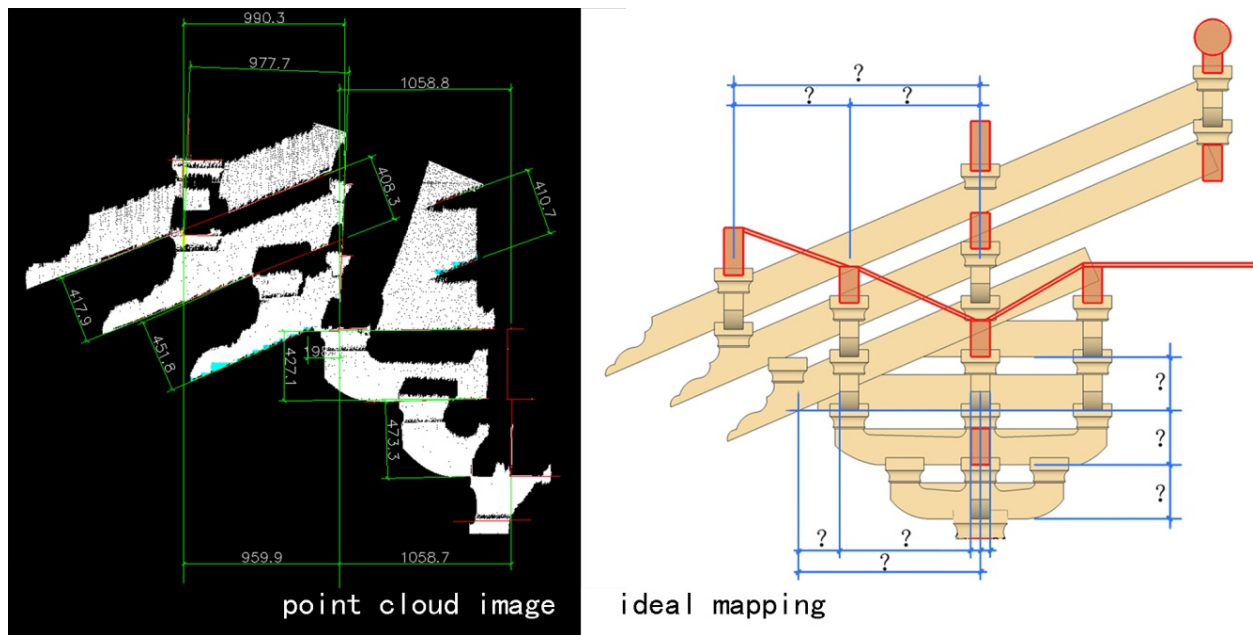


Figure 4: The comparison of scanning image and ideal mapping

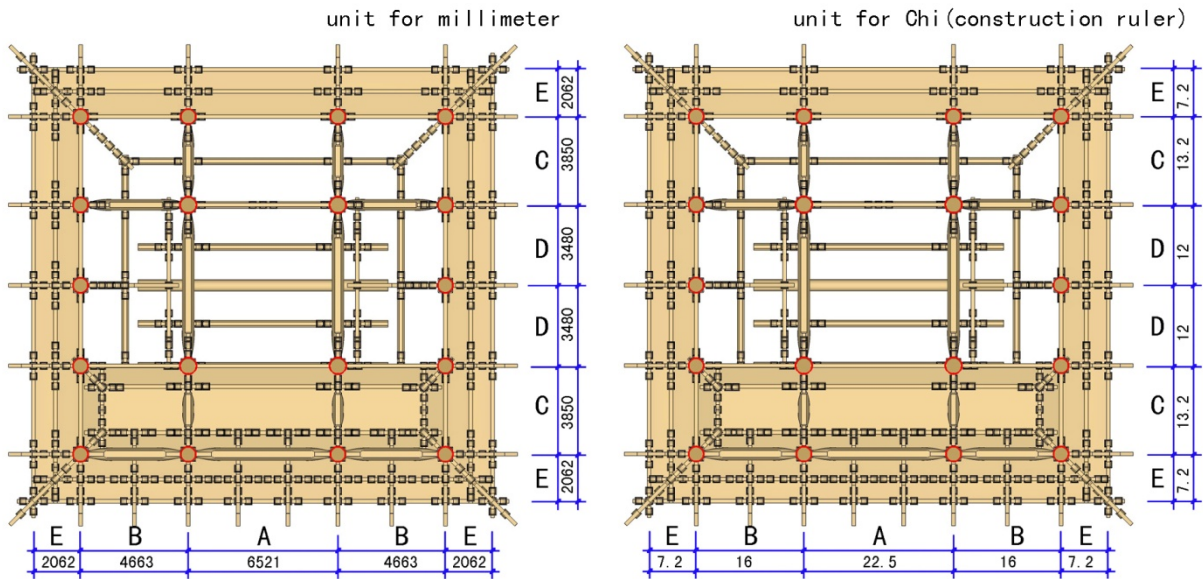
We put the measured data of the same position of similar sorts into a table together and can discover the dispersion of the group data clearly. For the specific data, the best approach to investigate the specific reason is to turn to the component of carbon-14 analysis and then to select the figure to represent the original size of the structure component according to the frequency of appearance in the data group. When lacking of the on-the-spot conditions or budget, we could adopt the simple method called “arithmetic average method”, which takes the average size to be the basic calculation for analysis after getting rid of the special size data.

3.4 Calculating and deducing

The so-called calculation is to test the possible proportion and geometrical relationship by “analyzing the processed data”. Here, we must clarify a metric difference between ancient and modern. The ruler used in Chinese ancient architecture (construction ruler) has a different length from the modern public system. Due to the different metric standard, the data measured by meter ruler can not reflect the relationship in ancient dimension directly. It is the reason that we emphasize the significance of data accuracy. Some irregular data may present integral number relationship after translating into ancient ruler scales. Thus it might create a distortion of the original size if rounding the measured data subjectively and ignoring the decimal fraction. Because the length of ancient ruler does not have a uniform size in different eras and regions, the research of the conversion relationship of the ruler should be the first task to be deal with. The basic principle of calculation is whether the data can show regular length under conversion relationship of the ruler hypothesis. (Table 1 & Picture 5)

Table 1: Processed data under different measuring standard (supposing 1 Chi=289mm)

	A	B	C	D	E
Unit for millimeter	6521	4663	3850	3480	2062
Unit for Chi	22.564	16.135	13.322	12.042	7.132
For integer	22.5	16	13.2	12	7.2
Fit level	99.72%	99.16%	99.08%	99.65%	99.10%

**Figure 5:** The comparison of the relationship between different measuring standard in plane design

Of course, the length of the ruler is a hypothesis, and showing some integer relations is just one of the measurement criteria. The logic relationship can't be deduced by certain formula because of the inter-constraint hidden under the numerous and unorganized timber structure. For instant, the design of the roof in a certain main hall might be based on a simple integral data proportion and in another hall the key point of design can be focus on the angle of Ang(a long slanted lever arm balanced in the Dou-Gong. Its tail bears the load of a purlin and is counterbalanced by the eave load at the lower end). An ancient timber building should be based on two metric systems such as "Cai-Fen(Module and Sub-unit)" and "length of construction ruler" at least. They are indispensable and complementary through the geometric constraints of the construction. All of these constraints should be taken into consideration of the data interpretation. (Figure 6)

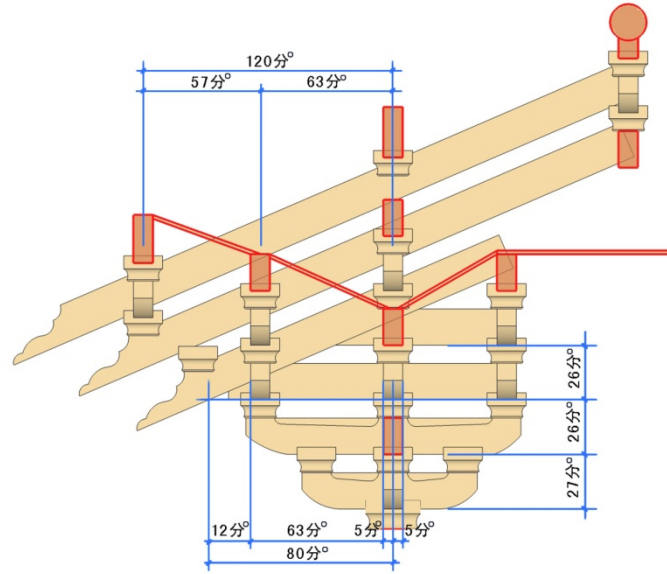


Figure 6: A hypotheses of the simple proportional controlling by Cai-Fen in Dou-Gong design

We put suppose related hypothesis of the origin of calculation and deduction based on the questions of construct ruler, Cai-Fen value, Dou-Gong design, plane of column top, curvature of roof and so on, and then we attempt to verify them by the analysis of the measured data. The process of the study is not linearity but a deduction accompanied with infinite possibilities. When the data can't present a relationship of self-justification, we have to review the reliability of measured data. Thanks to the scanning documents recording the objective appearance of the details of the building we can review data for checking carefully.

The fundamental of the research idea is to seek the simple proportional relationship and geometric constraints existed in the different components and size relationship. Then we attempt to reveal the original design with the help of clarifying hypotheses step by step. (Figure 7)

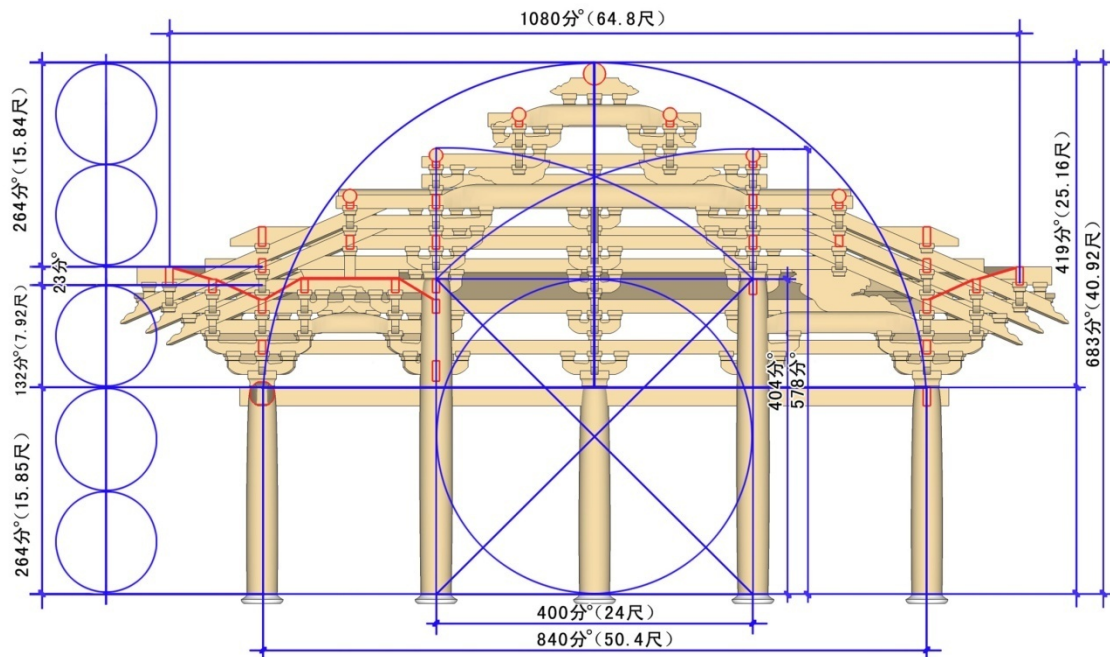


Figure 7: A hypotheses of the simple proportion and geometric design method of the timber frame

4. SUMMARY

It was a long-standing topic on the discussion of the design method and the size calculation of the timber architecture based on measured data. Nowadays with the rapid development in mapping technology, it is more reasonable for us to measure the ancient timber structure again and we hope to supply and improve the data repository by continuous researching. To restore the original design method of the timber structure is not easy and the answer of the hypothesis is not unique. But this doesn't prevent us to interpret the data and explain the design. Like the measurement itself, we could only get approximation of the true size. But the infinite close is much more similar to the reality. The measurement of timber structure is also a process of improvement. Too much historical information overlay on the building makes the original design hard to be identified. The interpretation of the design might be restricted to the assumption, but the cognition of the ancient architecture would be increased on the basis of the continuous approaching to the reality. It will make the study of the timber buildings beyond the form of portray and praise---the key point is to understand the "Grammar".

To sum up, a famous Chinese architectural historian, Liang Sicheng—has said "The section drawings are much more important than the elevations."^⑤

5. REFERENCES

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⑤ Liang Sicheng. *A Pictorial History of Chinese Architecture*. Beijing: The Joint Publishing Company Ltd.,2011.page 217.