The Space Information of Traditional *Dei-dou* Timber Frames in Taiwan and Their Applications

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Summary

The purpose of this study is mainly to understand the way of thinking for planning the dimensions of traditional *Dei-dou* timber frames in using *Gao-chi* (the ruler for dimensioning) by master carpenters in Taiwan. Mainly based on the space information done by traditional surveys and drawings, the written records from the manual of master carpenters and the oral materials from interviewing master carpenters, the meanings of marks on the *Gao-chi* and its functions and characteristics can be disclosed. In addition, by using 3D laser scanner, the space information of this kind of frame with more accuracy can be obtained from the existing building, so as to establish its 3D digital model. By comparing with these two kinds of information, the space information of a timber building with *Dei-dou* frames obtained from 3D laser scanner can be then used to trace the way of thinking for planning the dimensions done by the master carpenter who had been passed and any information had been disappeared in both written records and oral materials.

1. Introduction

In Taiwan, the *Dei-dou* timber frame is one of typical types of traditional frame. They are commonly used in temples, ancestral halls, and the corridors of traditional houses. Within them, the artist characteristics of traditional buildings are fully expressed. *Dei-dou* timber frames are also the artistic representative work of traditional buildings with woodcarving and painting.

When master carpenter plans and then constructs *Dei-dou* timber frames, they use “*Gao-Chi*”, a wooden stick for measuring height, to carry out the whole works from the beginning to the end. That means that the *Gao-Chi* can be treated as traditional blueprint for the planning of measurements, and then used as a full-scale tool in measuring important wooden structural components on the building site.

However, only few master carpenters make sense of the meanings of *Gao-chi*, and furthermore while the building works are finished, the *Gao-chi* is not preserved for the most part. If we want to analyze the space information of traditional buildings, we could only obtain them from surveying and drawing on site. In the process of surveying and drawing at present, the precise information of measurements and the relative position of wooden structural components are not so accurate. Until recently, the modern methods of 3D Laser Scanner technique are introduced for surveying historical buildings in Taiwan. Under this circumstance, the precise space information of historical buildings can be obtained.

By using the Bao-An temple as an example, the aim of this study is to trace the meanings of the *Gao-chi* and the construction procedure of this kind of timber frame. By interviewing the master carpenter (Han-Jen Hsu), we try to understand his thinking of planning and constructing this kind of frame. Moreover, after surveying the *Dei-dou* timber frames of Bao-An temple, we compare this information of traditional measurements with those from 3D laser scanner method so as to analyze
the differences of space information between records shown in the drawings and in the existing temple built. It helps us to realize the relative position and the measurements of various wooden components of traditional Dei-dou timber frames. In addition, with these data from 3D laser scanner method, it is expected to be able to trace this kind of traditional timber frame without Gao-chi and then can understand the master carpenter’s original concept of planning its dimensions furthermore.

2. Study Methods

The thinking of applying scientific methods to study the thinking of the master carpenters is evolutionary. Thus, there must be based on serious steps to design the study methods and then to prove furthermore. How to plan the timber frame of traditional building is always kept in the master carpenter’s mind. The full-scale ruler called Gao-chi, could fully express the thinking of the master carpenter in planning and constructing a traditional building. Combination scientific methods with the traditional tools is the most important basis of this study.

2.1 Interview to Master Carpenters

Shuen-ming Bau-An Temple in Tainan, designed by the master carpenter Han-jen Hsu in 1999, is chosen as our example.

Han-jen Hsu, born in Tainan in 1929, is a master carpenter professionally engaged in the planning and construction of temples with Dei-dou timber frames. Hsu inherited the skill from his father. Owing to where he was born and grew up, Hsu’s works mainly located in southern Taiwan. In addition to make the Gao-chi for each temple and construct it, Hsu was also influenced by the western design drawings of architecture during the Japanese colonial period. This is the reason why Hsu could make detailed design drawings. When Hsu was young, he only played the role as the planner of Gao-chi in constructing temples, and undertook the projects of designing and constructing traditional buildings. During that time, ground-plan and facade in the drawings of the Dei-dou timber frame only simply expressed the design concepts. However, Hsu gradually could make more complete and detailed drawings thereafter. Recently, he only does the drawings for the temple, and let other master carpenters to construct it based on his drawings [1].

As a row house of two building units with a skywell, Shuen-ming Bau-An Temple is composed of the traditional Dei-dou timber frames in the front hall. Hsu used the traditional Gao-chi for planning and construction and also made five important design drawings. This could offer us two types of design manuscripts for studying.

Through the interview to Hsu, this study would like to induce the planning processes of the Dei-dou timber frames. By decoding marks on the Gao-chi, analyzing principles of determining various marks on the Gao-chi which indicate dimensions of important wooden components, and then comparing them to those in the design drawings, we try to figure out the traditional thinking of the master carpenter.
2.2 Scanning the Main Timber Frame by 3D Laser Scanner

To obtain the space information of the Dei-dou timber frames by 3D Laser Scanner and to survey the accurate relative location and measurements of wooden components by 3D coordinate, the study applied Mensi GS100 3D Laser Scanner produced in France to get the related data. The dogma of this equipment is to calculate Time-of-flight, which means to calculate the distance by the forward and backward time span of laser between the scanner tip and the surveyed point. The location of the surveyed point in 3D coordinate could thus be determined (Fig 3). The massive, rapid and accurate 3D data of the surveyed construct precise 3D digital model. Any needed real size could be measured directly from the 3D digital model (Fig 4).

![Fig 3 Time-of-flight](image1)
![Fig 4 Measuring the dimensions from 3D digital model](image2)
![Fig 5 Picture of operating 3D laser scanner](image3)

2.3 Data Comparison

The study surveyed the spatial location of the main timber frames by 3D laser scanner (Fig 5). After the noise reduction, we obtained the 3D digital model and measured the precise size and spatial information, then compared to the scale information of the Gao-chi which had been decoded, and understood the difference between the size measured by the equipment and designed by the Gao-chi. Design drawings and interview data are analyzed at the last step.

3. Space Information and Design Thinking from Master Carpenter

In Taiwan, the three methods of designs and construction of traditional timber frame in the process of constructional project are as follows: (1) small-scale blueprint, (2) Gao-chi, (3) full-scale drawings.

(1) Small-scale blueprint
Some drawings in 1/30 to 1/100 scales includes the ground-plan, frame-section and facade of the building. Ancient Chinese also designed a building by simple ground-plan and section drawing. As the traditional Hans’ building styles in Taiwan were affected by those in Fuchien China, so as the building drawing sills. But not until the Japanese colonized period in Taiwan, with the import of Western architectural knowledge into Taiwan, some of the master carpenters became able to draw blueprint in reduce scale, and then describe their design to their proprietors. Most of the master carpenters were the one who set out the building scale on “Gao-chi”

(2) Gao-chi
Full scales for measuring rulers, including locations and dimensions of the wooden components set out on one or several wooden sticks are called “Luo-gao”, so that the stick named as “Gao-chi” became the criterion of constructions.

(3) Full-scale drawings
The drawing of full-scale timber frame sections and details on wooden or paper boards is called “Da-Pan”. Except the one who learned the modern architectural drawing skill, most of the
traditional carpenters did not have the knowledge to design the buildings in full-scale on boards.

After World War Two (1945), the fashion of building temples in R.C that substitute to original used timber frame building, made the traditional master carpenters learned the new building skill of R.C and modifying their design by experience. Somehow, the concept to design and build a timber building based on the skill to set out the building members on one or several sticks were still used by the carpenters. So that the step of “Luo-gao” means that the master carpenters became able to control the final results of the designed building.

3.1 **Gao-chi: a stick for measuring height**

*Gao-chi* is also called “Zhang-gao”. It is a wooden stick with rectangular section and its height over ten “Chi” (Taiwanese feet) for measuring the height of wooden structural components. *Gao-chi* is an instrument used by traditional master carpenter for measurements of wooden components in the process of the construction. It is treated as the representative of whole design concept including auspicious measurements, the taboo of construction, the idea of aesthetic, the plan of tenons and even the thinking of construction appraising. *Gao-chi* also imply the construction experience, knowledge of mechanics, the relative position of tenons, the building convenience in the course of constructing, and wooden components aesthetic.

*Luo-gao* is the process of designing and drawing *Gao-chi* by master carpenter. In this process, master carpenter has to keep the traditional concept of 3D space to control the relationship of wood structural components between themselves. On one hand, the concept of space is founded upon on-site experience with traditional technology, and the idea of aesthetic as well as concept of traditional taboo are included on the other. With this knowledge, original 3D information is simplified as 1D line of measurements to represent the relationships of various wooden structural components.

The man who could use *Gao-chi* must be an experienced master carpenter. He is a traditional architect to control the key points of design and construction. However, it is restricted to impart traditional craft and knowledge to others because of the master carpenter is hard to be training for drawing *Gao-chi*. With these special information, moreover, *Gao-chi* not only represents the master carpenter’s own opinion on special sign as well as design but also implies the meanings of construction aesthetics. The apprentice carpenter or unskilled workers will be uncertain of the meanings of *Gao-chi* because they lack for sufficient training and guidance given from master carpenter. The key factor of training for master carpenter depend on he has the ability to drawing and planning *Gao-chi* or not.

Therefore, *Gao-chi* can be regarded as a signification of the wooden construction knowledge, and also be represented the original blueprint and initial ideas of traditional timber frame from master carpenter.

3.2 **The Determination of the purlins’ Height by Gao-chi**

The plan of measurements designed by *Gao-chi* is the crucial to the form of main timber frame. The height of purlins showed on *Gao-chi* are decided by these steps:

1. At the first, the standard height of central purlin of building is determined under the rule of auspicious measurements.
2. Secondly, the width and depth of building are decided. According to traditional taboo, the depth of building and the height of central purlin have to be larger than width of building. Moreover, the depth of building is 1.37 to 1.4 times of the height of central purlin.
3. Finally, master carpenter decide the slope of the roof, and then to arrange the width between purlins. This procedure, the most essential process of the master carpenter’s skill, is named as
“Wen-shui”. After determining Wen-shui, the height of other purlin are decided according to the standard height of central purlin.

3.3 The Mark of Gao-chi

Take the Gao-chi used in building the Bao-An Temple in Tainan as an example, dimensions of the Gao-chi is 258.6 cm in length, 18 cm in width and 1 cm in thickness. As the Bao-An Temple is combined with entrance hall and central hall arranged in a row, dimensions of each hall was marked on both sides of the Gao-chi. In order to make the Gao-chi shorter, the master carpenter firstly drew lines from 9 “Taiwanese feet” (named as “Chi”) (273 cm) 1 to 16 “Taiwanese feet” (485 cm) on the Gao-chi, due to no significant horizontal structural components under 9 “Taiwanese feet” (273 cm). In other words, the actual height of the most important components, vertical and horizontal, can be set out by marks.

Among the whole structural components, master carpenters may mark the location of the central highest purlin and his height firstly as a reference point, and then mark the purlins nearest ones on both sides. After marking the position of all purlins on the Gao-chi, all components under each purlin is then marked from the top to the bottom in order, including both vertical and horizontal.

Usually the pure lines are drawn to represent the important components on the Gao-chi. However, besides the lines in diverse length to show the actual height of the vertical components, different marks are used by different master carpenters in marking the location of horizontal and vertical components on it, so that not everyone can understand the meaning of the marks on the Gao-chi and a secret is always kept in different carpenters. Those horizontal components marked on the Gao-chi include beams, purlins, bracket systems, and etc.

3.4 The Characteristics of the Gao-chi and its Dimensioning Planning

(1) Full scale marking
Recording the actual dimensions of components on the Gao-chi is valuable for making each component, making sure its location and then checking its accuracy, while building the whole frame.

(2) Mainly marking the vertical components in lines

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1 A tradition measure used in Taiwan is called Taiwanese feet and it equals to 30.3 cm.
While master carpenters set out the dimensions of important components on the Gao-chi from top to down, they firstly drew vertical lines representing those important vertical components, and then mark the locations of the horizontal components accompanying the vertical component on the vertical lines.

(3) Showing spatial information of each important component by marking in lines
On the Gao-chi, it mainly shows the vertical relationship between the vertical components of the frame only in lines. The height to the ground and the locations of joints for the horizontal members are then marked by a simple curve or a specific mark. Therefore, a thin stick with simple marks can show their spatial information for three dimensions.

(4) Not showing the constructional details and decorations of the components
On the Gao-chi, it does not show the constructional details and decorations of the components, such as the types of joints, the forms of carvings or the colors and themes of paintings etc.

(5) Marks on the Gao-chi depending on what the master carpenter learnt from his master
Every carpenter has his own marking systems that may only for members of his own guild can understand the meaning of different marks.

(6) A criterion for the constructing the frames
the Gao-chi records the original planning for the dimensions of the frames, so as to check the building accuracy during the building processes. Therefore, the Gao-chi owns meanings for both planning and construction.

4. Results and Analysis

4.1 Traditional space information within Gao-chi

(1) Establishing rules by the size of vertical components
Relationship among vertical components was marked through the series from the top to the bottom, therefore, spatial location along Y-axis was obtained.

(2) Relationship among pulins determining horizontal components
There are related series of vertical components under each purlin in traditional buildings of Taiwan, so Gao-chi firstly constituted the relative location and span among purlins (X-axis). After determining the slope ratio of the roof, relationship of dimensions among the series of vertical components would then be determined. Gao-chi didn’t mark the transverse size of each horizontal component. The span among purlins could fully represent all relationships of components along X-axis.

(3) Constructing the timber frame by the relative relationship of size among components
Gao-chi handles the relative relationship of size of wooden components in heights, joints, and tenons. Ideas of auspicious sizes and constructional taboos are also included. Only the most crucial sizes would be marked on Gao-chi by plotting specific lines for expressing relationship among components. Plan drawing is not made. As for the 3D model, outline, and the form of timber frames, they are remained in the brain of the carpenter.

(4) Layout from the top to the bottom
The key step of determining the first dimension of Gao-chi (Lo-gao) is to ensure the height of the central ridge. Once determining the height and dimension of the central main purlin, the carpenter would then determine other height and dimension of components by marks on Gao-chi. He started marking from the top to the bottom of the central main purlin. The relative combining height and location of each series of vertical and horizontal components would be marked on Gao-chi by plotting lines. The nearby components series are then marked one by one.
4.2 The Comparison Between the two methods

(1) By using the 3D Laser Scanner, with a 99% albedo, the standard deviation of the measured dimension and actual dimension is illustrated in Fig 8 as shown below. When measuring the Dei-dou Timber Frames, the maximum distance between the device and the measured components has consistently been within 10 meters. Therefore, according to the Fig 8, the deviation of the measurements gauged by the device has stayed within 3.5

(2) By comparing the 3D data gauged by the 3D laser scanner and the dimension measured by the master craftsman’s Gao-chi, the error ratio of the purlin’s height (measured from the ground; axis Y) approximately ranges between 0.08% and 0.93% (3.03 mm to 42.4 mm), while the error ratio of the distance between purlins (X-axis) approximately ranges between 1.36% and 7.32% (9.09 mm to 45.45 mm) (Table 1).

(3) The deviation is possibly derived from some construction flaws, earthquake after the completion of construction, or some human factors. According to the data described above, the measuring deviation of the device itself did not exceed 3.5 mm, and therefore an inference can be made to conclude that the deviation caused by the construction flaws is more possible. It is a top-down approach to annotate measurements when using Gao-chi, while assembling wood infrastructure is a bottom-up approach. Having gone through the sophisticated mortise procedure of the wood arching components, it’s highly possible that the deviation value of the accumulated total height (Y-axis), width (X-axis) occurs.

(4) On the other hand, wood is a sort of heterogeneous material. In addition to the possible deviation caused by construction, the wood components themselves can be easily influenced by the environmental changes and thus result in some insignificant changes in terms of size and volume. Furthermore, after the assembly is done and the usage by human beings, it is possible the components result in horizontal or vertical departure due to the weigh of the materials themselves or some external forces.
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* The scale of these dimensions is “Chi” (traditional Taiwanese feet), and it equals to 30.3 cm.

5. Conclusion and Acknowledgements

By interviewing with carpenters and the data analysis, this research acquires the information that the plan of measurements in the construction of Dei-dou timber frames is originally based on Gao-chi. As a key instrument in the process of the construction, Gao-chi not only becomes a basis of the plan of measurements but also implies concepts of aesthetics and traditional taboos. From the procedure of Luo-gao, the idea of construction and space information will be revealed. Therefore, Gao-chi can be regarded as an expression of the master carpenter’s knowledge on traditional constructions.

Applying 3D Laser Scanner, by which the measurements are more accurate and easily collected than the traditional surveying method, we try to construct 3D point-cloud model of Dei-dou timber frames. In this process, the measurements of the frames before and after construction were investigated to differentiate between the design measurements and real ones. With this modern technology, the traditional surveying method is considerably improved. On one hand, the Dei-dou timber frames can be accurately surveyed, and a detailed plan can be obtained on the other. Moreover, with these data, it can trace the traditional buildings without original plan of measurements and further realize the master carpenter’s initial ideas of drawing Gao-chi as well as the plan of constructions.

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6. References
