The Integration of Procedural Information in Traditional Architectural Design

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ABSTRACT

A bamboo pole called Gao-chi records and integrates procedural information of the carpentry work of ancient traditional architecture in the design stage and the construction stage in Southern Fujian in China. Modern industry is separated into two relatively independent programs, the design stage and the construction stage. The communication gap between designer and construction results in embarrassing instances of low quality in contemporary traditional architecture design. Unlike conventional CAD (Computer Aided Design) technology, which is based on geometric description, generative modeling technology should integrate the procedural information of traditional architectural design into the design model. This study discusses the role that generative modeling plays in the design process as a design tool on the perspective of communication theory. The study will efficiently revise the design model and maintain the necessary formal idiosyncrasy of traditional architecture. This study attempts to integrate the multi-disciplinary knowledge to improve the fluency of information transmission and reduce the communication gap between design and construction stages. In addition, carpentry work by traditional architecture in Southern Fujian is modeled by generative modeling technology according to the traditional construction principle. In this process, the procedural information of traditional construction principle is integrated into the models to reduce design cost and improve design quality in contemporary traditional architectural design practice.

Keywords: Traditional architecture, Procedural information, Communication theory
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1 INTRODUCTION

As an important traditional constructional craft, a bamboo pole called Gao-chi records the important information regarding carpentry work of ancient traditional architecture in Southern Fujian in China, which includes the component size, manufacture and assembly, Ji-xiong dimension, construction taboo and aesthetics [10]. However, the Gao-chi craft has gradually disappeared for several reasons, including the promotion of design technology and industry collaboration, particularly the labor division of design and construction. The gradual disappearance of the Gao-chi craft has resulted in the deficiency of procedural information, which leads to embarrassing instances of low design quality in the contemporary practice of traditional architecture design. These issues include disproportion of elevation, the error of tenon-and-mortise work and unreasonable bay width.

With the promotion of information technology, especially parametric technology and BIM (Building Information Modeling), increasingly numerous studies apply these advanced technologies to ancient traditional architecture design and maintenance in China. Professor Wang developed an ancient architecture design platform to model the components using BIM technology[8]. Architect can establish design model of ancient architecture and manage the information through the platform. The platform can also provide accurate information for maintenance of ancient buildings to improve maintenance quality. Sun proposed a theoretical framework for building an information model system of ancient architecture in his master`s thesis and used Revit to manage information of instance [7]. Zhang established a BIM model of ancient buildings of Ming-Qing Dynasty with ObjectARX technology and proposed an efficient and systematized method to protect ancient buildings [11]. Lin tried to analyze and record Gao-chi craft by data calculation. In addition, he obtained spatial information using 3D scanning technology and made a digital Gao-chi using AutoLISP and AutoCAD [4]. This research attempted to establish a platform mainly focused on the maintenance of traditional ancient buildings from the perspective of BIM. Unlike the software which based on object-orient technology in the BIM environment, generative modeling is more in line with architects' creation habits in the early design stage as a commonly used tool in digital architecture design in recent years.

This study shows that regarding the perspective of communication theory, the generative modeling based on procedural information should record and integrate the necessary procedural information in the traditional building construction process as a design tool in contemporary design practice of traditional architecture. This modeling should integrate multi-disciplinary knowledge, reduce the knowledge gap between design and construction, and improve communication efficiency. To illustrate the viewpoint above, a carpentry work model of traditional architecture in Southern Fujian is modeled using generative modeling. With the assistance of this building model, the contemporary architect should intuitively know the design and tectonic principles of carpentry work in the design process, just as craftsmen designed and constructed ancient buildings by Gao-chi craft. The model will also improve the design quality of traditional architecture design.

2 MAIN IDEA

2.1 Procedural Information in Traditional Architecture Design

Unlike the modern construction industry, which describes the building`s shape, construction materials and dimensions using drawings, such as planes, elevation, sections and perspective, Gao-chi craft is an important tool to replace drawings and assist craftsmen with design and construction in the traditional construction process in Southern Fujian[4]. As shown in Figure 1, through a series of specific symbols drawn on a bamboo pole in an overlapping way, Gao-chi records considerable important information, which includes two parts: the geometric information recorded on the scale of 1:1, which includes the vertical dimensions of components of carpentry work and dimensions of tenon-and-mortise work; the non-geometric information that facilitates component fabrication and assembly, such as the construction taboo and relative spatial location between components.

According to the summary by Wu, the design and construction process of traditional carpentry work includes four stages: architecture programming, design, construction and maintenance [10]. Gao-chi plays an important role in each stage, as shown in Table 1. Gao-chi craft includes two phases, which are Shui-gua diagram drawing and Gao-chi drawing in design stage. After plane configuration, the craftsman draws a rough mid-section drawing which called Shui-gua diagram as shown on the left of Figure 2. It is mainly used to determine some key dimensions of traditional carpentry work, including the height of ridged purlin, eaves height, etc., and estimates the Ji-xiong dimension. The Ji-xiong dimension and its estimation are the judgments of key dimensions under the influence of Chinese traditional Fengshui culture. These dimensions are required to be evaluated by Ji-xiong algorithms to determine if the building is auspicious for the owner. Although this is a somewhat superstitious, it is an integral part of the Shui-gua diagram drawing and directly affects the form of carpentry work of traditional architecture. In the Gao-chi drawing phase, the craftsman records the component dimensions and relative spatial location using Gao-chi for fabrication and assembly, mainly focusing on the component design and details of nodes, as shown on the right of Figure 2. This information includes the ridge height, purlins and eaves in the Shui-gua diagram; the dimensions of detail components, such as Dougong which is a bracket set on the bottom of a roof in Chinese traditional architecture, beams, crescent beams, component location, spatial relationships, tenon-and-mortise work, and structural considerations. In the subsequent stage of construction and maintenance, Gao-chi has the function of measurement, lofting, stock and checking, which spans almost the entire building lifecycle.

In a word, the procedural information about the design and construction of traditional architecture is well-recorded by Gao-chi. In other words, a craftsman has to consider not only the influence of factors such as the culture of construction taboo, assembly of construction and the building structure but also the space, form, and roof slope. This procedural information will be recorded and integrated into Gao-chi.

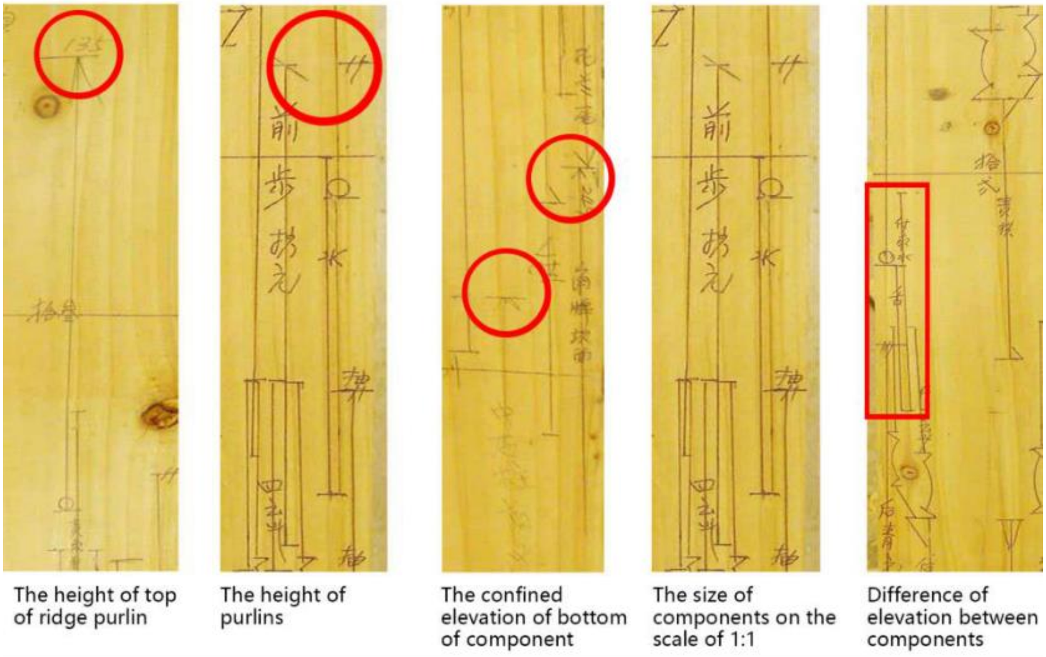

Figure 1: Integration of geometric information and procedural information by Gao-chi through specific symbols.

	Design		*Construction*
	Shui-gua diagram drawing	*Gao-chi drawing*	
Geometric information	Column position, Depth, Number of purlins, Distance between purlins, Roof slope, Roof radian	Height of ridged purlin, height of each purlin, eaves height, component size	The geometry information recorded by Gao-chi for stock preparation, lofting, checking and fabrication
Non-geometric information	Ji-xiong dimension, Construction taboo	Component location, Spatial relationship between components, Tenon-and-mortise work relationship between components, Consideration of Structure	The non-geometry information recorded by Gao-chi for assembling.

Table 1: Information recorded by Gao-chi in design and construction stage.

2.2 Lack of Procedural Information in Conventional CAD Modeling System

In the contemporary practice of traditional architecture design, Gao-chi craft was gradually replaced by the CAD modeling system due to the promotion of technology, materials and construction systems. Conventional CAD modeling is oriented to the building shape, tectonic and materials standards. The architect`s task is to express the key specifications of the expected completion of the building through various technical drawings. The way that an architect expresses a design is declarative information which focuses on the appearance of finished product of design. However, the architect's design process contains rich procedural information including geometric and non-geometric information [2]. With the limitation of existing drawing tools, little procedural information is recorded, and only the final results of drawing are retained [6]. BIM modeling tools are developed based on an object-oriented concept and only record a fragment of procedural information. Therefore, procedural information, such as how architects design building models and modeling rules, are lost in the conventional CAD modeling process.

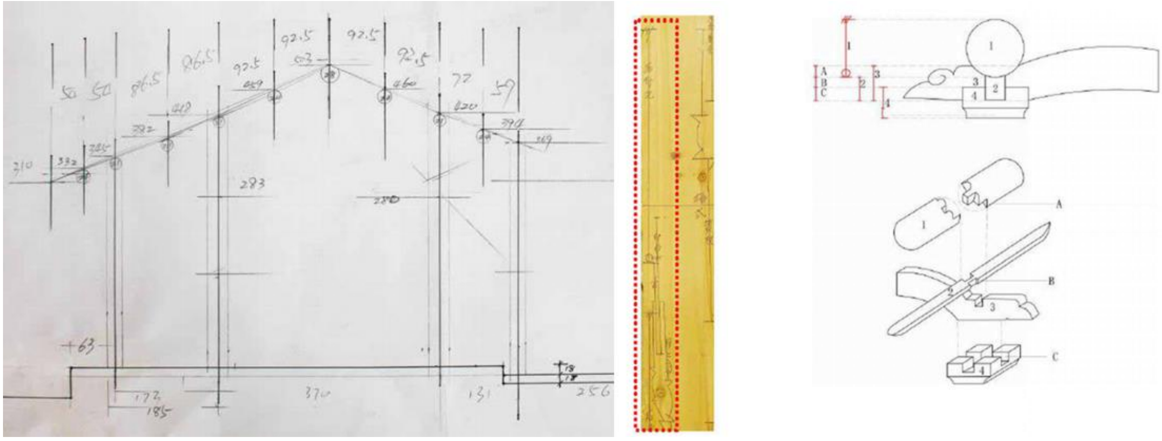

Figure 2: Shui-gua diagram drawing and Gao-chi drawing.

In the design process of contemporary traditional architecture design practice in the conventional CAD modeling system, the technical drawings delivered to the construction unit by architects contain more geometric information, such as plane dimensions and component dimensions of carpentry work. However, the procedural information related to tectonic principles of traditional architecture and construction taboo is lost. The resulting lack of procedural information implies that the construction unit cannot immediately and accurately grasp all of the information that architects want to convey. The construction unit must recheck the design, leading to a dramatic increase in the cost of modification in the design process or a disproportionality of elevation. The lack of procedural information is also an important reason for the low quality of traditional architecture design. Therefore, procedural information should be recorded and delivered to the construction stage, as well as the operation and maintenance stages, as an important part of architecture design.

2.3 Generative Modeling

Unlike CAD modeling, generative modeling is a technique using procedural information as its main subject [9]. GML (Generative modeling language) is a language proposed by Havemann for 3D modeling [3]. It is a language represented by constructive graphics and takes the basic information unit as its constructive process to present complex three-dimensional models. Therefore, it is more concerned about the process than how to generate a shape, and the shape is only a by-product of the program. Each part of design depends on other parts. Each modification by the designer allows the computer to recalculate all relevant parts via the program to ensure the consistency of the model. Generative modeling can construct complex shapes through the program using small amounts of appropriate data. Therefore, generative modeling has the following characteristics:

Design modification can be performed efficiently. In the modeling process, a computer records the design process in a systematic and structural way such that design decisions made in the early stage can be traced back and modified in subsequent design stages. The revised drawings and models can be generated by computer for recheck and communication. Additionally, the necessary intrinsic idiosyncrasy of form will be maintained. It can retain key information in the process of model modification; programs for modeling shape by designer usually represent the shape’s response pattern to various geometric transformations in subsequent editing processes, and represents how an existing design should be adjusted under different conditions to adapt to a new situation. Therefore, when a scheme designed through the program tracks back to the early stage, it can maintain the necessary idiosyncrasy. The subsequent program will be updated automatically by the system after modification at the same time.

2.4 Communication Theory

Claude Elwood Shannon proposed a mathematical communication model to measure the amount of information in a communication system which became the basis of information theory [5]. This model describes the process of communication. Information originates from the source and is encoded into a message via a channel for transmitting. The transmitted message is delivered to the recipient and then is finally decoded into information. The process of architecture design communication can also be explained using Shannon`s model: As shown in Figure 3, an architect uses drawings, models and sketches to express the design concept, that is, the process of encoding the information of design concept into messages. Drawings are delivered to the recipients, including the structural consultant and construction unit. The construction unit reads the drawings, which is the process of decoding the received message. Finally, the construction unit has its own knowledge of the design concept after decoding. It should be noted that due to the different knowledge backgrounds of architects and construction unit, encoding and decoding will be influenced by noise, which may lead to different perceptions in communication process.

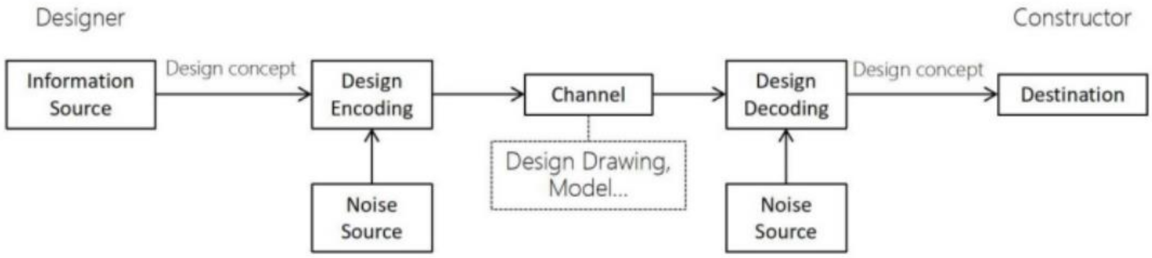

Figure 3: Communication model between designer and constructor.

For the construction and design of traditional architecture, drawing and reading Gao-chi is a process of encoding and decoding by craftsmen, as shown in
Figure 4. Gao-chi is the channel to transmit the design concept and design decisions. The architects encode the design into various specific symbols and record them on the Gao-chi. The Gao-chi is delivered to the construction stage, where the recorded symbols are decoded. Finally, the perceptions of design concept are achieved. It should be noted that craftsmen play the role of designer and also that of construction unit. Therefore, the same knowledge backgrounds will reduce the influence of noise in the encoding and decoding process to restore the design decisions made in the design stage to a maximum extent. This approach facilitates communication in the process of traditional building construction, thereby ensuring the final design quality.

The promotion of technology leads to industry division in the contemporary practice of traditional architecture design. The division between the design stage and construction stage makes the role of traditional craftsman in design and construction gradually separate. This severs the communication between designer and construction unit, so that the information does not flow smoothly. The division of the two disciplines means neither architect nor construction unit are able to construct their knowledge background in all aspects of traditional building, as traditional craftsmen do. This failure results in a knowledge gap. There is a lack of integration of construction information by architects in the encoding process of the design concept, that is, drawing of technical drawings; however, the construction unit has significant input in the process of decoding drawings delivered from designer such that the results decoded of information recorded on drawings is biased. Therefore, technical drawings are difficult to encode and decode as the communication channel between designer and construction unit, resulting in communication gaps between the two disciplines, and a decline in design quality.

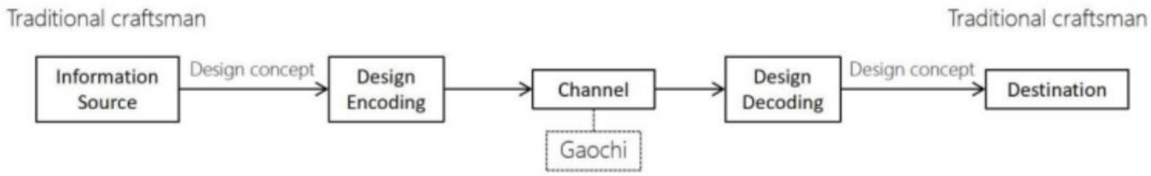

Figure 4: Communication model between designer and constructor in traditional architecture design.

As above, the generative modeling using the program as the main subject describes the basic geometric and procedural information, such as the rigorous tectonic principles between wooden components and construction taboo. As described in the communication model in Figure 5, generative modeling will integrate the multi-disciplinary knowledge as the channel between architect and construction unit, reduce the influence of noise in encoding and decoding process, and improve the fluency of information transmission [1].

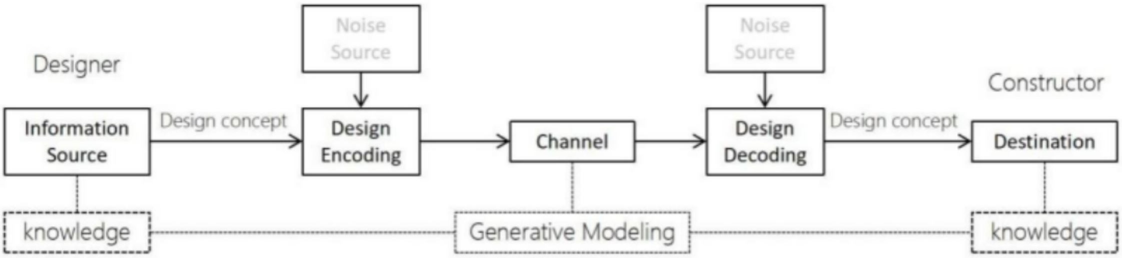

Figure 5: Communication model based on generative modeling between designer and constructor.

Regarding craftsmen's designs in the face of different conditions and environments in the traditional architecture design practice, important information such as the strict tectonic principles between wooden components is still the necessary intrinsic idiosyncrasy of traditional architecture. This is also one of the important reasons for traditional architecture to maintain a certain formal idiosyncrasy. Considering the characteristics above, generative modeling can assist architects with maintaining the necessary formal idiosyncrasy of traditional architecture in the contemporary design practice, similar to Gao-chi. This modeling can edit the design model efficiently to be appropriate for the traditional architecture design in different condition and environment, improve the communication efficiency between different disciplines, and improve design quality of design practice.

In summary, generative modeling is appropriate for contemporary design practice of traditional architecture design. Because the interface of visual programming is more in line with architects' design habits, this study builds a traditional building model in Southern Fujian based on Grasshopper, which is developed by MCNeel to illustrate the viewpoints proposed above.

3 CASE STUDY

This study builds a traditional building model using generative modeling to illustrate that generative modeling is conducive to the integration of procedural information and improvement of design efficiency and quality. Due to the complexity of carpentry work and the pertinence, this research aims at the following two parts to build the model: Shui-gua diagram drawing and Zhongze-jia modeling. Zhongze-jia is the mid-section of carpentry work.

3.1 The Shui-gua Diagram Drawing and the Integration of Ji-xiong Dimension Estimation

The Ji-xiong dimension is one of the important rules in the construction process of traditional architecture and the main content of the Shui-gua diagram drawn by craftsman, in Chinese traditional culture. It directly influences the form of carpentry work, with characteristics of factions [4]. Because of the different strategies adopted by different craftsmen, this research uses the Xidi school in Quanzhou of Southern Fujian as an example. The process of drawing Shui-gua diagrams is shown in Figure 6. The units mentioned in this article are chi and cun, which are Chinese traditional units of length, equal to 1/3 meters and 1/3 decimeter respectively.

On the left side of Figure 6, the architect first determines the bay width, depth and column position of the building, or plane size. The depth is 17.4 chi, bay width is 7.6 chi, 17.4 chi and 7.6 chi in this case, as shown on the left of Figure 7. Then, the architect determines the number of purlin and horizontal spacing between purlins. The horizontal spacing is usually between 2.9 and 3.6 chi. The horizontal spacing between purlins and number of purlins are 2.9 chi and 7 respectively, including ridge purlins in this case. Then, the architect determines the eaves height and roof slope. The eaves height is usually larger than 9.5 chi, while the number of purlins is 7 according to construction rules. The height of the lower eaves is determined to be 13.4 and 13.9 chi and the roof slope is 0.4 in this case. The height of the ridge purlins, which can be determined according to the roof slope, is 26.9 chi. The oblique line of the roof is concave downward based on the midpoint of the oblique line. The concave distance is 3 cm, a as shown on the right of Figure 8. Finally, the height of each purlin is adjusted. In this process, a series of logic relationships and dimensions are described using generative modeling. The architect only needs a series of given parameters to input, including each bay width, depth, the horizontal spacing between purlins, eaves height and roof slope. The Shui-gua diagram is generated automatically, as shown in Figure 8.

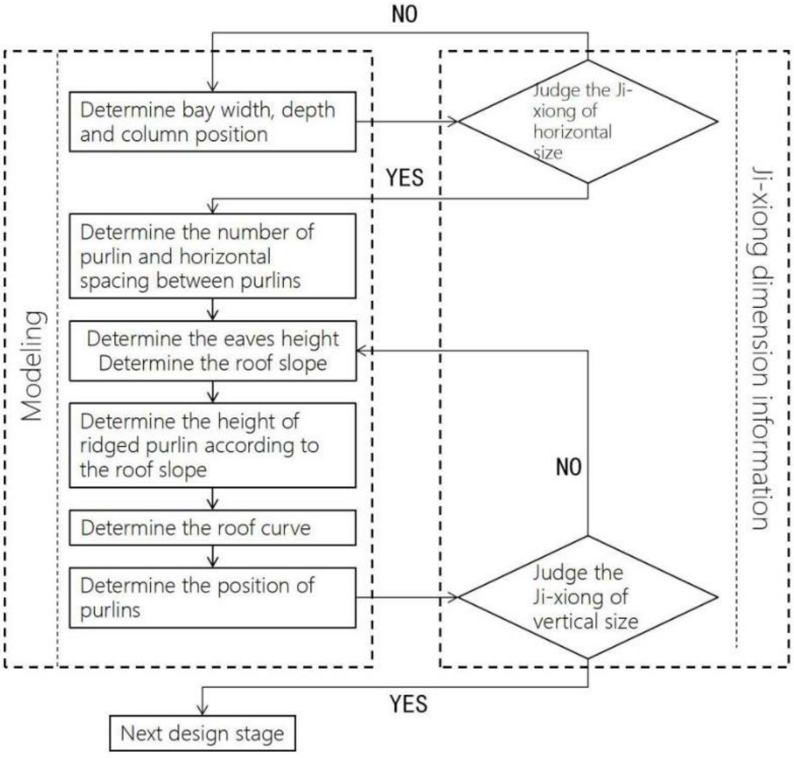

Figure 6: Process of drawing Shui-gua diagram of traditional building in Southern Fujian.

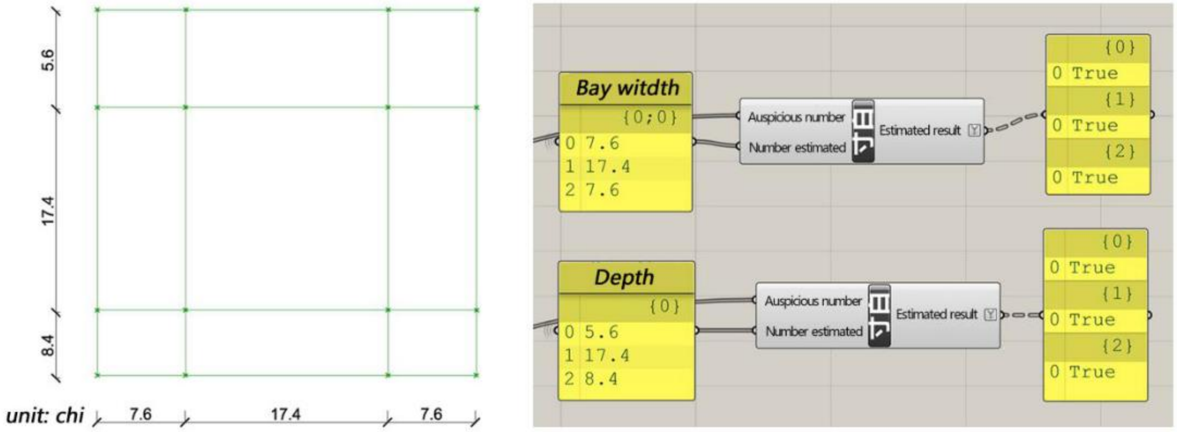

Figure 7: Ji-xiong estimation on horizontal dimensions of plane.

Some key construction taboo dimensions need to be estimated, if they are auspicious at the time of drawing Shui-gua diagram. This is necessary for information integration into the model by generative modeling and immediate judging in the modeling process, as shown on the right side of Figure 6. There are two aspects for Ji-xiong dimension estimation: Tian-fu, which means the vertical size, includes the height of ridge purlins and eaves height; Di-mu, which means the horizontal size, includes such parameters as the bay width, depth and spacing between columns.

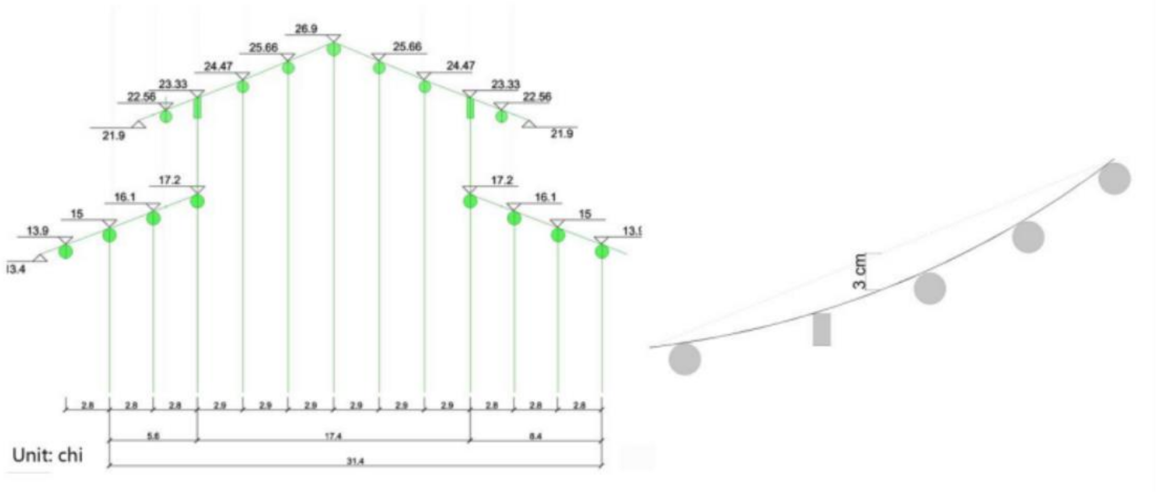

Figure 8: Determine the key height and roof slope by Shui-gua diagram.

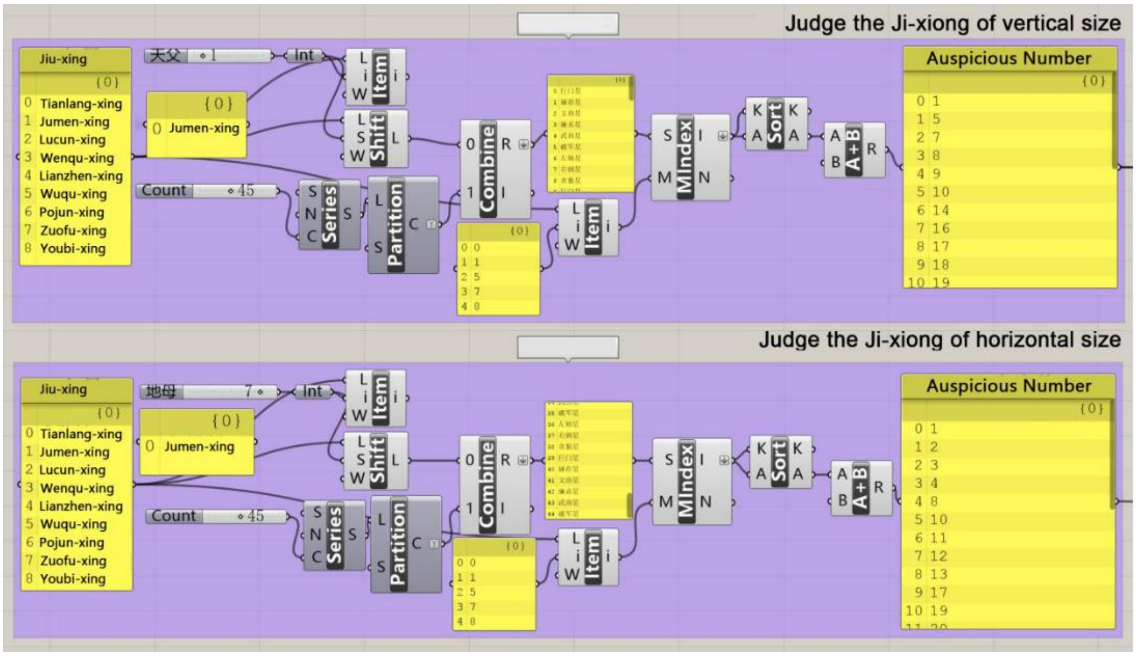

Figure 9: Algorithm of Ji-xiong estimation by generative modeling.

Jiu-xing	*Tanlang-xing*	*Jumen-xing*	*Lucun-xing*	*Wenqu-xing*	*Lianzhen-xing*	*Wuqu-xing*	*Pojun-xing*	*Zuofu-xing*	*Youbi-xing*
Ji-xiong (auspicious or not)	Auspicious	Auspicious				Auspicious		Auspicious	Auspicious

Tianfu(vertical size)		1	2	3	4	5	6	7	8
	9	10	11	12	13	14	15	16	17
					……				
Dimu(horizontal size)								1	2
	3	4	5	6	7	8	9	10	11
					……				

Table 2: Algorithm of estimation of Ji-xiong dimensions.

According to the formula for incantation of Fengshui, the initial position of Jiu-xing can be obtained through the algorithm [10]. The Ji-xiong estimation of Chi-bai and Cun-bai of horizontal size and vertical size is described in Table 2. Jiu-xing indicates the mysterious position of Fengshui of Chinese traditional culture, which will not be described at length. Chi-bai indicates the integer part of the size value, and Cun-bai indicates the decimal part of the size value. While the Chi-bai and Cun-bai meet the auspicious position of Jiu-xing, the size is auspicious. The number marked red in Table 2 is auspicious in this case. In fact, the algorithms can be encoded by generative modeling. As shown in Figure 9, the vertical size is started with Jumen-xing. The auspicious Chi-bai of vertical size is 1、5、7、8、9……, mainly used to estimate whether the height of ridge purlin and eaves height are auspicious. Similarly, the auspicious Chi-bai of horizontal size is 1、2、4、8、10……, mainly used to estimate whether the bay width, depth, spacing between columns are auspicious. In the same way, the auspicious Cun-bai of vertical size and horizontal size are respectively 2、4、9、11、13……and 4、6、8、13、15……, mainly used to estimate whether the vertical size and horizontal size are auspicious. In this case, the vertical sizes, such as height of ridge purlin, eaves height and horizontal spacing between purlins in the model generated are respectively 26.9, 21.9 and 2.9, which are all auspicious. So does the Ji-xiong estimation on horizontal size of plane as shown on the right of Figure 7.

Unlike conventional CAD drawings which only describe the geometric information, the non-geometric information which includes the construction taboo, Ji-xiong dimension, and the algorithms are integrated into models. The architect can adjust the key dimensions of the model such as planar size and height in consideration of the Ji-xiong dimension;, the information of Ji-xiong dimension estimation will be given as feedback automatically by the computer while the architect regulate the building massing. Therefore, architect should adjust the model according to the feedback instantly.

3.2 Mid-section Carpentry Work Modeling

According to the drawing process of Gao-chi craft, this study builds the Dougong models of Zhongze-jia, Qianfu-jia, Houfu-jia and Liao-jia. In other words, mid-section carpentry work modeling is used as an example. As mentioned above, after the key dimensions are determined, the designer will determine the size and location of each wooden component and record step by step on the bamboo pole on the scale of 1:1 in the subsequent stage. The mid-section carpentry work is also the first step of Gao-chi drawing.

- Determine the section size of the ridge purlin based on its location.
- Determine the size and location of Gui-she and Ze-shu, where Ze-shu intersects Gui-she, Gui-she is parallel to the ridge purlin and Ze-shu is perpendicular to the ridge purlin. The vertical size of the intersection is larger than 2 cun.
- Determine the size and location of Tongtou-dou, where its top intersects with Gui-she and Su-ze. The vertical size of intersection is less than 1/2 of the vertical size of Tongtou-dou.
- Determine the size and location of Gongwei-dou, where its top intersects with Gui-she and Su-ze. The vertical size of intersection is less than 1/2 of the vertical size of Tongtou-dou.
- Determine the size and location of Ze-gong, where its top connects with the bottom of Tongtou-dou.
- Determine the size and location of Shufu-hou, where it intersects with Ze-gong and intersect with column..

Obviously, there is a certain logic following the tectonic principles of the construction process to the spatial relationship and size between components of traditional building. The Gao-chi records not only the vertical size of all the components but also the relationship of location and tenon-and-mortise work between components on the scale of 1:1, as shown in Figure 10. However, in the contemporary design practice of traditional architecture, the procedural information is hard to encode and decode due to the specificity of the symbols recorded on the Gao-chi, both for architects and the construction unit. Therefore, recording the spatial relationship and size by generative modeling to generate the model is conductive to improving the communication efficiency between architects and construction units.

Figure 11 shows the model of mid-section carpentry generated by Grasshopper according to the tectonic principles mentioned above. The size of each component of the mid-section carpentry is recorded. The geometric information is not only utilized as a reference for component fabrication in the subsequent construction stage but also generates the volume as a reference for stocking and cost estimation more precisely. In turn, the feedback of these data can also assist architect in adjusting the parameters and making design decisions in the design stage. Generative modeling records considerable non-geometric information. The mid-section carpentry model is generated according to the logic relationship between components. Because generative modeling records the relationship of location between components, architects can obtain different sizes of mid-section carpentry model by adjusting the parameters of each component, and the mid-section carpentry still follows tectonic principles and maintain the relationship of location of components. In other words, architects can follow the rigorous tectonic principles to maintain the necessary formal idiosyncrasy of traditional architecture. In addition, this information can be used as a reference for the maintenance of traditional architecture in future.

Finally, a complete carpentry work model of traditional architecture in Southern Fujian is generated, as shown in Figure 12.

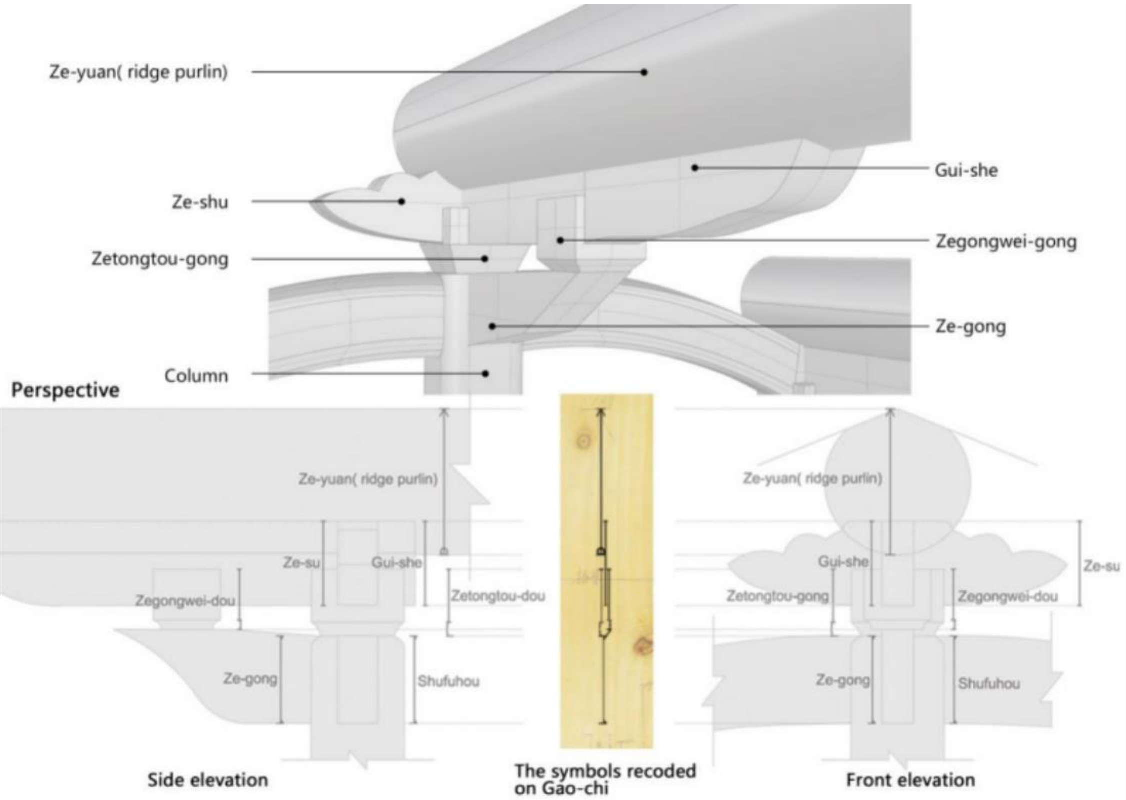

Figure 10: Gao-chi records the dimensions and location relationship.

4 CONCLUSIONS

This study uses the communication theory model to discuss encoding and decoding by craftsmen who utilize Gao-chi to communicate in the traditional architecture design process. The study proposes that generative modeling can efficiently maintain the necessary formal idiosyncrasy of traditional architecture in the design process. This study integrates multi-disciplinary knowledge and narrows the communication gap between architect and construction to improve communication efficiency. In this process, generative modeling integrates not only the geometric information, such as component size, but also procedural information, such as tectonic principles and construction taboo, into models to assist architects with the reduction of design cost and the improvement of design quality and efficiency in contemporary design practice of traditional architecture.

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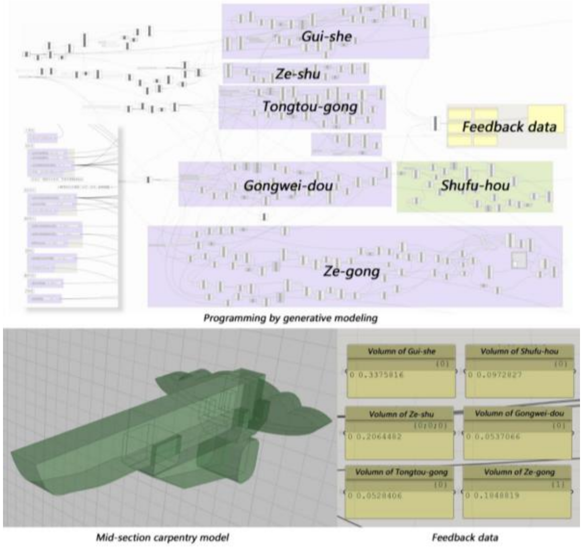

Figure 11: Information integration and modeling of Dougong of mid-section carpentry work.

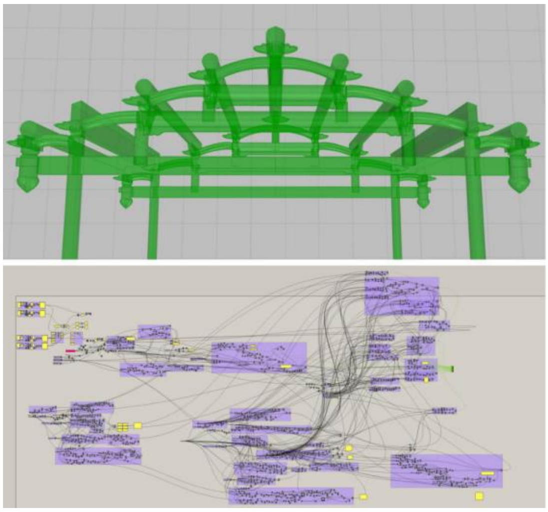

Figure 12: Carpentry work model of traditional architecture based on the programming.

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