

Parameterization of Chinese Ancient Architecture on the Basis of Modulo Relationships

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Abstract. Contemporary systems are trending toward 3D computer-aided design systems that integrate, network, and exhibit intelligence. The integration of parametric technology with ancient Chinese architecture can enhance the efficiency and quality of managing information on ancient buildings, thereby expanding the application scenarios of ancient architectural information models. By analyzing the construction characteristics of ancient Chinese carpentry work and modular systems, this research outlines the logic and methods for generating Chinese ancient architecture. The program's parametric technology allows for adjusting variable parameters to produce carpentry work structures of varying scales and forms. Furthermore, this research establishes a library of parametric 3D components for ancient architecture, which can simplify the design process of contemporary antique architecture. Additionally, the parametrization of Chinese ancient architectures can function as an auxiliary tool for maintenance and repair techniques, serving as a storage mechanism for whole-life cycle information. This can enable the digital archiving of component information and model entities in an informative manner for managing existing ancient architectures.

1. Introduction

The load-bearing structure of Ancient Chinese architecture mainly comprises of timber-framed elements such as columns, beams, purlins, and rafters, which are assembled using mortise and tenon construction. This construction technique has been used for centuries and presents a unique challenge for modern-day architects seeking to integrate traditional design elements with contemporary technology. The contemporary trend in 3D computer-aided design systems is characterized by the integration, networking, and intelligence of these systems. Computer parametrization forms the basis of this trend, and applying parametric design to ancient Chinese architecture is now imperative.

The design of ancient Chinese architecture follows the concept of "small to large," beginning with the modular system. The timber frame is constructed using a basic modulus for the building's dimensions. The geometric dimensions of each member are first determined and then combined to form the building. The dimensions of its components and the proportions of their combinations strictly adhere to the modular system, aligning well with the characteristics and requirements of computerized parametric design. The trend toward computer-aided design systems is increasingly characterized by the use of parametric modeling, which allows for the efficient manipulation of complex geometric forms. Applying parametric design to ancient Chinese architecture is imperative in order to preserve

and advance traditional design techniques while incorporating contemporary technology. Given the importance of preserving traditional design techniques and the need to incorporate contemporary technology, establishing a parametric model of Chinese ancient architecture is an important step in ensuring the efficient management of information on ancient buildings. By leveraging parametric modeling, architects can generate structures that adhere to traditional modular systems while incorporating contemporary design elements. Therefore, establishing a parametric model of Chinese ancient architecture is an inevitable process.

2. The Advantages of Parametric Techniques in Ancient Chinese Architecture

2.1 The Modular System in Ancient Chinese Architecture

In ancient Chinese architecture, the grades and scales of buildings were strictly regulated according to a hierarchical system. To achieve better control over the building's scale, a modular system was utilized by the ancients to determine the grade of materials used for each part of the construction. This system allowed for a clear dimensional relationship between the various parts of the ancient building and its components [1].

The modulus serves as the standard unit of dimensions for architectural design summaries and is the

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basis for coordinating architecture and related equipment dimensions with each other. The use of the modular system can establish building regulations and principles, reduce construction costs, and improve construction quality and efficiency. There are three primary types of modular systems used in ancient Chinese architecture: the cai-fen system, the doukou system, and the use of column diameter as a basic parameter.

2.2 Architectural Features of Ancient Chinese Architecture [2]

2.2.1 Integral Relationships and Separability of Component Details

The logic of architecture construction can be divided into two parts. The first part concerns the overall structural relationship of carpentry work, which is reflected in the components' relationship. The second part concerns the components themselves, which are of the same type and style and can be used in various forms and scales of timber architecture. The differences between them typically relate to overall proportions and length dimensions.

Therefore, choosing computer modeling methods for carpentry work should fully consider this characteristic. Appropriate modeling tools can be selected, and the modeling work can be split and coordinated reasonably to maximize modeling efficiency.

2.2.2 The Strong Logic of the Principle of Component Positioning

The second characteristic of carpentry work construction is the positioning of internal components, which follows clear laws and rules and has a strong logic. Construction work begins with a network of columns defined by a grade, volume, and slotted forms. Columns are interspersed with architrave and topped with paving ties, on which each paved work is aligned with the center of the column. The form of bracket sets determines the eaves' position, which dictates the overall roof level's form. Based on the building's depth and eaves' position, the purlin is positioned using the folding method. The hip rafter is placed above the corners of the eave purlin and the eaves, while the twork is placed below the purlin, and each layer is supported by a king post or tuofeng. The overall construction is generated by the principles of general connection with these key carpentry works. It can be observed that the position of almost all components in carpentry work construction is determined by the position of the components in the previous step of the logical chain of component positioning. This process develops in a clear, single cause-and-effect manner and is a strictly standardized process.

2.2.3 Quantitative Standardization of Form and Scale

Ancient Chinese architecture adheres to strict standards for the overall scale and component form, which are quantitatively bound in units such as chi, cun, and fen. The cai-fen system, the doukou system, and the jingzhu system provide quantitative specifications for nearly all dimensions of carpentry work buildings, from the overall scale to the components' detailing. This quantitative specification of carpentry work's form and scale is a more direct and efficient way of expressing it than a verbal representation. Computer technology can translate these specifications with parametric precision (Figure 1).

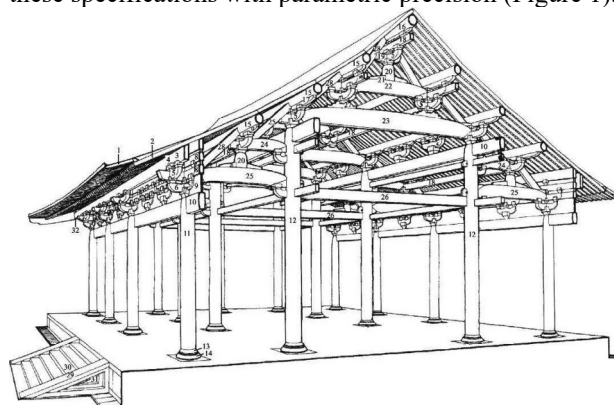


Figure 1. Example of a typical ancient Chinese building structure(1—flying rafter;2—eave rafter;3—liaoanfang;4—dou;5—bracketarm;6—flower arm;7—capblock;8—column-top lintel;9—apron flashing;10—architrave;11—eave column;12—hypostyle column;13—column foot;14—column base;15—intermediate purlin;16—ridged purlin;17—timu;18—straining tie;19—dinghuamoke-gong;20—king post;21—bracket;22—3-purlin beam;23—5-purlin beam;24—one-step cross beam;25—rufu;26—along-beam tie;27—tuofeng;28—chashou;29—drooping belt stone;30—step;31—triangular space;32—head-raising timber).

3. Parameterization of the Carpentry Work of Chinese Ancient Architectures

3.1 Parameterization Basis:Modular Relationships [3]

In ancient Chinese architecture, the width is measured by the "jian" and the depth is calculated by the "jia". The area of the entire wooden frame is determined by the "jian" and "jia", which follow the basic modular system as specified in the Engineering Practice. The size of each component of the ancient building is also determined by the modular system, with the diameter of the doukou and eave column serving as the base modulus to control the size of other components.

As a result, the width and depth dimensions are determined after selecting the base modulus, and the size of the wooden frame is correspondingly determined. Similarly, the basic modulus and component size can be inferred after determining the construction area. The

latter method is more commonly used in the design of antique buildings.

3.2 Basic Parameters of Parametric Modeling [4]

To begin with parametric modeling in ancient architecture, the active parameters need to be determined first. Utilizing the modular system concept of ancient architecture, the "doukou" or "caihou" can be defined as a global variable to establish constraint relationships with other features.

Next, an appropriate reference surface is selected based on the characteristics of the dougong to model individual components. Each dimension is then marked to form a parameter constraint, enabling the modeling of a single component. The series part design table is inserted, allowing for the automatic modeling of components for each grade of material by changing the value of the global variable "doukou" or "caihou." By following this approach, the required components of a single dougong can be parametrically modeled and then assembled using the arch assembly diagram, adhering to the assembly principle of bottom-to-top, sequential assembly, and associated features (Figure 2-4).

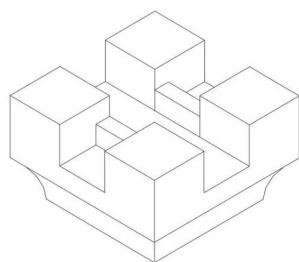


Figure 2. Cap block model

name	model	name	model
oval arm		cap block	
ang		jingkou fang(purlin)	
grasshopper head		small block	
connection block		architrave	
regular arm		long arm	
central fang		center block	
wall brander		apron flashing	

Figure 3. The model of the components of bracket sets between columns

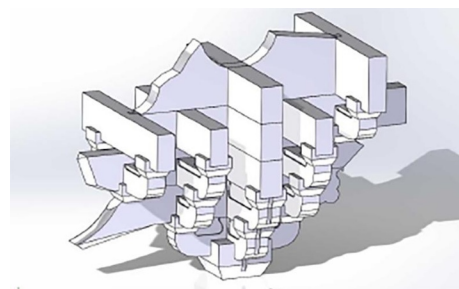


Figure 4. Model of bracket sets between columns

Note: In the large dougong-less or small type of ancient buildings, the eaves column diameter functioned as the basic modulus, and modeling ideas is the same as above.

3.3 The Process of Constructing A Carpentry Work Axis Model (Determination of Positioning Points and Lines and Its Steps) [5]

3.3.1 Column Network System (with Dougong)

(1) Column

Once the basic modulus has been determined, the width and depth of the building can be determined based on the number of rooms, in combination with the functional relationship. The construction of the building starts with the positioning point of the column head, which is determined by the width, depth, number of rooms, and form of the slots. Using the method of first determining the location of the eave column head and then the location of the column head in the slot, the column network can be generated.

(2) Architrave

The location of the architrave can be determined by calculating the position of the column head.

(3) Pupaifang

A square support for the paving layer is placed above the column head. For modeling purposes, the connecting line of the pupaifang is used as the positioning axis for the lower part of the square.

(4) Dougong

The column head laying process is achieved by using the offset post-positioning point of the column head, with the reference point set at the lower skin of the sitting square (Figure 5).

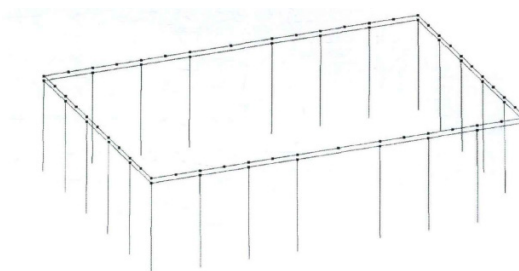


Figure 5. Positioning of the column network system

3.3.2 Liaoyanfang

To generate the liaoyanfang (liaofengpurlin), the first step is to generate its positioning line, which is used as the basis for calculating the purlin-raising. During modeling, two parameter values are used to indicate the position of the eaves relative to the dougong positioning point: total elevation and total jump. These values represent the longitudinal and lateral offset from the dougong positioning point to the upper skin of the liaoyanfang. The positioning line of the dougong is generated by offsetting these two amounts and connecting them to the outside of the building with the positioning points of the four corner dougong (Figure 6).

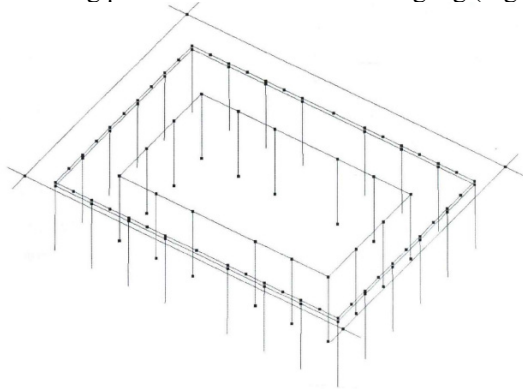


Figure 6. The location of liaoyanfang

3.3.3 Purlin-raising

The process of raising the purlin involves two distinct steps, namely lifting and folding. Lifting is used to calculate the total height of the roof frame by determining the location of the upper skin of the ridge girder, which is achieved by measuring the distance between the front and back of the liaoyanfang and dividing it into three from the back of the liaoyanfang to the back of the ridge girder. For instance, in the case of a temple pavilion, one copy is lifted. The folding of the rooms is the second step, which determines the position of each layer of purlin. This is accomplished by raising the height of the eaves to two feet and then folding each foot by one cun, reducing each frame by half from the top. To illustrate, the first seam is taken from the back of the ridge girder and goes down to the back of liaoyanfang, folding the second seam by one foot. If there are numerous rafters, then each seam is taken step by step until the position of the bottom eave purlin is calculated (Figure 7).

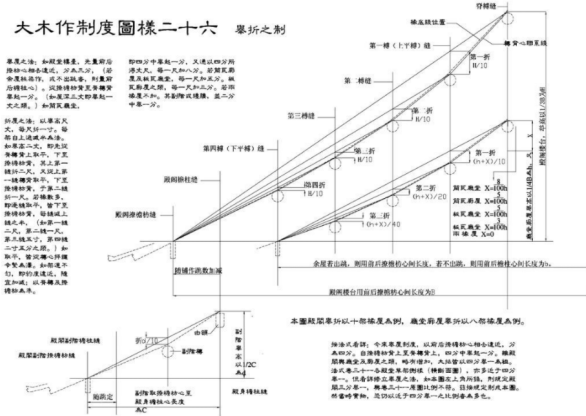


Figure 7. The system of purlin-raising of carpentry work (Photo credit: Liang Sicheng's Commentary on the Building Method)

By analyzing the generation logic of this approach, it can be observed that it is a typical iterative algorithm. Each iteration step follows the same logic and depends on the previous result. Therefore, the algorithms embedded in it can be utilized to conduct iterative computer calculations in the modeling process (Figure 8).

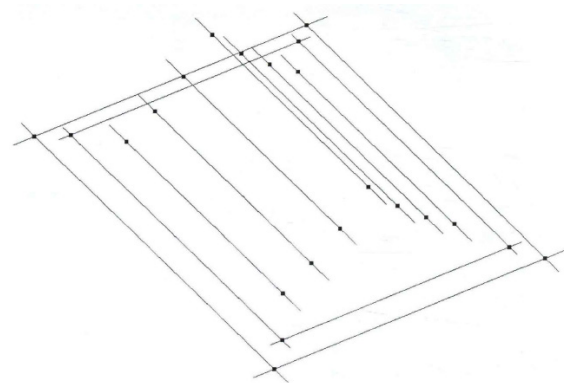


Figure 8. location of purlin-raising

3.3.4 Hip Rafer

The location and length of the large hip rafter are determined by the specifications: "the length of the hip rafter is from the eave purlin to the lower end of the eaves, extending outward." Therefore, the length of the large hip rafter is based on the distance from the eave purlin to the corner point of the liaoyanfang, with additional length required for the outward extension. The four corner points of the liaoyanfang serve as the lower positioning points for the four large hip rafters, while the upper positioning points are referred to as the basic end points of the eaves under each side, and their outward extension can be adjusted within a certain range. The positioning line of the large hip rafter is generated by adding a flexible amount to the connecting line of the two points and extending it to the lower end (Figure 9).

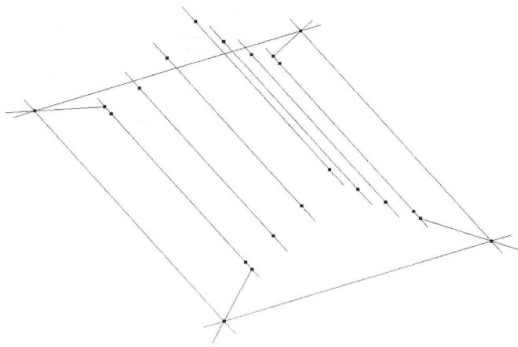


Figure 9. location of large hip rafter

3.3.5 Beam

The term “fu” refers to a beam. Starting from the eave beam, each level's eaves are supported by beams progressively higher up. Because the weight of the beam on each eave varies, the material used for the beams becomes wider from the bottom to the top. The width of the beam between each layer and the eaves it supports is roughly constant. In the modeling process, the positioning line of the beam is represented by its upper surface (Figure 10).

(1) Eave beam

To generate a positioning line for the eaves, the eave capitals of the front and rear columns are extracted and connected in a sequential manner. Two digital inputs, namely upward offset and outward interval at each end, are used for this purpose.

(2) Each layer of roof beam

Given that the beams for each layer have been previously generated, all layers except for the eave beams can be based on the positioning point of the eaves supported by that layer. The eaves amount relative to the ends of the eaves is consistent across all layers. The beam positioning line for each room is generated based on this logic, and controls the longitudinal offset and the amount of ends of the roof beam.

(3) Ding beam

The positioning points of the eave column head on both sides, excluding the corner columns, are extracted and then extended horizontally toward the outermost two sides of the eave position. The longitudinal offset is then controlled accordingly.

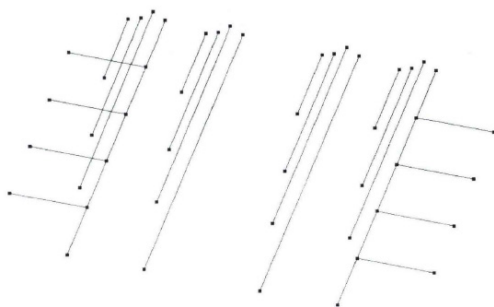


Figure 10. location of roof beam.

3.3.6 King Post and Tuofeng

The elevation of the layers is achieved through the use of king posts and tuofeng. The horizontal position of each king post and tuofeng on a given layer is the same as the eaves of the previous layer, and their height is determined by the distance between the top skin of the medical device on that layer and the bottom skin of the medical device on the previous layer. This determines the positioning line of the king post and tuofeng (Figure 11).

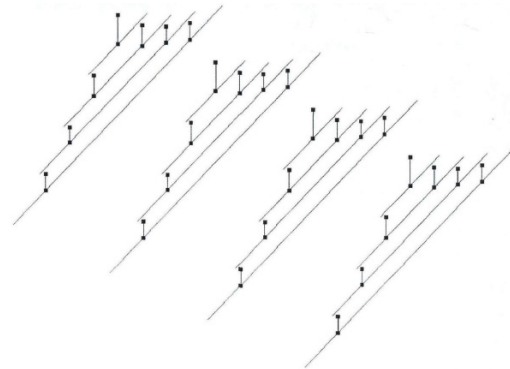


Figure 11. location of king post and tuofeng

3.3.7 The Complete Axis Model

A comprehensive axis model of the traditional building is obtained by integrating the axis models obtained from the previous steps (Figure 12).

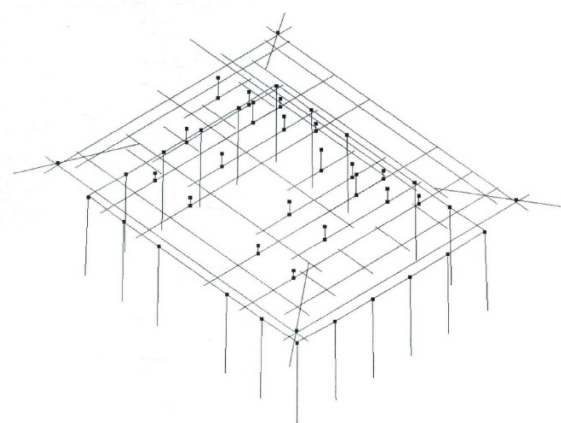


Figure 12. Example of axis model

3.4 The Complete of the Parametric Model

The architecture model was created by combining steps 3.2 and 3.3, resulting in a complete model of the ancient building. This model is capable of autonomous transformation by adjusting the basic modulus, which is considered an active variable (Figure 13-14) [6].

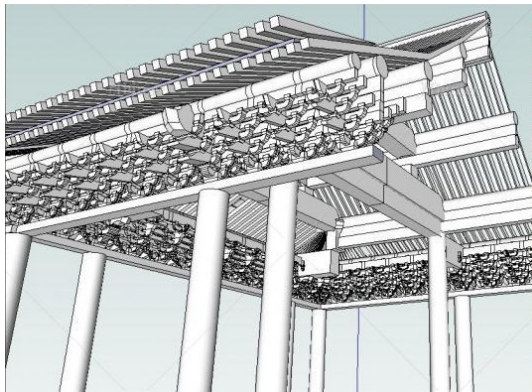


Figure 13. Example of the complete model

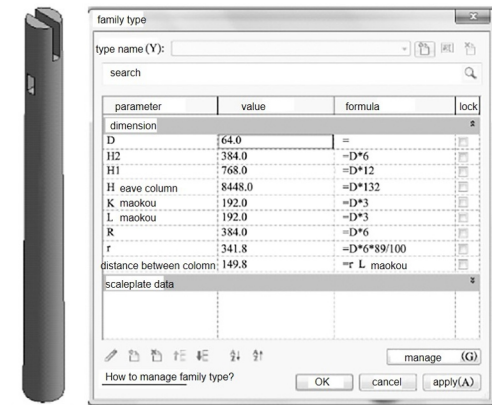


Figure 15. Parameterization of peripheral column

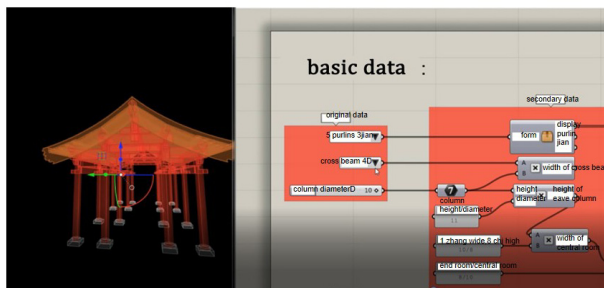


Figure 14. Changing the model by changing the base modulus

4. Parameterization of Ancient Building Components

The digitalization of components in ancient Chinese architecture and their management, whether as a supplementary instrument for maintenance and restoration techniques or as a storage system for information throughout the ancient buildings' life cycle, will be actualized in the form of a parametric three-dimensional component library for these structures. The digital archiving of component information and model entities will be accomplished through an informational approach [7].

Component models are constructed using parametric family models. Consider the peripheral column as an example. The dimensions of each part of the peripheral column, such as the column height, closing points, mortise and tenon joints, and the mortise, are determined by employing doukou D as the fundamental modulus. When creating a 3D member family model, set the parameters for each part, use the trade-off formula to establish a connection with the basic parameters of the doukou, and convert the formula. As a result, the entire member family model only requires modification of the doukou size D, and the overall family size adjusts accordingly. This also constitutes the fundamental requirement for the parametric design of wooden components [8].

The aforementioned procedures are executed for each component of the ancient structure and input into the library, resulting in a versatile and modifiable library of ancient architectural components that can be accessed and altered at any time.

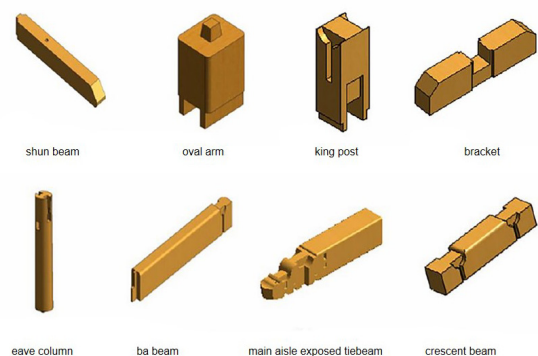


Figure 16. The establishment of a repository of ancient building components

5. Conclusions

In traditional building construction theories, the rationale behind carpentry work construction is conveyed through textual descriptions, and these explanations are often dispersed throughout various texts, lacking logical intuitiveness. Simultaneously, the actual execution of carpentry work features distinct modal control and stringent formal practices, which aligns closely with the way computer language programs operate. This article briefly presents the theory of architectural construction and the logic of construction, translating this logic into a digital language, and discussing the process of developing a parametric model of ancient Chinese buildings and establishing a library of ancient architectural components.

Upon acquiring information about ancient architecture, parametric technology can be employed to generate a 1-to-1 model of the original structure based on the actual dimensions of the historical building. This process uncovers the true appearance of historical buildings and the historical information embedded within their narratives. A data platform that combines modern electronic information technology tools with historical context is used to conduct digital preservation and heritage research on ancient architecture. The appearance, form, location, and historical and cultural

value of various historical monuments aid researchers in the maintenance and management of historical structures. The modular system of ancient Chinese architecture is linked to computer logic, which simplifies and streamlines the modeling process. Concurrently, the architectural characteristics of ancient buildings facilitate a step-by-step modeling approach. Ancient Chinese architecture naturally possesses parametric potential and modeling advantages [9].

Simultaneously, it is evident from this paper that parametric technology simplifies and streamlines contemporary antique architectural design, benefiting from the distinct advantageous conditions of China's ancient modeling number system. The building is created logically and seamlessly, and the existing component library can be directly utilized during the modeling process. After the initial modeling, parameters of various forms and scales of the carpentry work can be controlled to alter the shape and size of the carpentry work (such as width, depth, room quantity, and the number of horizontal spacing between purlins, etc.). Additionally, it is possible to flexibly adjust values that are not strictly defined, such as column height, the expansion of the center room's width, and the extent of eaves protruding from both ends. All these advantages make contemporary antique architectural design relatively effortless. On the other side, there are inevitable limitations and potential biases inherent in relying solely on textual descriptions and historical context for the development of the parametric model. Additional research and validation through physical measurements and assessments should be done to strengthen the model's accuracy and reliability.

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