Parametric Design and Aesthetics of 3D Appearance of Ancient Buildings

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Abstract: Ancient architectural design refers to the conservation repair and reconstruction of cultural relics and buildings as well as the design of antique-style architecture. This paper involves using the component-assembly method to perform the architectural design of ancient Chinese wooden buildings by 3D parametric means, including the application of the design method that combines modern industrial serialized group design technology contained in the above means with the trade-off of ancient building modularization. The model can be disassembled and converted into 2D engineering drawings.

1. Introduction
Ancient architectural design refers to the design of conservation repairs, reconstruction, and antique-style buildings of cultural relics. Computer 3D parametric modeling configuration design refers to starting with the establishment of a 3D model, which can be converted into a 2D engineering drawing; second, parameterization refers to driving model changes with dimensional parameters, if you change the model parameters, quickly change the shape of the model [1-2]. This advanced method is being extensively applied in the field of mechanical and other configuration design. The “component-assembly” method comes from the “part-assembly” way of mechanical structure design [3]. It can realize the exact configuration of each part model and accurately assemble it as an assembly model with various appropriate “mating surfaces” [4]. The ancient construction type can just choose the matching surface from the tenon-mortise structure to implement accurate assembly to form the assembly [5] accurately.

Since ancient buildings have existed standardized design norms-modular “balance” since ancient times, this precious legacy can be utilized more effectively. The series of group design techniques in 3D parametric means can be used for configuration design. They can be further established “Standard component library” can be used to form components from the library through “selection” and “setting parameters”, and then assemble, thereby greatly improving the design efficiency [6]. This method intends to use 3D parametric means to express the structural design and aesthetics of the wooden beam frame of ancient buildings in the form of “component-assembly”, that is, the 3D model can be expressed as an integrated document (Assembly Document) after installation, or a single component (Part Document).

2. Uses and Advantages
1) Unprecedented intuitiveness, accuracy, and measurement.
2) As a design method, the tenon and mortise structure is included, which is more conducive to
carrying forward ancient technology comprehensively and accurately. 

3) Compared with the design method of drawing 2D engineering drawings, not only can the 3D model be converted into a 2D engineering drawing, but because multiple 2D views come from the same 3D model, it can avoid multiple views in 2D drawing. There are contradictory errors.

4) Due to the tenon and mortise structure, some of the more difficult components are modeled with reference to the drawing process of large wooden lines, and the relationship between line drawing and configuration results can be observed repeatedly. It will improve the capability of designers to participate in on-site construction guidance.

5) It can be used to develop the computer model for the whole structure and components of wooden structure relics connected by tenon and mortise.

6) Its unprecedented intuitiveness can be used for teaching.

7) Standard components library can be established according to the ancient method modulus trade-off, to improve the configuration design speed significantly.

3. Basic Method for 3D Modeling of Ancient Buildings

3.1. Design Route

The part-assembly method is a consistent method of mechanical structure design. It is divided into two design routes: Bottom-up and Top-down. The former is to design components in an independent environment first, and then assemble as a whole (assembly); the latter is to design new components in the assembly environment, the new components form a closely related “reference” relationship with the existing components in the assembly, Referred to as “associated design”, as shown in Figure 2.

In the manual drawing and computer drawing design before, due to the limitations of the means, the two design routes can only choose one. However, under the 3D parametric means, these two routes can be flexibly converted at any time as needed.

For the 3D modeling of ancient buildings, the flexible conversion of the above two routes is both necessary and more likely. That is, if only the bottom-up route is used, it is difficult to accurately model some components (such as the rafters, the actual project also uses the design associated with the corner beam); if only the top-down route is used, the entire modeling process will be too complicated.

The computer 3D model made in this study is mainly based on Zang Erzhong’s “Qing-style bucket arch atlas”, Pan Dehua’s “Dou Gong” and Ma Bingjian’s “Chinese Ancient Buildings Woodwork
Construction Technology” and other documents.

3.2. Basic Modeling Methods

The 3D parametric design mainly includes sketches, features, entities, components, assemblies, and other links.

Because the modeling basis of components can be found in the literature, most components mainly adopt the “bottom-up” method, that is, the method of making a component (part) model first and then installing it in an assembly environment. One component model can be installed immediately or after multiple component models.

As components can be saved as “part files” separately, a component model can be used not only for an assembly but in different ancient assembly, the same component can be used repeatedly.

3.3. Modeling Based on Group Design Approach

The so-called improvement method means that in order to ensure accurate assembly, improve design efficiency, and reduce repetitive workload, modern serialized group design concepts and 3D parameterization related methods are combined with ancient modularization trade-off, which will provide an efficient approach for future design.

In the 3D parametric design, since changing the model size parameters can drive the model to change its shape, this provides the basic conditions for modular and serialized group design to a large extent.

The 3D parameter design is as follows, assuming that P is the unit vector in the selected forming direction, as shown in equation (1):

$$P = \begin{bmatrix} \sin \theta_1 \cos \theta_2, \sin \theta_1 \theta_2, \cos \theta_2 \end{bmatrix}$$

(1)

Where $\theta_1 \in [0, \pi]$, $\theta_2 \in [0, 2\pi]$.

![Figure 3 Modeling coordinate system](image)

In addition, the 3D printing molding time is used to evaluate the efficiency of 3D printing, as shown in equation (2).

$$Q = x \sin \theta_1 \cos \theta_2 + y \sin \theta_1 \theta_2 + z \cos \theta_2$$

(2)

Subsequently, the mathematical model of molding efficiency can be expressed as formula (3):

$$T = 1/h \left\{ \max(Q) - \min(Q) \right\}$$

(3)

Where T represents the number of molding layers/layer

(1) Multi-configuration components (components) method

Multi-configuration components mean that multiple part models with similar functions and similar shapes are simultaneously produced in the same model file. Its source can be seen in the method of “multiple components are designed in groups in the same picture” by serialized group design in developed countries from the 1980s to the 1990s.

For example, Figure 10 suggests that the upper Jin purlins in different installation positions of the temple-like beams are also “Shang Jin purlins”, which are similar in function; similar shapes refer to the same basic structure or the same key structure, but some details The size specifications are different. The method of making multiple configuration components in the same model file can be used.
Its advantages are as follows:
1) The key structures in different configurations are made uniformly (such as the tenon and mortise components) to avoid the slight interference in the shape and size of the key components when they are made separately, which may cause assembly interference or errors. Difficult to correct).
2) Improve professional efficiency when making component models.
   The same shape of the whole component (whether or not it is critical)
   It is not necessary to repeat the production, only re-made different components of the shape; some components of the same shape but different positions or symmetry, you can use a variety of copying methods, or find out the details of the established mature methods to produce similar components skillfully.

However, it should be noted that once the multi-configuration method is used for modeling, all aspects of component modeling include the selection of the location of the origin of the 3D coordinates, the direction and position of the datum plane, whether to select the sketch or “feature” for a specific part, select the driving size datum, select The details of the fixed size, the positioning dimensioning scheme and the selection of geometric constraints, etc. should be carefully considered to meet the requirements of the current multi-configuration and new configuration added in the future. Otherwise, it may bury the hidden danger of errors, making it difficult to find the corrected errors, or Adding new configurations creates obstacles.

After the components are made in this way, a component file becomes a “group”, including multiple components with similar shapes. When assembling, you can select the required configuration in the same “group” according to your needs and assemble it in the assembly environment.

The house model shown in the illustration in this article includes many multi-configuration components.

2) “Equation” component
   Parametric technology can also describe the correlation between the dimensions of the part model through equations, which provides further conditions for serialization design.
   Modularized design is always used in the design of common mechanical components, such as gears. That is, one size can be used as a basic modulus or independent variable and other sizes (partial or full size) as a function of an independent variable. This method is now a typical parametric design method.
   Since the ancient times, the size of each part of the ancient building components has such a trade-off (function) relationship, i.e., the diameter of the bucket mouth or eaves column is used as an independent variable, and other sizes have a functional relationship with it, so the “equation” method can be used simultaneously with the group design of components with the same shape and multiple sizes. For example, members of the same form but different modulus sizes in the bucket arch. When the independent variable parameters are changed (for example, from 1 bucket mouth to 1.5 bucket mouth), you can “drive” to change the size parameters of the component.
   The above “multi-configuration” and “equation size” methods can be used independently or mixed in the same component model file. At the same time, it provides sufficient conditions for establishing a standardized component library.

3) Standardized Component Library
   It is often necessary to “select” standard components in mechanical design, such as threaded fasteners, rolling bearings, etc. In the 3D parameterization method, a mechanical standard components library is provided. After selecting the type and setting the parameters, the type and size of the part meet the current design requirements and can be used as a part.
   Due to the “balanced relationship” of ancient buildings, if the above-mentioned “multi-configuration” and “equation” technologies are used properly, similar standard components and even standard components libraries can be produced and established to be used for assembly. The components modeled by the equation method can be regarded as standardized components. In fact, all the components of this bucket arch have been made into such standard components, and they have also been assembled into bucket arch assemblies with different basic modules.
   Studies have shown that the vast majority of components connected by mortises and tenons are
suitable as such “optional standard components”. When designing a new assembly, many components can use standard components without having to repeat the entire process of component modeling. Therefore, the design efficiency will be greatly improved.

3.4. Difficulties and Solutions

(1) Components without Tenon and Mortise

The load-bearing components of ancient buildings, including columns, beams, purlins, and arches, can be used as alternative mating surfaces during installation, so it is relatively difficult to make component models or install them as assembly models. The non-tenon-and-mortise components such as rafters and sheathing are relatively difficult because there is no ready-made optional mating surface.

The solution is to try to find the geometric elements that can be used to form the fit, and to make “invisible” geometric elements as the mating surface if necessary.

(2) The difficulties are about the architectural form

For example, the temple-like roof has a structure that is far more complicated than the hard mountain style, especially the wing corners. In order to meet the requirements of “running, three-turning, four-and-a-half rafters”, the difficulties include the complex configuration of each member itself and the relative position between the members. In components and assemblies, a large number of geometric elements (lines, planes) are not in the same plane, neither parallel nor perpendicular, which is a spatial tilt relationship and is also a tilt relationship to the standard projection surface. In addition, most of the members of the wing corner are non-tenon-mortise connections, which makes it tougher.

Solution: The drawing line of the big wood is imitated, and two design routes from top to bottom and bottom to top are adopted.

![Figure. 4 Qiaofei rafter modeling line drawing](image)

For example, the temple-like flying rafters are inclined between the lines and planes, as well as the standard projection surface. Some surfaces seem to be planes but not planes. Moreover, it has a complicated positional relationship with the corner beam and adjacent members in all directions. Therefore, the big wooden line drawing method is used for the modeling of this part, where the top-down and bottom-up design routes are converted repeatedly. As it is also difficult for the construction process, the proposed 3D modeling method has intuitive, accurate and other characteristics. It can be used to observe the relationship between the configuration process and the result repeatedly. Hence, it is of practical significance for designers to participate in guiding construction.

4. Conclusions

Since the Northern Song Dynasty at the latest, there have been standards and norms for ancient Chinese buildings, which seem to have a deeper “Interface” of information exchange with modern advanced design means today. Certainly, such standardization of ancient buildings is not exactly the same as the relatively modern serialization design. However, it is also far from “an initial bud” or “embryonic form”, but a mature and valuable legacy that contains modern design concepts. If it could be fostered and enhanced since ancient times, the significant impact on history would be immeasurable.

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