3D RECONSTRUCTION AND SIMULATING ASSEMBLY OF ANCIENT CHINESE TIMBER-STRUCTURE BUILDING

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ABSTRACT

In this paper, Chi Lin Nunnery, the imitation of early Tang-Dynasty timber-structure building in Hong Kong, is used as an example to perform 3D model reconstruction and demonstrate the assembling process, as well as make a digital database of buildings. This paper gives an introduction to the features of ancient Chinese timber-structure buildings and also the workflow of 3D reconstruction of ancient timber-structure buildings, and mainly discusses about ways of 3D database collection, 3D modeling, collision detection and other key technologies. The research of this article could provide effective methods to protect, research, repair and restore ancient timber-structure buildings and a potent way to manage project's quality.

1. INTRODUCTION

1.1 Features of Ancient Chinese Buildings

Compared with ancient western buildings, which mainly using masonry structure, one prominent feature of ancient Chinese buildings is the wide employment of timber-structure, every part of building is joined together by mortise-tenon.

Figure 1 beautiful roof

The most remarkable feature of ancient Chinese building is the big roof, which has a large shape and its curved surface. The eaves follow suit. Bracing santalums and rafters under the eaves, there is a need for a type of component on the column and beam, which is a bow-shaped short timber, named Gong, projecting from the column and beam, adding one layer after another if not enough, layer after layer, therefore the eaves is far away from the body of house. Between two layers of Gongs, there is a kind of square timber for padding which is called Dou. Multi-layer Dous and Gongs together form "a cluster of DouGong". DouGongs and beams combine into a DouGong layer, like a big elastic pad, which has load-transferring and anti-seismic function. Its shape and size have become mature in Tang and Song dynasty. However, with the development of building materials and technology, body of house mainly use brick and mason, and laber is no longer needed to reach that far, so DouGong has been reduced in its function as bracing under the eaves, and its size is shrinking day by day. In Ming and Qing dynasty's buildings, DouGong no longer has important structural function but as a decoration. Timber-structure building presenting and displaying numerous craftsmen's intelligence and wisdom has created a marvelous architectural miracle, therefore making China's ancient building showing a particular looking in the world architecture's picture.

Figure 2 DouGong

The biggest disadvantage of timber-structure building is they can easily catch fire. According to literature recording, from the Forbidden City's completion to late period of Qing dynasty, during the 400 years, the number of major fire has amounted to as much as 24 in the major buildings in the court. Besides, humidity, insect, especially war and destructive development construction, all will do great harm to ancient timber-structure buildings. Although all countries in the world have speared no effort to strengthen the protection of the historical and cultural heritage including cultural relics and historic sites it is a pity that a large amount of timber-structure building disappeared in the history as the perishing of time. At present, only 3 timber-structure buildings of Tang dynasty exist in the world, and more timber-structure buildings in Tang and Song dynasty can only be seen in fresco and literature!

1.2 Study Significance

In the past, timber-structure buildings have such characteristics like manual operation and oral inheritance, causing it difficult to preserve building technologies, as a result, timber-structure building's architectural art is lapsing, which adds the difficulty to reconstruct and protect the ancient buildings.
Traditional recording tools for historic buildings provide various formats to address different documentation focus, such as Measured drawing, Perspective Drawings, Photography, Sketching, Videos, Writing and so on but all have its own limitation. Fortunately, Computers provide us easier and faster storing, retrieving, and sorting information capabilities than traditional tools. By constructing a 3D model of a building, we are actually making a digital database of the building. By assembly demonstration, we can study the building technology of ancient buildings, and let ordinary pubic without architecture background understand and appreciate building by dynamic visible browser, so its significance is far-reaching!
The study mainly aims at realizing 3D reconstruction of ancient timber-structure building, simulating assembly by computer and making information system of ancient building.

Figure 3 Chi Lin Nunnery

1.3 Case and Workflow

Timber-structure building in Tang dynasty is most representative. Taking Chin Lin Nunnery for example (figure 3), which is imitation of Tang dynasty timber-structure building group in Hong Kong, its components are of various types, its style is vi rile and simple, and the general setting is rigorous and orderly, fully interpreting the artistic charm and building technology of ancient Chinese building.

Chinese ancient timber-structure building is a complicated construction joined by motise-tenon, and in ideal situation (data of building design), all components should be closely knitted without the likelihood of loose structure and impossible assembly. But in effect, a certain degree of deviation is unavoidable, such as precision of timber components mechanical processing, timer's deformation and so forth. If the error accumulates (sometimes even the problem in design) and can't be dealt with properly, assembly will face great difficulties.

Sticking points can be found through constructing 3D modeling and simulating assembly by computer on the basis of actual sample data, which can not only save timber but also avoid repetitive dismantling. That's to examine reasonability of components design and analyses manufacture error by computer collision detection. Workflow is as following (figure4):

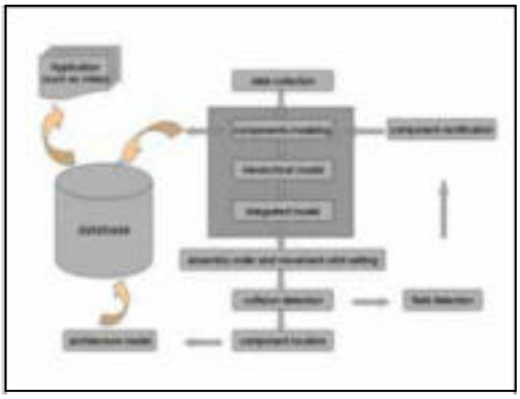

Figure 4 workflow

2. 3D RECONSTRUCTION

2.1 Data collection

Different data sources corresponds with different modeling approaches, for example, methods based on remote sensing image and air-born laser scanning are applied to a wide rang of three-dimensional city modeling data obtaining, vehicle-borne digital photogrammetry is applied to corridor area modeling like streets, and ground photogrammetry or close-range laser scanning are used for a single building' and a few buildings' modeling. In the case of working object, the major ways to obtain geometrical data are engineering surveying, close-range photogrammetry, close-range laser scanning and blue prints etc.

2.1.1 Surveying: For a large number of relatively regular wooden components, traditional surveying approaches can meet the requirements. In this tache, coplanarity of four points (or above four) and sampling frequence must be considered carefully.

Figure 5 sampling

2.1.2 Based on blue print: 2D data can be transformed into 3D data according to the design drawings, and this method is always used to determine object's shape primarily.

2.1.3 Laser scanning: For the irregular geometrical structure, like lotus on the roof, digital photogrammetry or laser scanning technology can be used.

Development of Laser rangefinding technology represented by laser scanning technology provides human beings with brand-new technological means in spatial information obtaining. Laser scanner can automatically finish its work in attaining points cloud consisting of discrete vector distance points on the surface of the object. Points of set is joined in different ways can get different 3D model, so the main work for 3D model reconstruction is to extract characteristic points, based on which characteristic lines and surfaces are constructed, and finally three dimensional object is reconstructed. A lot of manual operation is in need since automation level is not that high at present.

2.2 Components Modeling

For the moment, there are several ways for 3D modeling, such as laser scanning and image-based approaches which means processing digital image by computer, 3D identification and measurement realized calculating all elements by computer and do rectification. Semi-automatically or manually finish the extraction of image geometry and physical information, and this method is widely applied in digital city modeling field. By collecting texture with digital camera, after texture projection, building looks next to the real landscape.

Those small-scale scenes, which are demanding in architectural detail and need to display special relationship between indoor and outdoor space, are often constructed through "true-3D", such as CAD technology. Digital CAD Modeling can create visual geometric models that simulate the three dimensional form of a building or architectural detail. Once a digital model is constructed it can be used to generate elevations, sections, plans, and perspective views. It can also serve as a base for walkthroughs, flybys, and virtual reality tours

3D model in Cad system has two expressive ways: volume-based and surfaced-based. Volume-based model is expressed by so-called CSG tree, this method makes a hypothesis that the object to be expressed is constituted by some basic units, (such as sphere, cube and cylinder etc.), Namely, DIVIDE and CONQUER, constitute a complex 3-dimensional object through regularization BOOLEAN algorithm (parallel, intersection and subtraction).

Timber-structure buildings' components are regular on the average, they can be constructed by simple edition and operation of basic units, and the difficulty of component modeling lies in curved-surface structure modeling. Construction of the curved-surface structure in computer is constructed by simulation through plane. Because CSG model doesn't contain parameter-curved surface, it has difficulty in expressing details with curved surface, such as column. In consideration of structure, circle centers of the upper and low cross section are not in the same vertical line, its cross section is elliptical, and so it can't be constructed through cone, a basic unit. The way out in this paper is: the ellipsis can be simulated through the convex polygon at first, then construct a curved-surface structure with straight texture through the up and bottom ellipses, along which then use a bounding volume to do SLICE operation. One column needs 3 to 5 sections; they are joined through BOOLEAN algorithm. The bigger the simulating segmentation parameter SURFTAB1 of convex polygon, the more the structure result approximating to the column itself, and

the bigger the amount of data. To meet the need of collision detection in late period, simulate parameter if all components should have the same standard in the process of modeling.
Other structures with curved surface can be obtained through Boolean algorithm of some basic units and cross-section EXTRUDE operation. The following methods can also be applied to construct other more irregular curved-surface structures so long as getting enough characteristic points.
Concave curved-surface structure modeling is more tough, like BaoZhuCi, the surface integrated with the pillar is not regular, its modeling can be obtained by Boolean algorithm of constructing convex curved-surface structure through characteristic points.

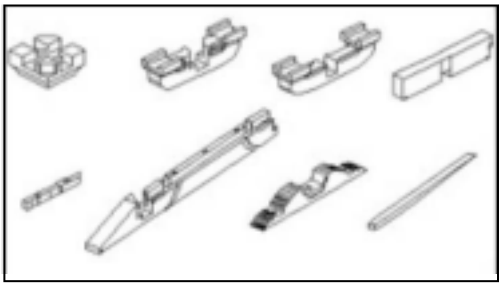

Figure 6. component model

2.3 Hierarchical Model and Integrated Model

After the completion of components model construction, components location and component integrating into a building model in CAD. Its position is decided by its coincidence with the geometrical center location in building blueprint as well as bottom surface Parallel. Although timber-structure building is complicated in structure but discernible in hierarchy. Data organization can be done hierarchically, forming column basis layer, DouGong layer, frame layer, roof surface layer roof layer and decoration layer, then combine layer models into an integrated one.
Chinese timber-structure building is Centro-symmetric, components should follow certain modules, and modeling technology of utilizing block operation can significantly reduce workload and model's data volume. The block technique was the driving method to construct the whole model. "Block" objects allow adjusting parameters of different dimensions of an element to compose variations of the same element. Similar components at various locations were constructed once, and then used many times.

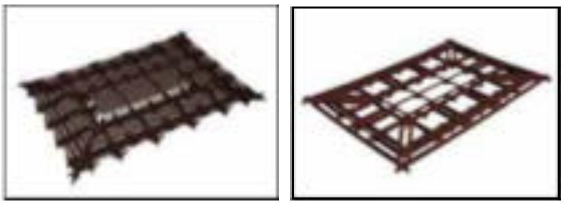

Figure 7 hierarchical model

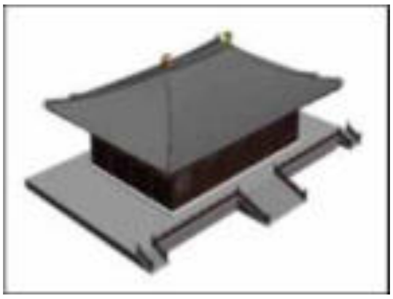

Figure 8 integrated model

2.4 Database of Buildings

Every component is given a special serial number and saved into a database system, table of database looks as followed (figure9-10). Geometry information will be collected automatically by system, and attribute information must be written by architects. In practice, the database includes also a lot of videos archives, all words which narrate functions and features of components can be made for commendatory of video archives. First components will be saved into database after sampling and modeling, if error happen during the process of simulating assembly, the component should be modified and renew the old one in the system.

serial number	component name	tile name	temple name	explanation	…
A06001	tile	t 06001	Heaven Hall	…	…

Figure9 table 1

length	width	height	vol.	location	…
				X Y Z	

Figure 10 table 2

The important function of the database system mainly includes two factors: one is used to record, another is used to support exploitation again.

3. SIMULATING ASSEMBLY

Based on components acceptance by using cad software and construction of database, imitation assembly process by computer can begin. It aims at recording timber's assembly order, examination 0f motise-tenon construction and DouGong's complicated and tricky assembly process, so that it can provide real and detail data for renovation, reconstruction, study and protection of future timber-structure buildings. This process is achieved by the usage of 3DS MAX.

3.1 Making Texture

The main task of generating material texture is to determine the color, texture and light and shade pattern of the material.
Texture describes the natural characteristics of the surface of an object, it can be generated by a 2D random function f(u,v), and also can be from a scanned image or generated by a graphic package. The feeling of actually texture should require help of digital camera, all surfaces of objects will be sampled ,and all map which has been dealt with in the Photoshop attach to object orderly, this work can be completed by multi/sub-material in 3DS MAX.
In fact, kinds of rich effects video can be produced by varying material in 3DS MAX, such as wash-drawing-style (a light tint or hue) video with artistic sense through falloff material

mapping, industrial effect videos through final render material mapping ,etc. (Figure 12)

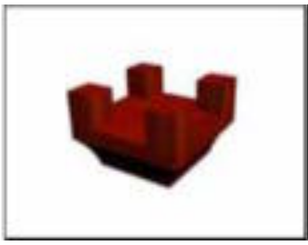

Figure 11 true texture

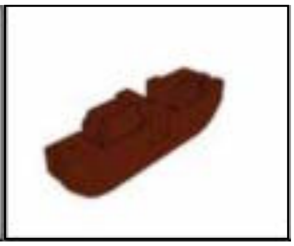

Figure 12 industrial effect

3.2 Order of Assembly

Assembly order of timber-structure building has strict construction processing, although some components' order can be reversed mutually, but in general, most follow the order of first the internal then the external, first the bottom then the top. In terms of form, timber-structure building's simulating assembly is a dynamic visible process. In line with the assembly order, that's, from the bottom to the top, from the internal to external, component models are packed into integrated model along certain movement orbit. In the beginning, the integrated model should be deflected from a fixed distance along z-axis, and then every component returns to its original position along z-axis in order.
The animation of 3DS MAX is based on key-frame technique. The core of this technique is to fix the so-called key-frames, and then let 3DS MAX software system to interpolate to generate those between key-frames. It can be used to carry out building's order of assembly, but interval among key frames and distance of movement (or angle of rotation) together will affect speed of the animation, so preparation of script is very important to control animation process.

Insert frame among key frames

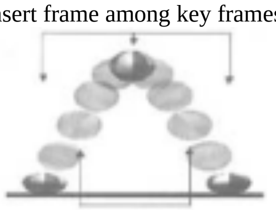

Figure 13 key-frame technique

The attribute values of key frames will be stored in a structure named curve node and will be controlled by the node, and speed of the animation can be adjusted by the tangent of a curve. It means that, if error of assembly order happened, adjustment of key frames will affect speed of the animation, so it is a good idea to save a middle file every other thousands frames.
By setting key frame of camera, movement, rotation, material and so on, rich outcomes will be gotten. In order to display such kind of construction art, a human-computer interaction visible environment can help users make sense of components' structure and function as well as browse building and building group dynamically. If needed, multimedia technique is another good idea, which can make outcomes more interesting and transparent.

3.3 Collision Detection

Because of mechanical processing error of timber component, timber deformation and error in design, unmatching in component position or size will be possible at the assembly spot. In fact, simulating assembly process is not only a displaying process of building constructing technology but also a test process for components position and size. Hence there have the following three reasons for collision detection when computer simulating assembly takes place: to detect whether collision happens between models, to report the place where there is already or will be a collision and the distance between dynamic Query model.
The initial motise-tenon connection algorithm is to do pairwise intersection test for all the basic geometrical elements in two input models. If there are n polyhedrons in virtual scene, m pinnacles for every polyhedron, the complicate degree of time of the collision detection will be $0(N^2 M^2)$, to the disadvantage of real-time interaction.
Reducing the amount of pairwise intersection test of basic geometrical elements, speeding up algorithm to assure real-time interaction in virtual environment are the cores for motise-tenon connection algorithm. Commonly used connection algorithm for the moment can be classified into two kinds: spatial decomposition and hierarchical bounding boxes.
Typical spatial decompositions are OCTREES, BSP tree and so on. For the sake of large memory and inflexibility, they are not used as widely as bounding box hierarchical approach.
According to difference in bounding boxes, bounding box hierarchical approaches can be divided into AABB(axis-aligned bounding boxes) OBB(oriented bounding boxes) DOP (discrete orientation polytopes, K-DOP is called FDH (fixed direction convex hull)) and etc. AABB is not closely knitted, but intersection test between AABB is simple, OBB is closely knitted caused by OBB arbitrary direction, but its intersection test is complicated; FDH goes between the two, its characteristic is that as long as reasonably selecting the number and direction corresponded with parallel plane, a flexible selection can be made between simple connection and close knitted packing object, namely, it is superior to AABB in knitting, it's not as complicated as OBB in intersection test, its complex function is the best. As for collision test of rigid bodies, judgment of function is based on OBB connection algorithm.
For n components in timber-structure building's 3D model, in most real environments, they can only with few approximating objects, there is no such necessity to do motise-tenon connection for all components and it is a waste of time to do so. Before collision detection, preselection can be done such as using sweep and prune algorithm to decrease the number of objects that will be done the connection. Timber-structure building has discernible hierarchical structure, a simple way is to use orthographic projection, that's, project object-compatible-volume onto coordinate surface (such as surface x and y), then use rectangular filing ordering algorithm to do selection, and finally verify whether overlapping rectangles have intersected with its projection on another coordinate axis (axis z).
Because of complication in assembly process and problem caused by massive data, using single detection method can't meet requirements. This paper will deal with it in four steps in terms of characteristics of timber-structure building:

1. motise-tenon connection preselection
2. use AABB, to do sketchy connection for most components, ruling out those objects that are far away and have not connected
3. using FDH or OBB's hierarchical structure to do accurate connection
4. doing initial connection

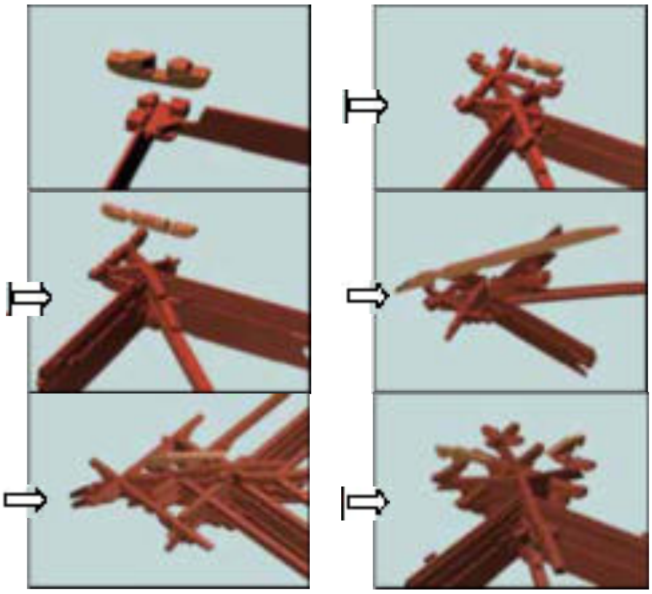

Figure 14 process of simulating assembly

Timber itself is different from other materials; it has a certain degree of elasticity. Components' partial and hierarchical spot assembly detection is an indispensable link, and it should be taken into consideration together with computer simulating assembly as an integration.
The result of assembly is showed as followed (figure 15).It can supply direction for reconstruction of ancient buildings.

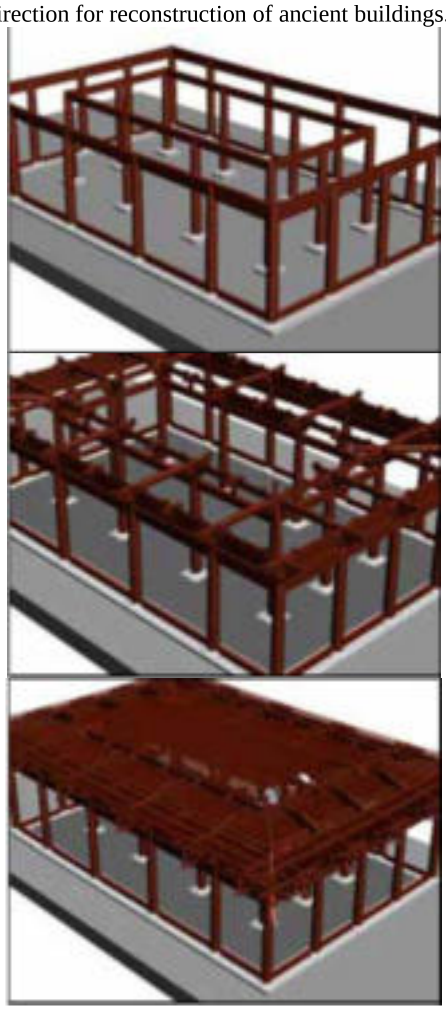

Figure 15 the result of building assembly

4. CONCLUSION AND FUTURE WORK

Computer technology, virtual technology is of vital importance to protection of cultural relics and historical sites such as ancient buildings. Through components modeling by computer, hierarchical assembly and integrated assembly, the purpose of examining and accepting project quality can be achieved. It is a new modal for overall quality management with high efficiency, overall, and low cost. By establishing database to preserve architectural file, architectural research and provide necessity for building's recover and reconstruction. And it can be and explored used for the second time based on that.
In future work, we are aiming to apply similar techniques for ancient buildings' preservation and recovery, project quality control and 3D reconstruction. An integration of 3D geographic information systems (3DGIS) and computer-aided design (CAD) would provide newer forms and better ways. In addition, we are seeking better understanding of integrating architectural art with computer technology for heritage recording purposes. This includes developing new tools and methods to streamline the digital recording process.

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