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Three-Dimensional Parametric Modeling and Digital Research of Ancient Architecture

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At present, our country's information base of ancient architecture has lagged behind the times. It has been the research focus that how to employ modern information technologies to protect and exploit ancient architecture. This paper uses three kinds of technologies and three-dimensional modeling to establish ancient architecture's 3D structural model and further to achieve quick reconstruction of ancient architecture's 3D engineering model. This provides new technological means of reconstructing and repairing ancient architecture.

1. Significance of Parameterization and Digitalization of Ancient Architecture

Around the world, ancient architecture has been important cultural heritage. Countries all pay high attention to the work of protecting and repairing ancient architecture. As computer technology grows mature, various digitalized protection techniques have been adopted to protecting and repairing ancient architecture. But at present, both computer technology means at home and abroad can only deal with certain architecture, measuring the specified architecture and obtaining digitalized materials and then achieving establishing ancient architecture's 3D structural modeling. How to establish commonly usable architecture model, accomplish the digitalization of ancient architecture and build 3D model based on the 2D images of vanished ancient architecture is of great practical significance to the protection and repair of ancient architecture in our country. For this purpose, this paper will illustrate the research progress and technologies of the parameterization and digitalization of ancient architecture's 3D model through three kinds of modeling methods.

2. Technologies of Parameterizing and Digitalizing Ancient Architecture's 3D Model

2.1 Technology of parametric modelling

Ancient architecture in our country usually has wooden structure. One piece of architecture generally consists of thousands of differently shaped and sized components, such as column, beam, square-column, corbel bracket, rafter and so on. Liang Si Chen (2006) reported. It seems that Chinese ancient architecture's structure is complicated and diversified, but actually, there are rules to some extent among these components. Although of different shapes, they have common standards of constructing and equipping. *Rules for Structural Carpentry* in Song Dynasty and *Imperial Specifications for State Buildings* in Qing Dynasty are two most thorough Chinese ancient books explaining the standards and also classics of summarizing Chinese ancient architecture, which is the basis for researching on Chinese ancient architecture.

First of all, the type of the architecture needs to be determined. Main parameters of lateral gate's modulus, shapes of stylobate, components of roof truss as well as the roof should be obtained. The information will be used to select and transfer 3D components from the 3D components bank to the corresponding positions at the image of the reconstructed 3D architecture. Figure 1 is the roadmap of producing ancient architecture's 3D model, that is, in a more detailed way, firstly based on data files, inputting parameters, and then generalizing the script files and finally producing the ancient architecture's 3D model. During the process of producing 3D model, it is needed to finish quick reconstruction of ancient architecture's 3D engineering model on different levels. Wang Ru reported (2010). Take the architecture with Wudian roof as an example, at first, it needs to

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input modulus of lateral gate, parameters of stylobate and sizes of other components and then the model will be produced. Figure 2 illustrates the composition of stylobate and steps.

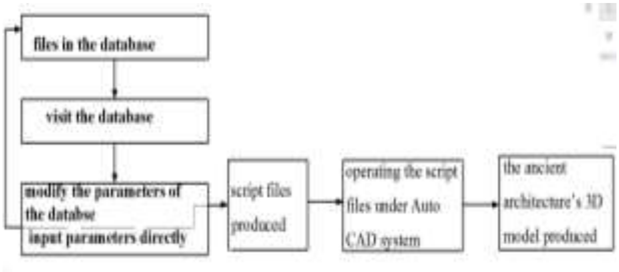

Figure 1: The Roadmap of Producing Ancient Architecture's 3D Model

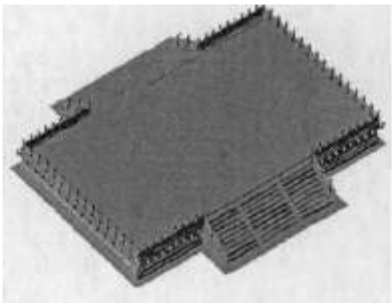

Figure 2: The Composition of Stylobate and Steps

According to the lateral gate, parameters of corresponding roof truss and the roof can be obtained. Parameters of part components of the architecture with Wudian roof are shown in table 1. Based on table 1, images in the base of ancient architecture's 3D modeling are used to direct the composition of columns, roof beams and roof. Analysis of hip-roofed architecture's main structure helps to determine the parameters in need and produce the corresponding AutoCAD script file. Operate the script file in AutoCAD and the 3D model of hip-roofed architecture can be generalized.
Figure 3 the 3D model generalized of typical architecture with Wudian roof. Rules of Wudian roof's reckoning algorithm are complicated. According to related reckoning formula, distance that the mountain face pushes can be obtained, which leads to corresponding changes of parameters of the generalized entity. The model of Wudian roof produced through programming is shown in figure 4.

Table 1: Parameter of Part Components of the Architecture with Wudian Roof

Names	Length	Width	Height	Thickness	Diameter
eave column					6.0
rafter		1.5		1.5	
small architrave			4.0	3 . 2	
old corner beam			4.2	2.8	
animal components	10 pieces				

Figure 3: The 3D-Model of Palace Structure

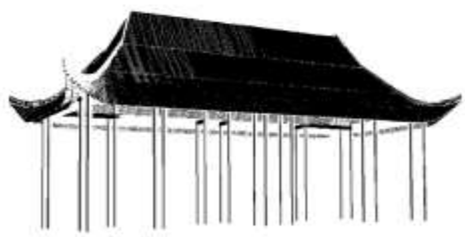

Figure 4: The Palace with Wudian Roof

2.2 Vanishing point for calibration method

According to the geometrical relationships among vanishing points, it is conductible to use the vanishing points to examine and emendate the images photographed by ordinary digital video camera and obtain camera's interior and exterior orientation parameters, and thus restore the 3D scene of a 2D image.

This method, based on one image of the ancient architecture, takes its own thread as the calibration object and achieves the complex proportional 3D transformation of ancient architecture. For the existing architecture, only if given a basic size, the ancient architecture's structural relations can be fully recovered, which provides an effective way for quick 3D reconstruction of complex ancient architecture.

Photographing is a process of optical imaging. This process can be divided into three steps: firstly, switch from the world coordination system to camera coordination system; then, switch from the camera coordination system to image coordination system; finally, switch to pixel coordination system. The switches follow the formulas below:

$$zc\begin{bmatrix}u\\v\\1\end{bmatrix}=\begin{bmatrix}\frac{1}{d_x} & \gamma' & u_0\\ 0 & \frac{1}{d_x} & v_0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}f & 0 & 0 & 0\\0 & f & 0 & 0\\0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}R & t\\0^T & 1\end{bmatrix}\begin{bmatrix}X_w\\Y_w\\Z_w\\1\end{bmatrix}=K\begin{bmatrix}R & T\end{bmatrix}\begin{bmatrix}X_w\\Y_w\\Z_w\\1\end{bmatrix} \tag{1}$$

Where K represents camera's interior orientation parameters, γ is the divisor of lens distortion; (u_0, v_0) is the coordinate of the image's main point in the image coordination system; R and T are camera's exterior orientation parameters.

According to formula (1), in perspective relations, the projection from 3D space to 2D space can be expressed by formula (2):

$$\lambda_i\begin{bmatrix}x_i\\y_i\\1\end{bmatrix}=\begin{bmatrix}p_{11} & p_{12} & p_{13} & p_{14}\\p_{21} & p_{22} & p_{23} & p_{24}\\p_{31} & p_{32} & p_{33} & p_{34}\end{bmatrix}\begin{bmatrix}X_i\\Y_i\\Z_i\\1\end{bmatrix} \tag{2}$$

Figure 5: Angular Points of Cube that Are Determined

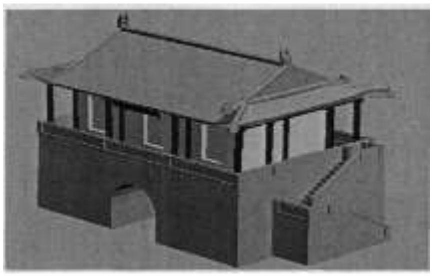

Figure 6: The Map of Reconstruction

As figure 5 shows, A, B, C, D are angular points of the foundation cube, E, F are the crossover points of the corner of the stairway and the foundation, and D is one point on the open-stair over the foundation's edge. Lengthen FE to cross DG at H. Operate the formula (2) with the 3D coordinates of A, B, C, D, E, F and the result is:

$$p=\begin{bmatrix}1.8803 & 0.7434 & 0.2260 & 334.4356\\0.3923 & 1.5209 & 1.5867 & 351.9812\\-0.001 & -0.005 & -0.0008 & 1\end{bmatrix}$$

Conduct the 3D reconstruction according to the feature points on the whole image from camera's matrix. The result is shown in figure 6.

2.3 Software technology of digital modelling

STL digital model is the model generalized by inputting parameters as STL file into the modeling software. In the STL file it is restored the information of all of the triangle patches on the external surface which makes up the entity model and recorded the normal vector and three vertexes coordinates of each triangle patch. In the reconstructed model, each side only has two triangle patches in common, in other words, there are only two common points between two triangle patches. Qin Qiang reported (2014), For each triangle patch, take out its vertexes arrays from the patches' data table, match the three vertexes arrays and establish three different side data.

Assume that the coordinates of two vertexes of triangle patch’s certain side are A (Xa, Ya, Za) and B (Xb, Yb, Zb), tangent plane’s label is Z = Zi , and the crossover point between the tangent plane and the side is (Xi, Yi, Zi), as the figure 7 shows, then:

$$x_i = x_a + (z_i - z_a) \times (x_b - x_a) / (z_b - z_a) \tag{3}$$

$$y_i = y_a + (z_i - z_a) \times (y_b - y_a) / (z_b - z_a) \tag{4}$$

Formulas (3) and (4) are for calculating the crossover points. According to the correlation among crossover points, for the tangent layer $Zi + 1$, Z= $Zi + \nabla z$, where ∇z represents the thickness of the tangent layer; the crossover point between the side and the tangent layer $Zi + 1$ is:

$$x_{i+1} = x_a + (z_{i+1} - z_a) \times (x_b - x_a) / (z_b - z_a) \tag{5}$$

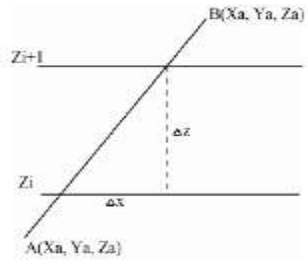

Figure 7: Calculating the Crossover Point Using Incremental Algorithm

Digital modeling software achieves quick gridding production and display of any complicated structure and designs the connection with STL file, which allows seamless integration with STL models generalized by various kinds of software.
Take the digital modeling of Penglai Pavilion as an example. The model is established under AUTOCAD. The gridding produced after using STLOUT to export STL file and calculating the field as 24M×16M×24M is shown in figure 8. Figure 9 illustrates the Penglai Pavilion.

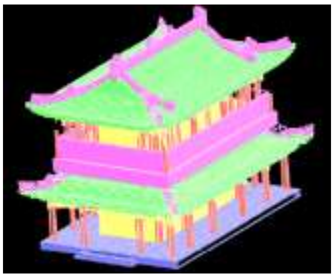

Figure 8: The Gridding Image of Penglai Pavilion *Figure 9: The Penglai Pavilion*

2.4 The technology of ground 3D laser scanning
The technology of 3D laser scanning ancient architecture is to conduct object scan of ancient architecture. During the scanning, several standing points need be set. Multi-angle scanning can help to obtain point cloud with relatively high density and richer texture information and thus ancient architecture’s 3D model wholly.
The procedure of 3D laser scanning can be divided into three steps: project design, data collection and data analysis. Many factors like control network and scanning roadmap should be considered during project design. Data collection means to collect the information of control network and point cloud as the project designed; during data collection, it is acceptable to observe from top to bottom in clockwise direction. After the observation is finished, it needs to further scan the fixed targets as much as possible. Attaching some fixed targets to the ancient architecture can improve the accuracy of neighboring observation stations’ joints. Data analysis includes rectification of data from multi stations, transferring of coordinates, denoising, re-sampling, outputting, etc. Modeling includes establishing 3D model based on point cloud’s information, and then texture

mapping of the model and finally accomplishing the reconstruction of 3D model. Table 2 exhibits the performance indexes of two typical 3D laser scanners.

Table 2: The Performance Indexes of Two Typical 3D Laser Scanners

parameters of scanner	VZ-1000	Focus3D
operating theories	pulse	Phase-shift
optical maser wavelength/ nm	1550	905
laser class	1	3R
pulse frequency/ khz	300	976
range of scanning angle	360°×100°	360°×305°
Firing range/ m	1-1400	0.1-153
range error	5mm@100m	2mm@25m

Models of point clouds established by using two typical 3D laser scanners with different operating theories are reconstructed in 3D way. Compare the two models without considering the quality of texture mapping and it can be found that the final model generalized based on the point cloud with high density which is produced by Focus 3D has better expression of details. It reflects the architecture's surface structural features accurately. Point cloud model and various line drawings can to certain extent express the target's spatial features, but their ability of such expression is limited. As the figure 12 shows, the point cloud model of ancient architecture can be divided into several parts based on which more delicate models are established. Then, integrate those sub-models and finally build up the whole 3D model, as what is shown in figure 10.

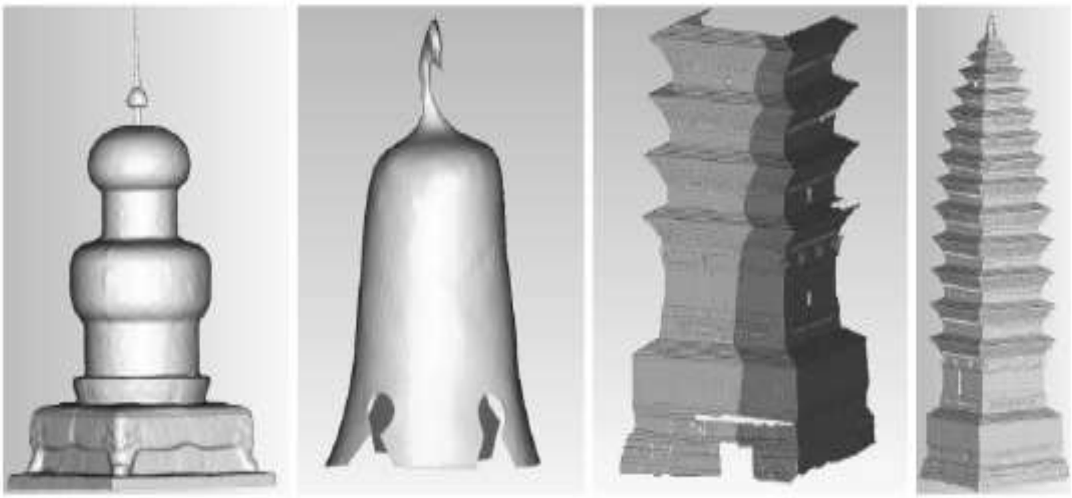

Figure 10: 3D Model of Ancient Architecture

3. Conclusions

It has always been the research focus to digitally reconstruct ancient architecture in three-dimensional way, and this is a promising technology for wide use in future. However, compared with China's advanced architecture achievements, the information base of ancient architecture in our country has lagged behind the times, which fails to dig out the huge help modern technologies can bring to protecting and exploiting ancient architecture. Research and exploration in this field can not only provide accurate and engineered basic data for repairing and recovering ancient architecture but also increase people's knowledge of details while decrease people's direct touch upon the entity; furthermore, recovering architecture heritage's original appearance virtually can simulate its evolution in dynamic way, which is a more vivid expression of information for archaeological research and tourists' visiting.

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