COMPUTER-BASED SIMULATION AND QUALITY CONTROL FOR BUILDING OF THE LARGE-SCALE TIMBER STRUCTURES

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KEY WORDS: 3D Simulation, Ancient Architectures, Quality Control, CAD

ABSTRACT:
The traditional two-dimensional plans and elevations of ancient structures have limited the applications of maintenance and reconstruction, and could not satisfy the current requirements. Based on the architectural survey project of the "Chi Lin Nunnery Redevelopment "in Hong Kong, which has been carried out during 1996-1998, this paper attempts to investigate the methods and techniques of building three dimensional digital documentation of large-scale timber structure and quality control during construction by computer-based 3D simulation for the whole project. There were several key issues including primary data acquisition, 3D modeling and display,pre-assembling the total building, quality examination and etc. In this paper, some useful experiments, such as the application of digital CCD cameras, image and graph processing software packages (CAD, Photoshop, Photomodeler, Vexcel and etc.) to the architectures were also presented. The methods introduced in this paper are suitable for image and graph integrated database building of complicated architectures, it is also useful for the convenient maintaining and reconstructing of the ancient architectures.

1 INTRODUCTION

China has a civilization and history over 5,000 years, and has developed a unique Chinese culture. Its architectural style has much to be admired, the hall, attic, porch and tower by timber components, such as tou, kung, ang, fang, beam, chuan, or column, are of the most valuable culture heritage in the world.

The Chi Lin Redevelopment will bring to life the artistic and architectural achievements of the Tang Dynasty which was over 1,000 years ago and this project built on an area of over 33,000 square meters of total 15 halls. After completion of this project, Chi Lin nunnery will be the largest group of handcrafted timber building in the present world. The general layout is illustrated in Figure 1 (provided by Chi Lin Nunnery)

Figure 1 The general layout of Chi Lin Nunnery

The Chi Lin Redevelopment is a group of magnificent ancient architectures. The project is an ingenious merge of ancient and modern architectural technology. A large number of historical documents, ancient plans and existing buildings were studied as reference, and the collective wisdom of specialists from China, Hong Kong and Japan were utilized in scale and frame. Every single item is meticulously planned and carefully researched, and is continually improved during design and construction. Survey is essential for filing of all structures' data and quality control during construction. Two dimensional plans and elevations were traditionally produced through surveying techniques. However, they have limited applications and not satisfied the real requirements. Fortunately, with the rapid growth of computer technology, the development of Computer Aided Design (CAD) system and graphic processing techniques, equipment and methodology in surveying is advancing with each passing day. This paper attempts to investigate the methods and techniques of 3D database building for large-scale timber structures and quality control during construction by computer-based 3D simulation. Some useful experiments, such as the application of digital CCD cameras within the procedures were also presented.

2 GOAL AND EQUIPMENT

Traditionally, two-dimensional designed blueprints of both components and general layout of ancient architectures are being employed during construction, and preserved as final documents. This brings out at least the following problems:

1. It is difficult for architectural projects to re-appoint designers, because each designer has different habit and designing style of design, and for common understanding of the plans due to their specialization and complexity. As a result, it is inappropriate to preserve 2D design blueprints as historic documents.

2. It is inconvenience to revise any of the original design. Any modification to a single component will affect all the connected drawings and causing a lot of drawing revision. It is time-consuming and comparatively labour intensive.

3. It is disadvantageous to quality control of buildings during construction. Nobody knows the details and real results of assembly before it is completed.

The goal of the architectural survey project of the "Chi Lin Nunnery Redevelopment" is to construct an entire three dimensional digital documentation of the complex temples and control project quality by computer-based 3D simulation. The following are several issues:

1. Acquiring real and entire dimensions of all components of temples during and after the assembling so as to conserve first-hand data, and examine primary quality of components.

2. Constructing the computer database of three-dimensional models and digital images of all components.

3. Pre-assembling components sets and entire building. Examining connected quality and comprehending the final effect of the structure from different visual angles and providing information and data to designers and craftsmen.

4. Evaluating project quality by engineering survey or close range photogrammetry after project was completed.

5. Acquiring some experience of adopting new techniques and new equipment to the ancient architecture

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The following hardware and software were used in the project.

Electronic theodolite (Topcon GTS 201D); metric-camera (Wild P31); digital CCD cameras (Sony MD-7, Fujifilm DS-7 and Kodak DCS-420); computers of PC-type; color scanner and printer Software including AutoCAD, Photomodeler , Vexcel ,Photoshop and some in-house developed software.

3 DATA ACQUISITION AND RECORDING

Whether a methodology is a successful one or not depends firstly on precision and efficiency of data acquisition. In general, error allowed in timber structure construction domain, including dimensional error of component and connected error among components, is very small and normally talking about mm. Thus, the surveying precision has to be very high. On the other hand, efficiency is very important for this project. The number of components are in a great quantity, for an example; there are 13,000 timber components in main hall only. Their shapes are manifold; there are components in irregular shapes, e.g. shua-tou, hanging fish and etc. together with those of regular shapes, such as square, circular and column. As a result, a rapid and valid way of data acquisition has to be adopted.

For simple components that consist of planes mainly, their dimensions were directly measured by calibrated rule or triangle measures. They were marked in drafts after taken the temperature factor into account.

The conventional surveying techniques are time-consuming and comparatively labour intensive. Close range photogrammetry is frequently used in architectural survey now. From the last decade Digital Photogrammetry has matured to an extent that it can serve as a precise and reliable technique nowadays. Moreover, it has become a viable measurement tool for a great number of different applications in science, art and industry. In this project, we adopted the CCD cameras and PCs for photogrammetric 3D data acquisition of points in object space on the basis of digital images for establishing complex surfaces of components. The dimensions of frameworks of components obtained by accurate measurements were regarded as relative controls in modeling process.

Quality control of the whole project were basically carried out by engineering survey and close range photogrammetry. Specific points location of relative coordinates of building were obtained and recorded.

4 3D MODELING FOR SINGLE COMPONENTS

Recent advancement in computer graphic design software allowed the creation of complicated surfaces. Meanwhile, Computer Aided Design (CAD) has been continually developed and extensively used because of its low cost, convenience and easy redevelopment. This shows the importance if a fully 3D surface model is to be obtained.

In this project, general AutoCAD software package, developed

by AutoDESK, was mainly adopted. It provides two ways to construct three dimensional models, i.e., line frame modeling and solid body modeling .The former technique is to implement enough coordinates and lines to construct 3D models; the latter is to compose a lot of simple modeling tools to construct various complicated 3D models. Furthermore, we have improved and strengthened the 3D functions of AutoCAD with AutoLISP programming language in practices, such as easy constructing plane from line frame of a component, hidden line rapid process and etc. In case that we can minimize numbers of labour and speed up the schedule of progress. Some examples of 3D models with and without hidden lines are shown in Figure.2.

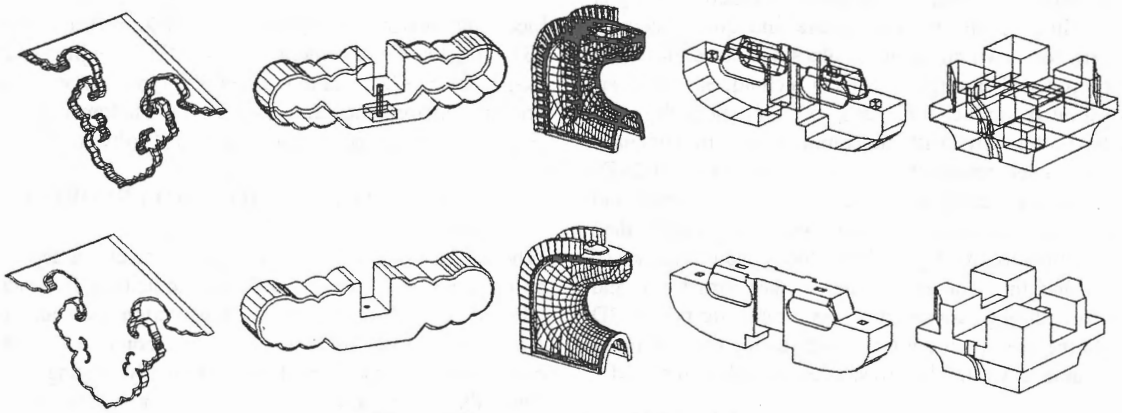

Figure 2 Some examples of 3D model

However, in the domain of ancient architectures, some components were constructed by special craft for structural stability or had a lot of decoration for aesthetic feeling. The ability of CAD system representing these detail features or complicated surfaces is limited. In our case of Chi Lin Nunnery, a suitable method was to take color photo of the component by digital cameras. After processed by image processing software, e.g. Adobe Photoshop, the image was merged with the model from CAD. In this way, any important structural ambiguities in computer model could be resolved by direct reference to highly detailed images

5 PRE-ASSEMBLY AND QUALITY CONTROL

There is a common saying, "the large-scale timber is afraid of assembly", in the domain of ancient architectures. It includes two means: the first is that the assembly is a rigid examination to construction. It can find any problems such as omitting, error, inaccurate dimensions, or bad quality during construction. The second is that the assembly is very difficult, a set of scientific and rigid regulations, and processes has to be followed for successful assembly. At the same time, we also have to consider the characteristics of computer, such as the ability and speed of process and display. We have to try to turn various CAD techniques into account, such as color, block, or layer. As a result, the practicing assembling way in computer is: from small to large, from inner to outer, from below to upper, assembly in sequence and repeatedly examination.

Firstly, the assembly of part of area, was applied in examining correctness of connected components and acquiring the assembling experience, and preparing for layer' assembly. An example was shown in Figure.3. Secondly, is the layer assembly. In general, a structure is divided into several layers. Each layer can be considered as an independent part, for an example, the hall of celestial kings of Chi Lin nunnery has: base layer, tou-kung layer, beams frame layer, roof layer, and etc. Figure.4 and Fngure5 illustrate computer-based assembly layouts of the base layer and tou-kung layer respectively. Eventually, is the entire assembly of building. It based on the framework to construct the whole building. It is a time-consuming work because there is a large quantity of data to be processed and presented in the computer. This problem has to be in further research. We have Figure.6 showing the assembled elevation of the main hall of Chi Lin Nunnery.

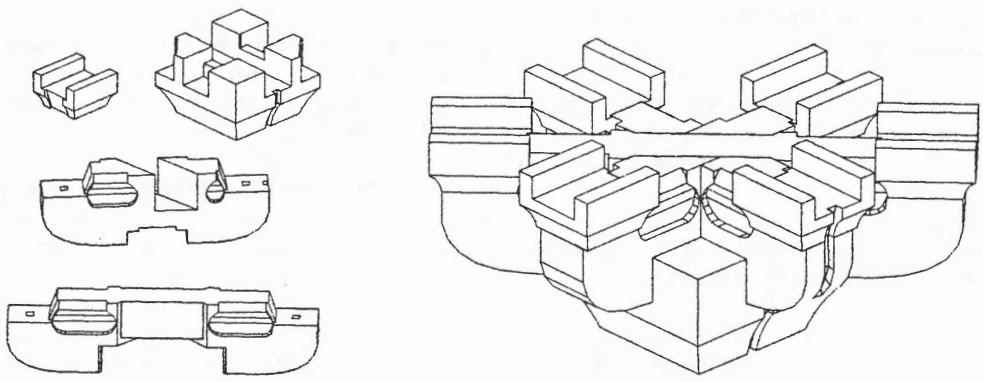

Figure 3 3D pre-assembly result of a set tou-kung

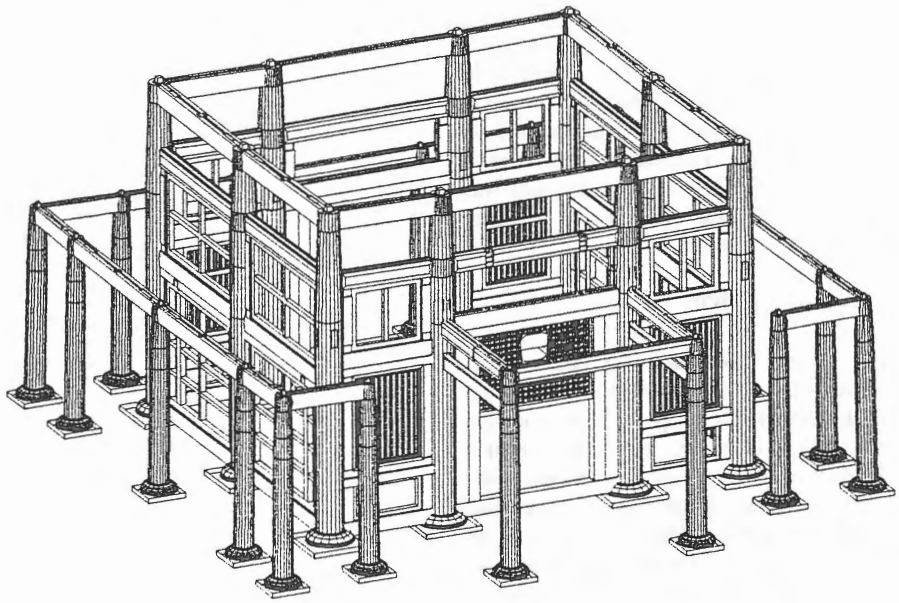

Figure 4 The base layer 3D pre-assembled result of the hall of C.K.

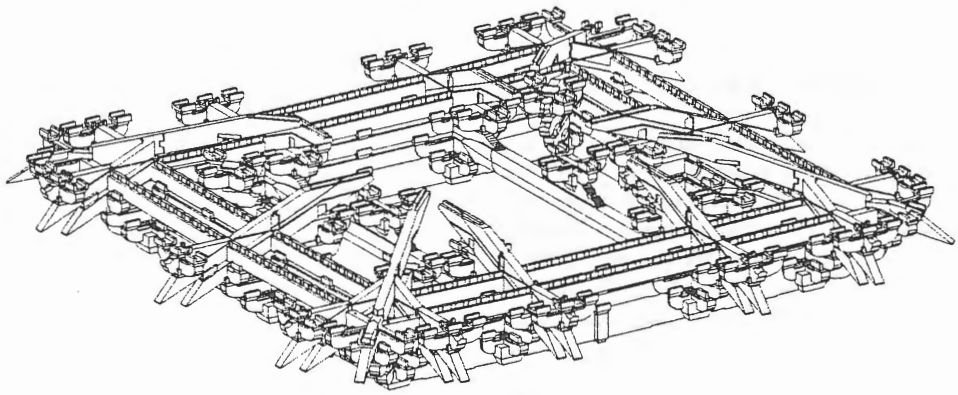

Figure 5 The tou-kung layer 3D pre-assembled result of the hall of C.K.

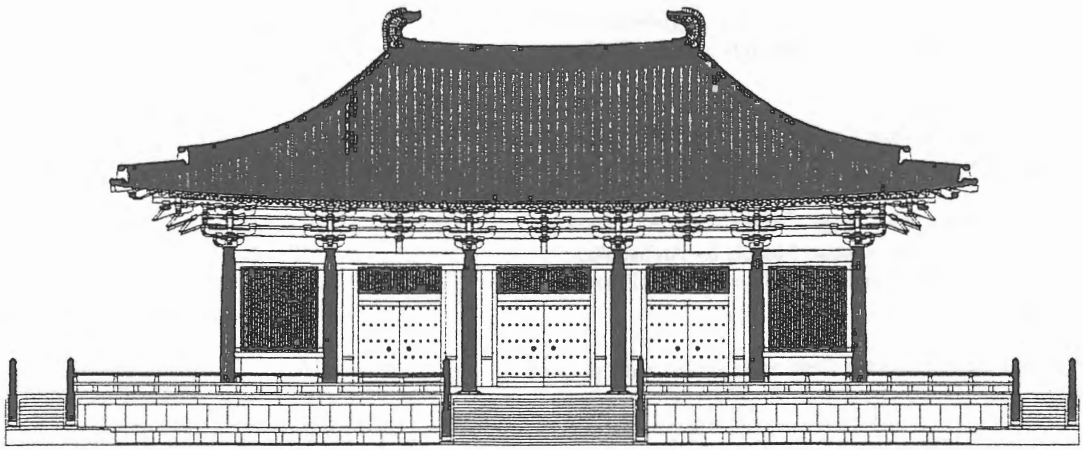

Figure 6 3D pre-assembled elevation of main hall

In practice, the course of our works is the quality control, including acquiring primary data of single component, pre-assembly for the building, and etc. Many quality problems were found during pre-assembly, such as the dimensions of some components were inaccurate, the shapes of some components were wrong. In some particular area, connected error of a set of components was larger than the standard or some structure was improper. After corrections within the construction, a higher quality and speed of the project was assured.

6 CONCLUSION

At present the project is still going on. The entire three-dimensional digital documentation of the main buildings has been constructed. Thereby, this makes it possible to print out manifold drawing including 2D plans, elevations, section profiles, or 3D architectural drawings including all the joints inside the structures at any time. Some results have been considered as "propaganda" materials, such as TV programme, commemorative stamps and souvenir. On the other hand, the surveying works also assure the higher quality with faster speed of "Chi Lin Nunnery Redevelopment". It proved that the computer-based three-dimensional procedures are important and also effective in maintenance and reconstruction of ancient architectures.

7 ACKNOWLEDGEMENTS

We would like to thank all the co-workers and the staff of Chi Lin Nunnery in this project. Special thanks to Mr. Li Xing, Chen Zhi-yon, Yang Jie, Wu Da-zhou, and Jian Wuan-shou of Wu-han Technical University of Surveying and Mapping in China for their extraordinary effort for this project. We also would like to thank Mr. Eddie Ho, from the Hong Kong Polytechnic University, for his helpful work in digital close range photogrammetry.

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