

RULE-BASED 3D MODELING FOR CHINESE TRADITIONAL ARCHITECTURE

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ABSTRACT:

The Chinese traditional architecture called as *DaMu* structure, which wooden materials were used mainly. The work of historic heritage conservation needs the surveying maps and the 3D model of the building. Laser scanning techniques can provide the best potential for high efficient and more safety recording of the 3D data. Recently, Terrestrial Laser Scanning (TLS) has been used in some architectural heritage maintaining projects in China. A Chinese traditional architectural element library has been built, which named wooden element templates. Each element of the library is represented as CSG (Constructive Solid Geometry) model. For converting the point cloud to CAD representation, the procedure of modelling is adopted, but the process is the most time consuming and costly during the reconstruction of any traditional architecture. Based on the inherent geometric and topological constraints in Chinese traditional architectures, six formations are used to express the rules. We develop a rule-based automatic modelling algorithm and apply it to extract the wooden structural elements.

1. INTRODUCTION

1.1 General

The buildings of Chinese traditional architecture can be called a masterpiece in world architectural history. Since the Tang Dynasty, Chinese architecture has had a major influence on the architectural styles of East Asia. There are certain features common to all Chinese architecture, regardless of specific region or use. Chinese traditional buildings may be built with either red or grey bricks, but wooden structures are the most essential part. The design specification of individual building is a hallmark of the Chinese historical architecture and the structural principles have remained largely unchanged, wherein pillars spaced at intervals, rather than walls, provided the support for the roof. Walls come to serve merely as enclosing screens. The roof rests on a series of four-part brackets, which in turn are supported by other clusters of brackets set on pillars. The wooden structure consists of finite number of well defined objects that called as wooden elements. Regardless of splendid as they were built, these wooden frames can be damaged or destroyed easily due to natural disasters and time elapsing. Therefore, it is very meaningful to digitally archive these wooden structures in order to permanently preserve the cultural heritage bequeathed by our ancestors. In most cases, the buildings were rebuilt maintained the original architectural style. Before renovating them, the surveying maps are necessary in that involving the exact measurement of the building appearance, wooden structural elements of the building and the relation proportions among them.

So far, Laser scanning can provide the best potential for automation of the recording and analysis of the measurement data. Recently, terrestrial laser scanning (TLS) has been used in some architectural heritage projects in China. For example, the 3D reconstruction project for the Forbidden City in Beijing, Leica HDS3000 and HDS4500 laser scanners are used to acquire data in the project. The 3D measurements with the laser scanner come in the form of a point cloud. For converting the point cloud to CAD representation, the procedure of modelling

is adopted, but the process is the most time consuming and costly during the reconstruction of any traditional architecture. Now, most of the processing software provides the limited automatic modelling facilities. Modelling still remains the major bottleneck. For example, if time of data acquisition using laser scanning is 2 days, the modelling is estimated to take 4 weeks, which is more by a factor of 10 (MENSI, 2002). Automatically detecting the wooden structural elements in the point clouds is a challenging task due to the complicated combination of wooden structural elements in Chinese traditional architectures. However, the presence of well-defined CAD objects on Chinese historical building along with their inherent geometric and topological constraints provides rich sources of a priori information which can be applied to the development of rule-based automatic modelling.

1.2 Literature review

There are various kinds of methods to automatically extract CAD models in the point cloud. The key technique in our process is template matching. The brute-force approach of template matching consists of translating each possible transformation of the object on the acquired data, calculating a similarity metric, and finding the points where this metric exceeds a certain threshold. The computational requirements of such an implementation are unacceptably high (Rabbini, 2006). As a result, most of the literature concerned with this method focuses on efficiency improvements. Various pyramid like multi-resolution methods have been suggested. A hierarchical representation of templates in the form of a tree has been proposed by Ramapriyan (1976). The success of such an approach depends on the effective tree-like representation of the templates. Similar tree based template matching method has been used by Greenspan (1998); Greenspan and Boulanger (1999) for object recognition. Moreover, hierarchical tree and pyramidal techniques can be combined to get further computational efficiency.

2. CHINESE TRADITIONAL ARCHITECTURAL ELEMENT LIBRARY

2.1 Introduction

The wooden structure of Chinese traditional architecture consists of finite number of well defined objects that called as wooden elements. According to the functions of the wooden elements, 12 basic types of them are classified and showed in table1.

No.	Element	No.	Element	No.	Element
1	Pillar	5	Timu	9	Ang
2	Erfang	6	Purlin	10	Juetou
3	Girder	7	Jiaoliang	11	Dou
4	Shuzhu	8	Rafter	12	Gong

Table 1: Wooden elements of Chinese traditional architecture

In geometry, the pillar as cylinder, and the girder as box. Other parts, such as Dou, Gong and the junctions, are complex in geometry, but can be combined of simple objects and represented as Constructive Solid Geometry (CSG) objects.

2.2 Wooden element library

This element library has more than 1000 models in 12 classes, arraigned in a hierarchy that is up to 4 levels deep. Our work is to take advantage of the relationships represented by the hierarchy to improve classifying and searching procedure.

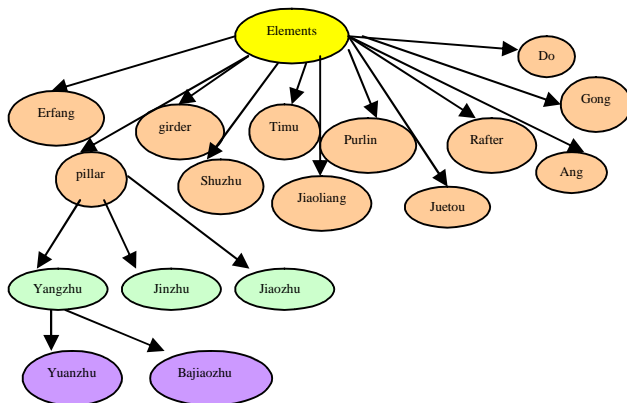


Fig.1 Hierarchy of wooden element library

The first level is the class of element which represent the whole wooden structure of the Chinese traditional architecture. The second level in the hierarchy is the 12 classes of the wooden elements. The third level is the sub class of each element, which classified by the different functions. The fourth level is the sub class of the third level, which classified by the different shapes. A tree structure is used for index the relationship of each class. Figure1 do not present the completed classes of the wooden element library. There are some other classes such as the junction part didn't show in it. The wooden elements are represented by CSG (constructive solid model). In CSG approach all objects are considered to be made up of one or more 'primitives' - basic shapes. The most common primitives include the sphere, box, cylinder, cone, and torus. They can easily be combined using Boolean set operations (*union*, *intersection* and *difference*) in order to represent more complex objects consisting of more than one primitive. Because all objects are made of one or some of these shapes, this technique

is suitable to create geometrically perfect objects. CSG is a very powerful concept for object modelling in automation procedures for building extraction and for 3D city models, especially well suited for objects which are relatively simple or which show symmetries. According to the shape features of the wooden elements of the Chinese traditional architecture, nine types of primitives are chosen and showed in figure 2.

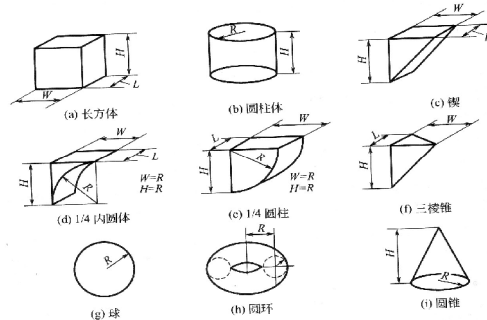


Fig. 2 The primitives (a) box (b) cylinder (c) wedge-shaped (d) 1/4 inside cylinder (e) 1/4 cylinder (f) triangular cone (g) sphere (h) torus (i) cone

In figure 3 shows some example models of girder in the wooden element library.

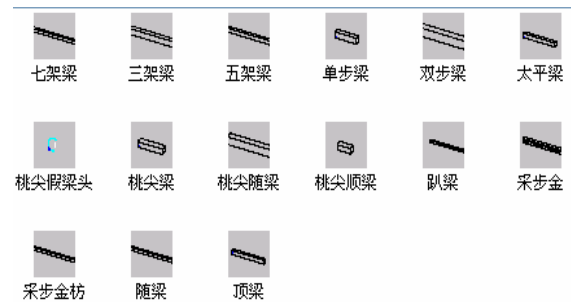


Fig.3 Some example models of girder in the wooden element library

The sizes or the parameters of the CSG model are defined according to the some classical literature of the Chinese traditional architecture such as *Architectural methods and rules* written by Li Jie in Song dynasty.

3. RULE LIBRARY

As mentioned above, one basic feature of Chinese traditional architecture is the standardization of single building and its wooden element. With the reference to Chinese historic architecture documents, we try to explain and classify the structural rules into four categories. Moreover, the mathematical formulations or "if ...then" formations are used to express the rules. The rule library is organized as below:

- Shape rule: for example, a girder is defined as a box. A box is represented by nine parameters in our element library. Three parameters of them are for the quaternion representation of the rotation, three for the translation, and three for the x, y, and z sizes.
- Size rule: each parameter has been given by a specific value of size or a range value expressed as equality and inequality constraints.

Position rule: this constraint can be used to specify the relationship between two parameters, either of the same primitive or of two different primitives, such as the axis of a box and a cylinder to be parallel.

Assemble rule: for example, the element linked two pillars is "Erfang" (a type of wooden structure element). We would use "if ...then" formation to define the assemble rule.

Rule based fitting method is frequently used in reverse engineering. (Rabbini, 2006) presents techniques for the specification of geometric constraints between sub-parts of a CSG tree and their inclusion in the model estimation process. The taxonomy of commonly encountered geometric constraints and their mathematical formulation is also given. Here is the expression of the four rules:

(1) Parameter constraint

This constraint can be used to specify the relationship between two parameters, the general form of the constraint can be given by:

$$p_1 = c_2 p_2 + d \quad (1)$$

Where p_1 and p_2 are the parameters
 c_2 is the scaling factors
 d is a constant offset.

Inequation is a variation of this constraint. For example, the ratio of the Yanzhu's diameter and height is 1:10 to 1:8. By using an inequation parameter constraint it can be expressed as:

$$r/h=c$$

$$1:10 < c < 1:8$$

Where r is the diameter of Yanzhu
 h is the height of Yanzhu
 c is the ratio

The Size rule and Position rule mentioned above can be expressed by this type of constraint respectively.

(2) Rotation constraint

This constraint is used to specify the angle between two coordinate axes a_1 and a_2 . Mathematically this constraint can be expressed as below:

$$\cos^{-1}(a_1 \cdot a_2) + c_1 p_1 = c_2 p_2 + \theta \quad (2)$$

Where a_1 and a_2 are two coordinate axes
 p_1 and p_2 are the scaling factors
 c_2 is the constant offset
 θ is the fix angle

This constraint also can include an inequation which specify angle bounds.

(3) Translation constraint

This constraint gives the relationship between the translations of two primitives. Mathematically it is given as follows:

$$t_1 + c_1 a_1 = t_2 + c_2 a_2 \quad (3)$$

Where t_1 and t_2 are the translations of primitives
 a_1 and a_2 are the directions for translation
 c_1 and c_2 are the constant offsets

(4) Connection constraint

It is defined by the following constraints when two or more wooden elements are connected, for example showed in figure 4, the Jingkoupaliang and the Chongyanzhengxinlin will meet such constraints:

- i. Parameter constraint. The diameter of Chongyanzhengxinlin is equal the height of the section of the Jingkoupaliang;
- ii. Translation constraint. Translating along the axis of the Jingkoupaliang equals to its length to find the position of the Chongyanzhengxinlin.

- iii. Rotation constraint. The axial direction of the Jingkoupaliang is vertical to the axial direction of the Chongyanzhengxinlin.



Fig.4 Connection of the Jingkoupaliang and the Chongyanzhengxinlin

(5) Bounded translation constraint

This is the inequation constraint which is an extension of the translation constraint. Locating one element is constrained to the position between two limits which depend on the parameters of another element. For example in the connection of Danbuliang, Shuangbuliang and Tongzhu as showed in figure 5, Danbuliang in the middle is constrained to lie between the limits defined by the positions of the height of Tongzhu and above the Shuangbuliang. This constraint can be enforced by using the following inequations:

$$(t_1 + h_1) < t_2 < (t_1 + (l_1 - h_2)a_1) \quad (4)$$

Where l_1 is the height of Tongzhu,
 a_1 is the axial direction of Tongzhu
 h_1 is the height of Dangbuliang's section



Fig.5 the Jingkoupaliang and the Chongyanzhengxinlin

(6) Rule defined by production

Only the mentioned above five types of constraints are not enough to represent the complex rule in the Chinese traditional architecture. In order to express the rule more flexibly, the production system is created. The basic format is as below:
 IF P THEN Q

Where P is the precondition

Q is the result or some action

In the Chinese traditional architecture rule library the production system is stored by the following format:
 RULE <NO.>: IF<P1> and <P2> and ... THEN <Q1>
 <Q2> ...

For example,

RULE 1: IF <the type of element is pillar> and <the position is at the front row of the building> THEN <the element is Yanzhu>

RULE 3: IF <the type of element is Erfang> THEN <height = the length of the building>

4. RULE BASED EXTRACTION

The rule based extraction is developed and the idea can be presented through the extraction of Erfang as below. Firstly, suppose the pillar has been extracted and we find the pillar's production format rule from the rule library. Next, decide the approximate the position of Erfang and extract the point cloud from this extend. The CSG model of Erfang is obtained from

the wooden element library and the parameters of Erfang are defined by fitting method. The workflow is showed in figure 6.

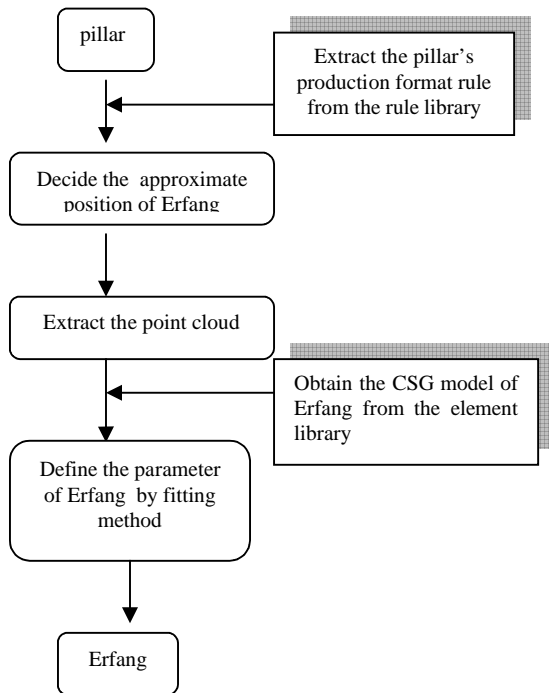


Fig.6 Workflow of extraction of Erfang

Figure 7 shows the process of the above method. Algorithms for fitting simple models to the point clouds and for the calculation of their approximate distance values are developed by (Rabbini, 2006). Once the scans have been registered, the models are fitted by the algorithms and CSG model templates on the basis of the rules mentioned above. The key problem in fitting a given point cloud to a selected CSG model is to calculate the orthogonal distance of a point from the model surface. In this method, the CSG model is converted to a B-rep and the distance is computed from a given point to the closest surface in the B-rep. The sum of the squares of the orthogonal distances is minimized, which are from the points to the surface of the fitted model.

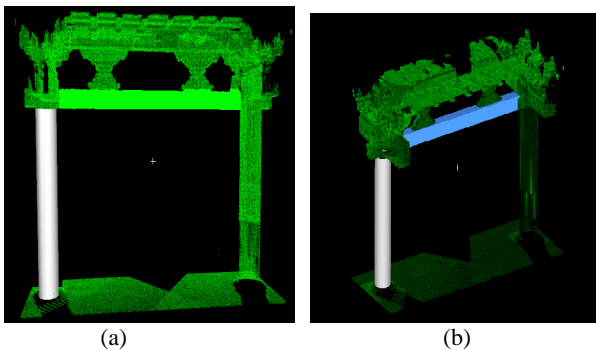


Fig. 7 (a) Obtain the point cloud of Erfang (b) Estimate the parameter of Erfang by fitting method

5. TEST AND RESULT

The method of 3D reconstruction has been applied to the sixth separate of the Hall of Golden Chimes (Tai He Dian) inside the Forbidden City in Beijing. As a result shown in Figure 8, seven scans are made using a Cyrax laser scanner. Each scan includes approximately one million points with a standard deviation of 5mm. For this instance, the rule-based method of 3D reconstructing for the wooden elements is efficient and accurate.

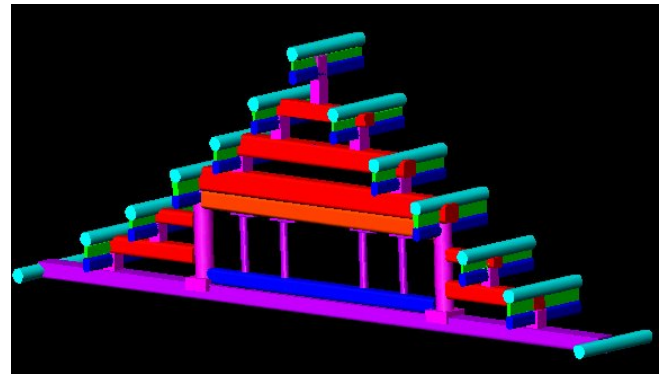


Fig.8. A result of 3D reconstructing elements in the sixth separate of the Hall of Golden Chimes (Tai He Dian)

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