3DGIS-BASED DIGITAL RECONSTRUCTION AND DYNAMIC VISUALIZATION OF TIMBER-FRAME BUILDING CLUSTER

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ABSTRACT

Timber-frame buildings in T'ang style play an important role in the Chinese architectural history. So far, however, there are only a few T'ang buildings and also a few literatures that record the arts and crafts about them. It becomes a critical task to research and protect ancient architecture by computer and information technology. As a key technology, Three-Dimensional Geographic Information System (3DGIS) is considered as a sophisticated 3D digital information system platform for the digital architectural heritage in this paper. A dynamic visualization system based on 3D GIS for T'ang timber-frame buildings is presented particularly. The design of the system framework is introduced at first. For the purpose of real-time photorealistic visualization, combination of the levels of detail (LOD) strategy and CAD data is discussed in detail; and LOD models are planned in 4 levels according to the different distance from the building to the viewpoint. Then integrated database management and real-time applications are available. The database management engine supports the seamless integration and efficient access of digital elevation model (DEM) database, 3D city models, attribute database, and media database; especially the LOD-R-tree and dynamic data loading are designed to accelerate data access. Moreover, occlusion culling and progressive rendering are applied to data preprocess for enhancing rendering frequency. Finally, a practical application shows the feasibility of the 3DGIS-based interactive dynamic visualization system as an efficient tool for the protection and research of ancient architecture.

1. INTRODUCTION

The architecture in T'ang style plays an important role in the Chinese architectural history. The technology and art of the architecture matured into full glory and vigor in T'ang (618-907 A.D.), which is the most flourishing and strongest era during the Chinese feudal period. The architecture, especially timber-frame building, is characterized by magnificent, unpretentious and religious architectural style. On the one hand, the timber-frame building has retained its organic qualities, which are due to the ingenious and articulate construction of the timber skeleton where the size, shape, and position of every member is determined by structural necessity (Liang, 2001). This is also distinct from European architecture. On the other hand, the building in T'ang style looks grand and generous due to it has broad and curved roof, unadorned and practicable doors and windows, and concise and bright color. Importantly, timber-frame buildings in T'ang style are held together by wooden columns, beams, and bracket sets and without nails.

The research and protection about timber-frame buildings in T'ang style become a critical task. So far a few T'ang timber-frame buildings are conserved because the timber is highly perishable and the construction of timber structure can be easily razed by wars or religious struggles (Liang, 2001). Importantly, many crafts have seldom survived to this day due to the manual skills and crafts of timber-frame building are orally passed from a master to his prentices; and a few literatures record the arts and crafts about them hardly exist.

With the increasing importance of preserving historical remains and rapid development of computer technology in the past decade, methods and measures are diversified for protecting and researching ancient cultural heritage. Three-Dimensional Geographic Information System (3D GIS), as one of the key computer technologies, is developed well and offers general users and experts new ways of solving virtual preservation, information presentation, and visualization of ancient architecture. Using 3D digital reconstruction of ancient buildings or places within 3D GIS, it is possible to simulate, discuss, and evaluate diverse solutions to archaeological, cultural, or restoration-

related problems without touching the original (Berndt, 2000).

In this paper the framework about a 3D Demonstration System of Timber-frame Building Cluster in T'ang Style is introduced; and methods and techniques applied to building model reconstruction, management of data, and dynamic visualization are stressed especially. The design goal of the system is to find out a new method for protecting and researching ancient architecture and its culture. The difficult problem is how to render a scene that has a small range but huge volumes of data on a low-cost personal computer (PC). Our system's focus is on:
 accurate and detailed reconstruction,
 optimized data structure and rapid data transfer, and
 photorealistic and dynamic rendering.

Section 2 provides an overview of related work which includes digital reconstruction of building models, dynamic visualization, and content of workflow. The framework of the system is sketched in section 3 and LOD modeling is described particularly in Section 4. The organization and management of scene data set and accelerate techniques related to dynamic visualization are the topic of Section 5 and the results of an experiment are sketched in Section 6. Conclusions and some ideas about future work are given in Section 7.

2. RELATED WORK

2.1 3D Reconstruction of Buildings

The reconstruction methods of 3D models depend on data sources, which include far-distance data, near-distance data, and export data (Zhu, 2004). The image data is importantly one of data sources and the automatic reconstruction of 3D models from image sequences is an active field within the computer vision community (Zach, 2002; Pollefeys, 2000; Zisserman, 2000). 3D block models based image modeling methods can not particularly describe the all details or features of buildings although they can be used in rapid modeling urban scene. The 3D models, moreover, can not satisfy the requirement that users closely observe the models or virtual roaming indoors.

The 3D CAD (Computer-Aided Design) model has become another important data resource for GIS due to the technical predominance of CAD in graphic process and real-3D modeling (Kofler, 1996). A 3D CAD model is composed of one or more polyhedral models and can represent detailed geometric characteristics of a building. These models show not only the detailed appearance but also inner complicated structure of objects comparing with the models established by imaged-based modeling method. But the modeling process is involved in sophisticated man-machine interaction, overload manual work, and higher cost.

In our method (described in Section 3 particularly) the focus of modeling is set on the effective combination of LOD strategy and CAD modeling methods.

2.2 Dynamic Visualization of Scene

Visualization has become an integral part in many GIS and their applications (Dollner, 2000) and has also become an important instrument of data representation. It can offer near-real (photo-realistic) solutions based on the detailed representation of textured 3D models in order to benefit to users' special analysis and making decision. The users can actively roam and walk in a virtual scene as well as explorers without passive reception.

The fidelity of display and real-time degree of interactive response are the key indicators for judging the running effect of visualization. How to use the core system memory and the display memory of a computer is the emphasis on improving the effect of 3D dynamic visualization (Zhu, 2004). For this purpose 3DGIS-based interactive and dynamic visualization need to be supported by special hardware and software, e.g. advanced graphic boards and excellent graphic libraries. Moreover, some techniques, such as occlusion culling, LOD, dynamic loading, and progressive rendering, have proven to be the most critical techniques for dynamic visualization (Gruber, 1999). Additionally, seamless database integration and rapid data transfer are also necessary for dynamic visualization.

2.3 Overview of the Workflow

The workflow includes four steps (Figure 1): data preparation, data processing, data organization, and visualization. Obtaining CAD reference models by traditional surveying approaches and collecting relative information are the main tasks in the process of data preparation. Man-machine modeling, the most la-bor-intensive course, shows the whole course from CAD refer-ence models acquired by the traditional surveying method to detailed textured models. Terrain reference model is also trans-formed to DEM. Data organization mainly refers to organize all of the data into LOD-R-tree. The virtual scene is used in inter-active roaming after the data are processed by occlusion culling and progressive rendering.
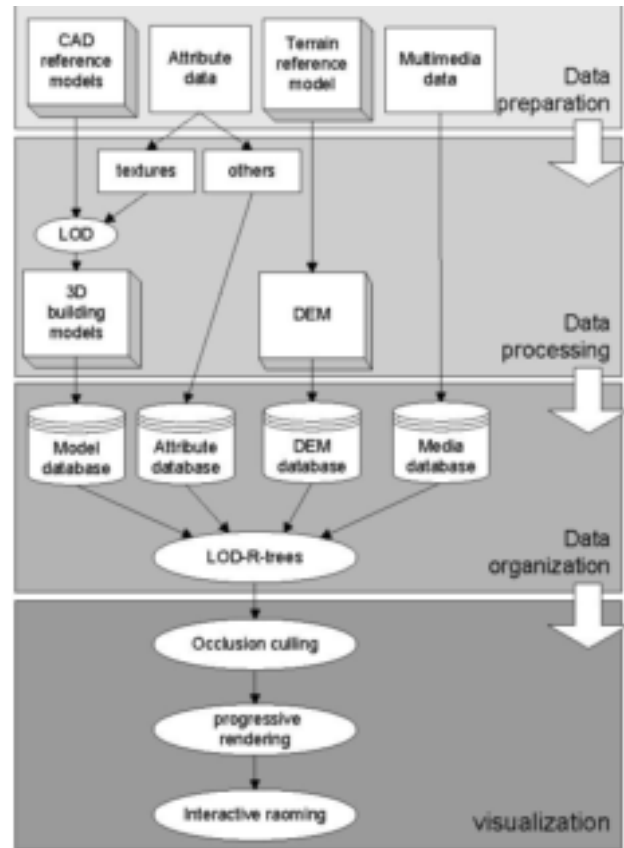

Figure 1. Workflow

3. 3 DGIS-based Demonstration System Framework

Based on the study of 3D GIS and LOD technique, a 3D Demonstration System of Timber-Frame Buildings in T'ang Style has been developed by using VC^{++} 6.0, VB 6.0, and OpenGL. The system consists of three parts, which are database, modules and graphic user interface (Figure 2). The system mainly includes four functional modules, which are 3D display module, data transfer module, information query module, and spatial analysis module. Of course other modules designed to professional field can be integrated into the system according to users' demands. Interactive roaming in the virtual buildings freely or at a fixed path is the primary function of the system. The basic operations, such as pan, scale, and rotation, are given in order to enhance the interaction of the system. Importantly, this system also provides multi-levels query of spatial or non-spatial information in the process of dynamic roaming, so that users can realize arts of Chinese timber-frame architectures and understand ancient Chinese culture.

The characteristics of this system are:

- to represent the meaning of Chinese culture and arts of timber-frame buildings in T'ang style,
- to break through the limitation of special field by providing flexible Application Program Interface (API), and
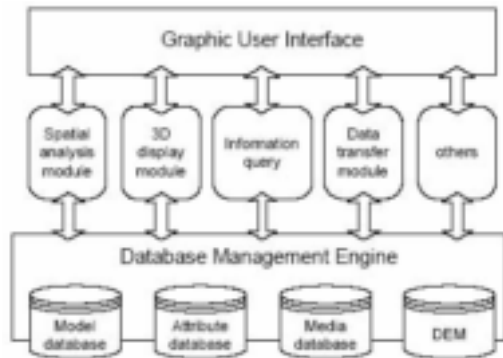- to meet the requirement of restoring ancient buildings and conserving historical documents.

Figure 2. Architecture of the demonstration system

4. SCENE MODELING

4.1 Using LODs

An accurate and complex scene model consists of a large number of triangles, so that even most high performance graphics computers have great difficulties to display at smooth frame rates. The common solution is to reduce the complexity of the scene through decreasing the quantity of triangles and vertexes. LOD, a simplification method, refers to use simpler versions of the geometry for objects that had lesser visual importance (Clark, 1976), such as those far away from the observer. LOD technique is increasingly used by 3DGIS developers to attain the balance between attractive virtual worlds and smooth, flowing animation.

A modeling approach on discrete LOD is chosen in this system. There are two implementations of LOD: discrete and continuous (Luebke, 2002; Schmalstieg, 1997). In continuous LOD, a set of models are established in the running process in order to insure continuous and smooth transition between different levels of models according to some critical conditions or algorithms. Therefore the sophisticated algorithms for continuous LOD are computationally expensive although observers do not noticed abrupt changes. Moreover, the research for continuous LOD concentrates on the objects that has continuous curved surface, such as terrain, but ignores the structure of architectural data. The continuous LOD generation algorithms work well in the rectangular buildings but fit poorly to cultural heritage data set where buildings seldom fulfill the rectangular constraint (Zach, 2001), especially hardly adapt to represent the ancient tim-ber-frame buildings of China. In discrete LOD, a finite number of models are created manually for an object and a single LOD model is used in rendering scene according to the distance from the viewpoint to itself. The approach on discrete LOD has fea-tures of its own although it can not avoid "popping effect" : firstly, discrete LODs need not address real-time rendering con-strains due to the offline production; secondly, run-time render-ing need only pick LODs instead of computing LODs; thirdly, each LOD can be easier to compile into triangle strips, display list, vertex array, and etc. Moreover, there are some measures against "popping effect", such as rational planning discrete lev-els of models, insuring to align LODs of an object, and using the texture of same pattern (but different size). Therefore an approach based on discrete LOD is sufficient for the application considered in this project.

4.2 Hierarchical Planning of LODs

The purpose of LODs modeling is to acquire the possible best quality of rendering images and to achieve the demand of inter-

active roam at smooth frame rates. For the purpose it is a critical problem to establish multiple levels of detailed models. The finite system resource will be used in over-frequent locating and loading huge volumes of data from storage so that real-time rendering is not enough smooth or sharp if many versions of a model are chosen. If choosing over-less levels of detail the "popping effect" caused by LODs changing is noticeable to the viewer. Therefore to choose reasonable levels is one of the most important tasks for the applications of discrete LODs. Further-more, complexity and distribution of buildings, detailed situa-tion of every level of models, and configuration of computer used in rendering are the critical foundation for deciding the levels of detail.

In our project, the scene is small and exquisite. The emphasis on modeling stands out the delicacy and accurate of timber-frame buildings in T'ang style or decorations. In addition not only the appearance but also the inner structure of timber-frame building needs to be presented to viewers. So 4 discrete LODs are used for an object; and their picked conditions and basic require-ments are following:

Special Level (SL) is only used in the represent of building model. It is the finest model because it includes the whole structure and all textures of a building, so that it can not only support walkthrough indoors but also be used in querying the attributes of single components. Only is it invoked from the storage when the distance between the model and viewpoint is less than 10M.

High Level (HL) expresses the appearance of a building as well as the SL through using model and texture. It can describe the whole appearance of an object whether it is a building or a decoration. It is invoked and rendered when the distance be-tween the model and viewpoint is from 10M to 20M.

Middle Level (ML) is created on the basis of HL through man-ual reducing the quantity of an object's triangles and vertexes and man-made modifying the sizes of textures. Buildings, decorations and terrain are created in this level and the range between 20M to 50M from the viewpoint is their location.

Low Level (LL) is the simplest model in all of LODs. It only represents the façades of a building, decoration or terrain by textures and the simplest models. When the distance is over 50M, the models in this level are invoked.

4.3 LODs Modeling

The scene consists of buildings, decorations, and terrain. The complexity of a building's model depends on that of compo-nents due to the building modeling is finished through modeling and assembling its components. Decorations' model include three types of object: the first can only be represented by model; the second can only be represented by texture; and the third can be represented by both model and texture. LODs of decorations are mainly designed to the models of objects. The LODs of terrain is in the ML and LL because the scene's range is small and they are mainly represented by surface and texture. As shown as Figure 3, the LODs of Bell Tower and the number of triangles illustrate the consequences of discrete LOD modeling.

It is essential to reasonably divide the complex LODs of build-ings into several suitable parts for smooth visualization. There are huge differences in the quantity of triangles and textures between different LODs shown in Figure 3. The time of invok-ing a complex LOD is longer than that of invoking a simple LOD, so that the course of rendering is disconnected. Balancing the data quantity of LODs provides a smooth data stream for rendering, so SL is divide into components; HL is fallen into several groups of components according building's structure; and ML is separated into two parts: *upper* and *down*.

Figure 3. Bell Tower's models of different LODs

5. DYNAMIC VISUALIZATION

The ongoing developments of researching and protecting ancient cultural heritage show the current importance and attractiveness of 3D visualization of different information for researchers as well as for decision makers and for the public. For supporting different potential users, a 3DGIS-based visualization system can provide abundant photorealistic information through real time display and dynamic interaction.

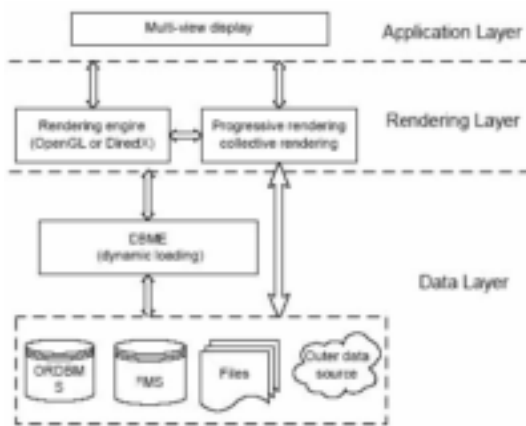### 5.1 Architecture of Visualization System

Figure 4. Display architecture of visualization system

The structure of the system consists of data layer, rendering layer, and application layer (Figure 4). The data layer supports API (Application Program Interface) for calling the integrated database, such as DEM database, model database, and attribute database, especially for dynamic loading program interface. The standard rendering engines, such as OpenGL and DirectX, are included in the rendering layer. The different rendering strategy is given through the progressive rendering engine and the conservative rendering engine encapsulated in OpenGL and DirectX. The application layer provides an independent-running desktop system platform and an ActiveX based controllers designed to two developments.

5.2 Data Organization

It is important to establish an appropriate spatial index in order to accelerate calling and invoking 3D vector model data for a metadata scene (Li, 2003). Spatial index is regarded as a sort of spatial data structure and the spatial objects not related to a given spatial operation are excluded for more efficient

operation. LOD-R-trees, which is perfectly suited to organize and manage large amounts of 3D data (Kofler, 1998), is designed to organize 3D data in this system. As shown as Figure 5, the majority of models in the scene are subdivided into several parts according the different detailed representation (as described in 4.3) for establishing LOD-R-trees index. The method of disassembling models not only satisfies the requirement of establish the spatial index as LOD-R-trees, but also serves the purpose of 3D space partitioning. Moreover, the 3D data organized in LOD-R-trees are contributed in smoothly real-time rendering photorealistic images and meets the goal of multi-scale spatial query and spa-tial analysis by integrated applications of database management techniques.
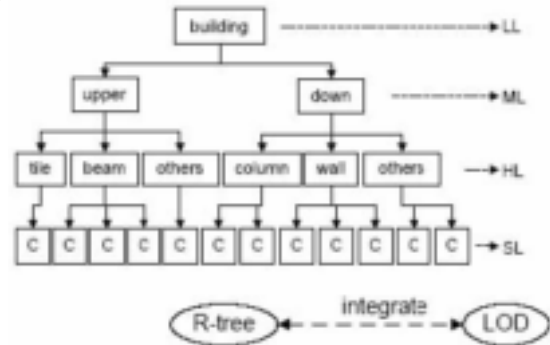

Figure 5. Illustrate LOD-R-tree by a building as an example

5.3 Integrated Database Management

The system applies an independent-developed 3D model Database Management Engine (DBME) that is based on the integration of Oracle 8i/9i database and file management system (FMS). Oracle 8i/9i database provides an open management mechanism for spatial data through an interface designed to manage and manipulate spatial data, and it has the all capacities of RDBMS (relational database management system), so that storage, calling, and analysis of spatial data are faster and more efficient than before. Tables are created within the Oracle 8i/9i database that can be assembled to store model components, including information about nodes, elements, and calculations at a given time step. On the other hand, it is well known that FMS has some characteristics, such as flexibility, speediness, generality, and lower environment dependent. FMS adapts to the management of isolated files, such as sound, video files. Therefore the ideal combination of Oracle 8i/9i and FMS allows for efficient management and rendering of the data within the 3DGIS visualization environment.

5.4 Acceleration Techniques

While interacting in the small and fine scene, a perfect image quality is the same important as a quick response time. Some acceleration techniques, such as occlusion culling, LOD, and progressive rendering, are studied widely and deeply for balancing between the highest rendering quality and smooth animation. But data needed to render always exceed the capacities of graphic hardware, so that it is also necessary to use software techniques to resolve the problem.

Occlusion culling is designed to cull the invisible objects. When the user is walking through the scene, many buildings and decorations are not visible although they are within the view frustum because they are occluded by other buildings closed the view point. The most culling algorithms are based on partitioning the view position space or finding out the set of potential visible objects. The real-time culling algorithm that stems from an algorithm put forward by Coorg and Teller (1997) is used in

the system due to it is sufficient to utilize the spatial and temporal consistency. When the height of viewpoint is above the roofs the algorithm is not efficient, but the algorithm is sufficient to cull the majority of invisible objects if the user is walking through the scene. Therefore the algorithm is effective because the navigation of users is mainly used in simulating human activities in the virtual scene.

Progressive rendering technique is one of the most effective real-time rendering approaches for obtaining a balance between image realism and smooth display. It is impossible to achieve the satisfied display speed although the multi-levels data management and occlusion culling technique are designed to rendering process. Therefore the progressive rendering is implemented: whenever flying over or walking through the scene, the refreshing frequency is optimized with matched graphic quality of rendering, so that the rendering contents of the scene are updated timely.

6. EXPERIMENTAL RESULTS

Chi Lin Nunnery in Hong Kong, founded in 1934, was completely rebuilt in 1998. Covering space of 30,000 square meters, Chi Lin Nunnery consists of twenty-four timber-frame buildings, architectural decorations, and plants. 3D reconstruction scene of Chi Lin Nunnery is the emphasis on a large number of data within a close range. The distribution of buildings is shown in Figure 6, and the length or width of the first compound is about 45 meters. The three compounds are surrounded by the tim-ber-frame buildings, such as halls and galleries. There are some bonsai, tree and lotus pools in the compounds.

Figure 6. Distribution of buildings in the scene

The 3D scene model is reconstructed according to the combination of LOD and CAD. The total data of SL models are more over 7,000,000 triangles and 200 Megabyte textures, and contrastively the data of LL models are about 308,000 triangles and 26 Megabyte textures. Moreover, three lights are added into the scene in order to improve realistic effects of the representation. A test is conducted on a PC with a 2.8GHz P4, 1GB of memory, and a GeForce FX5700 graphic card and the test result that the rendering speed is from 12 fps to 18fps addresses that the smooth animation with possible high quality image and dynamic query can be finished in the 3DGIS-based demonstration system.

7. CONCLUSIONS AND FUTURE WORK

In this paper, the 3DGIS-based demonstration system for timber-frame buildings in T'ang style is presented. It is shown the 3D GIS, as a key technique, is suitable to research and protec-

tion of ancient Chinese architectures. The system can afford various demands from users whoever are archaeologists, architects, or general users due to flexible API and various modules are embedded into the system. Importantly, the application of 3D GIS provides a new method for research and protection of ancient cultural heritage. Spatial analysis is one of the features of GIS and more analytical functions are provided to users on 3D spatial analysis or professional analysis. On the other side, the system should expand the web-based application.

A modeling method integrated LOD and CAD is presented and is very suitable to accurate reconstruction the ancient Chinese architectures, which traditional photogrammetric approaches and techniques can not obtain and represent. This method is contributed to improve the detailed degree of models and enhance the connection between indoor models and outdoor models, so that it is possible to wholly represent both delicate appearances and complex inner structure of buildings. Though the modeling method provides accurate and detailed models, la-bor-intensive work is necessary to be avoided. For ancient and modern architectures, the methods to automatic obtain and reconstruct 3D model and continuous LOD method is essential for extending the modeling and management approaches, especially on the basis of CAD.

The combination of LOD-R-trees method and DBME also become a solid foundation for hierarchical query and dynamic visualization. LOD-R-trees method applied in the system optimizes the organization structure of various types of GIS data, accordingly improves the transfer efficiency of data. DBME needs to harmonize the data streaming between RDBMS and FMS and should integrate data streaming occurred by pure DBMS to tailor to the development of DBMS.

Finally the accelerate techniques, such as occlusion culling and progressive rendering, has widely used in dynamic visualization. New algorithms about the techniques are increasingly put for-ward but practicability of the algorithms should be improved to meet various applications. On the other side, it is significant for reducing the amount of data to integrate these algorithms into rendering system.

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