Building 3D Cadastral System Based on 2D Survey Plans with SketchUp

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Abstract Three-dimensional (3D) land development and utilization has become the trend for urban planning in the current metropolis. This paper presents a method for building a 3D cadastral management system from survey plans with SketchUp. It concentrates on the geometric representation and topological consistent maintenance of 3D cadastral objects. In this system a complete topological model is built to express the body construction and spatial relationships among 3D property units. SketchUp is used to automatically construct 3D models with attributes and thematic information from 2D survey plans. Spatial topological relationships and operations are analyzed with the programming and development of Ruby language. The resulting system can manage 3D cadastral objects and manipulate them with spatial operations to support spatial analysis.

Keywords 3D cadastre; topological model; spatial operation

Introduction

Human beings act not only on the earth’s surface, but also above and below it. Population growth and intensive land development have resulted in 3D land use and development. The key task of governmental and municipal administrations in land development and utilization is the precise and consistent registration of land parcels and real estate. Traditionally, individual property units are expressed by 2D planar land parcels using boundaries. However, the rights of 2D land parcels are related to a space in 3D. Furthermore, the true property units exist in 3D environment. For either legal social system or physical features, accurate 3D descriptions of cadastre and property become important needs of governmental management and citizens’ rights. There are many 3D models generally produced by architects with the help of some software or packages. However, a 3D cadastral model is different from the architectural model. A 3D cadastral object is a 3D spatial unit that describes the space that the owner possesses; moreover, semantic attributes and 3D rights must be attached with the 3D cadastral object. A 3D cadastral object has its own physical space and legal space, represented by corresponding mathematic model and legislative definition. However, here this paper only refers to the physical and geometric objects, and takes little of the legal aspects into account. In addition to the 3D representation of a cadastral model, a 3D cadastral system requires the spatial relationships of cadastral objects,

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such as adjacency, incidence, and directional relations, to support spatial operations and analysis.

Unfortunately, many architects emphasize the construction of 3D objects and not on the cadastral boundaries. Usually, this procedure is a long and tedious process. Architectural 3D environments pay more attention to functional partitions such as walls, windows, rooms, floors, furniture, and so on and facility layouts, especially in one apartment or suite. Most methods or tools for 3D modelling focus on the concrete shape or visualization of 3D entities, but not whether the 3D model is really a closed geometric 3D body. In contrast, 3D cadastral models not only care about the closed boundary of 3D bodies, but also the semantic information about the cadastral objects and the relationships among them.

This paper aims to define a cadastral model and build a prototype 3D cadastral management system corresponding to a 3D cadastral partition of space. Each 3D cadastral object should occupy a regular and fixed geographic space which is represented by a closed and restricted body or polyhedron that consists of incident, and closed faces. The 3D cadastral objects can connect and be neighbors with each other, but they cannot intersect or penetrate.

A 3D cadastral object is a synthesis of geometry, attributes and social and legal semantics. The process to build a 3D cadastral management system we propose is based on the following four phases: (1) processing of a 2D survey plan; (2) 3D cadastral object construction; (3) topological reconstruction and semantic information joining; and (4) spatial query and analysis with the aid of Ruby programming. During the first phase, most 2D survey plans are automatically corrected with GIS software like ArcGIS. Semantic attributes can be imported from the survey plans when they exist, or defined manually by the user. The extrusion operation is guided by the elevation and the height of the cadastral objects that can be accessed from the tables of survey plans. The resulting 3D cadastral system has been designed so that 3D cadastral objects can be efficiently managed about their attributes, and the system can manipulate the topological construction and spatial operations of 3D cadastral objects to support certain spatial analysis for decision making. Also, the environment, which is integrated with Google SketchUp, is suitable for various applications such as visualization, walkthrough and other functions that the software provides.

The paper is organized as follows. Section 1 describes the existing literatures about the fields related to our research. Section 2 discusses the 2D surveying plans suitable for 3D cadastral units. Section 3 presents the extrusion and linking of the attribute data and geometric model. Section 4 details the geometric and topological processing with Ruby language based on SketchUp and addresses topological reconstruction, spatial query, spatial operations and implementation. Finally, conclusions are drawn in Section 5.

1 Related work

A 3D cadastre is superimposed by RRR (Right, Restriction and Responsibility) on its geographic space, which is represented by geometric shape.\[1\] The FIG (International Federation of Surveyors) and some scholars have studied the contents of 3D cadastre.\[2,3\] 3D cadastre emphasizes the 3D boundary of each property unit and their spatial relationships. A 3D cadastre is a partition of the geographic space and the ownership or possession of this space is an essential right of the owner. Generally, the cadastral space depends on the land parcel or property. One architectural building space may be composed of many 3D cadastral/property units with different vertical or horizontal partitions at the same time. We argue that the geographic space is the "gene" of a 3D cadastre and other elements, like rights and attributes, depend on this gene and attach to it.\[4\] That is why we will pay more attention to the mathematic/geometric representation of 3D cadastral objects and spatial analysis, as this paper develops. Here, the 3D property unit of a real estate is taken as an example to discuss the details of the prototype of a 3D cadastral management system.

Many studies on 3D buildings are related to 3D simulation and visualization. According to visual rules, each building is only a whole inseparable box without any partition. There are many methods related to 2D plans or digital 2D drawings with the exception of 3D building reconstructions based on images or laser.\[5\] Some works are based on the CityGML
or architectural plans of the architectural or indoor built environment. [6-10] CyberCity or digital city are more complex urban scenes that need more procedures for simulation with specific visualization techniques for buildings, terrain with DEM or DOM and other elements of landscape. [11,12]

Several approaches deal with topologic relationships among geometric body, surface, edge and point. Many developed 3D models exist, such as the 3D Formal Vector Data Structure (3D FDS) [13] and the Simplified Spatial Schema (SSS). [14,15] 3D topological descriptions are discussed based on boundary-representation model or (non-)manifold. [4,16-18]

Several software packages can design 2D plans and 3D buildings, like AutoCAD and Microstation. Most of them are devoted to simulation and visualization of various types of constructions and buildings. However, they do not provide topological description or maintain topological consistency. Google SketchUp provides flexible tools to construct various 3D models and allows secondary programming development with Ruby language to deal with spatial topologic information, as well as geographic reference and geographic coordinates. Evidently, it is an actual and feasible approach to build a 3D cadastral system based on SketchUp.

2 Survey plan processing

As we have mentioned each 3D cadastral object is made up of a body that occupies a certain geographic space and is an orientable 3D object. Generally, the source spatial data is obtained from the common survey plans. The survey plans express explicit descriptions in 2D space, but they offer an implicit profile and open the possibility to build a representation of 3D cadastral space. Furthermore, with survey plans only few 3D spatial analysis and operations can be performed since they cannot deliver the 3D relationships among cadastral objects. The challenge is handling the planar drawings in such a way as to construct 3D bodies to represent 3D cadastral spaces as described by geometric bodies with automatic modification of topologic relationships.

In order to extrude a 3D cadastral object, a 2D survey plan should be organized with a valid topology. Therefore, the dataset has to comply with three fundamental characteristics: (1) polygons should be closed, (2) the boundary of polygons should not self-intersect, (3) ring should be handled properly and the polygons should create a planar partition, i.e., they do not overlap and have no gaps between them.

The original survey plans are composed of line segments; we pre-process them to insure the consistent planar partition and correct topologic relations as specified above. For example, each pair of lines is checked for intersections. If an intersection is found, a vertex is added at the intersection point. From the original survey plans, the boundary polylines are created as Fig. 1(a) and (b) show. Next, the polylines are organized topologically into polygons (Fig. 1(b)) and the ring should be represented correctly (Figs.1(c) and (d)). Each polygon should be assigned to one planar partition, and has unique ownership of the land parcel or property unit where the boundaries represent their planar geometric range. After the topological construction, the 2D plans consist of closed polygons, i.e., with no dangling polylines or line segments.

To construct a 3D body from the planar polygon, each polygon should have its own geographic elevation and physical height. We need to add and modify the attributes of the planar cadastral units to adapt to this requirement. Moreover, for many property units in the buildings, the code and floor numbers must be recorded. Fig.2 illustrates the example of one property unit with attributes for the elevation and height, and this unit locates at the 8th floor in the 6th building which can be parsed from the name “b6k008”.

Fig.1 Organization of faces with correct topology
It should be noted that although the 2D topological relationships are built in horizontal direction, the survey plans cannot convey a precise description of 3D property boundaries in a 3D environment.

3 Extrusion and link

To get the correct representation of 3D cadastral units with the help of SketchUp software, the survey plans must deliver precise geometric shapes and consistent topology. The starting point of 3D extrusion is that the 2D plan is composed of only polygons without any dangling line segments.

Although several software or packages are applicable to the architectural and urban visualization fields, there are still too few that can perform correct 3D modeling, or software or packages devised for 3D topological extrusion. In this respect Google SketchUp is an excellent software, and it provides basic planar topological description and geometric operations, which we can use to develop various controls for the 3D objects. SketchUp provides convenient tools to pull and push a polygon to close a body. But to deal with sets of faces with different height and elevation, we developed a program. In fact, SketchUp (v6.0) has an API plug-in provided for ArcGIS.

The extrusion of boundaries of polygon produces many vertical faces, and the ceiling top polygon is replicated from the bottom polygon to close up and seal the body (Fig.3). Since there are no dangling line segments in the 2D plans, 3D cadastral objects have no dangling faces. Moreover, as we use the processed survey plans, our reconstruction of 3D cadastral objects is completely delimited and closed by polygons. Thus, validity and closeness is ensured, and therefore provides perfect topological descriptions to implement spatial analysis. This reconstruction approach from a 2D survey plan is automatic as soon as the original 2D set of polygons complies with the rules discussed in Section 2. For the polygon with a hole shown in Fig.2, the extruded model is illustrated in Fig.4 from two different view modes. It is a closed body or polyhedron composed of many faces, and has an inner hole. Fig.5 illustrates the 3D extrusion model of a floor of a building with many property units. Through the transparent view, we can see the faces that neighboring units share.

Thematic attributes can be deduced from the plans when they exist, or defined manually by the user. Every cadastral object has its own semantics according to certain surveying specifications and registering rules. If main thematic information is stored in the tables we can create a link or join between the objects and the tables in Ruby programming based on SketchUp. However, the identifiers (IDs) of entities in SketchUp are merely persistent in one session, which means we cannot keep the ID unique all the time. Therefore, more deep programs must be developed to integrate the cadastral attributes with the interior of SketchUp. As for 3D cadastral objects, the measure of volume must be added to the attributes because the occupied geographic space...
4 Topological reconstruction and spatial operations

4.1 Topological reconstruction

There are concepts about line and face in SketchUp, but none about body. Therefore, we must define the body with the help of Ruby. Many faces are closed up to form a body. The concept of “group” in SketchUp can be used to represent the body. The faces that are extruded or produced by extrusion are grouped together to define a body as Figs. 4 and 5 show. After correct construction of a body, the topologic relationships among 3D cadastral bodies become the key problem that we need to handle.

All the 3D cadastral units generated as Section 3 described are separate objects and the connectivity among them must be created. As we have declared, the cadastral geographic space represented by geometry is mutually exclusive, i.e., there is no overlay or mutual penetration among them. Therefore, the “disjoin” and “touch” are the main relationships among the 3D cadastral objects. However, the “touch” relationship is more essential. The spatial topological connections are embodied in the spatial adjacency and neighborhood relationship. From the viewpoint of geometric morphology, 2D parcels can share the edges or vertex, and 3D objects can share the faces, edges, and vertex (not for extruded buildings). In this paper we only discuss the touch relationship based on shared faces among 3D cadastral objects.

To analyze the topologic relationship among 3D cadastral objects, the basic structure of couple-face should be explained as used in SketchUp. Every face in SketchUp has “two hemi-faces” with a different normal vector (Fig.7). This presentation can link the
existing connected or adjacent 3D bodies. Actually there is only one geometric face with identical geographic coordinates with different normal vectors.

![Fig.7 Double-faces structure of SketchUp](image)

In order to construct the topologic relationships among 3D bodies, inclusion and identification of faces should be determined. For two 3D objects in Fig.8(a), surface $f_1$ in body $B_1$ and surface $f_2$ in body $B_2$ have an identical face. However, the surface the two bodies share has different normal vector directions. Other cases are, however, possible as well. (Fig.8(b)). There is only one surface $f_1$ in body $B_1$, but in geometric aspect, surface $f_1$ has two faces that individually respond to the surface $f_2$ in body $B_2$ and the surface $f_3$. Therefore, the judgment of inclusion or co-planarity of faces between $f_2$ and $f_1$ is another technical problem whose solution is preceded by programming in Ruby.

![Fig.8 Identity (a) and inclusion (b) of face between two 3D bodies](image)

4.2 Spatial query and operations

General semantic query and display of geographic coordinates are common functions in our system, and can be easily realized. Fig. 9 shows an SQL query to the database with the sentence “FloorNO>=0007” and the corresponding results of this query. The important issue in a 3D cadastral system, however, is a spatial query, especially the query based on topologic relationships among 3D cadastral objects.

Having constructed the topologic relationships, the topological query can be carried out. In this prototype of a 3D cadastral management system we have implemented topological query of touch relationship. We can find all the neighboring bodies of a given body. Fig.10 illustrates the results of the neighboring query for the polygon with a hole. The 3D property unit with a hole (Fig.10(a)) has 6 adjacent units, including one inner hole, one unit shared by one edge and other four units shared by faces (Fig.10(b)). A topological query can handle queries in 3D environment regardless of different directions or floors.

![Fig.9 SQL query (a) and corresponding result (b)](image)

![Fig.10 Topological query (a) and corresponding result (b)](image)

With the generic functions of SketchUp, several basic computations for 3D objects can be calculated, such as bottom area, surface area and volume of 3D cadastral units. More complex spatial operations can be implemented with programming in the Ruby language. The major code modules and the operations we have implemented include the subdivision or split of one 3D object, and the combination and mergence of multiple 3D objects.

3D cadastral objects can be reshaped and re-grouped according to urban planning, commercial
transactions or business deals, creating different statuses for property units with different temporal information. Spatial operations on 3D cadastral objects become a crucial technical problem for 3D cadastral management. Two 3D property units can be combined or grouped together if they are owned by one legal owner or have the same/similar legal explanation. During this operation, two property units merely join together, and still reserve their own geometry, attributes, and social semantic information.

Different from combination and grouping, mergence of 3D objects indicates another situation. Through the mergence operation, multiple 3D cadastral objects become one identical object with homogenous semantic information. Their geometric shapes are fused as the previous boundaries between them are removed and the new merged object is represented by one geometric body. As Fig. 11 demonstrates, when two apartments merge into one, the “wall” between them is gone, and they become “one family”.

Subdivision of 3D cadastral objects is the opposite operation of mergence and the cutter-plane is applied to subdivide the body. One 3D property unit space can be subdivided into several spaces so that each can be handled separately, such as for sales or leasing.

Mergence and subdivision of cadastral objects have vital effects in many aspects. Mergence and subdivision of houses or property units result in alteration and exist as commercial transactions in the real estate field. Mergence and subdivision of land give rise to the change of backoff of “redlines”, plot ratio, even affecting land development and planning more generally within a city or urban area.

4.3 Implementation

Our prototype of the 3D cadastral management system has been implemented on the basis of SketchUp Software (v6.0) with additional developments in the Ruby language (1.8.0). The source files for survey plans have been produced by surveyors in shape file format. The computer environment is based on the Intel Core Duo CPU 2.1GHz and 1GB of RAM. The system manages 1519 3D property units, including 7 buildings, one underground garage and one underground basement. Fig. 12 illustrates the test area integrated with Google. Moreover, all the topologic and semantic information are being controlled by a Ruby program and automatically propagated. The system supports attribute editing and query, spatial query and operations described above.

5 Conclusion

This paper presents a method for constructing a 3D cadastral management system from 2D surveying plans. During all the processing, consistent topology is created and the valid 3D data structure is developed. On the basis of the data structure and with the help of Ruby programming language several spatial operations are developed. The prototype makes a complete
use of SketchUp functions for the correct topological structure, spatial analysis as well as to provide a flexible visualization. Our tests have shown that this environment is easy to use, extend and adapt for the purpose of a 3D cadastral system.

The next step in this work consists in supporting just-in-time editing and automatic on-line topological reconstruction of the 3D cadastral objects, as well as automatic body construction with given faces, not using the operation of pushing/pulling. The method merely supports the bodies that have vertical boundaries and the same geometric shape about the bottom and upper profile, but many 3D cadastral spaces are not so clearly defined, e.g., store, detail or other property that may have an irregular polyhedron shape. To support curved surfaces or NURBS surfaces and very large volume data, more deep insights about function-oriented development of Ruby on SketchUp should be investigated. We believe our prototype can be applied to the fields of urban planning and land and real estate management.

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