Urban 3D Building Model Applied to True Orthoimage Generation

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ABSTRACT

Three dimensional (3D) building models are increasingly necessary for urban planning, tourism, etc. How to effectively describe the architectural objects becomes a key point due to the fact that the urban buildings extremely vary in height, sizes, shapes, textures, etc. This paper presents a model for exactly describing urban 3D buildings for large-scale urban true orthoimage generation. This method is based on CSG (Constructive Solid Geometry), belonging to volumetric representation in computer graphics. This method is well suited to describing complex shapes, which can be composed by a set of primitives. Within this proposed approach the buildings are described by combining a set of basic primitives, such as box, wedge, and rectangular pyramid. This representation model is particularly useful for urban true orthoimage generation because a complex building in this model can be partitioned into many simple building parts, each of them corresponding to a basic building model. We implemented this work using the ground plan information according to digital surface model. The ground plan of a building is divided in rectangles, arcs, and circles - each of the primitives representing the ground plane of a building part. The primitives are combined by means of the Boolean operations union, intersection, and difference. So, the buildings will be described as a CSG tree. Our experimental result in Downtown, Denver, Colorado demonstrated our method can effectively and exactly represent the complex buildings, and produce high accuracy when applied in urban true orthoimage generation.

INTRODUCTION

Theoretically, the digital orthoimages should be a spatially accurate image with ground features represented in their true planimetric positions. However, the algorithms and procedures in traditional digital orthoimage generation did not consider the spatial objects, such as buildings, resulting in the spatial objects of orthoimage in urban areas are distorted from their true positions (Zhou et al., 2005). In order to orthorectify a building to its correct, upright position, the building must be represented as part of the surface to be rectified. Therefore, an exact digital building model, which describes the building structure, three-dimensional coordinates, topologic relationship, etc., is required.

Aiming at this purpose, the researches about automatic or semiautomatic building extraction (Gűlch, 1996; Förstner, 1996; Vosselman, 1999; Heuvel, 2000; Gerke, 2001) become a key problem. Many different approaches and algorithms were addressed with different source image type, terrain complexity and field of application etc. In recent decade years, CSG model, as a kind of model-based building extraction, is commonly used for building extraction in the field of computer vision and photogrammetry (Braun et al., 1995; Englert and Gűlch,1996; Lang and Förstner, 1996; Tseng 2003), because of its flexibility for the representation of buildings and its diversity for containing object constraints and classification. CSG model is composed of a combination of volumetric primitives. It is possible to construct a complex model with a small set of primitives, depending on the required detail. A primitive is a simple solid model to determine the interior geometric properties of a building, and is associated with some transformation parameters. The combination of primitives can finish via Boolean set operations, such as union, intersection, and difference.

PARAMETERIZED CSG BUILDING MODEL

CSG modeling is time-consuming process. Tseng presented a semi-automated building extraction method from aerial images (Tseng 2003). The fitting CSG model is selected interactively by the operator, and then optimal model-image fitting is performed automatically with a least-square algorithm. Gűlch addressed a semi-automatic method of fitting parametric models to multiple overlapping images and then combining them into the whole model. They can reach about 20 seconds for the modeling of a volumetric primitive (Gűlch 1999). However, for large urban area, it is impossible to construct CSG model with human interaction.

a) Data structure

The generation of a 3D urban building model is a rather challenging task, because different applications (e.g., city planning, communication design, tourism, pollution distribution, etc.) require different data types and manipulation functions (Breunig 1996, Graz 1999, Grun and Wang 1998, Zhou et al. 2000). For the purpose of true orthoimage generation, the data structure to be developed in this paper requires not only the fitness for generating the DBM-based high-quality orthoimage, but also easily creating, storing, designing, analyzing and querying city objects for orthoimage-based urban applications (Zhou et al. 2005).

CSG model is composed of many CSG primitives. Any 3D primitives come from 2D basic graphs with different parameters of Heights. This paper presents the technique of three-level data structure. The first level is 2D basic graphs with parameters, such as rectangle, circle, triangle, polygon etc. Each graph has respectively parameters of its own, such as length, width, radius, position of point etc. The second level is 3D primitive. 2D basic graph with height parameter becomes 3D graph. For example, rectangle with height is box; circle with height is cylinder. Box, cylinder, cone, pyramid etc. belong to single primitives. Furthermore, we can obtain the multi primitives with different single primitives. The third level is building model. The combination of 3D primitives can generate the CSG building model. In this process, topological relationship should be considered for the convenience of data retrieve.

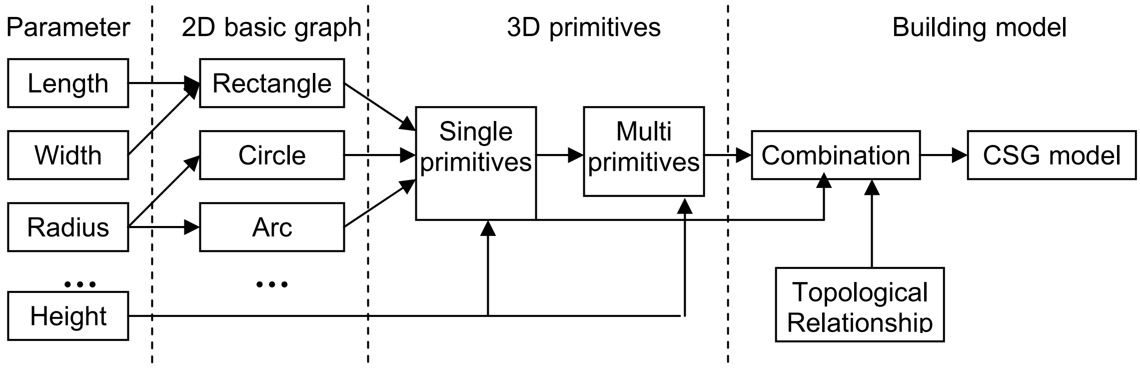


Figure 1:Three-level data structure

b) Automatic CSG model extraction

From digital surface model, the edges of buildings can be detected. These line features are only the low-level depict, not the whole model depict. Feature grouping should be applied by grouping these isolate, partial vector features into the whole semantic coherent symbol structures. Recently, feature grouping based on similarity relationship is commonly adopted. In this method, the geometric relationship (such as position, direction) and area property (such as color, gray value) are taken into account.
Taking the line feature for example, this paper quantitatively depicts the similarity relationships of line feature. Six parameters (i.e. distance of points, collinear difference, collinear distance, degree of overlapping, gray value and texture) are adopted to measure the combining probability of line features (Henricsson 1996). This paper only takes two of them for example to illustrate it.

1) ***Distance of points.*** If one of two points Q_1 and Q_2 of line L_2 is in the perceptual field of line L_1, the similarity depict of distance of points is shown as Fig. 3(a). The perceptual field is defined as a circle where the center is one point of line L_1, the radius is R, R is related with various factors such as edge quality, density of lines etc.

$$S_{Pt\_Dis}(\Delta D_{ij}) = e^{-\frac{1}{2}\left(\frac{\Delta Dij}{\Delta D_V}\right)} \qquad \left(0 \le \Delta D_{ij} \le \Delta D_V\right)$$

Where, $S_{Pt\_Dis}(\Delta D_{ij})$ is the depict value, ΔD_{ij} is length of line, ΔD_V is the minimum distance of connection.

2) ***Collinear distance.*** The collinear distance of two lines L_1, L_2 is defined as the vertical distance from the mid-point of L_2 to line L_2 (shown as Fig. 3(b)). Its depict is:

$$S_{Col\_Dis}(\Delta C_{ij}) = e^{-\frac{1}{2}\left(\frac{\Delta Cij}{\Delta D_C}\right)} \qquad \left(0 \le \Delta C_{ij} \le \Delta D_C\right)$$

Where, $S_{Col\_Dis}(\Delta C_{ij})$ is the depict value; ΔC_{ij} is the Euclidian distance of two lines; ΔD_C is the minimum distance of connection.

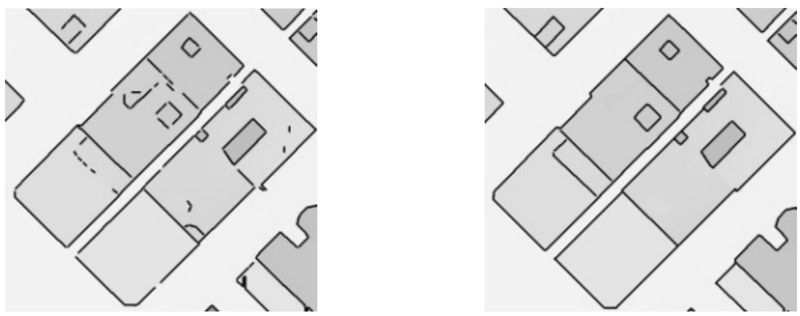
Suppose that other similarity relationships of four parameters can be respectively depicted with symbols $S_{Angle}, S_{overlay}, S_{Gray}, S_{Texture}$. According to the degree of effect, the six parameters illustrated above have different weights. Suppose that the weights of these parameters are respectively P_{Pt_Dis}, P_{Col_Dis}, P_{Angle}, $P_{Overlay}$, P_{Gray}, $P_{Texture}$, thus the grouping probability P of two lines is:

$$P = S_{Pt\_Dis} \cdot P_{Pt\_Dis} + S_{Col\_Dis} \cdot P_{Col\_Dis} + S_{Angle} \cdot P_{Angle}$$
$$+ S_{Overlay} \cdot P_{Overlay} + S_{Gray} \cdot P_{Gray} + S_{Texture} \cdot P_{Texture}$$

(a) Distance of points (b) Collinear distance

Figure 2: Line feature grouping

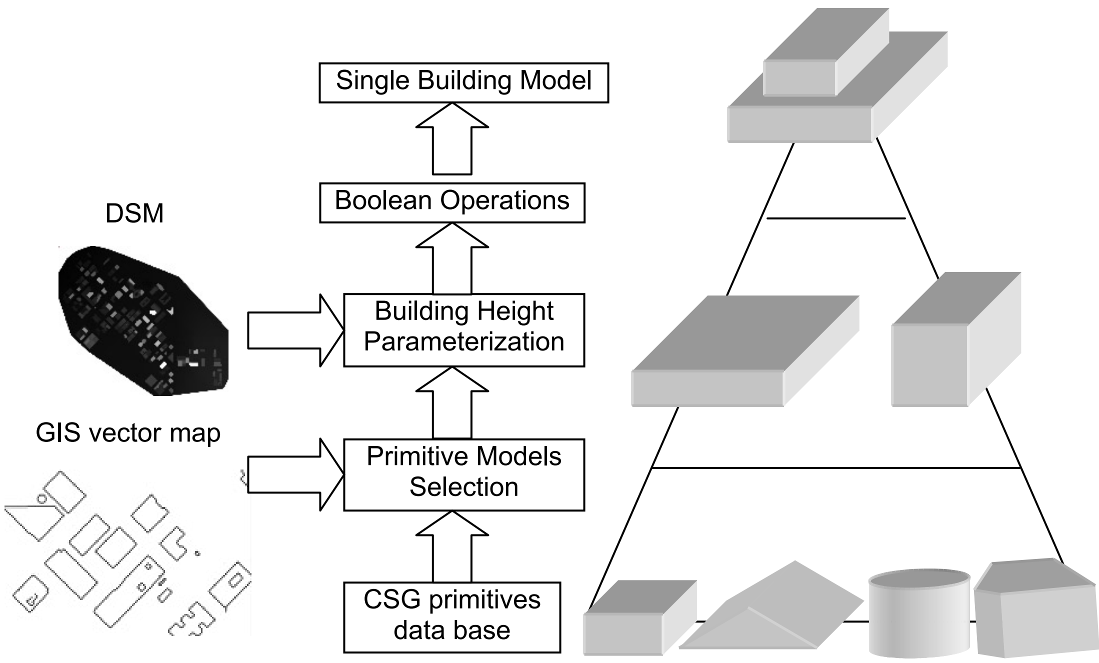
For other geometric features, there are also the similar perceptual grouping algorithms as the line feature. While for the grouping of building outline, we can change the conditions of similarity relationships according to the geometric property of building. Fig.3 (a) shows the 2D discrete edges of some buildings, from Fig.3 (a), we can see all the segments are isolated and irrelevant. According to the algorithm mentioned above, we can obtain consecutive building outlines with topology, which is shown by Fig.3 (b).



(a) Before grouping (b) After grouping

Figure 3: Feature grouping

The process of extracting building knowledge is a bottom-up procedure from low-level data to high-level information. The workflow is illustrated by Fig. 4(a). First, we can obtain the vector edge data of buildings from aerial images or LIDAR data by using a series of image processing such as edge detecting, tracking and segmenting etc. after feature grouping, the upper-level building outline is generated. As we know, most of architectures are with regular shapes, where the lines and planes on them have the properties of parallel, vertical, orthogonality etc. With these geometric constraints these outlines can be matched with corresponding CSG primitives in the database of primitives. And then these CSG primitives are parameterized by the building heights from digital surface model. For the complex buildings, they are decomposed into several parts. We can combine a complete building model via Boolean set operations, which include union (□), intersection (∩), and difference (－) etc. Boolean operations make the CSG model more flexible. For example, the redundancy in space may be occurred for complex building where some parts cover the others in the ground map. In this case, the Boolean difference operated can reduce the data redundancy. With the connection of Boolean operations, the whole composition process of a complex building model likes a CSG tree (see Fig. 4(b)). The leaf nodes are those CSG primitives; the middle node links two branches of combined parts and the root is the complete building model.



(a) Flow chart (b) CSG tree

Figure 4: Procedure for extracting CSG building model.

EXPERIMENT

The experimental field is located in downtown Denver, Colorado, where the highest building is 125m, and many others are around 100m. The six original aerial images from two flight strips were acquired using an RC30 aerial camera at a focal length of 153.022mm on April 1,2000 (Zhou et al. 2005). One part of scanned aerial images is shown as Fig. 5. Fig. 6 shows the 2D representation of the digital surface model of the same area. The range from the highest altitude to the lowest altitude is reflected to the range of gray value from 255 to 0.

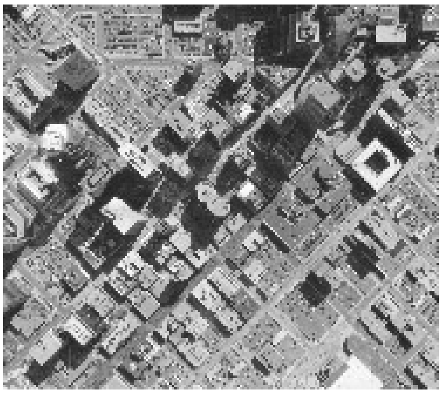


Figure 5: One part of original aerial images

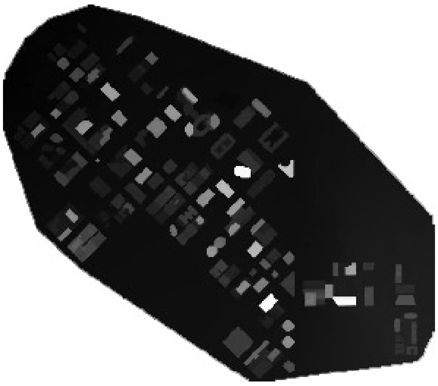


Figure 6: 2D representation of digital surface model in downtown Denve

From the digital surface model, we extract 1386 edge objects including point, line and arc objects. After feature grouping, 249 building parts is used for 2D GIS vector map where every object has the property of height. According to 2D geometric information and the third dimensional height information, all the GIS vector objects can be matched with parameterized CSG primitives. In this experiment, by combining CSG primitives, 106 buildings are finally extracted. Fig. 7 shows the partial extracting result compared with corresponding aerial image.

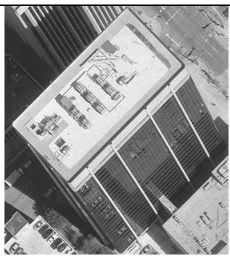
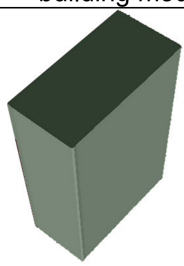
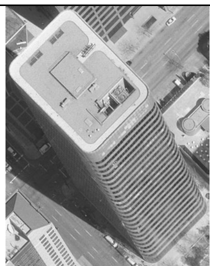
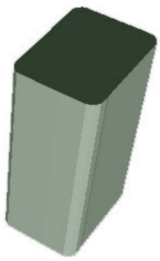
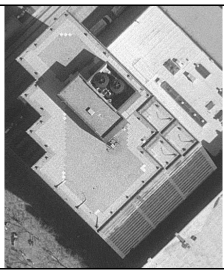
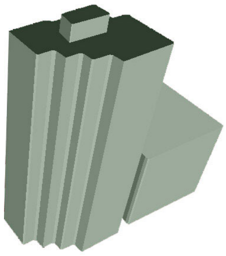
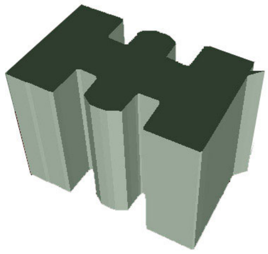
Aerial image	Corresponding building model	Aerial image	Corresponding building model
			
			

Figure 7: The extracting result compared with corresponding aerial image

Moreover, with the accurate digital building model superimposed by orthoimage (shown as Fig. 8), 3D visibility analysis can be applied to true orthoimage generation including: Occlusion detection and compensation. In a true orthoimage, buildings should be presented in their true upright planimetric positions. One only can see their roofs. However, the walls in original images occluded streets or other objects. Based on urban building model, Z-buffer algorithm can be adopted to occlusion detection. And occlusion compensation is implemented by refilling the occluded areas from neighbor slave orthoimages; Shadow area detection. Uran large-scale orthoimage generation requires detecting and removing shadow. Shadow area depends on the factors such as building style and height, the zenith and position of the light source etc.

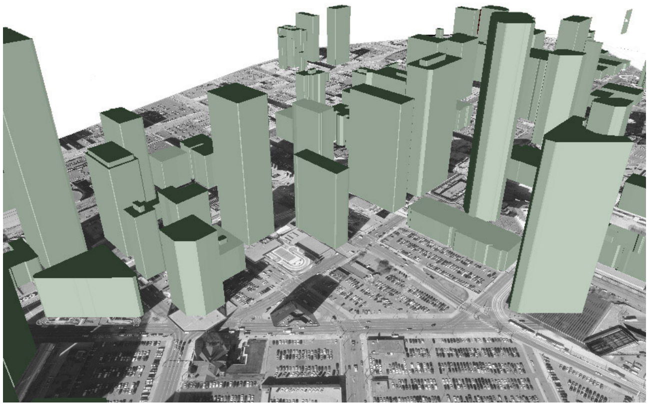


Figure 8: 3D urban building model superimposed with orithoimage

CONCLUSION

This paper presents the data structure and representation of urban 3D building model. The technique of three-level data structure is presented for true orthoimage generation. This structure mode is used not only for CSG model, also for other 3D volumetric models. And then, based on parameterized CSG model, this paper presents a method of extracting the building model. This method parameterizes the CSG primitives with different heights and adjusts the parameters of primitives by using the Boolean operator, this method greatly increases the efficiency of extraction.

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