Automatic generation of 3-d building models from multiple bounded polygons

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Abstract

Based on building polygons (building footprints) on the digital map, we are proposing a GIS and CG integrated system to generate 3-D building models automatically. Most building polygons’ edges meet at right angles (orthogonal polygon). A complicated orthogonal polygon can be partitioned into a set of rectangles. In order to partition an orthogonal polygon, we proposed a useful polygon expression and a partitioning scheme in deciding from which vertex a dividing line (DL) is drawn. After partitioning, the integrated system will place rectangular roofs and box-shaped building bodies on these rectangles. In this paper, we propose a new scheme for partitioning building polygons and for creating a complicated shape of building models based on orthogonal multiple bounded polygons.

Keywords: GIS, CG, 3-D urban model, 3-D building model, automatic generation

1 Introduction

Based on building polygons or building footprints on digital maps shown in Figure 1, we propose a GIS and CG integrated system that automatically generates 3-D building models. A 3-D urban model as shown in Figure 2 is an important information infrastructure that can be utilized in several fields, such as, landscape evaluation and urban planning, and many other business practices.

However, enormous time and labour has to be consumed to create these 3-D models, using 3D modelling software such as 3ds Max or SketchUp. For example, when manually modelling a house with roofs by Constructive Solid Geometry (CSG), one must follow these laborious modelling steps: (1) generation of primitives of appropriate size, such as box, prism or polyhedron that will form parts of a house (2) Boolean operation among these primitives to form the shapes of parts of a house such as making holes in a building body for doors and windows (3) rotation of parts of a house (4) positioning of parts of a house (5) texture mapping onto these parts.

In order to automate these laborious steps, we proposed the GIS and CG integrated system that automatically generates 3-D building models from building polygons on a digital map (Sugihara, 2005). As shown in Figure 1, most building polygons’ edges meet at right angles (orthogonal polygon). A complicated orthogonal polygon can be partitioned into a set of rectangles. The integrated system partitions orthogonal building polygons into a set of rectangles and places rectangular roofs and box-shaped building bodies on these rectangles. In order to partition an orthogonal polygon, we proposed a useful polygon expression (RL expression) and a partitioning scheme that is used in deciding from which vertex a dividing line (DL) is drawn (Sugihara, 2006).
In this paper, we propose a new scheme for partitioning building polygons and for creating a complicated shape of building models based on orthogonal building polygons. Since 3-D urban models are important information infrastructure that can be utilized in several fields, the researches on creations of 3-D urban models are in full swing. Procedural modelling is an effective technique to create 3-D models from sets of rules such as L-systems, fractals, and generative modelling language. Müller et al. (2006) have created an archaeological site of Pompeii and a suburbia model of Beverly Hills by using a shape grammar with production rules. They import data from a GIS database and try to classify imported mass models as basic shapes in their shape vocabulary. If this is not possible, they use a general extruded footprint together with a general roof obtained by a straight skeleton computation (Aichholzer et al., 1995).

The straight skeleton can be used as the set of ridge lines of a building roof, based on walls in the form of the initial polygon (Aichholzer et al., 1996). The roofs created by the straight skeleton are limited to hipped roofs or gable roofs with their ridges parallel to long edges of the rectangle into which a building polygon is partitioned. However, there are many roofs whose ridges are vertical to a long edge of the rectangle and these roofs cannot be created by the straight skeleton since the straight skeleton treats a building polygon as a whole and forms a seamless roof so that it cannot place individual roof independently on partitioned polygons. To create a various shape of 3-D roofs, building polygons are to be partitioned into sets of individual rectangles.

Laycock et al. (2003) have combined the straight skeleton method and polygon partitioning in the following steps; 1) Partition the polygon into a set of rectangles by horizontal and vertical lines from all reflex vertices. 2) Construct the straight skeleton and grow an axis aligned rectangle (AAR) from each of the lines. 3) For each AAR, collect the rectangles which are interior to AAR and union them to obtain an exterior boundary. 4) Assign a roof model to each exterior boundary. Merge the roof models. This method seems effective in independently choosing a roof model for each rectangle and merging the roof models for polygons with a small number of vertices. However, for polygons with a large number of vertices, implementation of partitioning along all DLs (dividing lines from all reflex vertices) often results in an unnecessarily large number of rectangles and collecting and merging steps become so cumbersome that they don’t succeed in doing this.

In our system, one has an option to choose partitioning scheme; prioritizing separation or prioritizing shorter DL. Our system tries to select a suitable DL for partitioning or a suitable separation, depending on the RL expression of a polygon, the length of DLs and the edges of a polygon.
2 Flow of Automatic Generation

The automatic generation system consists of GIS application (ArcGIS, ESRI Inc.), GIS module and CG module as shown in Figure 3. The source of a 3-D urban model is a digital residential map that contains building polygons linked with attributes data such as the number of stories and the type of roof. The GIS module pre-processes building polygons on the digital map. Pre-process includes filtering out a ‘short edge’ (a short edge that is between long edges of almost the same direction) and unnecessary vertices of a building polygon, partitioning orthogonal building polygons into sets of rectangles, generating inside contours for positioning walls and windows of a building and exporting the coordinates of polygons’ vertices and attributes of buildings. The attributes of buildings consist of the number of stories, the image code of roof, wall and the type code of roof (flat, gable roof, hipped roof, oblong gable roof, gambrel roof, Mansard roof and so forth). The GIS module has been developed using 2-D GIS software components (MapObjects, ESRI).

The CG module receives the pre-processed data that the GIS module exports, generating 3-D building models. CG module has been developed using Maxscript that controls 3-D CG software (3ds MAX, Autodesk Inc). In case of modelling a building with roofs, the CG module follows these steps: (1) generation of primitives of appropriate size, such as boxes, prisms or polyhedra that will form the various parts of the house (2) Boolean operation on these primitives to form the shapes of parts of the house, for examples, making holes in a building body for doors and windows (3) rotation of parts of the house (4) positioning of parts of the house (5) texture mapping onto these parts according to the attribute received (6) copying the 2nd floor to form the 3rd floor or more in case of building higher than 3 stories.

3 Polygon Partitioning

3.1 Proposed Polygon Expression

At map production companies, technicians are drawing building polygons manually with digitizer, depending on aerial photos or satellite imagery as shown in Figure 1. This aerial photo and digital map (Figure 1) also show that most building polygons are orthogonal polygons. An orthogonal polygon can be replaced by a combination of rectangles. When following edges of a polygon clockwise, an edge turns to the right or to the left by 90 degrees. Therefore, it is possible to assume that an orthogonal polygon can be expressed as a set of its edges’ turning direction.
We proposed a useful polygon expression (RL expression) in specifying the shape pattern of an orthogonal polygon (Sugihara, 2005). An orthogonal polygon with 22 vertices shown in Figure 4 is expressed as a set of its edges’ turning direction: LRRRLRRLRLRRLLRRRRL where R and L mean a change of an edge’s direction to the right and to the left, respectively. The number of shapes that a polygon can take depends on the number of vertices of a polygon. The advantage of this RL expression is as follows.

1. **RL expression specifies the shape pattern of an orthogonal polygon without regard to the length of its edges.**
2. **This expression decides from which vertex a dividing line (DL) is drawn.**

### 3.2 Partitioning Scheme

The more vertices a polygon has, the more partitioning scheme a polygon has, since the interior angle of a ‘L’ vertex is 270 degrees and two DLs(dividing lines) can be drawn from a ‘L’ vertex. We proposed the partitioning scheme that gives higher priority to the DLs that divide ‘fat rectangles’ (Sugihara, 2006). A ‘fat rectangles’ is a rectangle close to a square. Our proposed partitioning scheme is similar to Delaunay Triangulation in the sense that Delaunay Triangulation avoids thin triangles and generates fat triangles. However, our proposal did not always result in generating plausible and probable 3-D building models with roofs. In our new proposal, among many possible DLs, the DL that satisfies the following conditions is selected for partitioning.

1. **A DL that cuts off `one rectangle`**.
2. **Among two DLs from a same ‘L’ vertex, a shorter DL is selected to cut off a rectangle.**
3. **A DL whose length is shorter than the width of a `main roof` that a `branch roof` is supposed to extend to.**

Our newly proposed partitioning scheme as shown in Figure 4 leads to a plausible and probable 3-D house model: a main roof is higher than a branch roof.

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**Figure 4, Partitioning process of orthogonal building polygon into a set of rectangles**
3.3 **Partitioning Process**

Figure 4 shows the partitioning process of an orthogonal building polygon into a set of rectangles. The vertices of a polygon are numbered in clock-wise order as shown in Figure.4. Stage 2 in Figure 4 shows an orthogonal polygon with all possible DLs shown as thin dotted lines and with DLs that satisfy condition (1), shown as thick dotted lines. The example of a branch roof is shown as the rectangle formed by vertices 6,7,8,9 cut off by DL. Here, how the system is finding ‘branches’ is as follows. The system counts the number of consecutive ‘R’ vertices (= n_R) between ‘L’ vertices. If n_R is two or more, then it can be a branch. One or two DLs can be drawn from ‘L’ vertex in a clockwise or counterclockwise direction, depending on the length of the adjacent edges of ‘L’ vertex.

The reason we set up these conditions is that like breaking down a tree into a collection of branches, we will cut off along ‘thin’ part of branches of a polygon. Therefore, we propose a scheme of prioritizing the DL that cuts off a branch roof, based on the length of the DL. Since each roof has the same gradient in most multiple-roofed buildings, a roof of longer width is higher than a roof of shorter width and ‘probable multiple-roofed buildings’ take the form of narrower branch roofs diverging from a wider and higher main roof. Narrower branch roofs are formed by dividing a polygon along a shorter DL and the width of a branch roof is equal to the length of the DL.

In the partitioning process as shown in Figure 4, the DLs that satisfy the mentioned conditions are selected for partitioning. By cutting off one rectangle, the number of the vertices of a body polygon is reduced by two or four. After partitioning branches, the edges’ lengths and RL data are recalculated to find new branches. Partitioning continues until the number of the vertices of a body polygon is four. After being partitioned into a set of rectangles, the system places 3-D building models on these rectangles. Figure.5 shows a variety of shapes of orthogonal building polygons with DLs implemented and 3D building models automatically generated from partitioned building polygons. The rectangle partitioned is extended to a wider and higher main roof so that it will form a narrower and lower branch roof.

Figure 5, Orthogonal building polygons with dividing lines and 3D building models automatically generated
4 Conclusion

Figure 1 shows building polygons manually drawn on an ortho photo of residential area in Google Earth. After automatic generation process, 3-D house models are created on building polygons as shown in Figure 2. This process shows we can get 3-D house models immediately if we have a residential area ortho photo with building polygons. For residents, citizens or even students as well as the researchers, a 3-D urban model is quite effective in understanding what was built, what image of the town were or what if this alternative plan is realized. This model can act as a simulator to realize alternative ideas of urban planning virtually.

In this paper, we propose a new scheme for partitioning building polygons and show the process of partitioning orthogonal building polygons. By applying polygon partitioning algorithm, the system divides polygons along the thin parts of its branches.

Future work will be directed towards the development of methods for:
1) the creation of general shape of roofs by a straight skeleton computation based on general shape of building polygons.
2) 3-D reconstruction algorithm to generate any objects in 3-D urban model by using Computer Vision that defines the geometry of the correspondences between multiple stereo views and leads to 3-D reconstruction.

References


