Automatically Generating Roof Models from Building Footprints

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ABSTRACT

Modelling Large Urban Environments using traditional modelling techniques would prove too time consuming a process. Consequently a method is required for generating large urban environments quickly without requiring a labour intensive process or expensive data. Some approaches to resolve this problem have been undertaken through the use of procedural modelling or statistics. However the test subject is usually a dense urban environment where the primary buildings are of the skyscraper style. This paper presents the initial design and implementation towards a method for modelling a large environment based on building footprint information. It shows the use of the straight skeleton method with modifications to allow several different roof styles to be generated.

Keywords

Roof Modelling, Straight Skeleton, Virtual Environments, Building Footprint, Rectilinear Polygon

1. INTRODUCTION

The ability to model Large Urban Environments in a computer has many important applications in industrial, recreational and educational fields. A variety of projects have been undertaken around the world to develop applications that model dense urban environments. These range from those that attempt to model a particular town or city [Urba] to those that create purely artificial environments [Ing96a].

2. PREVIOUS WORK

One approach to generate a large environment is to model some of the landmark buildings and surround them with randomly positioned vernacular buildings. To improve on this Flack et al, [Flack01], use the road network obtained by digitising the road layout from the raster map. This permits the buildings to be positioned more accurately into the scene. Recently Yap et al, [Yap02a], have documented a method for modelling Manhattan. Their approach begins by partitioning a city block map into building footprints. These building are subsequently extruded and textured based on data recorded from the environment. This approach has the advantage of representing the real world more accurately, but requires time for data capture as well as roof modelling. The roof modelling is a manual procedure.

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3. MOTIVATIONS

In summary the aim of this work is to produce a method which will enable the generation of a model which represents a particular location. To achieve this several algorithms are required to automatically construct a roof model of various styles for any given building footprint.

4. OUTLINE

This paper illustrates a method for generating a three dimensional urban environment based on Ordnance Survey LandLine.Plus building footprint data, [Orda]. The method has the following stages.

Input: LandLine.Plus data, Building Features

Stage 1: Building Footprint Generation

Stage 2: Roof Modelling

Stage 3: Building Height Determination

Stage 4: Roof and Wall Texture Generation

Stages 1 and 2 will now be explained.

5. BUILDING FOOTPRINT GENERATION

Ordnance Survey LandLine.Plus data is available for coverage of the United Kingdom. The data contains information on many features such as building footprints, road networks and the location of trees. Unfortunately the data is held with no topological structure. Consequently the building footprints have to be constructed by connecting the line segments in the data file. The following summarises the algorithm that has been developed for stage 1. Figure 1 illustrates the steps involved in building footprint generation.

Procedure: Building Footprint Generation.

Input: LandLine.Plus data in NTF format

Step 1: Read in the data and collect all building footprint line segments and roof indicator points.

Step 2: Use the Merge-Find Set data structure to group connected line segments

Step 3: For each group of connected line segments determine the exterior boundary

Step 4: Perform validation to introduce further vertices at junction points.

Step 5: Partition the connected set of line segments into building footprints, using roof indicators. From the roof indicator construct a horizontal ray. Perform a boundary walk from the first line this ray intersects. Always take the next connected line segment which makes the least interior angle.

Step 6: Process the connected set of line segments to obtain a list of vertices and a list of integers indexing the vertex list.

Output: A linked list of building footprints where each footprint is a linked list of integers. The integers index the vertex list to return the vertices on the building footprints boundary.

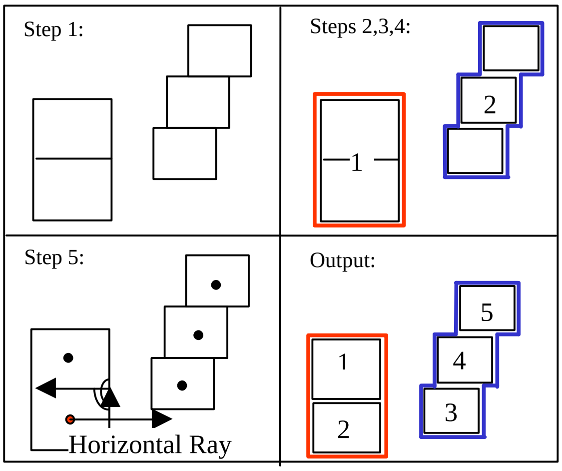

Figure 1: Building Footprint Generation Algorithm

6. ROOF MODELLING FOR SIMPLE POLYGONS

Once the set of building footprints has been obtained, each footprint then requires to be capped with a roof. One method for modelling a hip roof is to use the straight skeleton as documented in [Fel98a]. Below is a summary of how this can be achieved.

Procedure: Hip Roof Modelling

Input: Polygonal Footprint

Step 1: Construct the Straight Skeleton

Step 2: Determine the distance, d, each vertex is from its supporting edge.

Step 3: Perform a boundary walk, using the least interior angle, to determine the roof planes.

Step 4: Raise the vertices according to their distance from the supporting edge.

Figure 2 illustrates the hip roof algorithm.

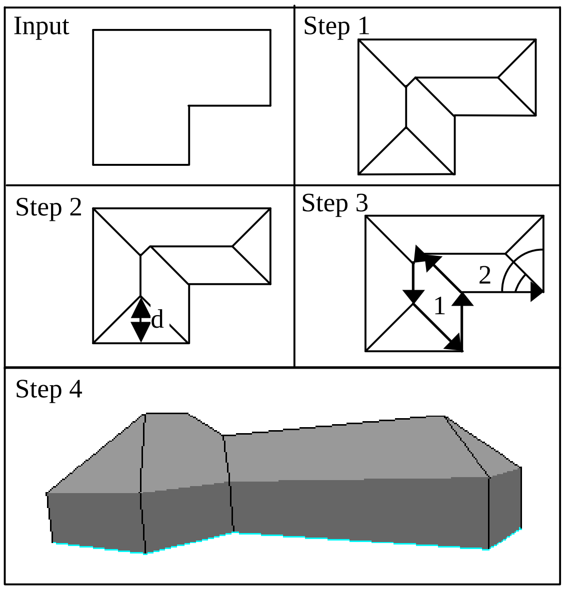

Figure 2: Hip Roof Modelling, [Fel98a]

In a large urban environment more roof styles can be observed other than the hip roof. To generate a model which resembles the real world location more roof types should be created for any given simple polygonal footprint. The next two sections illustrate some modifications to the straight skeleton to permit different roof styles to be constructed.

6.1 The Gable Roof Style

The gable roof style is obtained by altering step 1 of the hip roof method. This is done to enable the roof planes at either end of the building to have an infinite gradient. Figure 3 presents the results and modifications required.

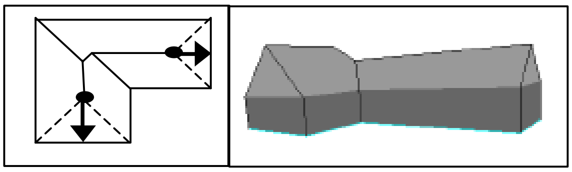

Figure 3: Left: Gable Roof Adjustment, Right: Gable Roof Style.

Step 1: Identify a vertex that was created by the intersection of two bisectors. These bisectors emanate from the corners of the original polygon.

Step 2: Move the vertex from its original intersection position to the midpoint of the line which is incident to both the bisectors that created the intersection point.

6.2 Additional Roof Styles

The following summarises three modifications made to the straight skeleton approach to vary the roof style created.

Mansard

1) Determine the distance at which the first split or edge event occurs during the computation of the straight skeleton.
2) Shrink the polygon to 85% of this distance.
3) The roof planes are formed from the original polygon edges and those edges determined in step 2.

Gambrel
Extend the mansard roof style by repeating steps 3 and 4.
Thus enabling the roof to exhibit different gradients within the roof planes.

Dutch Hip
This is created by first constructing a mansard roof style followed by the gable roof style.

7. ROOF MODELLING FOR RECTILINEAR POLYGONS

Using the straight skeleton as the basis for roof modelling has its advantages in terms of speed of computation and the ability to be modified to generate different roof styles for any simple polygon. However many vernacular buildings start their life as simple footprints with few vertices and become more complicated through the addition of extensions. Each extension having it's own roof model, which is subsequently merged with the original building. Consequently a method is required for partitioning a building footprint into pieces, assigning roof models to each of the pieces and merging the roof pieces to achieve the final roof model. Below is an algorithm for achieving this with rectilinear polygons.

Procedure: Roof Modelling for Rectilinear Polygons.

Step 1: Partition the polygon into a set of rectangles, R, by shooting horizontal and vertical rays from all reflex vertices

Step 2: Construct the straight skeleton and identify the horizontal and vertical lines.

Step 3: Grow an axis aligned rectangle, AAR, from each of the lines determined in step 2.

Step 4: For each AAR collect the rectangles from R which are interior to AAR. Perform set difference on the collection of rectangles found.

Step 5: Union the rectangles to obtain an exterior boundary.

Step 6: Assign a roof model to each exterior boundary. Merge the Roof Models. See merge cases in figure 6.

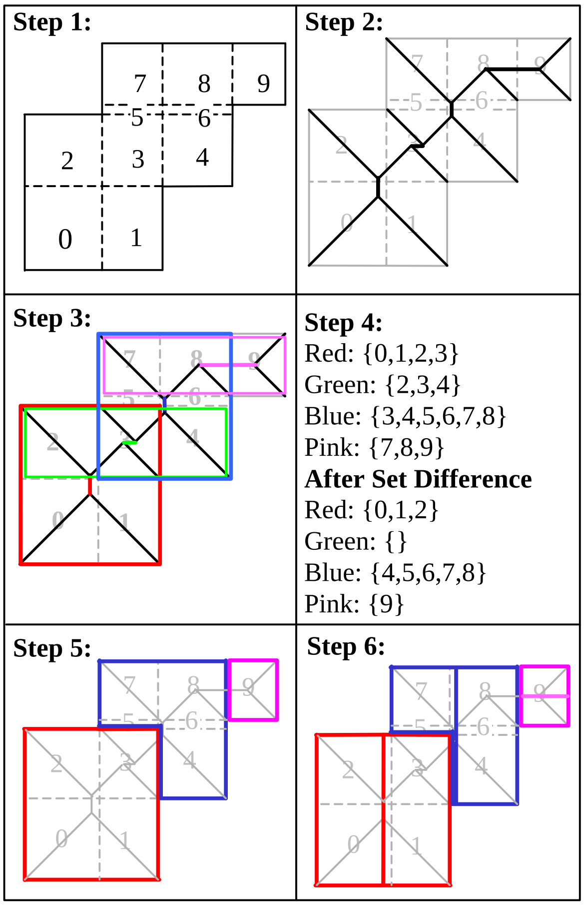

Figure 4: Rectilinear Polygon Algorithm

Figure 4 illustrates the roof modelling algorithm for rectilinear polygons. Figure 5 shows the three dimensional view of the roof generated. Figure 6 presents the two cases used to merge the roof models.

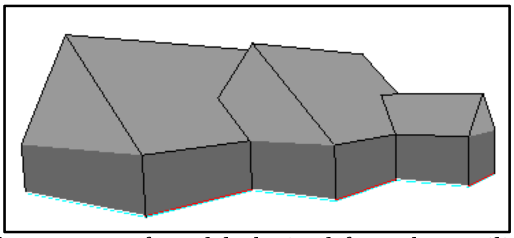

Figure 5: Roof Model obtained from the rectilinear roofing algorithm

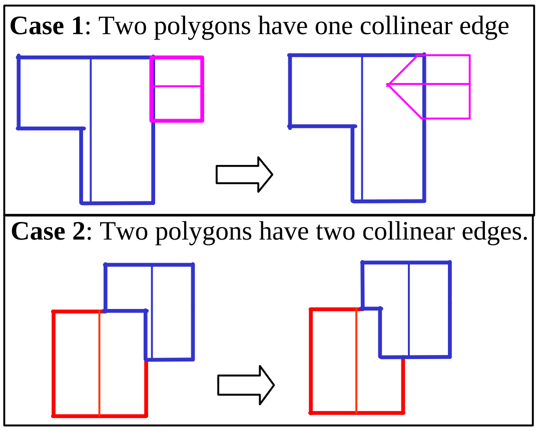

Figure 6: Merge cases used in the rectilinear roofing algorithm.

7. Results

Table 1 shows the times taken for aggregating the line segments into building footprints. Table 2 indicates the times required for performing the roof modelling. The first row of these tables refer to the $500m^2$ urban environment and the second row refers to the $1000m^2$ rural environment. The computer used to time the programs was a Pentium III 1GHz. In table 1 the times are dependent on the number of line segments but are significantly affected by the number of buildings which share the same line segments. This can be seen by observing the increase between the rural and urban environments.

Area, m^2	Number of Lines	Number of Buildings	Footprint Generation, s
500*500	11800	636	11.31
1000*1000	3440	230	0.92

Table 1: Building Footprint Generation Times.

Area, m^2	Roof Modelling Time, s			
	Hip	Mansard	Dutch Hip	Flat
500*500	22.42	5.5	31.03	1.83
1000*1000	6.23	0.92	6.59	0.36

Table 2: Roof Modelling Times.

8. CONCLUSION

This paper has described a new method for generating buildings from Ordnance Survey LandLine.Plus building features. The approach uses the Merge Find Set data structure to connect building features into building footprints. These footprints enable the buildings to be positioned into the correct locations. Thus providing more accuracy in realising the actual physical location to be modelled. This is one advantage of this approach over other methods using statistics or a road network as a basis for the model. Furthermore this paper introduces new techniques for generating various roof styles for any simple polygon such as the gable or mansard roof styles. In addition to this a method for constructing roofs for rectilinear polygons is described. This approach permits building footprints to be partitioned into several roof models rather than a complete roof model for the entire polygon.

Having achieved an urban environment with variation in roof type the next steps will involve generating the wall and roof texture. This will need to be achieved in such a way as to use minimal storage, be fast to render and variable in the materials that it imitates.

9. ACKNOWLEDGMENTS

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11. REFERENCES

[Yap02a] C. K. Yap, H. Bierman, A. Hertzman, C. Li, J. Meyer, H. K. Pao, T. Paxia, A Different Manhattan Project: Automatic Statistical Model Generation, Proc. 14th Ann. Symp., Electronic Imaging 2002, San Jose, California, Jan 2002

[Rap00a] Rapid World Modelling Project, http://www.sys.uea.ac.uk\research/rwm/rwm1.htm

[Fel98a] P. Felkel, S. Obdrmalek, Straight Skeleton Implementation, 14th Spring Conference on Computer Graphics, pp 210-218, Budmerice, Slovakia, April 1998.

[Orda] Ordnance Survey Web Site, http://www.ordsvy.gov.uk/

[Ing96a] R. Ingram, S. Benford, J. Bowers, Building Virtual Cities: applying urban planning principles to the design of virtual environments, Proceedings of the ACM Symposium on Virtual Reality Software and Technology (VRST96), pp 83-91, 1996.

[Urba] Urban Simulation Team, http://www.ust.ucla.edu/ustweb/ust.html

[Flack01] P. A. Flack, J. Willmott, S. P. Browne, A. M. Day, D. B. Arnold: Scene Assembly For Large Scale Reconstructions. Proceedings of VAST 2001, Athens.