Automatic Generalization of Digital Building Models

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ABSTRACT: For interactive 3D visualization of a cyber city, the efficiency of browsing is highly depended on the number of triangles and textures to be rendered. Many algorithms regarding to terrain simplification has been discussed in the field of computer vision. In this study, we will focus on the generalization of 3D building models. In the paper, an automatic approach to generate three levels-of-detail building models is proposed. The most detailed one is the polyhedral building model that is generated using the SPLIT-MERGE-SHAPE algorithm. Buildings with gable roof, flat roof, with regular or irregular ground plan could be described. The second level is called the prismatic building model that has a flat roof only but remaining its elaborate ground plan. In which, all connected building primitives are merged into one building with the most appropriate height. The third level of building model is called the quadrilateral building model that is generalized from the prismatic building model using the dynamic-piping technique. All levels of generalization could be performed in an automatic way. Experimental results demonstrate that the proposed method is capable of generating three discrete LODs of 3D building models automatically and reduce the total of triangles effectively.

1. Introduction

The process of building model reconstruction is a generalization procedure from real 3D world to a digital earth in the computer. Important spatial features such as road, building, bridge, river, lake, tree, etc. are digitized as two or three dimensional objects to create an electronic map. Above them the 3D building models is the most significant one in a cyber city. From the application point of view, the more detail of a building model will provide more geometrical information for spatial analysis. However, since the computer has a limit capacity of resources in computation, storage and memory, the geometry of building model has to be generalized further to reduce its complexity and then the efficiency in demonstration or computation will be increased. That means, different Levels-Of-Detail (LODs) have to be generated for real-time visualization applications under the compromise between detail structures and browsing efficiency.

In computer graphics applications, the efficiency of browsing is highly depended on the number of triangles and textures to be rendered. Many algorithms regarding to terrain simplification have been discussed in the field of computer vision. For example, Hoppe [1] and Garland & Heckber t[2] introduced an edge collapse operation to simply surface geometry and result in continuous LODs that can be applied to progressive meshing applications. For 3D building models generalization, Sester [3] proposed a least squares adjustment method to simply building ground plans. Kada[4] adopt a similar concept but applied to 3D polyhedral building models. Based on scale-spaces theory, Mayer [5] suggested using a sequence of morphological operations to generalize 3D building models. However, the proposed method is suitable for CAD type and orthogonal building models only.

In this study, we will focus on the generalization of 3D building models in polyhedron. Three levels-of-detail of 3D building models will be generated automatically based on the SPLIT-MERGE-SHAPE algorithm [6]. The most detailed building model is the “polyhedral building model” using 3D building structure lines that are measured from aerial stereo-photos. Buildings with gable roof, flat roof, regular or irregular ground plan could be described. The second level is called the “prismatic building model” that has a flat roof only but remaining its detailed ground plan. In which, all connected buildings are merged into one building with the most appropriate height. Assuming most of buildings are in rectangular or orthogonal structure, the third level of building model is called the "quadrilateral building model" that is generalized from the ground plan of the prismatic building model using the dynamic-piping technique. Basically, the second LOD is to generalize the third dimensional building structure while for the generation of the third LOD is performed on the horizontal plane only. The whole procedure could be accomplished in an automatic way. In the following three sections, the generation of three LODs will be discussed. Some case studies will be demonstrated in the fifth section. Finally, some concluding remarks and outlooks will be addressed.

2. Methodology

In the following three sections, the method for the generation of three LODs building models will be described.

2.1. LOD-1

The first LOD building model is called the polyhedral building model which has the most elaborate building structures. We adopt the SMS method for polyhedral building modeling utilizeing 3D building structure lines that are manually measured from aerial stereo-photos [6]. Before reconstruction, due to manually measurement errors or building occlusions problem, some situations may happen, such as (1) two collinear lines maybe biased, (2) a rectangular building maybe skewed, and (3) two connected lines maybe intersected with overshooting or undershooting. To solve those problems four preprocessing steps are designed to regularize the measured line-segments preventing erroneous results.

We assume that a roof unit has a coplanar surface with a polygonal outline on the ground. The key point to realize the whole method is to create an initial building model. The operator creates the initial building model by creating an area of interest (AOI), which covers all interested 3D line segments for process. The height of the AOI could be assigned as any reasonable value. After preprocessing, three steps for building reconstruction, called SPLIT, MERGE, and SHAPE, will be applied. An example of the polyhedral building modeling using the SMS method is illustrated in figure 1.

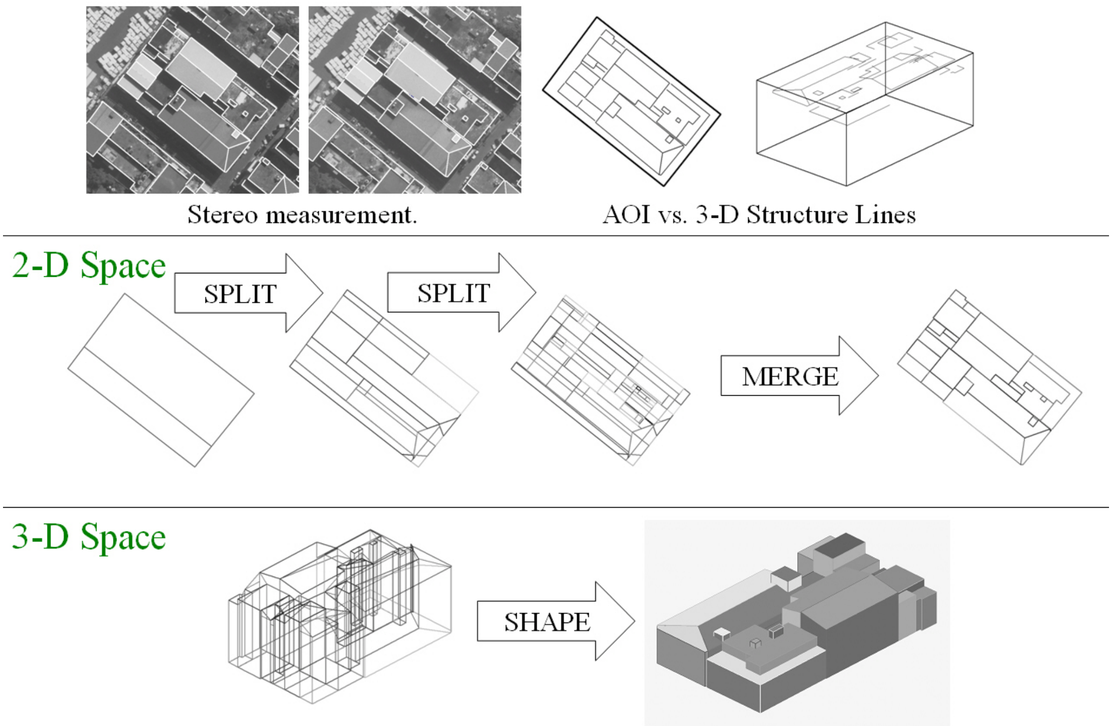


Figure 1. Example of polyhedral building modeling using the SMS method.

The SPLIT process is able to cope with building occlusion problems. Originating from the idea of "dripping-eaves" this process is worked on the 2-D horizontal plane. One line-segment is chosen as reference. Any roof contains this line-segment will be split into two roofs. For successive line-segments, a combination of the possible roofs is constructed. However, some of them are not exist. They will be checked and dissolved in the next merging step. The sequence of splitting is free from constraints. We assume the walls of buildings are all vertical, and the hidden roof-edges can thus be inferred by the higher and visible roof-edges. This procedure is similar to the manual inference of hidden corners.

The MERGE process is the second step for rebuilding the topology of consecutive line-segments. The process is also worked on the 2-D horizontal plane. At first, all created roofs related to the initial building model should be removed, because the initial building model is only a virtual shell that encloses all the 3-D line-segments. Every two connected roof-primitives are analyzed successively. If their shared boundary between them does not correspond to any 3-D line-segments, then they will be merged into one. Finally, the topology between all line-segments was rebuilt but its actual shape or height has not been decided yet.

We assume that a roof has a planar rooftop with polygonal outline on the ground. The SHAPE process is working in 3-D object space. At beginning, a possible height for each roof-edge is assigned from its corresponding 3-D line-segment. When two roof-primitives share a common boundary or shared roof-edge, the height of the shared roof-edge will not be assigned directly, because there may be a hidden roof-edge with a lower height. Therefore, every roof-edge is automatically labeled as a shared edge or an independent edge at first. The height information for an independent edge can then be assigned and fixed from its corresponding 3-D line-segment. The second step is to define the shape of a rooftop according to the height of the independent edges. If only one independent edge is found for a roof-primitive, it is necessary to check whether the surrounding rooftop is fixed or not. If it is fixed and higher then such a rooftop can be inferred from the independent edge. If more than two independent edges exist and are sufficient to fit into a planar face, then least-squares coplanar fitting can be applied. Otherwise, the system will provide the most possible solution by consecutive-coplanar analysis. Two consecutive line-segments are always coplanar, because their line terminals are contiguous in 3-D object space. However, two non-consecutive but independent roof-edges may be coplanar, so consecutive-coplanar analysis is used to find a possible planar rooftop using consecutive line-segments or any two non-consecutive but coplanar ones.

2.2. LOD-2

The second LOD building model is called the prismatic building model that has flat roof-top only but remains its detailed ground plan. This level is to generalize the building's third dimensional structure only. At this stage, a group of connected roofs with different height or shape will be processed concurrently. The generalization algorithm is simply to merge those connected roofs into one building model given an appropriate height. So, two steps are performed. The first one is actually the same as the MERGE step in the SMS method but doesn't matter about the 3D structure lines. The second step is to assign its height using the weighting average of each roof via its area. The result will be close to the roof height with the largest area one. An example is given in figure 2 to demonstrate the difference between those two LODs. In which, Figure 2(A) and 2(C) are for LOD-1, while Figure 2(B) and 2(D) are for LOD-2.

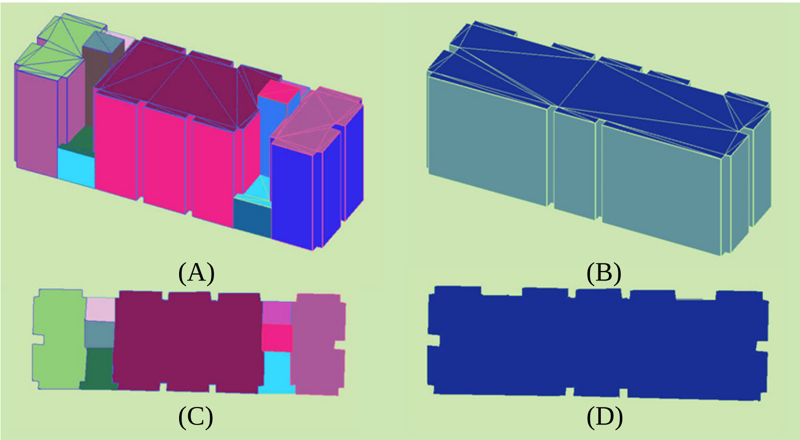


Figure 2. Example of building model generalization from LOD-1 to LOD-2.

Figure 2(A) and 2(B) are in 3D perspective view, in which the TINs of each rooftop are drawn for reference. Figure 2(C) and 2(D) are on the top view for comparison. In the figure, different color denotes different roof that have distinct height or roof-shape. For LOD-2 there is only one roof. The total number of TINs on the roof-top for this group of buildings is 85 and 42 for LOD-1 and LOD-2, respectively. The total number of walls is 103 and 44 for LOD-1 and LOD-2, respectively. Although the generalization from LOD-1 to LOD-2 is only for the third-dimensional structures, the number of TINs and walls are reduced effectively.

2.3. LOD-3

This level of generalization is performed on the 2D ground plan only. We assume most of buildings are in orthogonal or rectangular structure, so the purpose of LOD-3 generalization is to generate a quadrilateral building model. Figure 3 illustrates the flow chart of whole process. The input is a series of vertices denoting building corners position. Every two consecutive vertices represent a wall. The length of wall was calculated at first. The pipe with is changed iteratively from one meter to the longest wall length. The whole process will be stop until the pipe with has reached to the maximum or the total number of vertices is equal or less than four which represent a quadrilateral building model with the most compact geometry. Since the principal axis of the building orientation has to be kept. So the pipe's inclination angle and location is assigned using the longest un-processed wall. Figure 4(A) illustrates the original building outlines. Figure 4(B) shows the detected longest line-segment (dashed line) and its corresponding pipe (two solid lines). The pipe will always intersect with some walls due the building outline is a closed polygon. The next step is to detect the walls that were intersected by the pipe as shown in Figure 4(C), i.e. the green dashed lines. Then calculate the intersection point using the longest wall and the intersected walls. One pipe will have even number of intersection points. Those vertices located within the pipe should be removed and replaced with the new wall that was constructed by two intersection points. Figure 4(D) demonstrates the result after piping process for one side of the building. Iterative piping will be proceeded to create a quadrilateral building.

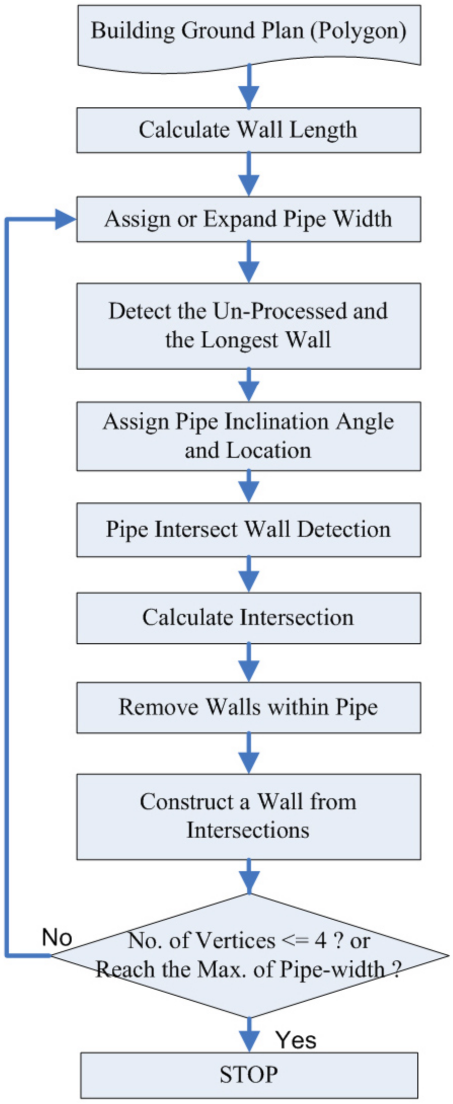


Figure 3. Flow chart of LOD-3 generation.

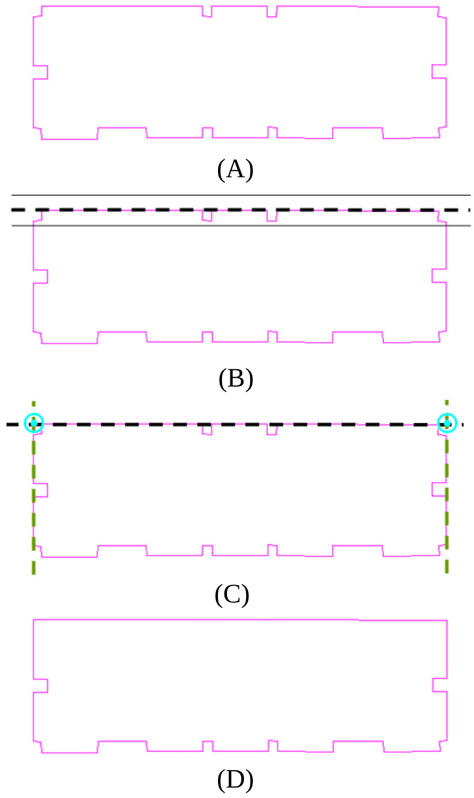
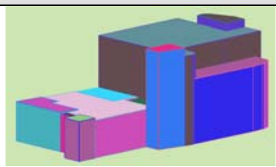
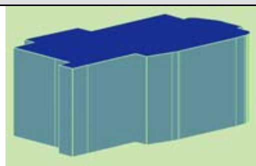
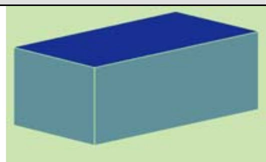
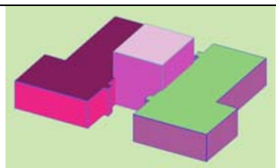
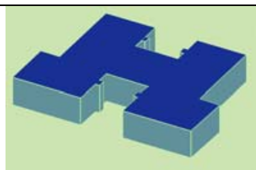
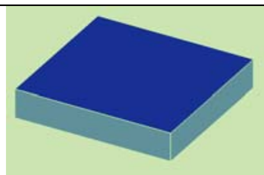
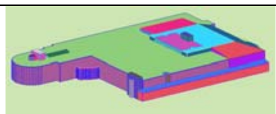
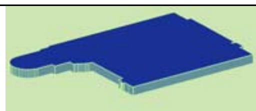
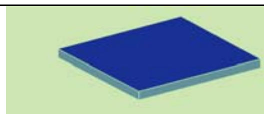
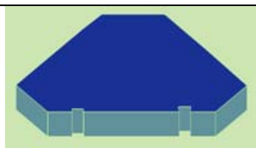
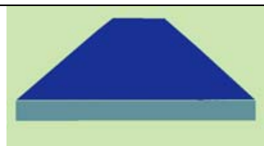
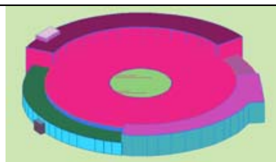
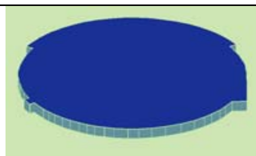
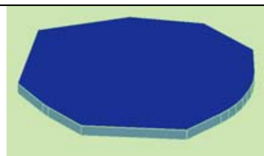
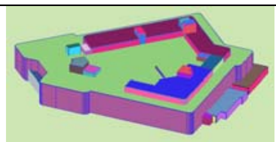
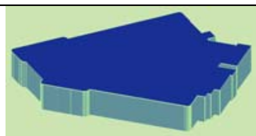
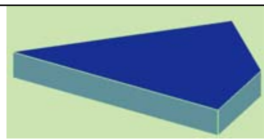


Figure 4. Example of piping process for LOD-3 generalization.

3. Case Study

In this section, six groups of buildings with different geometrical structures are tested to demonstrate the capability of the proposed algorithm. The results are depicted in table 1. Group 1 is in rectangular, group 2 is an “H” type building, and group 3 is a combination of circular and rectangular structure. Group 4 is in hexagon, group 5 is in circular, and group 6 is close to a pentagon. After applying the proposed algorithm most of them are generalized as expected. Except for group 6 the algorithm creates an intersection point far from the building and introduces a weird extrusion. Below each drawing, the total number of TINs on the rooftop and the total number of walls are illustrated. Except for LOD-3 of group 5, the number of TINs and walls are all remains at 2 and 4, respectively. Since the building in group 5 is in circular structure, the result is reasonable. It demonstrates that the number of TINs and walls have decreased effective while still preserving the primary geometrical structure. For 3D visualization applications, LOD-1 will be closer to the viewer. As the distance getting longer, an elaborate structure is no longer important. In such a circumstance, the experimental results can also retain an acceptable visual impression.

Table 1. Results of case studies.

Case Study	LOD-1	LOD-2	LOD-3
Building Group 1			
No. of Roof TINs	92	44	2
No. of Walls	114	46	4
Building Group 2			
No. of Roof TINs	34	30	2
No. of Walls	40	32	4
Building Group 3			
No. of Roof TINs	192	83	2
No. of Walls	230	83	4
Building Group 4			
No. of Roof TINs	57	15	2
No. of Walls	71	17	4
Building Group 5			
No. of Roof TINs	209	71	15
No. of Walls	225	73	17
Building Group 6			
No. of Roof TINs	259	85	2
No. of Walls	309	87	4

4. Conclusions and Outlook

An automatic generation and generalization of digital building models is present. Since a continuous generalization is not applicable to the 3D building models, we propose the creation of three discrete LODs of 3D building models. The number of triangles and walls has reduced dramatically between each LOD. Although the orthogonal structure building is the basic assumption for LOD-3 generalization, the proposed algorithm may be applied to irregular shape of buildings. The result is applicable for 3D real-time visualization applications of Cyber City as the viewer's distance is considered but the popping effect will remain. In the future work, the intersection point has to be constrained to avoid un-necessary extrusion. The enhancement of the approach could be made considering the concept of visual resolution to eliminate small structures for near visually continuous generalization. Additionally, combining aggregation in generalization for adjacent buildings may necessary to further reduce the amount of geometry data. For photo-realistic visualization applications, automatic generation of multi-resolution façade texture from its corresponding level of building models is necessary. Then, the generalization results would be ideal for diverse applications.

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