A Dynamic Typification Method of 3D City Models using Minimum Spanning Tree

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1. Introduction

Generalization is required for effective visualization of 3D city models. As one of important operations of generalization, typification replaces a large number of objects by a smaller number of objects while trying to ensure that the typical spatial structure of the objects is preserved (Shea and McMaster 1989). There are two types of typification methods: typification with and without structural knowledge (Anders 2005) which have been much studied in 2D cartography. Typification methods with structure knowledge try to detect the geometrical structures in the object groups and generalize the groups based on these structures. For examples, Regnauld (1996, 2001) uses minimum spanning tree (MST) to detect the building structures, and Burghard and Cecconi (2007) use Delaunay triangulation. Methods without structural knowledge try to employ some common rules to generalize the groups (e.g. Müller and Wang 1992). One such method is presented in Sester and Brenner (2004) where every four nearby buildings are replaced by a new polygon connecting the centroids of the four removed buildings.

Typification of buildings in a 3D city model is in many cases slightly different than typification in a 2D map. The reason is that the view point is different in a 3D city model. Here the street view is common and hence the typification should support good visualisation along roads. This should be compared to typification in 2D maps where the orthogonal view is applied; in this case the large scale patterns of the buildings are of more importance.

2. Typification Implementation

2.1 Methodology

The methodology proposed in this study is presented in Figure 1 and described as follows. First, the 3D city models are converted into CityGML (2010). Then the buildings are typified in two steps: group the building (section 2.2) and typification of the building groups (section 2.3). The typification method is based on identifying the structure using an MST, modified from Regnauld (2001). The result of the typification is a multiple data structure that is stored in X3D scenes (cf. Mao et al. 2009). Finally, the city model, stored in a multiple representation data structure, can be visualised dynamically.

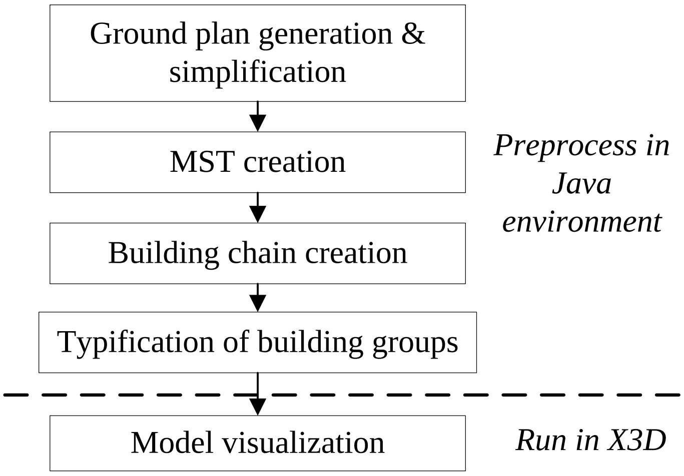


Figure 1. Work flow chat of dynamic typification.

2.2 Creating building groups

The building groups are generated by three steps.

Ground plan generation & simplification. Firstly, all surfaces in 3D building models are projected into the horizontal plane (cf. Mao et al. 2009), then are unified into the ground plan. Finally, merge the ground plan to one polygon. If a building generates separate polygons, each polygon will be treaded as a single building. For ground plan simplification a method developed by Sester and Brenner (2004) and Fan et al. (2009) is used. The outcome of this step is a CityGML model of LoD1.

MST Creation. Prim's algorithm (Prim 1957) is used to create the minimum spanning tree (MST). . The algorithm continuously increases the size of a tree, one edge at a time, starting with a tree consisting of a single vertex, until it spans all vertices. The MST graph is created from vertices set *V* which contains all building ground plan centriods and edges set *E* which is weighted by the Euclid distance of the ground plan polygons. The Prim's algorithm is processed as follows:

Initialize: $V_{new} = \{x\}$, where *x* is an arbitrary node (starting point) from *V*, $E_{new} = \{\}$
Repeat follow two steps until $V_{new} = V$:

(1) Choose an edge (*u*, *v*) with minimal weight such that *u* is in V_{new} and *v* is not (if there are multiple edges with the same weight, any of them may be picked)
(2) Add *v* to V_{new}, and (*u*, *v*) to E_{new}

Output: V_{new} and E_{new} describe a minimal spanning tree

When the MST of whole area is generated, the MST is divided into sub-MSTs by the roads. It is reasonable to divide the buildings into groups according to the road in the area. First, buildings in the two sides of the road should not be typified as long as a road exists. Second, it will improve the process performance by clustering buildings, since the building number is smaller in a group than whole area, which is essential to certain algorithm such as searching and sorting.

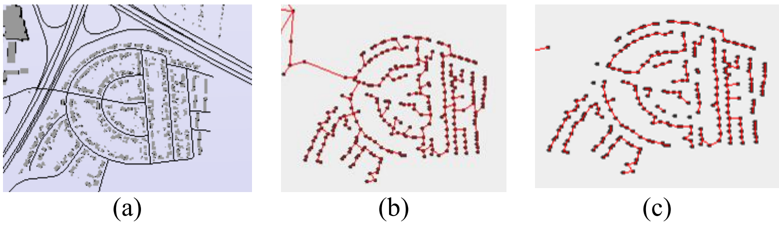


Figure 2. MST creation and clustering.

Building chain creation. Building chains are created from the sub-MSTs in the following steps. First, the branches of the sub-MST are separated to create a linear structure. As shown in Figure 4, the MST is divided in all nodes with a degree larger than 2; the nodes that has a degree of 3 and more should now be part of more than one chain shown in Figure 4(b). After this division a number of chains of buildings are created, where the chains overlap at the end buildings.

Then, go through each chain of buildings. Cut the chains into separate chains if the angle is larger than about 30 degrees or the height difference between connected buildings is bigger than 5 meters. Again, let the end buildings in the chain be part of more than two chains. Now the chains of building should lie on a fairly straight line and of same height/type shown in Figure 4(c).

Next, select the chain which has 3 or more nodes for typification shown in Figure 4(d). Since the end node will be unchanged in location, chain with 2 nodes will not be affected.

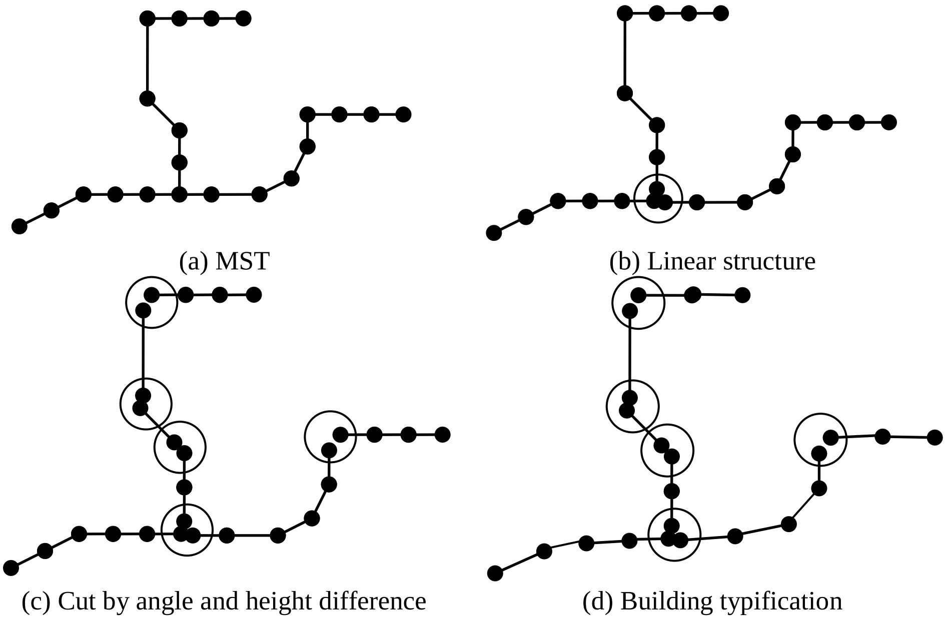
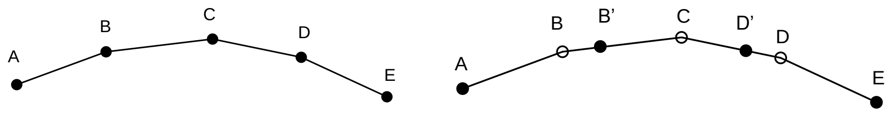


Figure 3. Building chain creation and typification.

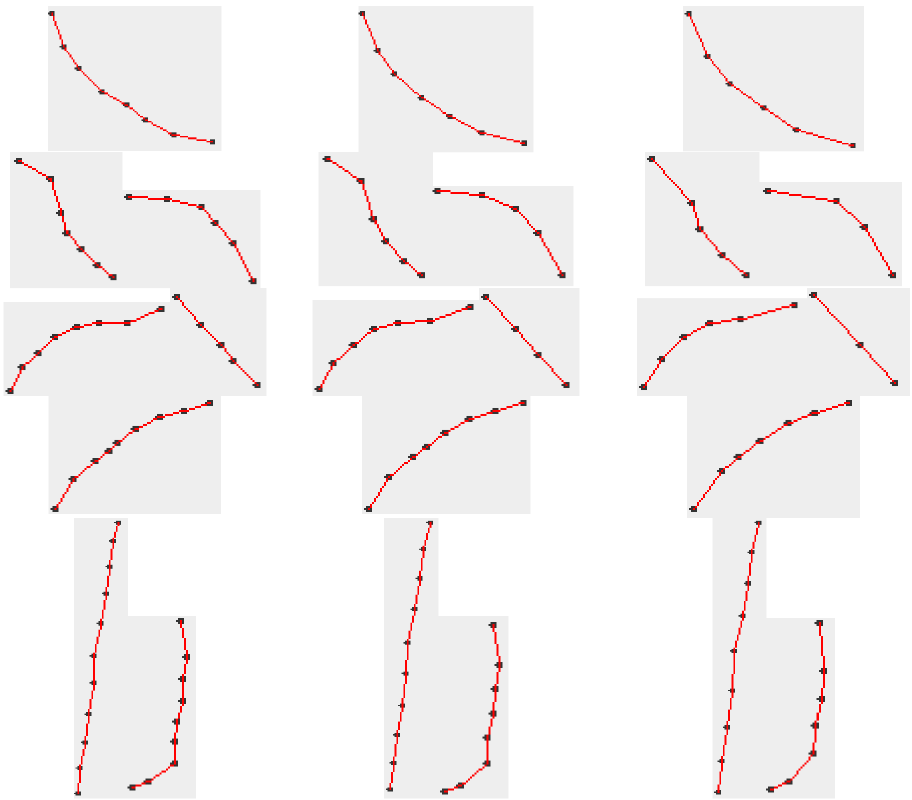
2.3 Typification of the building groups

When the building groups are created the next step is typification of the buildings. Each group is treated separately in this process. In the typification the location of end buildings in the chain is unchanged. But some interior buildings in the chain (start with the one with smallest ground area) are removed. The positions of the remaining buildings are then changed along the line that passes through the building (this line could be straight, but also slightly curved which is represented by a vector line with straight line segments). At this stage the size of the buildings remained in the chain should be increased. Figure 4 gives an example of removing a node (C) from building chain and adjusting the remaining nodes (B, D) to new location (B', D'). Some typification results of building chains are shown in Figure 5.



(a) Original building chain (b) Typified building chain

Figure 4. Building movement



(a) Original chains (b) One building is removed (c) 2 buildings are removed

Figure 5. Building chain typification.

2.4 Model visualization

In most applications, the interactivities between users and the 3D city models are essential. Therefore, the 3D city models should be generalized dynamically based on the view point of the user to improve the system performance while maintain the high quality of the user experience. The structure proposed in this paper supports the user viewpoint-based visualization. As shown in Figure 6, less buildings are visualized when the user zooms out. Figure 7 gives a visualization result of 3D city models in street view, in which the building chain is more typified if it is far away from the view point (shown in the rectangle) while the building chains along the viewpoint are not typified.

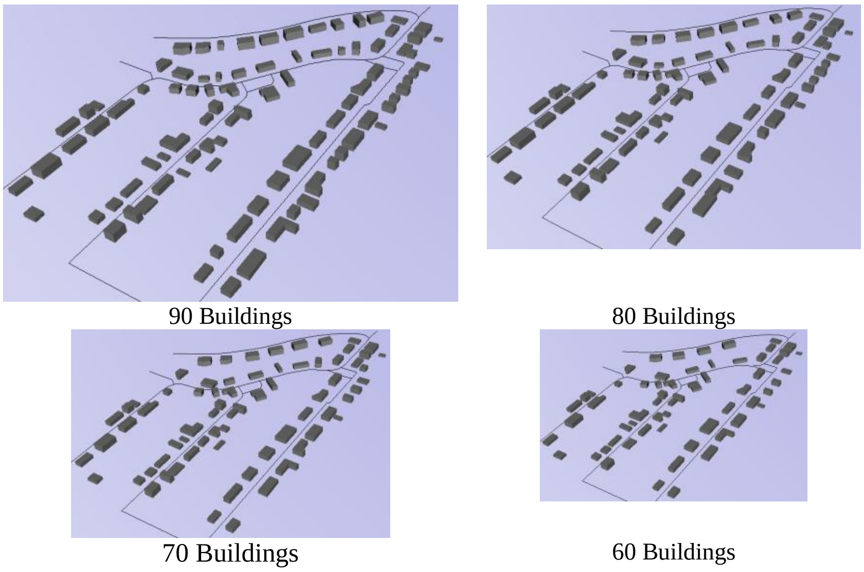


Figure 6. Dynamic Visualization Results.

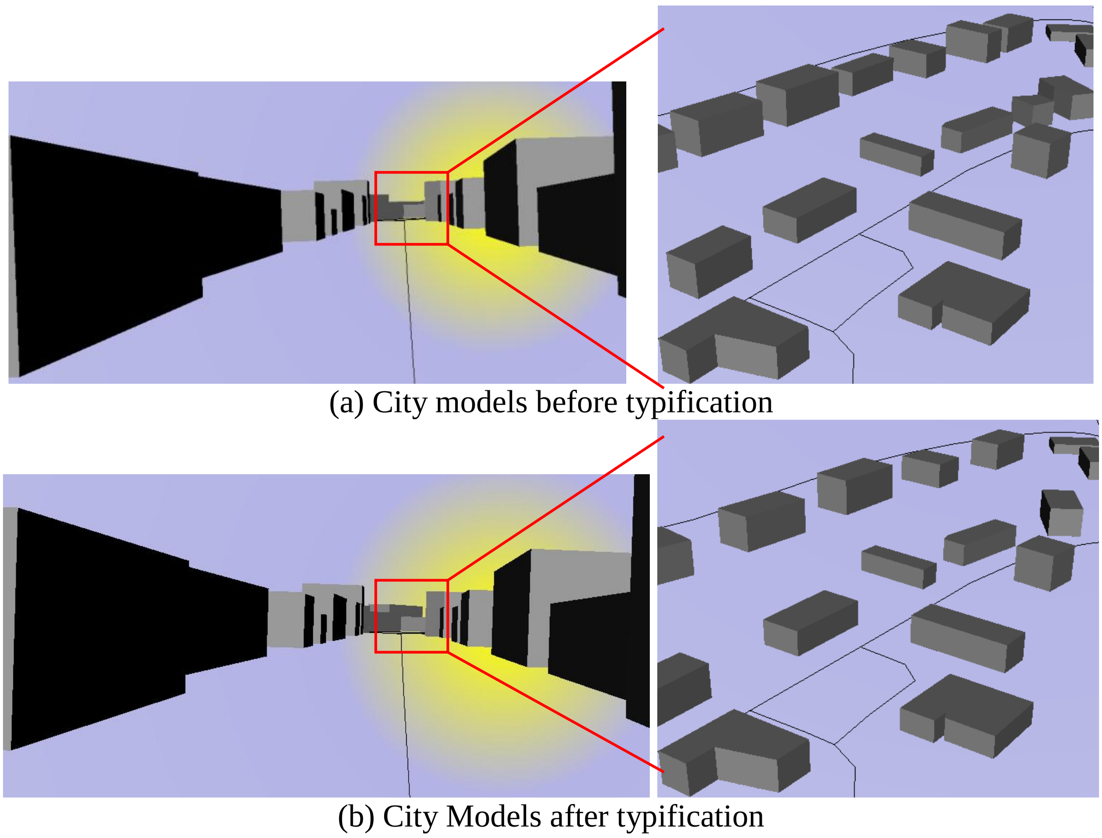


Figure 7. Street view typification results

3. Implementation and computational efficiency

The typification and visualization were implemented Java. The platform is Eclipse 3.4.1 running on a PC with Inter 2.4GHz Core2 Duo CPU, 2.39GHz 3.25GB RAM, and Microsoft Window XP SP3. The CityGML data is parsed by citygml4j (2010). The 3D city model is visualized with Xj3D (2010). The test datasets come from the CityGML.org (2010).

To make typification and create a multiple data structure for an area containing 152 buildings (shown in Figure 7) took 2141 ms. The visualisation of the multiple data structure is in real time.

4. Discussion

As argued in the introduction, a main property of a typification method of city models is that it provides nice street view. In our method we treat buildings on different side of the road as well as different sections separately. Therefore, it will not happen that all small buildings in one side of road are removed while all big buildings in other side of the road are still there. By using the building chain, it is easy to implement different typification strategies while preserving the pattern of building groups as illustrated in Figure 7. For some part of city with no obvious linear pattern, the created building chains are quite short with only 2 or 3 nodes and some other typification strategies can be performed for these areas.

5. Conclusions

In this paper, a dynamic 3D city building model typification method is proposed. Minimum spanning tree of simplified building ground plan centroids is used to generate the linear building chain structure. The linear building chain structure is then divided by large angle and height difference to get building chains that lie on a fairly straight line. The smaller size buildings in the chains are removed and the remaining buildings are adjusted in location and size. The experiment results of 3D typified city models show that the pattern is well preserved by our typification method when a number of buildings are removed for typification.

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