

# PRESERVING GROUND PLAN AND FACADE LINES FOR 3D BUILDING GENERALIZATION

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## ABSTRACT:

As 3D city models are becoming available and attractive for consumer purposes in personal navigation systems or visualization applications, the hardware used to visualize these models changes from special to consumer PCs or even to handheld and wireless devices. As a consequence, tools have been developed to alter single building models in their LOD in order to reduce the amount of data to be transmitted. While these generalization algorithms construct less detailed representations of the input models, they will also produce inconsistencies. In the case of single stand-alone building models, this may result in mismatches between the original and generalized buildings' ground plans, causing visual inconsistencies and topological inconsistencies in the interaction with other objects like streets. When adjusting simplified neighboring and adjacent models to the original models' ground plan, additional errors may occur in features like common façade lines to be lost or the development of unintentional new features like gaps. While these errors visually disturb the transition between different LODs, the topological correctness of the resulting city model may also be degraded by overlaps evolving from the treatment of single buildings throughout the generalization process. Means for preserving visual and topological correctness in the generalization process will be presented in the paper.

## 1. INTRODUCTION

For years, 3D city models were used as specialist tools in a variety of applications, spreading from city and radio network planning to disaster management. These applications make use of highly sophisticated hardware, while the required building models vary from simple block models to medium detailed representations.

Evolving from the increased availability of consumer products like virtual globes and 3D navigation systems, the hardware used for the visualization of such geo data has changed to consumer PCs and mobile devices. While modern high-end PCs have the ability to display complete city models (Kada et al., 2003), the visualization of 3D building models on small, mobile devices yields some problems. The usage of 3D models for navigation purposes for example enables the user to apply his capability of visual navigation. However, the excessive use of detailed models may also lead to an information overflow, especially on small and tiny displays used in these devices. For this reason, it is necessary to reduce the amount of information by only displaying fully detailed and textured models for important buildings like churches or the like and using simplified representations for the remaining buildings. Furthermore, simplified building models are necessary for the realization of user-friendly frame-rates by the use of different Levels-of-Detail depending on the distance of the viewer with respect to the model to visualize.

In research, a shift from location-based services to context-aware applications can be seen. In contrast to the above mentioned applications, geometrical reliability here is more important than a correct visual appearance. Like positioning

systems in the case of location-based services, context-aware applications make use of building models in multiple representation structures as a kind of sensor information. Similar to every other sensor information available to the application to determine the context the user is actually in, building models degrade the result by inconsistencies between different Levels-of-Detail. In contrast to e.g. positioning sensors, these inconsistencies may however be minimized offline. Necessary tools to overcome for this task will be presented in the following.

The structure of the paper is as follows: Firstly, a short overview to related work concerning generalization is given. Section two outlines the approach used to adjust the ground plans, which is then extended for the adjustment of the 3D model described in chapter 3. In section five we will describe approaches to avoid errors evolving from the treatment of neighboring buildings. Chapter 5 gives a short discussion of the results.

For 3D model generalization, three main approaches have been published. (Thiemann and Sester, 2004) propose a segmentation of 3D building models using their boundary planes and storing the features found in a CSG-tree. This allows for quasi-continuous LOD-structures. (Forberg, 2004) however uses three dimensional extensions of the morphological operators *opening* and *closing* to fill gaps or separate objects. The algorithm presented by (Kada, 2007) aims to reconstruct a generalized representation of the input building model by means of searching the main planes of the original model and subdivide these planes in order to build a correct boundary representation. This is extended by a specific treatment of special features like circular towers.

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Concerning the adjustment of differently detailed 3D building models to each other, (Thiemann and Sester, 2006) present an approach adjusting templates of common simple building structures to models of high detail. This is done by resampling of one of the models' faces by pseudo-randomly distributed points and minimizing the distance to the other model's faces using least-squares adjustment.

## 2. GROUND PLAN ADJUSTMENT

While building models are significantly simplified by the algorithm presented by (Kada, 2007), the ground plans of the resulting models differ from those of the original models due to weighted averaging during the generalization process, besides the inevitable inconsistencies evolving from the simplification. These differences have to be minimized in order to preserve consistency between different LODs. In order to achieve this goal, the original ground plan has to be analyzed and compared to the generalized one in an appropriate way.

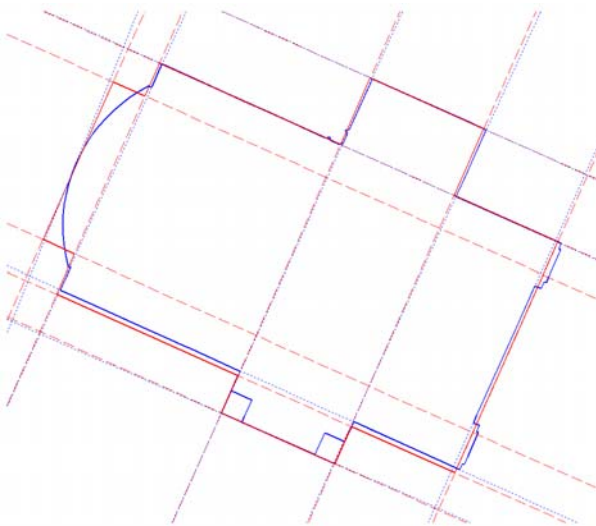


Figure 1: Original model (blue), main lines (blue dotted); generalized model (red), main lines (red dashed)

### 2.1 Preparations

Caused by the algorithm the generalized models may still contain superfluously cut faces where adjacent and coplanar faces were not merged together because of small differences in direction. To avoid a potential disturbance of the result by these inner edges, at first the surrounding polygon's vertices have to be found. While the inner edges have two nearly coplanar neighboring faces, the border edges' adjacent faces differ clearly in their directions. The resulting list of faces states the topology of the final model, the remaining superfluous vertices will be omitted after the adjustment.

### 2.2 Model Analysis

The analysis aims at finding the main lines of the original models' ground plans. This is done by selecting collinear edges by comparison of the angle between them to a threshold and restrict to a small distance. For each edge its length is computed and stored as weight. Starting with the longest edge in every set

of collinear edges, the main line is constructed as the line with maximum weight using a strict distance threshold.

To ensure a meaningful comparison to the main lines of the original model, collinear edges of the generalized model are merged to lines. As all collinear edges were derived from the same plane subtended with the ground plane, the result is less depending on threshold values than in the case of the original models.

### 2.3 Comparison

In a last step, the computed main lines of both models are compared so as to find corresponding ones. The set of lines is first reduced by an angle threshold, for every remaining generalized line  $i$  the ratio

$$r_{ij} = \frac{p(O_j)}{d(O_j - G_i)} \quad (1)$$

where  $p(O_j)$  - weight of the original line  $j$  and  $d(O_j - G_i)$  - distance between original line  $j$  and generalized line  $i$

is computed and the corresponding original line  $j$  with  $\max(r_{ij})$  is chosen. Obviously, it is not reasonable to connect lines to others that are nearby but derived only from small edges in other parts of the model. This is avoided by choosing a maximum and minimum point for each line and checking if the interval plus a small buffer contains either the maximum or minimum point of the other model's line.

In some parts of the models, no corresponding lines can be found due to major changes during the generalization process (see

Figure 2) or special procedures like the simplified circular tower elements depicted in

Figure 2. In these cases, the existing generalized line is considered to be the best solution and is kept fix throughout the adjustment process.

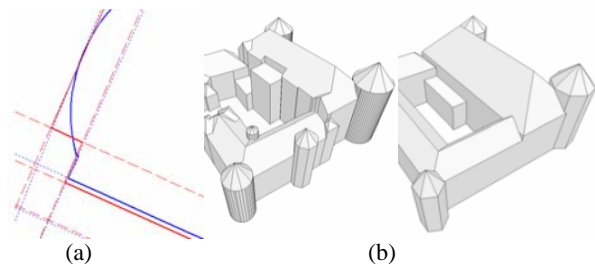


Figure 2: No corresponding lines due to (a) major changes during the generalization process and (b) special treatment of circular tower elements (image taken from (Kada, 2007))

## 3. ADJUSTMENT OF THE 3D MODEL

While the analysis of the ground plan delivers the desired shifting targets for the wall faces adjacent to the ground plan, the remaining faces are not changed until now. This obviously makes sense in the case of flat roof faces, however leaving

sloped roof faces unchanged will result in different eaves heights or even topological errors in extreme cases. Furthermore, the height of a building's highest point is an important feature for many applications and should not be changed, according to (Sargent et al., 2007). Consequently, reasonable means have to be found to express the faces not adjacent to the ground plan subject to those adjacent to ground plan lines.

### 3.1 Analysis

Due to the models' reduced LOD, the analysis is strongly simplified. After merging coplanar faces to planes, these are categorized according to the faces they contain into

- a) ground planes
- b) fixed wall planes: wall faces contained in a plane directly connected to the ground plan
- c) free wall planes: wall faces not connected to the ground plan
- d) flat roof planes
- e) roof planes

whereat every category needs different elements to describe the respective elements uniquely.

As changes only occur in the ground plan, the ground plane and parallel flat roof planes remain the same during the adjustment process. In both cases, no elements contribute to the parameter estimation. The new locations for the fixed wall faces are given by the previous ground plan adjustment. Free wall faces are defined by two parallel and connected fixed wall faces in front of and behind it. These and the ratio

$$\text{ratio} = \frac{d(\text{AP}, \text{BP})}{d(\text{FP}, \text{BP})} \quad (2)$$

where  $d(\text{AP}, \text{BP})$  - distance of actual plane to back plane  
 $d(\text{FP}, \text{BP})$  - distance of back plane to front plane

are saved to allow for a displacement of these faces keeping the proportions of the input building. Obviously, special care must be taken when choosing the fixed wall faces. These may only be connected to the actual face using flat roof faces or parallel free wall faces/roof faces.

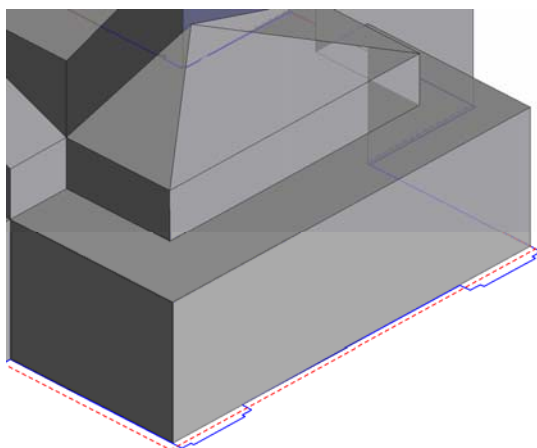


Figure 3: Building adjusted to the original ground plan (blue line); generalized ground plan before adjustment (red dashed)

In order to keep ridge and eaves heights during the adjustment process, the normal directions of roof planes, however, have to be changed. Therefore the elements needed for a non-ambiguous description are on the one hand the location of their ridge line with respect to two fixed wall faces. This is in line with the procedure used for free wall faces (see equation 2). A slight extension here is to project the normal vector of the roof plane into the xy-plane and using it to determine front and back face. On the other hand, the fixed height difference  $dh = z(\text{HP}) - z(\text{LP})$  and furthermore the ratio

$$\text{ratio}_{\text{rf}} = \frac{d_{\text{xy}}(\text{HP}, \text{LP})}{d(\text{FP}, \text{BP})} \quad (3)$$

where  $d_{\text{xy}}(\text{HP}, \text{LP})$  - distance between highest and lowest point in the xy-plane

have to be computed. With these elements, it is possible to compute the new normal direction from the changed ground plan.

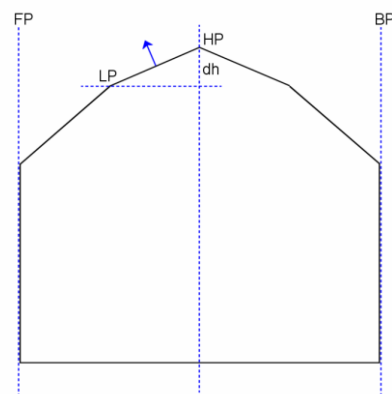


Figure 4: Elements for roof planes

Using the plane parameterization  $Ax + By + Cz + D = 0$ , differently categorized planes contribute different unknowns to the adjustment process. In order to keep characteristics like perpendicularity and parallelism, wall faces are changed only in their  $D$  parameter, meaning a parallel shift in or against normal direction. Sloped roof faces, however, change in normal direction to keep ridge and eaves heights. Therefore, their plane parameters  $A$ ,  $B$ ,  $C$  and  $D$  are unknowns, additionally  $A$ ,  $B$  and  $C$  have to be normalized throughout the adjustment.

### 3.2 Adjustment Using Least-Squares

The final result is achieved using a least-squares adjustment with constraints. In a combined approach the lines found in the ground plan adjustment together with the elements saved for the free model faces are used to compute the resulting best-fit model.

Unknown parameters are the new plane parameters as described in chapter 3.1 and the vertices of the final model which are found as intersection points of the adjusted planes. To ensure good results even with small angle differences between the

connected lines, the lines found by the ground plan adjustment are resampled using the minimum and maximum point of their generalized partner as boundaries. The final D parameters of the fixed wall faces are then computed minimizing the distance of these sampled points to the generalized plane, similar to the procedure used by (Thiemann and Sester, 2006). The remaining planes are represented in the adjustment using the pre-computed ratios and fixed elements like  $dh$ . As in the case of roof planes, the elements of the normal vector are recomputed, additionally, the constraints

$$A_i^2 + B_i^2 + C_i^2 = 1 \quad (4)$$

have to be included for every roof plane  $i$  in order to normalize the new normal vectors.

#### 4. FACADE LINES

The algorithm presented above is suitable for minimizing inconsistencies between different LOD representations regarding differences in the ground plans of single buildings. But additional problems occur when generalizing adjacent buildings even after or because of their adjustment to the original model's ground plan. The problems can be categorized into an evolution of gaps and overlaps and the loss of a previously common façade line. Overlaps are errors disturbing the topological correctness of the models. Gaps and a common façade line state features important for the human recognition of building models. Therefore they may not be removed nor generated during generalization and adjustment.

##### 4.1 Gaps

Gaps between previously linked buildings can emerge in cases as shown in

Figure 5. In these cases every building model will be adjusted to the ground plan of its corresponding original. However by not explicitly regarding the linkage between them, this feature will be lost. This problem is solved by extending the analysis of the ground plan in such way that collinear edges of all connected models contribute to one main line. Consequently, the main line containing the connecting edge, gets additional weight and will therefore be chosen as shifting target for the generalized wall faces.

##### 4.2 Loss of Common Façade Line

An important feature which must be retained during the generalization and adjustment process is a façade line, which is common for different buildings. In this case, the façade line itself is not the dominating feature. However, there are features evolving from the loss of it, which can be misleading in the recognition of the modeled buildings. Analogue to the approach described in chapter 4.1 this is solved by simultaneous treatment of all adjacent buildings in the analysis of the ground plan. Consequently, the façade line will get the highest weight.

##### 4.3 Overlaps

A topological error which can be seen during the adjustment is the occurrence of overlaps between adjacent buildings. This error constitutes a conflict during adjustment which must be solved in order to represent correct models and to ensure visually clean representations. In this case, the adjustment has to be carried out in two steps. In the first step, the buildings are

adjusted to their ground plans, following the rules described above, as a second step, the occurrence of overlaps is recognized and corrected by the solutions stated in the following.

There are multiple solutions to this conflict. Firstly, a combined analysis of the adjacent ground plans may be carried out. Here, the conflicting areas are partitioned according to the areas of the ground plans before the adjustment. This partition delivers a common line as shifting target for both models' wall faces. Another approach only changes the smaller building concerning the ground plan area by shifting the conflicting edge(s) and adjusting the remaining building structure using the presented algorithm. The generalization algorithm by (Kada, 2007) preserves features like circular towers, the occurrence of these or other semantically prominent characteristics of the original model may be used to decide which building is visually more important. This semantic importance may also be taken into account when choosing the model to change.

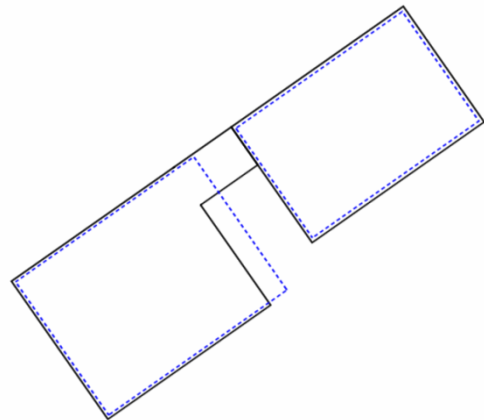


Figure 5: Gap between two adjacent buildings

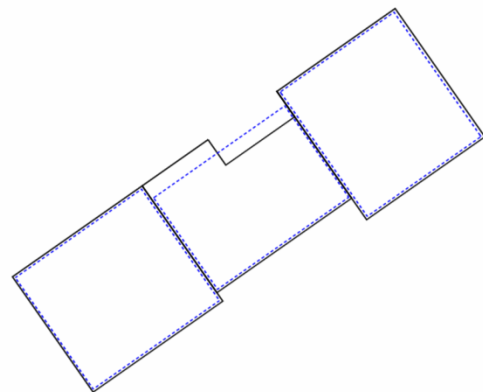


Figure 6: Loss of common façade line

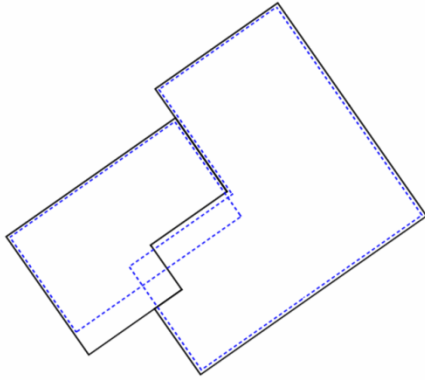


Figure 7: Overlapping buildings after generalization

## 5. DISCUSSION OF RESULTS

As all wall faces are only shifted without changing their normal direction, the presented approach does not alter the resulting models' perpendicularity and parallelism properties. For the benefit of keeping the generalized models' ridge heights, changes in the ground plan generate slightly different normal directions for the affected roof faces. Apart from minimized inconsistencies between both LODs, the approach can help to reinstall symmetry lost during the generalization process (see Figure 1 - both sides of the round extrusion feature). Until now there are no metrics for the evaluation of inconsistencies between different representations of 3D building models available.

However, for the evaluation of the improvements made by the ground plan adjustment, the approach proposed by (Filippovska et al., 2008) may be used. They present a metric for the evaluation of the consistency between a given original model and its generalized representation. This metric uses a vector of characteristics like the sum of the area of intrusion and extrusion features or the Hausdorff distance. By the comparison of the elements of this vector for original-generalized and original-adjusted model pairs, improvements in nearly all characteristics stated by this metric can be seen (cp. (Filippovska et al., 2008)). Some models, however, contain features that are important in the ground plan, but not so much in the 3D structure and are therefore omitted during the generalization process. For these models, the Hausdorff distance cannot be significantly reduced by the adjustment.

## 6. CONCLUSION

In this paper, we present tools to adjust generalized 3D building models with respect to the ground plans of their initial predecessors. This is achieved using an approach to decomposing the simplified 3D building models into elements only depending on faces adjacent to the model's ground plan. Consequently, the generalized representation may easily be adjusted to main lines deduced from the original model. This approach not only aims to minimize problems evolving from inconsistencies between both data sets, but is also important for topologically and semantically correct treatment of neighboring buildings, as shown in Chapter 4.

In the future, we aim to extend the presented algorithm for extension of the displacement operator for use with 3D building models. For example, emphasizing certain buildings in a 3D city model could be realized by enlarging the buildings to emphasize which results in the need to displace the surrounding models. To avoid impact on too much models, they may be altered in form without losing detail by shifting only certain lines of the ground plan and adjusting the remaining building faces using the presented approach. Another extension may be the more precise adjustment of the complete model to the original one in order to build hierarchical LOD structures as the differences of original and generalized representation. Furthermore, the presented approach may be usable to adjust typified models to the ground plans of the originals.

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