Simplification of 3D Building Data

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Summary

We propose an approach for the simplification, i.e., generalization, of three-dimensional (3D) building data. Buildings consist mainly of structures characterized by perpendicular or parallel facets. To simplify them, parallel facets are moved towards each other until 3D features under a certain extent are eliminated or gaps are closed. For the treatment of non-orthogonal structures, we differentiate between wall- and roof-level. For the walls, non-orthogonal structures are important for the characteristic shape of a building and therefore have to be preserved in many cases. For the roof-level, a squaring approach is proposed that works by rotating roof-facets around one of their bounding edges, i.e., either their eave- or ridge-line. Results for generalization and roof-squaring are presented and tasks for further research are summarized.

Zusammenfassung

Im Folgenden wird ein Ansatz zur Generalisierung von dreidimensionalen (3D) Gebäudedaten vorgestellt. Gebäude zeichnen sich durch viele rechtwinklige bzw. parallele Flächen aus. Für die Generalisierung werden parallele Flächen aufeinander zu bewegt bis kleine 3D Merkmale eliminiert oder Lücken geschlossen werden. Für die Behandlung von nicht-orthogonalen Strukturen wird zwischen Wand- und Dachebene unterschieden. In der Wandebene sind nicht-orthogonale Strukturen entscheidend für die Charakteristik des Gebäudes und müssen daher oft erhalten bleiben. Für die Dachebene wird ein Ansatz zur Erzwingung von orthogonalen Strukturen vorgeschlagen, der Dachflächen um eine ihrer umgebenden Kanten, d. h. den First oder den Giebel, rotiert. Abschließend werden Ergebnisse für die Generalisierung und die Dachorthogonalisierung präsentiert und mögliche Aufgaben weiterer Forschung zusammengefasst.

1 Introduction

When representing three-dimensional (3D) city models using the Level of Detail (LOD) concept, for an object several models with different levels of detail are used. Which model is chosen for the display from a specific point of view depends on the object's distance. Objects far away are displayed with less detail than closer ones (cf. Fig. 1). Thus, the number of displayed polygons is reduced and the performance of the visualization is enhanced when visualizing a larger number of objects. Additionally, the derivation of less detailed, i.e., coarser, representations is useful also for applications such as radio wave propagation for telecommunications, when coarse geometric models are sufficient, helping to speed up computations.

In order to derive a coarser representation of an object, simplification is employed. Heckbert and Garland (1997) give a summary of common approaches for surface simplification. Varshney et al. (1995) and Schmalstieg (1996) present approaches for automatic LOD generation. All of these approaches from computer graphics

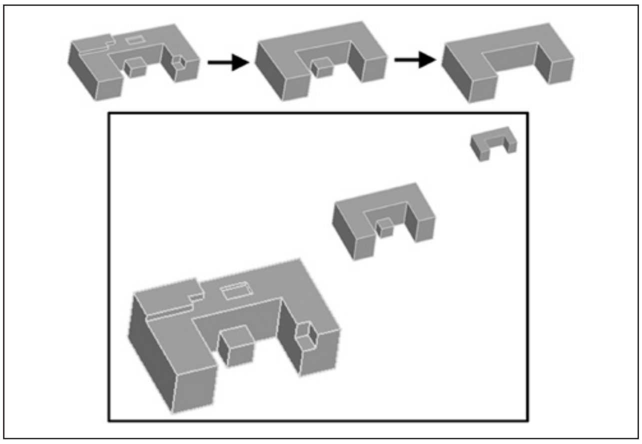

Fig. 1: Different Levels of Detail (LOD) of a building automatically generated by simplification

and computational geometry have in common that they are developed for general objects and do not consider the specific structure of buildings, which is dominated by right angles and parallel planar facets. Approaches especially developed for the simplification, i.e., generalization, of buildings stem from cartography or Geographic Information Systems (GIS), but they mostly focus on two-dimensional (2D) generalization. Many of the older approaches are summarized in Mackaness et al. (1997), Meng (1997), and Weibel and Jones (1998), as well as Mayer (2005), who additionally presents much of the basics of this paper in more detail. For the generalization of building ground plans, Sester (2000) uses the old but important approach of Staufenbiel (1973) together with least squares adjustment. One of the rare approaches for automatic 3D generalization of buildings is Kada (2002). Least-squares adjustment is combined with an elaborate set of surface classification and simplification operations. Thiemann (2002) decomposes a building into basic 3D primitives and eliminates primitives of small extent. For the decomposition, the algorithm of Ribelles et al. (2001) is used. With it, specific features of polyhedra are found and removed based on planar cuts. Kada (2005) generalizes 3D buildings by the use of approximating planes. These are determined from the highly detailed building model and are used in a further step to build a generalized model of the building.

In Mayer (1998) and Forberg and Mayer (2003) 3D generalization is realized based on scale-space theory.

Two scale-spaces, namely mathematical morphology and curvature space, are applied separately in order to simplify building models consisting of parallel or orthogonal planar facets. In the following, we propose an approach which combines the advantages of both scale-spaces in one procedure. In section 2 the approach is described in detail and results obtained by an implementation in Visual C++, using the ACIS class library (www.spatial.com), are presented. As buildings consist not only of perpendicular parts, an approach for squaring non-orthogonal structures, especially roofs, is introduced in section 3. The paper ends with conclusions and an outlook.

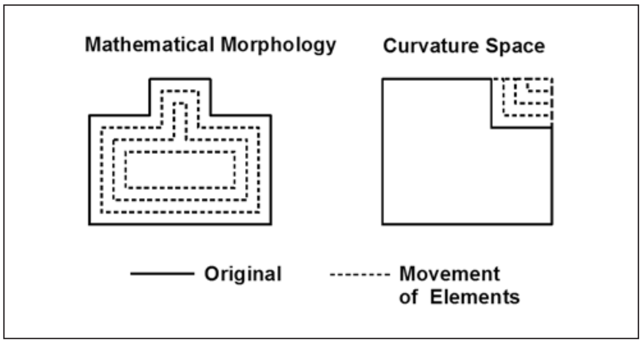

Fig. 2: For mathematical morphology all elements are moved simultaneously by the same amount, while for curvature space only specific elements are shifted.

2 Simplification of parallel structures

2.1 Scale-Spaces and Generalization

In image analysis, a scale-space is obtained by deriving representations at different scales from an image, e.g., Lindeberg (1994). For the derivation of the representations with coarser scales, different approaches exist. One of them, the reaction-diffusion-space of Kimia et al. (1985), combines a scale-space constructed based on mathematical morphology (Serra 1982) with a curvature dependent diffusion part. The latter is termed »curvature space« by Mayer (1998), who extended the reaction-diffusion-space to suit the requirements of the simplification of vector data representing buildings. The complementary reaction (mathematical morphology) and diffusion part (curvature space) are applied sequentially by incrementally shifting elements in or opposite to the direction of their normals, until an event, e.g., the elimination of a small protrusion, occurs. For mathematical morphology, all elements are shifted simultaneously by the same amount, either inwards (erosion) or outwards (dilation). For curvature space, only specific elements are shifted and the direction of the movement can differ (cf. Fig. 2). The elements to be shifted are edges for 2D ground plans and facets for 3D building data.

The two scale-spaces can handle different kinds of object structures. By means of mathematical morphology all elements that are parallel but with opposite directions of the normal can be simplified. That means U-structures in 2D or protrusions in 3D can be eliminated and gaps can be filled (merge), or building parts can be separated (split). For elements with normals with the same direction (Z-structures) or with perpendicular directions (L- or box-structures and step-structures), curvature space is needed. Fig. 3 compares different 2D and 3D structures for mathematical morphology and curvature space.

Whereas mathematical morphology is easy to realize, for curvature space a complex analysis is necessary to decide which elements have to be shifted in which direction. Forberg and Mayer (2002) present a procedure for curvature space in 3D, which is based on the analysis of the convexity and concavity of vertices and their relations within facets. The procedure is complex, as many constraints have to be considered. As it is still not guaranteed that the result is satisfactory, a new approach termed »parallel shift« has been developed, combining advantages of mathematical morphology and curvature space for it. The sequential combination of two separate scale-spaces is not necessary anymore.

2.2 Parallel Shift

For mathematical morphology all facets are shifted until parallel facets collide in one plane. For curvature space, perpendicular facets collapse in the same edge for step-structures or vertex for box-structures. Though, the latter practically works because the parallel facets collapse into planes. Understanding this has lead us to a new approach, which follows a rather simple principle: Parallel facets are determined and if their distance is under a certain threshold defining the present scale, the facets are shifted towards each other so that they merge into

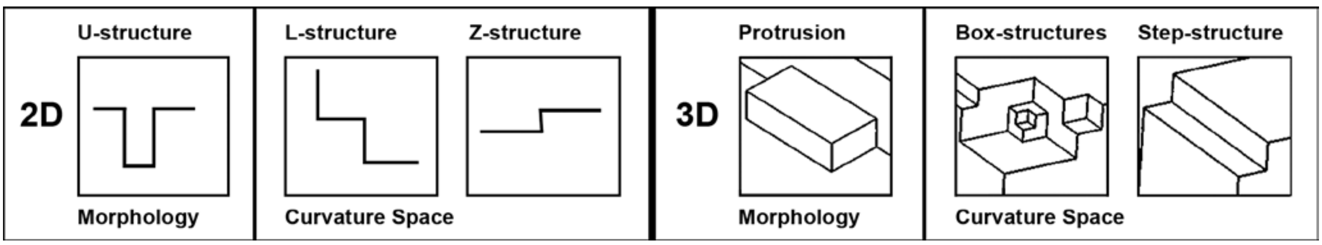

Fig. 3: U-, L-, and Z-structures in 2D versus protrusions, box-, and step-structures in 3D and their suitability for mathematical morphology versus curvature space

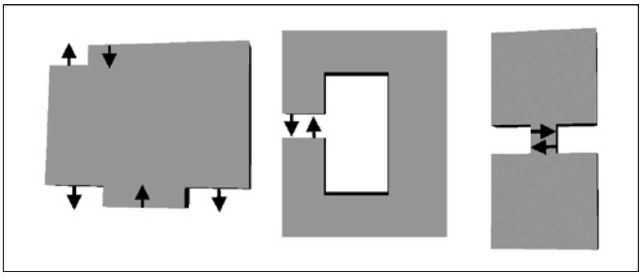

Fig. 4: Parallel facets under a certain distance are shifted towards each other until the facets merge.

one facet (cf. Fig. 4). By this means, the merge or split of building parts, as well as the elimination of protrusions, box-, and step-structures is feasible in one single procedure. By gradually increasing the threshold, a scale-space is created, where every feature in coarse scale has a reason in fine scale. This is called causality and is a basic constraint for scale-spaces (cf. Lindeberg 1994).

For parallel shift no incremental processing is necessary. The two parallel facets are only shifted if their distance is under the threshold. The shifts of both facets have to sum up to bridge the distance. A weighting that depends on the ratio of the areas of the two parallel facets can be applied. For the results shown in Fig. 5, two kinds of weighted movements were used. If both facets have approximately the same area, each facet is shifted half of the distance. Thus, structures do not simply vanish, but a shape adjustment takes place, which can even slightly emphasize certain structures (cf. Fig. 5, 3rd example from the left). This is in contrast to the approach of Thiemann (2002), where small features are simply eliminated. If the area of a facet is much smaller than the area of the other one, it is shifted for the whole distance. By this means, symmetry can be maintained in case of small box-structures. Otherwise, the result would be ambiguous, as one of three pairs of parallel facets has to be chosen randomly for the parallel shift for a symmetrical configuration (cf. Fig. 6). For the given examples, a smaller facet has got approximately the same area as its parallel facet, if its area is bigger than one third of the other. This weighting has been determined empirically and works well for most of our test buildings.

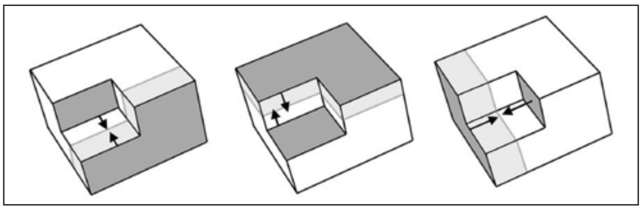

Fig. 6: Within a symmetrical box-structure, a pair of parallel facets (dark grey) is chosen randomly. If both facets are shifted by the same amount, the result (grey line – white) is not predictable and the symmetry is lost. To avoid these ambiguities, only the smaller facet is shifted, if the area of one facet is much larger than the other one.

The proposed rather simple procedure is very general and, therefore, also suitable for complex combinations of orthogonal structures. As there is no need for a complex analysis regarding the convexity or concavity of vertices and facets anymore, it is rather simple to implement and fast to compute.

3 Squaring

Building simplification using scale-spaces or parallel shift is based on the assumption of given exactly orthogonal structures. Even neglecting inaccuracies during acquisition, which could be, e. g., handled by a least squares approach such as Kada (2002), buildings do not only consist of parallel or perpendicular structures. Therefore, the treatment of non-orthogonal structures is necessary. For this, we differentiate between the wall- and the roof-level. Non-orthogonal facets belonging to the roof-level are inclined, i. e., they are neither horizontal nor vertical. For squaring, they have to be forced into the horizontal or vertical direction. The decision whether they have to be squared depends on the scale, i. e., the current LOD, and the size of the roof-structure. The walls are vertical facets. For them, strong deviations from perpendicular or parallel structures have to be preserved in order to keep the characteristic shape

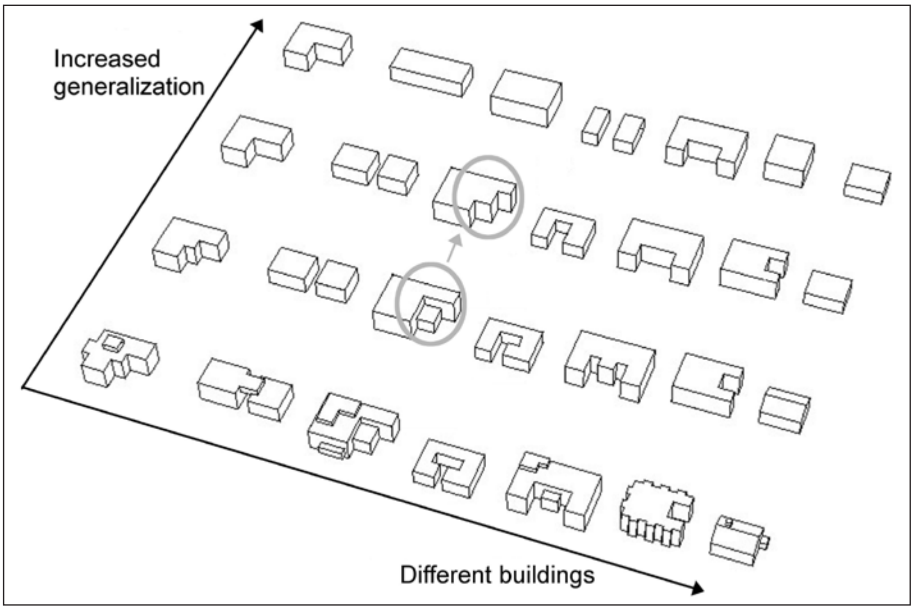

Fig. 5: Results for the simplification based on parallel shifts. In the example marked by circles, not only object parts are eliminated, but some are adjusted, so that the characteristic shape is preserved or even slightly emphasized.

of the building. Only small deviations or small structures have to be squared. Wall-squaring can be reduced to a 2D problem. Main directions in the x-y-plane are determined to be able to force a facet into one of them while squaring. The problem of obtaining the main directions could be solved, e.g., by the approach presented in Faber and Förstner (1997). We focus on the squaring of roof-facets.

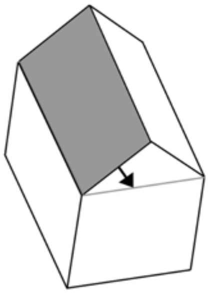

Fig. 7. The roof-facet (grey) is rotated (tapered) around the eave-line so that the roof-facet becomes horizontal (grey line).

If a roof-facet is to be squared at a given scale, we force it to be horizontal or vertical by rotating it either around its eave- (cf. Fig. 7) or its ridge-line. In ACIS this rotation is termed »tapering«. The decision, around which edge of the eaves or ridges the facet has to be rotated and whether it should be rotated into a horizontal or vertical plane, depends on the neighboring facets, i.e., those facets that share ridges and eaves with the facet to be tapered. As two neighboring facets are available for most roof-facets, which are classified into horizontal (H), vertical (V), or inclined (I) facets, nine different cases have to be considered. Fig. 8 shows that in some of these cases additional information is needed, as, e.g., if the facet on the ridge is increasing or decreasing, or the angle ω between the facet on the eaves and the inclined facet that is to be squared. Triangular facets, which in most of the cases have no ridge-line, are forced into the vertical direction by rotating them around the eave-line. This way, e.g., a hip-roof becomes a simpler saddleback-roof.

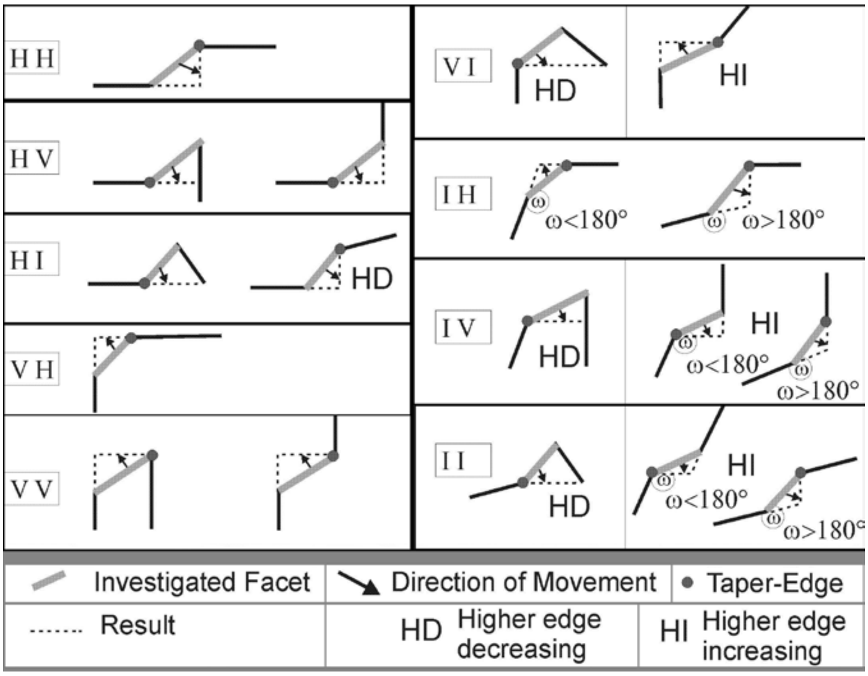

Fig. 8: Taper-edge (grey circle) and -direction (marked by an arrow) depend on the relation of the inclined facet of a roof to its neighboring facets (horizontal – H, vertical – V, inclined – I). In some cases additional information as, e.g., the angle ω is needed.

For a reasonable generalization, the context of the inclined facets has to be considered. If, e.g., only one part of an L-shaped roof is squared, the result is not satisfactory. Therefore, additionally to the decision, in which direction and around which edge a facet is rotated, related facets have to be determined. We term these »roof-units«, and they are defined as roof-facets with connected ridge-lines. For each unit, the average facet-area is computed. If it is under a certain scale-dependent threshold, the facets are tapered, i.e., the roof structure is reduced to a flat-roof. In Fig. 9 left, a building consisting of two roof-units is shown. The roof-unit with the smaller average facet-area is marked with a black ridge and is generalized first. To employ the slope of the facets as criterion for generalization could be one direction for further research.

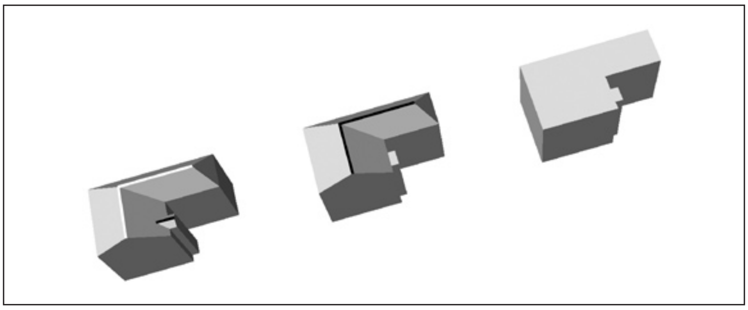

Fig. 9: Connected horizontal ridges determine two roof-units (black and white, left). Depending on the size of the structure, i.e., the average facet-area, roof-units are eliminated (center, right).

Results for this approach are presented in Fig. 10. While squaring, the height of a building can change.

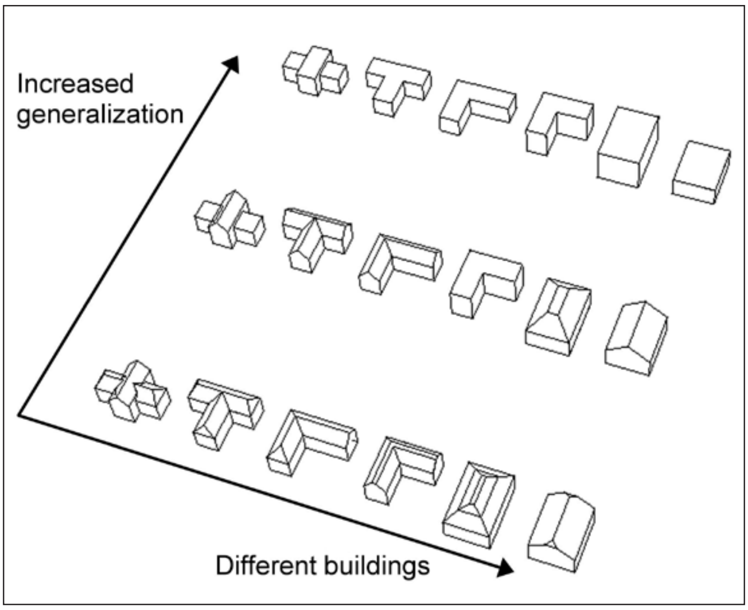

Fig. 10: Results for the roof-squaring

Sometimes the building height after squaring corresponds to the former ridge height, sometimes to the former eave height.

4 Conclusions and Outlook

A new approach for the generalization of 3D vector data for buildings has been proposed. It combines the advantages of the scale-spaces mathematical morphology and curvature space into one procedure, is easy to implement, and fast to compute. It works by shifting parallel facets towards each other until the facets merge and a simplification takes place. Results show that the approach can be used also for complex buildings.

Concerning non-orthogonal parts, a procedure for squaring roof-structures has been proposed. It works by tapering (rotating) inclined facets either around their eave- or ridge-line until they become horizontal or vertical. Rules to choose the specific taper-edge and -direction are introduced. Units of connected roof-facets are determined and treated together. Results show the potential of the approach.

Directions for further research comprise, e. g., a more sophisticated weight of the movements of the facets for the parallel shift or the scaling of the building height after roof-squaring, as it has been scaled either to the eave, or the ridge height, both of which might not be correct. The scaling has to concentrate on the local structure affected by it, but it also depends on the users' needs. For the squaring of the walls the approach of Faber and Förstner (1997) could be adapted to determine the main horizontal directions. Wall-facets that deviate from these directions have to be forced into the nearest main direction, if one of the following holds: either the structure is small enough to be eliminated during the simplification process in case of parallel structures, or the deviation from the main direction is small.

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