SIMPLIFICATION OF 3D BUILDING DATA

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ABSTRACT:

An approach is presented 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 a 3D feature under a certain extent is eliminated or a gap is closed. For the treatment of non-orthogonal structures we differentiate between wall- and roof-level. For the wall-level 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 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 still to be performed are summarized.

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 available. Which model is chosen for the display from a specific point of view depends on the objects distance. Objects that are far away are displayed with less detail than closer ones (cf. Fig. 1). That way, the number of displayed polygons is reduced and the performance of the visualization is enhanced.

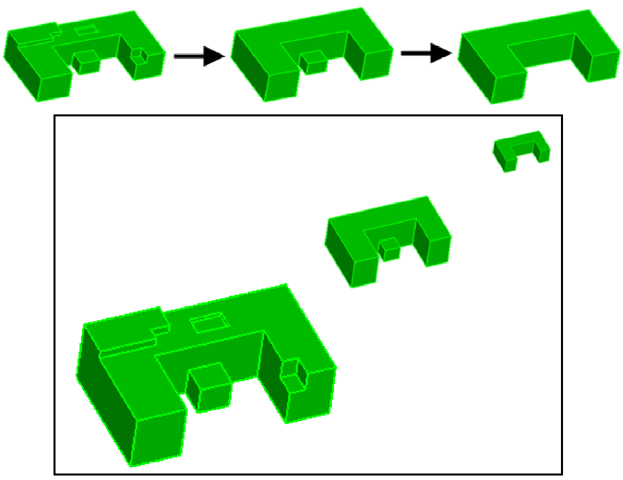

Figure 1: Different Levels of Detail (LOD) of a building automatically generated by scale-space based generalization

In order to derive a coarser representation of an object, simplification is necessary. (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 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 facets. Approaches especially developed for the simplification, i.e., generalization of buildings come from cartography or Geographic Information Systems (GIS), but they mostly focus on 2D generalization. Many of the older approaches are summarized in (Mackaness et al. 1997, Meng 1997, and Weibel and Jones 1998). 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. (Thieman 2002) decomposes a building into basic 3D-primitives and eliminates primitives with a small volume. For the decomposition he uses the algorithm of (Ribelles et al. 2001). There, specific features of polyhedra are found and removed based on planar cuts.

In (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. In the following, an approach is introduced, 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 elements, an approach for squaring non-orthogonal features, especially roofs, is introduced in Section 3. The conclusions and an outlook follow in Section 4.

2 SIMPLIFICATION OF PARALLEL STRUCTURES

2.1 Scale-Spaces and Generalization

In image analysis, a scale-space is obtained by deriving representations at different scale from an image (Lindeberg 1994). For the derivation of the representations of coarser scale, 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 of 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, either inwards (erosion) or outwards (dilation). For curvature space, only specific elements are shifted and the direction for the movement can differ (cf. Fig. 2). The elements to be shifted are edges for two-dimensional (2D) ground plans and facets for 3D building data.

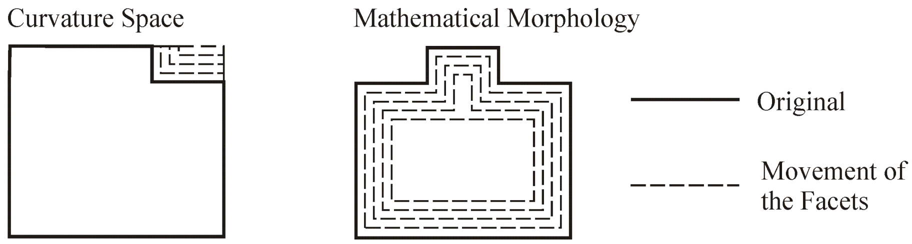

Figure 2: For curvature space only specific facets are shifted, while for mathematical morphology all facets are moved simultaneously.

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

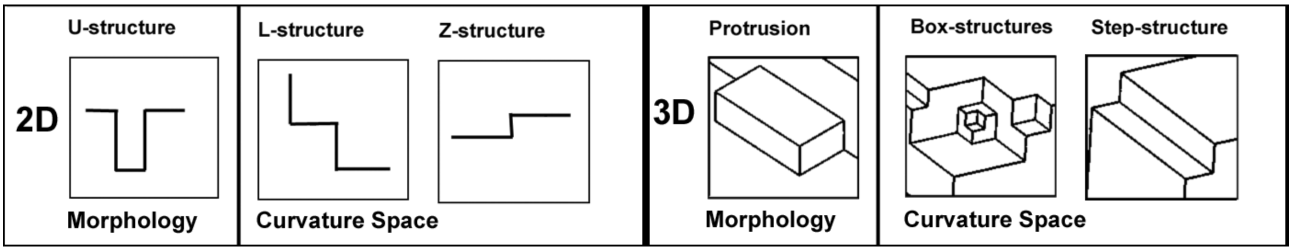

Figure 3: U-, L-, and Z-structures in 2D versus protrusions, box-, and step- / stair-structures in 3D

Whereas mathematical morphology is easy to realize, for curvature space a complex analysis is necessary to decide which specific elements have to be shifted in what 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 still cannot be guaranteed, that the result is satisfying, a new approach was developed, which combines the advantages of mathematical morphology and curvature space. 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 the same plane. For curvature space perpendicular facets collapse in the same edge for step-structures or vertex for box-structures. Though, the latter works mainly because the facets collapse in the planes of parallel facets. Understanding this leads 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 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. The parallel shifting is realised by the ACIS function 'api_offset_faces_specific'. There, for each facet to be shifted a specific offset distance can be chosen.

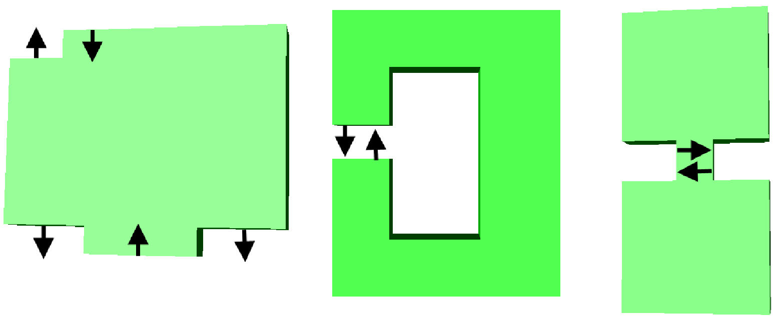

Figure 4. Parallel facets under a certain distance are shifted towards each other, until the facets of the building merge.

In contrast to mathematical morphology and curvature space, 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 size-relation between the two parallel facets can be applied. For the results shown in Figure 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 other one, it is shifted for the whole distance. By this means, symmetry can be maintained in case of small box-structures. Done otherwise, the result would be ambiguous, as one of three pairs of parallel facets has to be chosen randomly for the parallel shift (cf. Fig. 6). For the presented results, a smaller facet has got approximately the same size as its partner facet, if its area is bigger than one third of the other ones area. This threshold is chosen intuitively and can be easily changed.

As by now the order of the shifting is not fixed for different possible pairs of parallel facets with the same distance between them, the result is not always predictable. E.g., in the 4th example from the left of Figure 5 a facet has the same distance to two parallel facets. The selection of the partner-facet takes place randomly, which leads to an unexpected result. A human would most likely prefer to close the gap instead of eliminating the building part. A hierarchy considering those more intuitive decisions is not yet included in the generalization process.

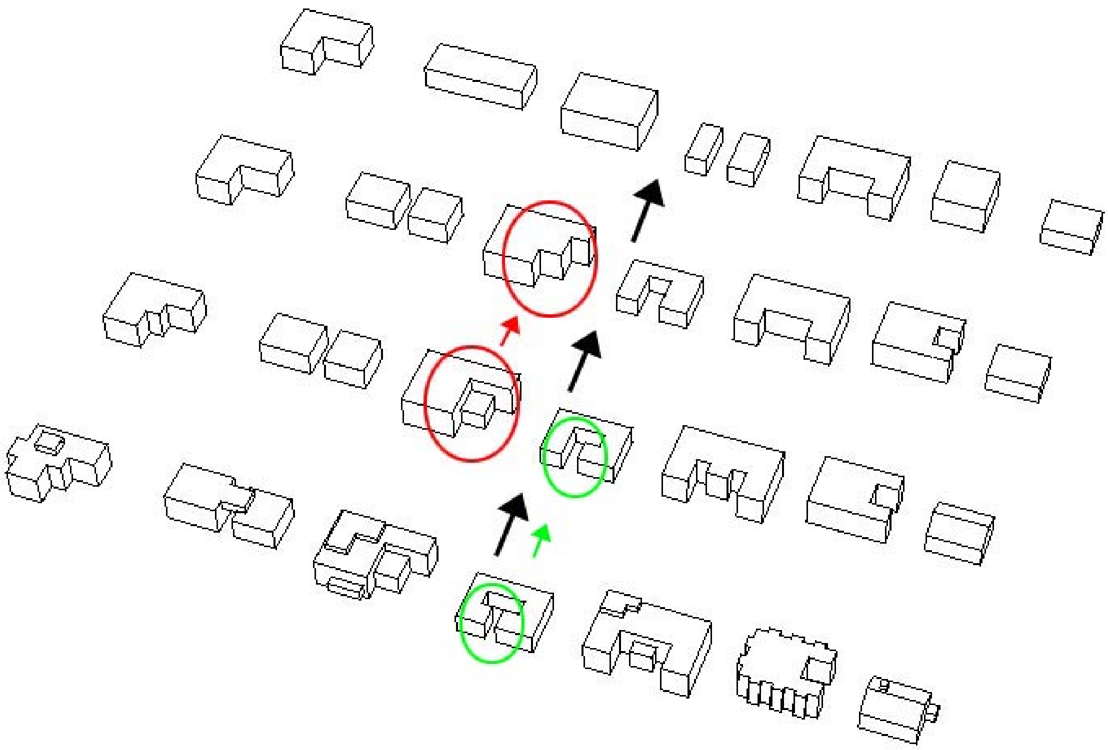

Figure 5: Results for the simplification based on parallel shifts. As can be seen, e.g., in the 3rd example from the left (marked in red, dark), object parts are not only eliminated, but they are adjusted, so that the characteristic shape is preserved, or even slightly emphasized. The 4th example (marked in green, bright) shows a problem due to randomly selecting one of two possible pairs of parallel facets.

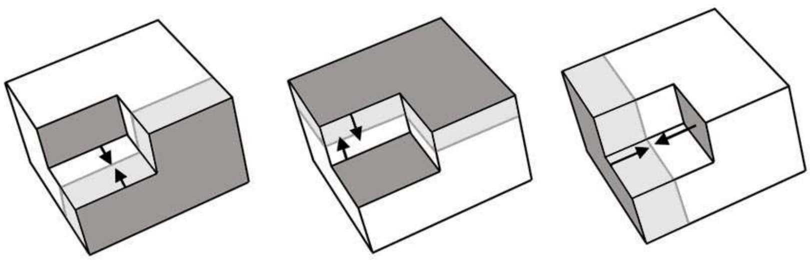

Figure 6: Within a symmetrical box-structure, a pair of parallel facets (dark grey) is chosen randomly. If both facets are shifted for the same amount, the result (white) is not predictable and the symmetry is lost. To avoid these ambiguities, only the smaller facet is shifted, if one facet is at least more than three times larger than the other.

Nevertheless, the parallel shift is a rather simple and general procedure and is therefore suitable for also 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 process.

3 SQUARING

Building simplification using scale-spaces or the parallel shift approach assumes exact orthogonal structures. Otherwise facets are not merged correctly and the generalization fails. As buildings do not consist only of parallel or perpendicular structures, the treatment of non-orthogonal structures is necessary. For this, we differentiate between the wall- and the roof-level of the building. 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 if they have to be squared, depends on the scale and the size of the roof-structure. The walls are vertical facets. For them strong deviations from a perpendicular structure have to be preserved in order to keep the characteristic shape of the building. Only small deviations or the orientation of small structures have to be squared. The wall-squaring can be reduced to a 2D problem. Main directions in the x-y-plane have to be determined in order to force a facet into one of these directions while squaring. The problem of obtaining the main directions can be solved, e.g., by the approach of (Faber and Förstner 1997). The focus of our work lies on the squaring of roof-facets.

If a roof-facet has to be squared at a given scale, it is forced to be horizontal or vertical by rotating it either around its eave- (cf. Fig. 7) or its ridge-line. In ACIS this rotation process is termed tapering and the used function is called 'api_edge_taper_faces'. The decision, around which edge (eaves or ridges) the facet has to be rotated, and if it is rotated into a horizontal or vertical plane, depends on two neighboring facets, one sharing the ridges and one sharing the eaves of the investigated facet. If both neighboring facets exist, i.e. the facet to be tapered is not, e.g., triangular, each of the two facets is classified either as horizontal (H), vertical (V) or inclined (I). Therefore, 9 different possible combinations of the two neighboring facets exist, which have to be considered for the decision process. Figure 8 shows that in some cases additional information is needed. These are, e.g., if the facet on the ridges 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 have no ridge-line, are always forced into the vertical direction by rotating them around the eave-line. This way, e.g., a hip-roof becomes a more simple saddleback-roof.

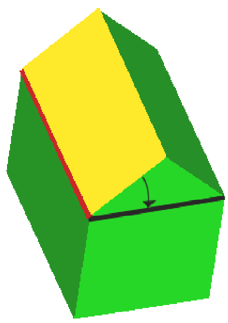

Figure 7. The roof-facet (yellow, bright) is rotated (tapered) around the eave-line (red, dark) so that the roof-facet becomes horizontal.

For a reasonable generalization, the context of the inclined facets has to be considered. If, e.g., only the smaller part of an L-shaped roof is squared, the result is not satisfying. Therefore, additionally to the decision, in which direction and around which edge a facet is rotated, related facets, i.e., roof-units have to be determined. Here, roof-units are defined as roof-facets with connected ridge-lines. After their detection, the average facet-area is computed for each unit. If the area is under a certain threshold, the facets are tapered, i.e., the roof structure is reduced to a flat-roof. In Figure 9 a building with two roof-units is shown. The roof-unit with the smaller average facet-area is marked with a red ridge and is squared first.

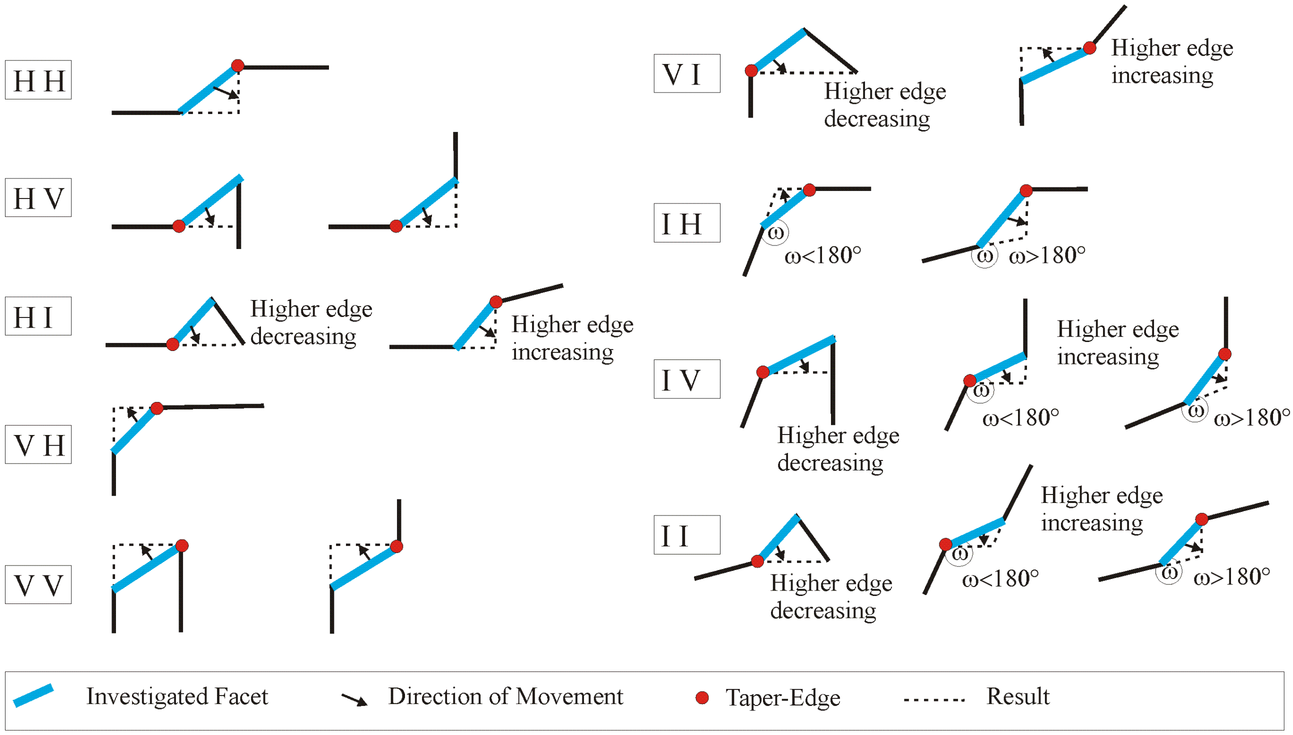

Figure 8: Taper-edge and –direction depend on the relation of the inclined facet to its neighboring facets (horizontal – H, vertical – V, inclined – I). In some cases additional information, e.g., the angle ω, is needed.

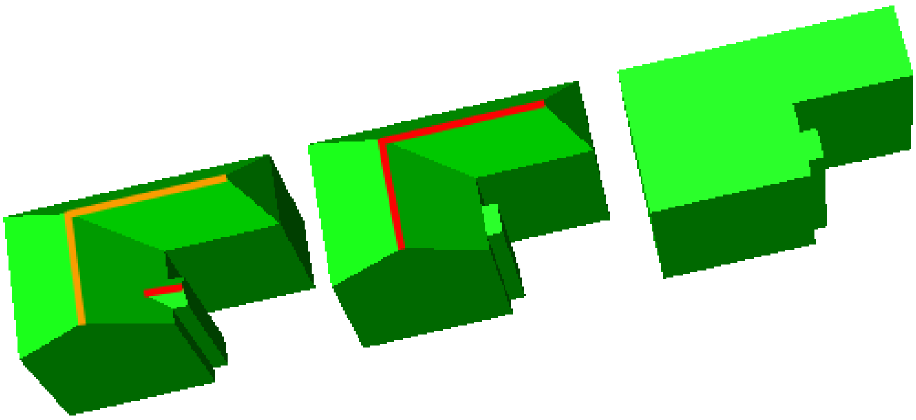

Figure 9: Connected horizontal ridges determine two roof-units (dark red and bright yellow). Dependent on the size of the structure, i.e., the average facet-area, roof-units are eliminated.

Results for this approach are shown in Figure 10. While squaring, the height of a building can be changed. Sometimes the building height after the squaring corresponds to the former ridge height, sometimes it corresponds to the former eave height. Parallel shift and roof-squaring are separate procedures, i.e., the combination of both methods into one consistent generalization-tool is not yet realized.

4 CONCLUSIONS AND OUTLOOK

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

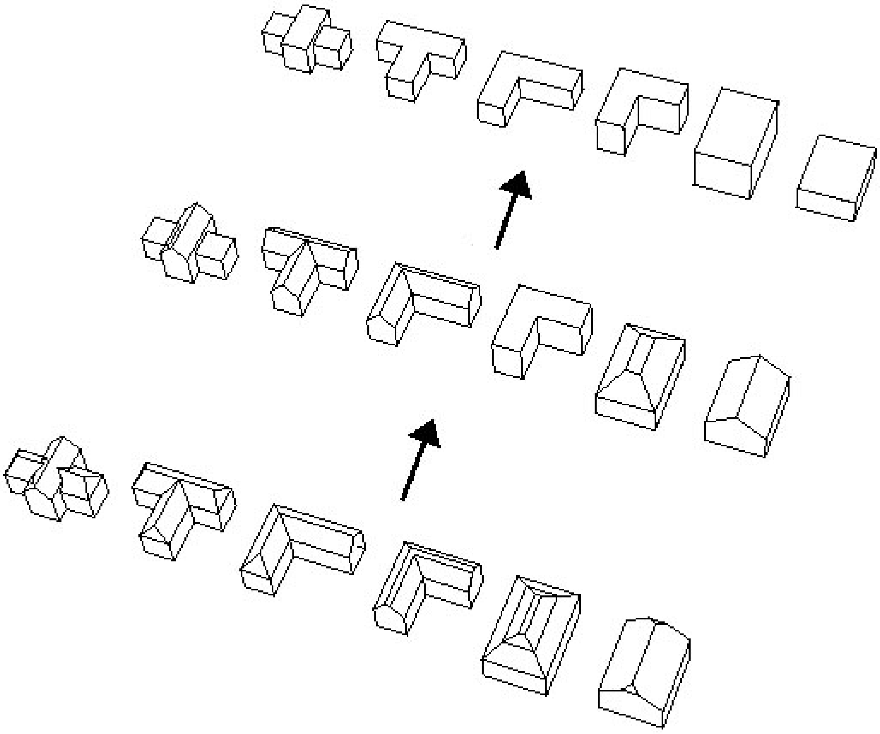

Figure 10: Results for the roof-squaring

As buildings consist also of non-orthogonal parts, a procedure for squaring roof-structures is proposed. It works by rotating (tapering) inclined facets either around their eave- or their 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.

Tasks still to be performed comprise the scaling of the building height after roof-squaring. It has to concentrate on the local structure, which was affected by the squaring. The scale value depends on the users' needs. For the squaring of the walls the approach of (Faber and Förstner 1997) should 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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