SCALE-SPACE EVENTS FOR THE GENERALIZATION OF 3D-BUILDING DATA

Helmut Mayer
Institute for Photogrammetry and Cartography
University of the Federal Armed Forces Munich, D-85577 Neubiberg, Germany
Helmut.Mayer@UniBw-Muenchen.de
http://www.BauV.UniBw-Muenchen.de/institute/inst10

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ABSTRACT

In this paper we aim at generalizing, i.e., simplifying, 3D building data automatically employing vector-based morphology and discrete/continuous curvature space. So-called "scale-space events", for which the link to the semantics of objects has been shown, play a major role for the simplification. The simplified data can be used to build up a level of detail (LOD) structure making the visualization of large data sets feasible by visualizing objects at a larger distance from the viewer based on a less detailed representation. Another point of view on our approach is that we base model-generalization from cartography which transforms data to the right level of abstraction for a particular analysis task on the formally well-defined theory of scale-spaces. Results for an implementation of the approach based on the computational geometry algorithm library (CGAL) public domain library show the validity of the approach.

1 INTRODUCTION

Recent developments such as the VRML '97 (the virtual reality modeling language, ISO/IEC 14772-1:1997) standard, allow for an easy visualization of complex 3D data like buildings. Apart from the fact that building acquisition is quite labor intensive, for visualization or GIS data analysis the problem is encountered that the data have too low an aggregation level, i.e., they are too complex, or at least one additionally would like to have a less detailed representation. A typical example using a series of such less detailed representations is the level of detail (LOD) concept from computer graphics. It is employed to reduce the effort for the visualization of objects at a larger distance from the point of view. To satisfy the need for simplification of the data, there are many approaches from computer graphics and similar areas. They deal with this problem by means of surface simplification often resulting in multi-resolution surfaces. Common to all these approaches is that they try to be general, not regarding specific properties of the objects. Yet, to obtain high quality, it is reasonable to employ a simplification procedure adapted to the specific object, i.e., the building.

"Model-generalization" from cartography and geographic information systems (GIS), for which the main idea is to transform data into the right level of abstraction for a particular analysis task, is an area which deals with this kind of problem mostly in two dimensions (2D) employing for instance rules in expert systems. We propose to geometrically base the model-generalization of building outlines in 2D and three dimensions (3D) on the formally well-defined theory of scale-spaces from image analysis, particularly, on "scale-space events".

Mathematical morphology and the so-called "discrete" and "continuous curvature space" are the main scale-spaces used in this paper. They are employed on vector data, i.e., polyhedra, defining the building outline. Vector data provide means to preserve as well as enforce right angles. We apply the scale-spaces incrementally, i.e., the outline is shifted in small steps. An important reason for an incremental processing is the occurrence of scale-space events. They occur, when parts of the building like an annex are eliminated, when a building is split into parts, when an inner courtyard arises, or when two buildings are aggregated.

In Section 2 we give an overview over the state of the art of surface simplification, model-generalization, scale-space theory, and the link of scale-space events in an image or a geometry based representation to the abstraction in a symbolical representation. Section 3 presents the morphological scale-space for the simple case of 2D building outlines in the form of opening and closing as well as the definition of internal and external events and the discrete curvature space. Section 4 discusses tools, morphology, curvature space, and the combination with the rectification of non-orthogonal structures for LOD generation in 3D. In Section 5 we present a summary and draw conclusions.

2   STATE OF THE ART

2.1   Surface Simplification

There are many approaches from computer graphics, computational geometry, computer vision, and cartography to deal with the problem of surface simplification. A good survey is given in (Heckbert and Garland, 1997). Typically, the approaches focus on general objects made up of triangles. The goal of many of the approaches is the construction of the LOD. It can consist of different levels but also of a sequence of refinement transformations like in (Popović and Hoppe, 1997). Examples for recent approaches to simplify surfaces and to generate a LOD description which try to balance mathematical soundness, speed, and quality are (Garland and Heckbert, 1997) where short edges are contracted but also close-by points are merged and (Varshney et al., 1995) where so-called ϵ-offset surfaces (parallel surfaces with distance ϵ) guarantee, that the approximation is closer to the original than ϵ. In (Schmalstieg, 1996) an approach to produce LOD for VRML 1, the predecessor of VRML '97, based on octree-clustering is presented. Common to all the approaches is that they try to be general, not using the specific nature of objects, like for instance buildings.

2.2   Model-Generalization

The task of model-generalization is the simplification of the geometry, topology, and semantics of objects, but not of their graphical representation (cartographic-generalization). It results in a modeling of geographical information on different levels of abstraction. Ideally, this renders it feasible that data are analyzed on the level of abstraction, where their variance is maximum, or where the spatial processes are understood best (Müller et al., 1995). The state of the art of automated generalization approaches, as presented in (Mackaness et al., 1997, Meng, 1997) have a strong tendency to use object-oriented structures and rules.

A rather old, but important approach **for the automatic generalization of buildings** is (Staufenbiel, 1973). For the outlines a fixed processing scheme is proposed based on techniques like the intersection of straight lines. The merging of buildings is made dependent on the change of the position of a building and the treatment of the corresponding region. One step further is taken in (Meyer, 1989). It does not only focus on the simplification of the building, but the building is classified if possible. Classes besides the rectangle are, e.g., L-, T-, U-, and Z-shaped regions. The classification is based on correlation of the rasterized buildings with a template. If a classification is not possible, a simplification according to (Staufenbiel, 1973) is employed. (Powitz, 1993) extends and combines (Staufenbiel, 1973, Meyer, 1989) with approaches for the generalization of roads and for cartographic displacement. The latter one is done iteratively. (Regnauld, 1997) shows how rows of buildings can improve the generalization of suburban areas. A so-called "production-net" is used in (Stilla et al., 1998) to generalize building outlines from different information sources. This is done to compare and combine the different sources.

(Li, 1996) deals with scale-spaces, particularly with binary morphology (Serra, 1982) on raster data. Opening and closing based on simple structuring elements are employed for the generalization of regions with smooth outlines. How to treat "changes of the type of geometry" when changing scale (scale-space event) is shown in (Schoppmeyer and Heisser, 1995). An example for such a change is when a region becomes a line or a point during generalization. The new geometry has to be delineated and a treatment of the neighborhood might be necessary.

2.3   Scale-Spaces

Scale-space theory deals with the formal definition of the concept "scale" (Lindeberg, 1994) in terms of signals/images. The basic idea is to generate a multi-scale-representation from a one parameter family of derived signals. Data are systematically simplified and details, i.e., information with high "frequency" are eliminated. The scale parameter $\sigma \in R_+$ is intended to describe the current level of scale. If isotropy, i.e., independence of direction, and homogeneity, i.e., independence of location, are combined with causality and a continuous scale parameter, it can be shown, that the scale-space family necessarily satisfies the so-called "diffusion equation". This results in the so-called **linear scale-space**. Another way to define a scale-space is **mathematical morphology** (Serra, 1982). The so-called **reaction-diffusion space** (Kimia et al., 1995) for gray-scale images combines linear and morphological scale-space. It comprises a (inhomogeneous) diffusion as well as a morphological component and is defined based on closed contours. The diffusion part is termed **curvature space** in this paper. Smoothing is done by embedding the contours into a surface function. For this, e.g., a signed distance transformation is well suited.

The introduced scale-spaces have **different characteristics**. While the linear scale-space smoothes the image function more or less continuously, the morphological scale-space eliminates regions with a too small spatial extent. The reaction-diffusion space integrates the above two scale-spaces. Besides this, its inhomogeneous diffusion component, i.e., the curvature space, has – compared to the linear scale-space – the interesting property to preserve elongated regions by taking into account the curvature of the contours of the image function.

2.4 Scale-Space Events and Abstraction

For this paper the connection of scale-spaces and symbolical information is of special interest. We (Mayer and Steger, 1998) have shown that essentially two things may happen simultaneously, when an image comprising features which represent objects is transformed in scale-space from a finer to a coarser scale: The information density of the image is reduced by means of **scale-space events** by eliminating points, edges, lines, and regions; noise as well as meaningful information is removed. The elimination of meaningful information can be considered equivalent to the elimination of parts of objects. In addition, it results in a simplification, i.e., an **abstraction**. With these means it becomes possible to link a symbolical representation based on a part hierarchy and a transformation by changing the scale in the image.

3 GENERALIZATION OF BUILDING OUTLINES IN 2D

On one hand, generalization is much simpler to achieve in 2D than in 3D. On the other hand, generalization in 2D is a prerequisite for the 3D case. Therefore, we use the 2D case to introduce the basic methodology for basing generalization on scale-spaces.

3.1 Morphological Scale-Space and Internal/External Events

The abstraction capability of scale-spaces suggest to employ scale-spaces for generalization. That this is basically possible was proven in (Li, 1996) for the morphological scale-space. In image analysis, scale-spaces are mostly employed in a raster-based way and are always applied on smooth contours. The typical rounding of right angles when using Gaussian scale-space or morphology with circular structuring-elements is not suited for the simplification of buildings, in terms of generalization. For this it is obvious to use a vector-based representation, where discontinuities, particularly right angles, can be represented and enforced easily. For opening and closing the contours are shifted in this case inward or outward like for the reaction part of the reaction-diffusion space (cf. left side of Fig. 1).

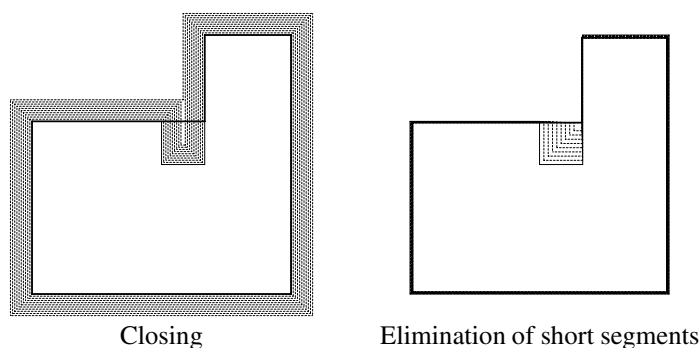<center>Closing   Elimination of short segments</center>

Figure 1: Result of different scale-spaces based on a vector-representation (input = thin line, intermediate steps = dashed line, result = thick line)

Also in this case scale-space events occur. In Figure 1 it is the elimination of the inward pointing notch in the middle of the upper part of the building. Scale-space events are classified in this paper into internal and external: **Internal events** occur in topologically local areas and are synonymous with one or more "unnecessary" points or very short segments. These points or segments emerge when an incremental displacement like in Figure 1 is employed. We use the incremental displacement also for the remainder of this paper.

External events emerge when topologically non-local segments of one or more buildings touch or overlap. Typical examples are the split of objects connected by narrow connections in the course of Opening, and the elimination of small gaps, e.g., a passage, when Closing (cf. Fig. 2). Similarly to the latter, the merge of two or more buildings can be treated.
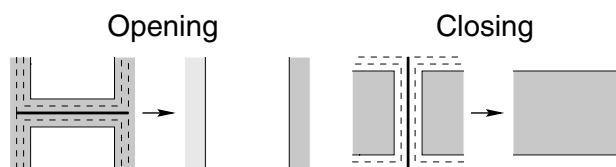

Figure 2: External scale-space events

3.2 Discrete Curvature Space

Another scale-space is the discrete curvature space. It is obtained when only the segments under a certain minimal length are shifted. This leads to results like on the right side of Figure 1. The procedure is illustrated in Figure 3. For details please refer to (Mayer, 1998). The procedure is similar to curvature space. If the curvature radius is defined "regionally", it corresponds to the half length of a segment. The proposed procedure does not shift points more or less depending on the curvature like in curvature space. Instead, short sides below a certain length, i.e., points with high curvature, are shifted, while other points are not shifted at all. With this, the minimal curvature radius is eventually enlarged to the half minimal length of the segment. This is the reason why this procedure is described as *discrete curvature space*.
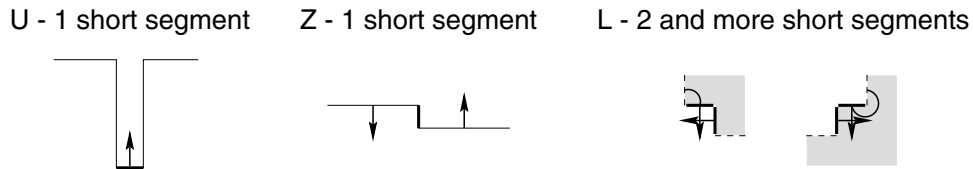
Figure 3: Discrete curvature space – Procedure

4   LOD GENERATION FOR BUILDING OUTLINES IN 3D

4.1   Example and Tools

The LOD generated from some of the examples for generalization in this paper is shown in Figure 4. As can be seen, not only a narrow connection between two parts of a building is eliminated and the two buildings are merged into one building later (left), but also different kind of step-/stair-structures as well as inward and outward pointing box-structures are eliminated (center), and the non-rectangular roof of a buildings is rectified after eliminating an inward pointing box and an annex (right).
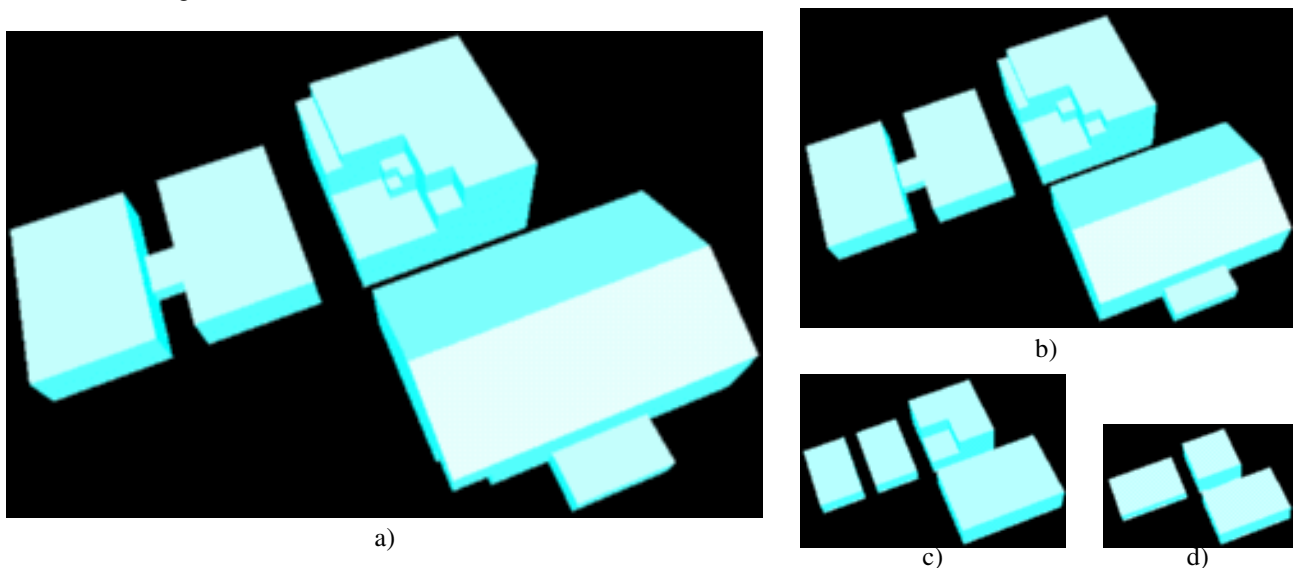
Figure 4: Level of Detail – a) Input data b) - d) First to third level (cf. also Fig.5, 8, 9)

In this paper, we assume that buildings are polyhedra, i.e., orientable 2D manifolds made up of planar surfaces. In addition, we expect that buildings are mostly orthogonal. This means that when structures of a building are not rectangular at the beginning of the generalization process, they have to be rectified (cf. Sect. 4.4). This is a restricted type of a model for buildings, though it was thought to be general enough to reveal the potential of scale-space based generalization.

As the modeling of geometry and especially topology of buildings represented by polyhedra in 3D is not trivial, a computational geometry tool box, particularly the Computational Geometry Algorithm Library (CGAL; http://www.cs.ruu.nl/CGAL) was used. For the representation of input and output data the VRML '97 standard was used. This choice makes it also possible to present not only the resulting images but also the complete 3D building data on the internet (http://www.photo.verm.tu-muenchen.de/staff/helmut/b3d).

4.2 Opening and Closing

Opening or closing in 3D is synonymous with moving the facets in the direction of the normals inward or outward, respectively. As CGAL guarantees that all the normals are oriented outward, this is fairly easy as long as a building is orthogonal. An example for a purely orthogonal building is shown in Figure 5. In c) the input is presented as a white wire frame and the four steps of incremental inward going opening and outward going closing are drawn as red (light gray in the printed proceedings) wire frames. The final result is shown as a green (dark gray) solid. To arrive at the solid where the gap is closed and the "doughnut" is obtained, the **external event** in the gap, occurring when the facets collide while closing (cf. the blue (dark) facet in c), has to be dealt with. Again, like in 2D, the criterion in 3D is that the width of a gap or a facet or at least a part of it is very small or even zero. This is the 3D version of a very short segment (cf. Sect. 3.1). An example for an event while opening is presented in Figure 6: Here the building has to be split twice. As one building part, namely the connection between the buildings, has no volume it is abandoned.
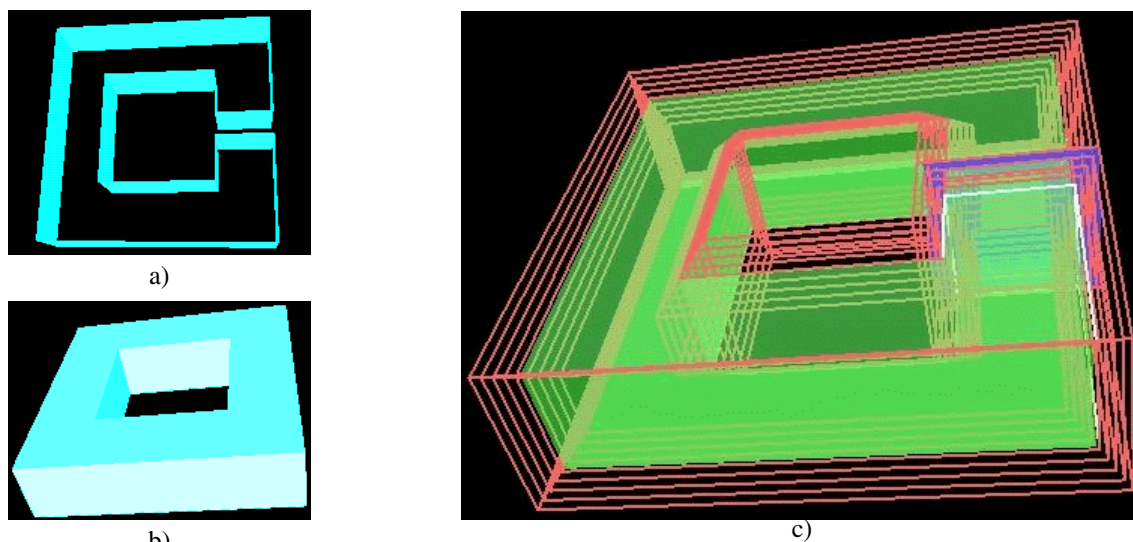

Figure 5: External Event while Closing – Doughnut a) Input data b) Result c) Steps of incremental processing (Input: white; Opening – closing: red (light gray); Scale-space event: blue (dark) facet; Result: green (dark gray) solid)
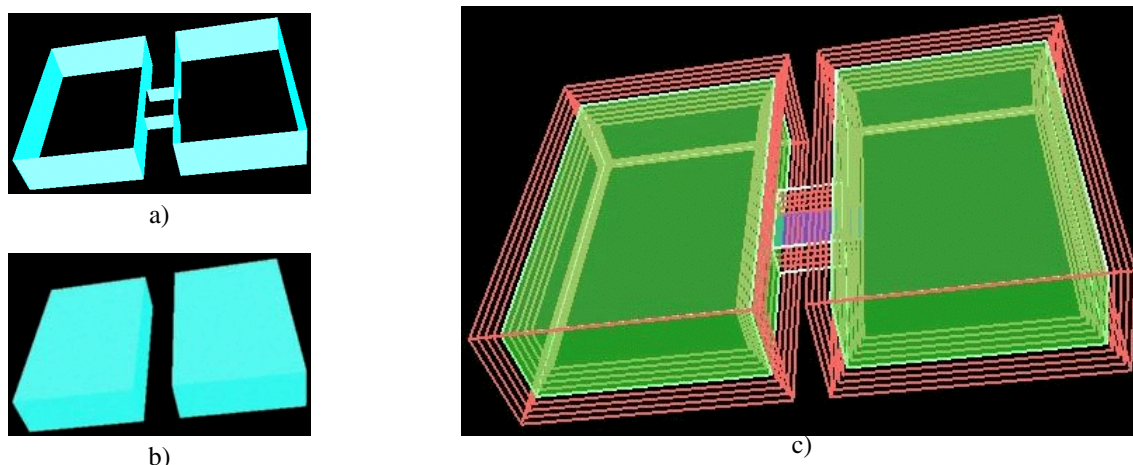

Figure 6: External Events while Opening – Split a) Input data b) Result c) Steps of incremental processing t (Explanation: cf. Fig. 5)

4.3 Discrete and Continuous Curvature Space

The basic question for curvature space in 3D is: How to move the facets? For the simple example presented in Figure 7, again like in 2D a Z-shaped structure, here for obvious reasons called "step", has to be eliminated by averaging the lower part on the left side and the higher part on the right side. Basically, the movement of the facets is controlled by the relations of the normals. Details can be found in (Mayer, 1998).

In Figure 8 three different kinds of structures which can only be eliminated by means of the curvature space are shown: First, this is the small step at the upper left side. Similar to the step is the inward pointing box at the right side, only
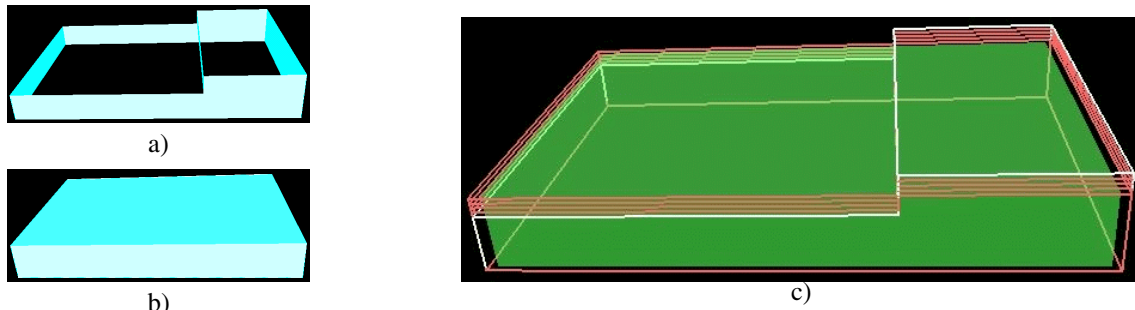
Figure 7: Event in Discrete Curvature Space – Step a) Input data b) Result c) Steps of incremental processing (Explanation: cf. Fig. 5)

it is bounded from three sides. In the center of the figure is shown that the curvature space can also deal with outward pointing boxes. Here a first modification compared to 2D has been introduced. When one inspects the facet on the lower part approximately orthogonal to the viewing direction more closely, one finds that there are also short concave segments which lead to a movement of the ground plane of the large inward pointing box. To keep the movement small in this case, it is weighted with the area of the facet. Thus, small areas move fast, while large areas nearly do not move. In (Mayer, 1998) we have defined a more or less "continuous" version of the curvature space by accepting that the movement depends on the area of the facets.
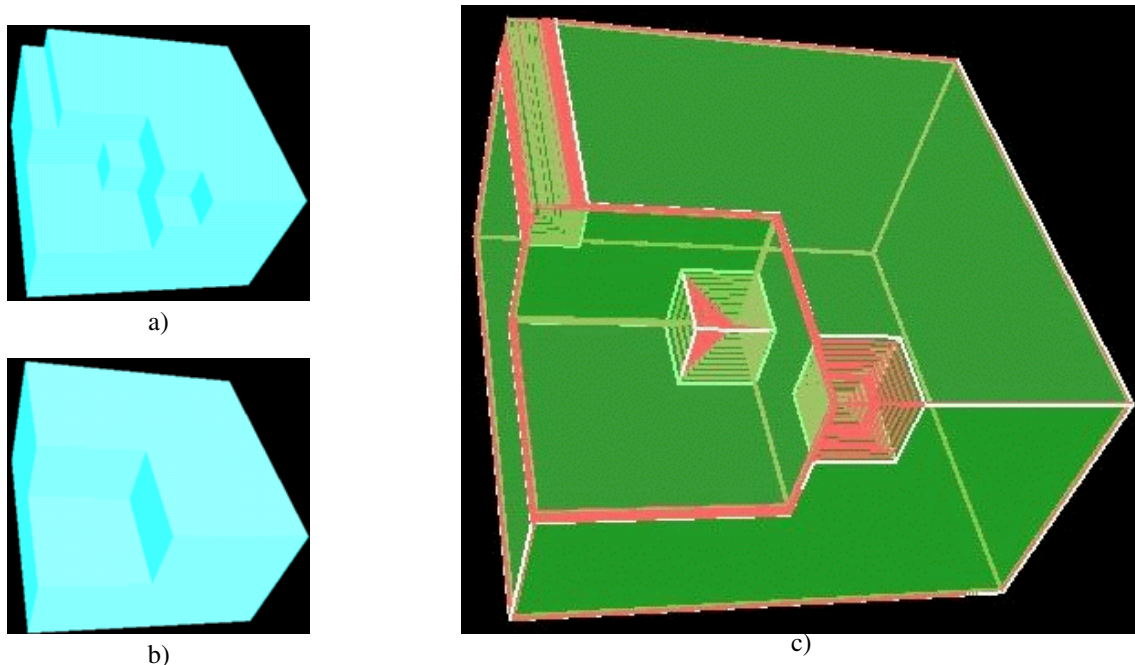

Figure 8: Events in Discrete Curvature Space – One step and two boxes a) Input data b) Result c) Steps of incremental processing (Explanation: cf. Fig. 5)

4.4 Combination of Opening, Closing, Discrete Curvature Space, and Rectification

To rectify buildings in 3D, a 2D procedure based on the Thales circle was employed. Unfortunately, the facets depend on each other in 3D. One problem stemming from this is that when opposite facets are not symmetric, points are shifted differently due to the different lengths of the sides of the triangle inscribed to the Thales circle. This problem can be solved by moving the points in the direction of the bisector of the enclosing sides as this is independent of the lengths. In Figure 9 a combination of the proposed scale-spaces with the rectification of right angles is presented. The annex in the center and the inward pointing box of the entrance at the left side are eliminated by opening and curvature space, respectively. In parallel the sloping roof is rectified.
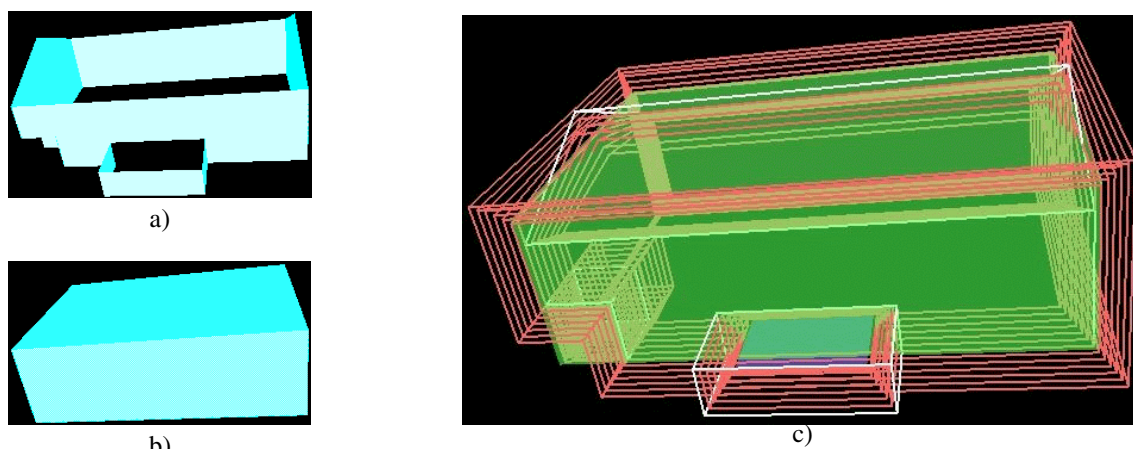
Figure 9: Rectification of the roof, elimination of the annex and of the inward pointing box of the entrance a) Input data b) Result c) Steps of incremental processing (Explanation: cf. Fig. 5)

5 SUMMARY AND CONCLUSIONS

In summary, from the point of view of scale-spaces internal and external scale-space events occur. For generalization, which is the main issue of LOD generation, only relatively few parameters with precisely defined semantics, namely the scale-space and few additional parameters, the step size, and the number of steps are sufficient. By incremental processing the emerging internal and external scale-space events can be handled by simple basic operations and right angles can be enforced. Additionally, the link to cartographic displacement is relatively simple. This results from the experiences in (Powitz, 1993) stating that cartographic displacement should be done in an iterative fashion. Particularly, the proposed approach seems to be well-suited for a simple plug-in of iterative techniques for cartographic displacement like the one presented in (Burghardt and Meier, 1997).

By and large, the **major advantages** of the scale-space based approach to model-generalization are that it is based on the sound scale-space theory and that it interacts fairly well with other generalization operations due to the incremental processing.

Though, there are some **known weaknesses, but also some ideas how to handle them**. We have applied for a joint project together with Prof. Liqiu Meng of the Chair for Cartography at Technische Universität München where we want to overcome most of the weaknesses. Unfortunately, at the time of writing this paper not even funding is clear. Thus, instead of writing about new results we can only present our experiences and ideas.

First, the **change of the topology for the events** took most of the effort. If a tool to intersect polyhedra with other polyhedra or with itself had been available, it would have been possible to implement a much more general solution in a relative short amount of time. We are planning to use ACIS 3D Toolkit from Spatial Technology, Inc to overcome for most of this deficit.

Experience shows that a **fixed sequence of opening, closing, and curvature space** with fixed parameters leads to acceptable results for a wide variety of buildings. The most important reason for this is that morphology and curvature space complement each other: While curvature space is the only means to eliminate step-structures, it cannot be used to aggregate or split objects which is the strong point of morphology. In spite of the satisfying results, the tuning of sequence and parameters still needs further investigation. Particularly, we want to link it to a high-level, e.g., rule-based, control of the generalization based on the structure analysis of the scene including not only buildings, but also roads, vegetation, etc.

A major design issue but still a weakness of the approach is its **focus on rectangular structures**. While this is useful for many buildings and their aggregation in Europe and North America, for other parts of the world and for specific buildings other models are needed. For instance, the generalization of steps into bigger steps, thereby maintaining the characteristics of a building, is an accomplishment for modern block-structures, on the contrary, for a Roman amphitheater, a sloped surface is a better approximation. Again, this kind of problems are the ideal point where higher level knowledge about the semantics of objects from a structure analysis, controlling the generalization, might come into play. In this context also rectification has to be dealt with. It is the geometrical problem least understood: When one makes one facet orthogonal in 2D, in most cases neighboring facets get sheared, and thus become non-orthogonal. A 3D version based on the idea of making the angles at the vertices orthogonal was tested, but discarded due to similar shortcomings. The outcome of the analysis mostly points at using the facets as the basic elements of the rectification.

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