AGGREGATION OF 3D BUILDINGS WITH A HYBRID DATA MODEL

Martin Kada

Institute for Geoinformatics and Remote Sensing (IGF), University of Osnabrück
Barbarastr. 22b, 49076 Osnabrück, Germany
martin.kada@uni-osnabrueck.de

KEY WORDS: Generalization, Algorithms, Building, Three-dimensional, Visualization

ABSTRACT:

The cartographic generalization prepares and arranges the contents of a map for a given scale and application in order to improve its comprehensibility. In recent years, the data sets for map-like presentations in 3D has become widespread available. Concerning urban areas, the most important objects therein are buildings. Whereas quiet a number of generalization algorithms for 3D data have been proposed, most are concerned with the geometric simplification of buildings models under building-specific constraints. However, the simplification of single objects can only reach a certain degree of abstraction. To obtain further levels, adjacent buildings or even blocks of buildings have to be regarded, e.g. by aggregation or typification.

In previous work, a simplification approach for 3D building models by means of cell decomposition has been proposed. A simplified version of a polyhedral 3D building model is constructed by intersecting a minimum number of planes that approximate well the initial shape. In this process, the space around a building is decomposed into building and non-building cells. To determine which cells are building cells, an overlap test with the original building is conducted in raster space. As the cell decomposition features already the necessary cells for an aggregation of buildings, which are, however, discarded due to their low overlap, it is suggested to use morphological operations to close the space between buildings in the raster model and therefore improve the overlap value of the cells. It is shown that the morphology of raster data can help the algorithm to aggregate polyhedral building models.

1. INTRODUCTION

With the increasingly widespread availability of 3D landscape models – particularly of urban regions – the adequate presentation of this type of data becomes more and more important. As photo-realistic views pose huge information loads on humans, such data is often generalized under cartographic considerations with the purpose to make spatial situations easier and faster to comprehend. While there has been (and still is) a lot of work done in the 2D domain, the topic of 3D generalization is rather new. Only few approaches have so far been presented and most focus on the geometric simplification of single buildings. Whereas surface simplification approaches known from the field of computer graphics are meant for general shapes, the simplification of 3D building models in a cartographic sense is commonly expected to preserve existing shape symmetries and regularities like co-planar, parallel, and rectangular alignment of façade walls. For this purpose, 3D generalization approaches have been proposed that add restrictions to surface simplification operators (Coors, 2001; Kada, 2002; Rau et al., 2006), use mathematical morphology and specially designed curvature-space operators (Forberg, 2004), apply feature segmentation, recognition, and elimination (Thiemann and Sester, 2004), match and replace complex shapes with coarse parameterized templates (Thiemann and Sester, 2006), and detect shape symmetries by crystallographic analyses (Poupeau and Ruas, 2007).

However, a significant characteristic that is specific for current large-area 3D city models is that the majority of buildings are of rather low geometric complexity, while their numbers can easily reach into the hundreds of thousands. Therefore, the simplification process on its own has a natural limit up to which the complexity of such models can be reduced without violating the above-mentioned restrictions. The classic motivation of cartographic generalization also states that if some feature cannot be properly recognized in a map due to its scale, then it should be eliminated, accentuated, or replace by something that allows for better readability. Regarding closely located buildings that are often found in urban areas that cannot be distinguished as single objects anymore, their aggregation to a larger building block can help to further reduce the complexity without changing the appearance of the spatial situation. Small gaps or even wider openings between the buildings are eliminated in the process with regard to some distance criteria. One of the few approaches for the geometric aggregation of 3D buildings is presented in (Anders, 2005): building groups are projected into three orthogonal directions, their silhouettes simplified in 2D, the results extruded and then intersected to form the generalized 3D building group. The simplification of the silhouettes is conducted by the 2D generalization software CHANGE. For the purpose of interactive visualizations of 3D city models, Glander and Döllner (2009) show abstraction techniques that also include the aggregation of city blocks. Depending on the context, certain landmarks are maintained in their original state to better help the viewer to focus on the current task. However, both aggregation approaches have only shown to produce flat roof shapes.

In this paper, we introduce an extension of a simplification algorithm, so that it is also able to aggregate buildings. An overview of this simplification algorithm is given in section 2. As will be seen, it relies on a raster representation to perform some overlay tests. This test is altered with the use of morphological operations to allow for an aggregation of buildings (section 3 and 4). A conclusion is given in section 5.

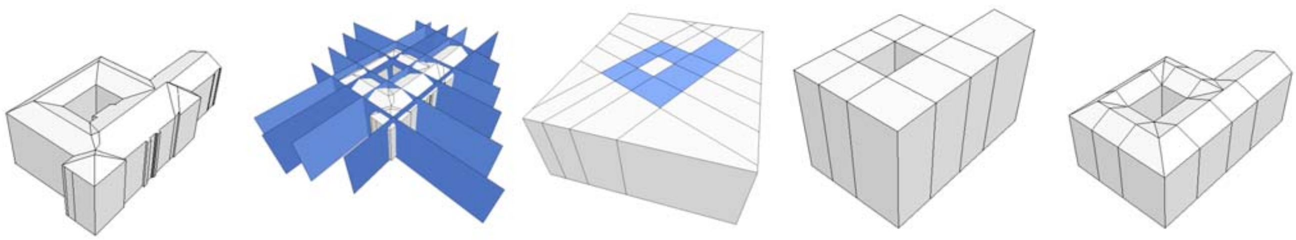

Figure 1. The generalization algorithm determines from the facades of the original 3D building model (leftmost) a set of approximating planes (left), constructs a cell decomposition (middle), and keeps only the cells featuring a high overlap (coloured blue for better clarity) with the ground plan (right). Then a roof is constructed for each cell by repeating the steps with the roof facades (rightmost).

2. 3D BUILDING SIMPLIFICATION

In previous publications, e.g. (Kada, 2007), we have described a generalization approach for generating low detailed versions of given polyhedral 3D building models. Here, the simplification is not an iterative process, but rather a construction of new models whose shapes resemble well the original ones. It is performed in cell decomposition, which is a representation form of solid modeling (see e.g. (Foley et al., 1990)). In short, the cells are solids of predominantly simple shapes that must not intersect one another, but can be "glued" together to construct more complex shapes. However, models in cell decomposition are usually not constructed, but rather generated in a decomposition process in order to gain cells of simple shape for which geometric computations become much easier. Now the generalization of a 3D building model works in two phases (cp. Figure 1): at first, a ground plan decomposition is generated from the building façade. Here, a minimum set of planes is determined from the façade polygons, which approximates well the façade within a given tolerance distance. Then, a solid block with a size larger than the original building is taken and divided along these planes. For the resulting cell decomposition, the cells with a low overlap with the original ground plan are discarded. The ones with a high overlap are kept for further processing or could be glued together at this point to form a generalized ground plan.

In order to gain a real 3D building model with a simplified roof structure, the former three steps of finding approximating planes, decomposing cells, and testing the overlap are repeated, but now with planes generated from the roof polygons. The desired level of detail can be controlled by the tolerance distance: the greater this value, the fewer planes are needed to approximate the original shape, which results in fewer cells and therefore a model of fewer details. Two tolerance distances can be defined: one for the ground plan and another for the roof structure.

Alternatively, the original roof structure can be analyzed in order to determine the general building roof type. Each cell is then given a parameterized shape with the best fit. Special care has to be taken for cells that form corners and junctions, so that different roof types fit well to one another. Whereas the first approach for roof generalization works on general shapes, the second one is restricted to standard roof shapes like flat, pent, saddleback, hipped, etc. However, due to its shape restrictions, it also only produces valid roof shapes, which is not a given for the first.

Based on the described simplification approach, an extension is suggested in this paper that also allows for an aggregation of buildings. If more than one building is given as input, it already considers them as one and aggregates them if they are close to one another (see e.g. Figure 2). Here, the set of approximating planes is determined from all buildings, which results in a common façade and roof structure.

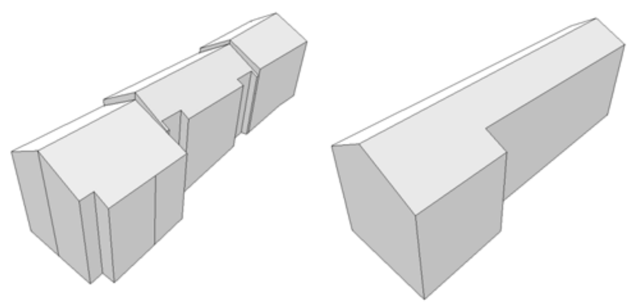

Figure 2. Three 3D building models (left) and their aggregation (right) produced by the simplification approach.

As illustrated in Figure 3, the algorithm becomes less reliable to produce results if there is some space between the buildings. On the left side, the rectangular footprints of two buildings with increasing distances are depicted from top to bottom. If the distance is smaller than the simplification threshold, then the space between the buildings is only split once in the cell decomposition (middle). The resulting building cells are elongated towards each other and meet at this plane, having no overlap with the original building footprints in that elongated (red) area. The greater the distance, the larger that area becomes, resulting in lower overlap values for these cells. At some point, the overlap values are too low for the cells to be considered building cells and they are omitted from the result (middle row). As a consequence, no model can be produced by the algorithm. This is of course dependent on the overlap threshold and could be counteracted by lowering that value. This is, however, not a sound solution as it will inevitably lead to other problems and will not improve the reliability of the algorithm. Once the distance becomes greater than the simplification threshold, two decomposition planes are generated and an additional cell in between with no overlap. So, no aggregation occurs.

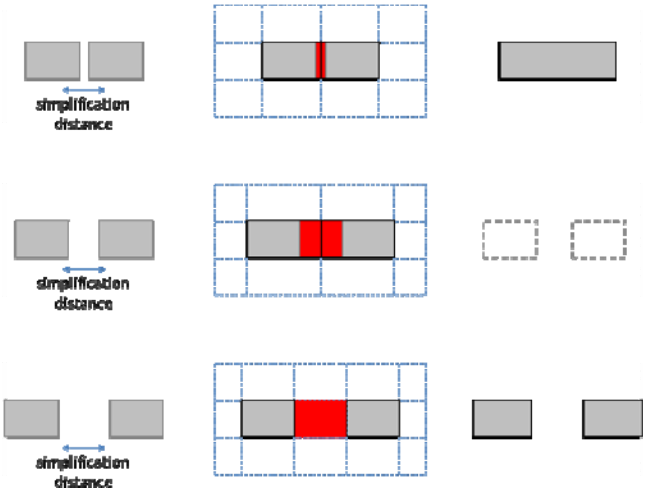

Figure 3. With increasing distance between the two rectangular building footprints (left), the cell decomposition itself and the overlap of the building cells changes (middle), which leads to different results (right); or no result as indicated by the dashed grey boxes in the middle row.

In summary, the simplification approach is able to aggregate adjoining buildings, but produces less reliably valid models if more than one object is processed at a time.

3. 3D BUILDING AGGREGATION

Even though the simplification fails to generate valid models for more than one building, the cell decomposition itself already produces all the necessary building blocks for their aggregation. The problem is the overlap test, which correctly detects for cells in the aggregation area a low overlap with the ground plan and therefore discards them. If this test could be altered to obtain higher values for the cells in these areas, then the simplification approach would also be able to aggregate buildings.

As describe in (Kada and Luo, 2006), the overlap test is performed in discrete space, i.e. the ground plan and the cell decomposition are both converted into 2D raster images. The images cover the same area and have the same size and pixel dimensions. Each pixel stores a reference to the building or cell that occupies the respective space. When overlaid with the ground plan image, it can be determined for each pixel of the cell decomposition if it is inside or outside the ground plan. The ratio that denotes the number of cell pixels that are inside the ground plan to the overall number of cells concludes if the cell is regarded as a building cell or discarded if otherwise.

Figure 4 shows an example of two buildings being generalized. On the right side, the 2D raster representation of the buildings is overlaid with the cell decomposition. Here, only the two middle cells are of any relevance as the other cells are boundary cells of the decomposition and deleted in the process. Thereby correctly removing a small portion in the front of the green building as it is smaller than the simplification threshold in this example. The cell with the main part of the green building has a high overlap with the original building and is therefore kept. The red cell, however, is rather large and due to the empty area between the two buildings has a low overlap and the algorithm discards it. This would not be considered a valid result.

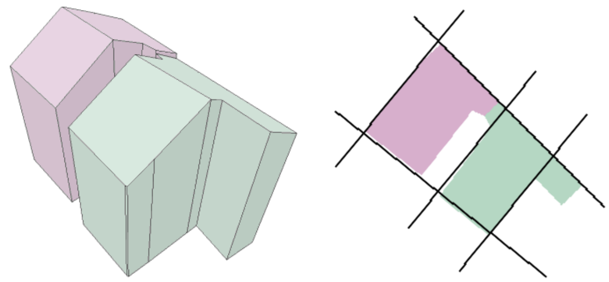

Figure 4. Two 3D building models (left) and their cell decomposition overlaid on the raster representation of the original ground plan (right).

On a side note, a single building with a unified shape of the two example buildings would face the same problem. The suggested change to the generalization algorithm aims therefore both at improving the reliability of the simplification in face of the above mentioned shapes and to allow for an aggregation of non-adjacent buildings. In order to achieve a better overlap of the cells with the ground plan, the image of the ground plan is processed using the mathematical morphology operators dilation and erosion (see e.g. (Serra, 1982)). Li (1996) and Mayer (1998) have already successfully applied morphology on binary images and vector ground plans as a tool for generalization. Here, the space between buildings or building parts is filled by repeatedly applying a dilation operation on the image. As structuring element, a 3 × 3 square mask around the probed pixel is applied: a pixel is set if either the pixel itself or one of its eight neighbor pixels are set; otherwise it is not set. The number of repetitions depends on the distance within which buildings are meant to be aggregated and is divided by the image resolution. After dilation, the boundary of the ground plan is restored as best as possible by the same number of erosion operations. Here, a pixel is only set if all of its eight neighbor pixels are also set. As depicted in Figure 5, the morphologically altered ground plan almost completely covers the prior critical area of the "red" cell and its overlap with the ground plan increases from 78% to 98%.

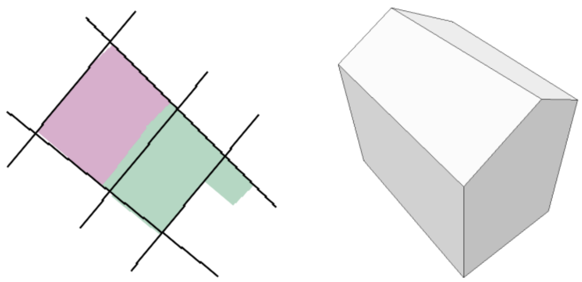

Figure 5. Cell decomposition overlaid on the morphologically altered ground plan (left) and the resulting aggregated 3D building model (right).

Another example is given in Figure 6. Because the buildings are rather small and farther spread apart, the “blue” cell exhibits a low overlap of only 64%. Although the threshold that classifies a 2D cell as a building block could in this particular case also be lowered without any consequences to the new ground plan, this is generally not a viable solution. The 3D overlap threshold, e.g., would need to be lowered also, which could negatively affect the classification of the 3D cells. However, with the morphologically altered ground plan, the overlap of the “blue” cell increases to 99%, which allows a reliable classification of the cell as a building block.

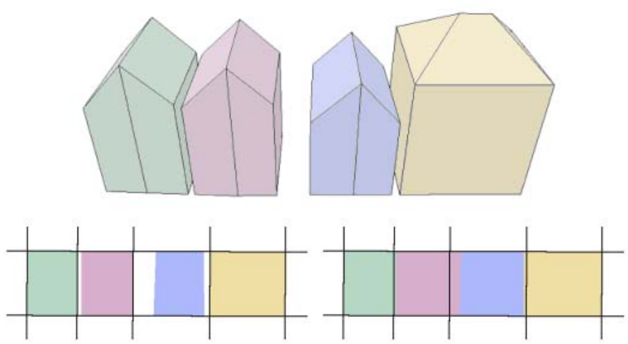

Figure 6. 3D building models (top) and their cell decomposition (bottom) overlaid on the original (left) and morphologically altered (right) raster model of the ground plan.

One problem that morphology exhibits is that the boundaries are changed if they are not aligned with the edges of the structuring element. After repeatedly applying the aforementioned operations, the boundaries are forced to align with the structuring element. This is depicted in Figure 7 for one of the previous examples.

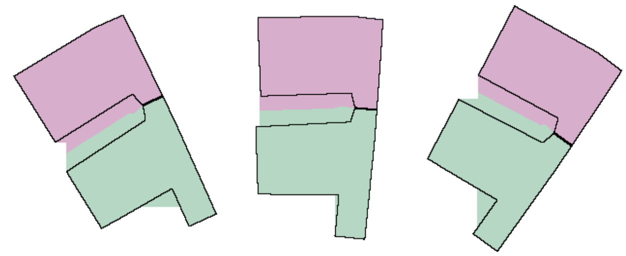

Figure 7. Three results of the morphological operations on two building footprints at different rotation angles.

To counteract this phenomenon, all buildings are rotated prior to their generalization so that their main directions coincide with one of the axis of the Cartesian coordinate system. This lessens the effect, but cannot completely remove it, especially for building models whose two mayor directions are not perpendicular to one another. The raster model cannot easily be adapted to this, as those building usually have even more than two main directions.

4. ROOF SHAPES

Up to now, we have only discussed the part of the ground plan generalization and left out how to handle the roof structures. For 3D building groups, where the objects are directly adjacent to one another, the original approach can be used: approximating planes are first generated from the roof surfaces, then the ground plan cells are decomposed and the overlap of the resulting cells with the original model determined in 3D. For spaced out buildings, the morphological operations are additionally applied similar to the 2D case, but now with a 9 × 9 cubic mask as structuring element on a volumetric raster model. Figure 8 shows two aggregation results for a group of four buildings with 3m and 2m ground plan simplification threshold. To obtain a fairly detailed roof structure, the responsible generalization threshold is 2m in both examples. For aggregation, a raster model of 0.1m resolution was dilated by 1.5m in order to include all four buildings in the result. The example shows, that the simplification thresholds for the ground plan and the roof and the aggregation threshold can be independently set in order to allow for highest flexibility.

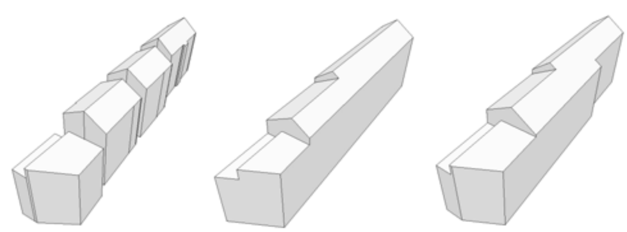

Figure 8. 3D building models (left) aggregated with 3m (middle) and 2m (right) ground plan distance threshold.

As mentioned in section 3, morphological operations smoothens structural concavities if their faces are not aligned to the elements of the raster model. Saddleback roofs whose ridges roughly follow a line like in Figure 8 are not affected by this. Only if the slopes form a valley, it closes them and the cells in between gain more overlap. As the overlap of the cells with the morphologically altered building models is in general better, using a higher overlap threshold can help to avoid any erroneous classifications of cells.

A general problem is how the shape of aggregated 3D building models is supposed to look like in the presence of valleys. Figure 9 shows the front view of two buildings with saddleback roofs for aggregation and their decomposition planes (as dashed blue lines) determined from the roof faces. As the morphological operations closes the space between the two buildings, the area below the eaves shall at this point not be considered anymore. The simplification distance is lesser than the perpendicular distances between the two pairs of parallel roof faces, so there are four decomposition planes, which results in a building model with two ridges. As depicted in the middle of Figure 9, the two ridges remain at their original position and the roof slopes are the same. The valley that is formed therefore lies below the eaves (dashed grey line). The further the buildings are apart from each other, the lower the valley and the larger this asymmetry of the two saddleback roof parts become. To work against this, the ridges could be pushed towards the middle until the valley is at the same height as the eaves (Figure 9 right). However, the roof generalization with decomposition planes does not accommodate for this.

Figure 9. Front-view of two saddleback building models and their cell decomposition (dashed blue lines) and two possible aggregation results.

A workaround could be to add horizontal decomposition planes at the eaves and ridge heights (dashed red lines in Figure 10). Depending on how much of the space between the planes gets filled by the morphological aggregation operations, the result would be the partially flat roof shape as depicted in the middle or right of Figure 10. Both results have their drawbacks: in the first version, a small flat element is introduced, which stands against the goal of generalization to simplify shapes, and in the second version the saddleback roofs are not apparent anymore and thus an important characteristic of the buildings destroyed.

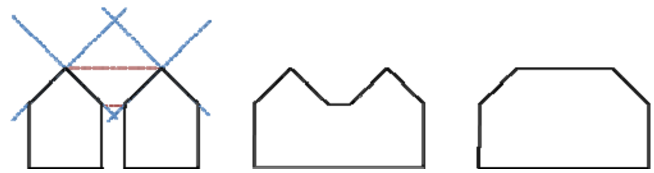

Figure 10. Front-view of two saddleback building models and their cell decomposition (dashed blue lines) and two possible aggregation results.

A third alternative is to include the (grey) cell in the middle of the four decomposition planes as depicted in Figure 11. The result is a large building with a saddleback roof. However, it is unclear how the rather generic algorithm would need to be altered for this. Even after morphological alteration, the raster model will only fill a small portion of this cell. But once the saddleback roof is generated, the height of the eaves and ridge could be altered to better fit the original shape.

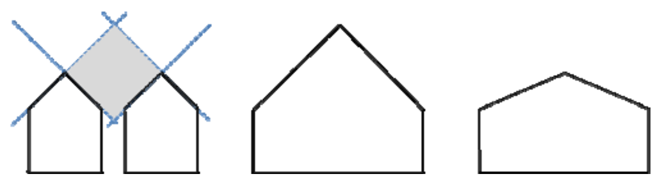

Figure 11. Front-view of two saddleback building models and their cell decomposition (dashed blue lines) and two possible aggregation results.

Even for this simple example of two buildings, the handling of the roof for the aggregation of 3D building models proves to be very difficult and offers many shape variations as possible results. Not all are possible to generate with the presented algorithm. In our opinion, the resulting roof type should at least be the same as the most dominant one of the original buildings. General shapes that are correct from an algorithmic point of view, but are not a shape that resembles a real roof shape are not acceptable. It is therefore suggested to use parameterized roof shapes as presented in (Kada, 2007). Here, the roof types of the original model are determined and the most dominant one given to the generalized version. The advantage is, that the roof shapes can be defined to produce all the results as seen in this subsection, so that different applications can get specific models.

5. CONCLUSION

The presented extension of the generalization algorithm for 3D building models allows for a more reliable classification of cells into building and non-building cells for both the simplification of single buildings as well as blocks of buildings. Due to the morphological operations on their raster representations, an aggregation of spaced out buildings is now possible. One limitation is, however, that the repeated execution of the morphological operations can change the shape of the boundaries. The data sets need therefore be first rotated in order for their main direction to be aligned according to the edges of the structuring element. This is most often possible with ground plans and therefore leads to good results for this part of the algorithm. The problem does remain for the handling of roof structures. If the roof does not form valleys, it is not apparent and the algorithm has shown to produce valid results. In the other cases it is still unclear what a correct result should look like. This has been discussed and some possibilities for the aggregation of such roofs with valleys presented. The use of parameterized roof shapes seems to be a promising solution that offers a high degree of freedom to adjust to different application fields.

6. REFERENCES

Anders, K.-H., 2005. Level of Detail Generation of 3D Building Groups by Aggregation and Typification. In: *Proceedings of the XXII International Cartographic Conference*, La Coruna, Spain.

Coors, V., 2001. Feature-Preserving Simplification in Web-Based 3D-GIS. In: *Proceedings of the 1st International Symposium on Smart Graphics*. Hawthorne, USA, pp 22-28.

Foley, J., van Dam, A., Feiner, S., Hughes, J., 1990. *Computer Graphics: Principles and Practice (2nd Edition)*, Addison-Wesley.

Forberg, A., 2004. Generalization of 3D Building Data based on a Scale-Space Approach. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Istanbul, Turkey, Vol. XXXV, Part B, pp. 195-199.

Glander, T., Döllner, J., 2009. Abstract Representations for Interactive Visualization of Virtual 3D City Models. In: *Computer, Environment and Urban Systems*, Vol. 33 (5), pp. 375-387.

Kada, M., 2002. Automatic Generalisation of 3D Building Models. In: *Proceedings of the Joint International Symposium on Geospatial Theory, Processing and Applications*, Ottawa, Canada.

Kada, M., 2007. Scale-Dependent Simplification of 3D Building Models Based on Cell Decomposition and Primitive Instancing. In: *Proceedings of the International Conference on Spatial Information Theory: COSIT '07*, Melbourne, Australia, pp. 222-237.

Kada, M., Luo, F., 2006. Generalisation of Building Ground Plans using Half-Spaces. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVI Part 4.

Li, Z., 1996. Transformation of Spatial Representation in Scale Dimension: A New Paradigm for Digital Generalization of Spatial Data. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXI, Part B3, Vienna, Austria, pp. 453-458.

Mayer, H., 1998. Model-Generalization of Building Outlines Based on Scale-Spaces And Scale-Space Events. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXII, Part 3, Columbus, Ohio, USA, pp. 530-536.

Poupeau, B., Ruas, A., 2007. A Crystallographic Approach to Simplify 3D Building. In: *Proceedings of the 23rd International Cartographic Conference*, Moscow, Russia.

Rau, J.Y., Chen, L.C., Tsai, F., Hsiao, K.H., Hsu, W.C., 2006. Automatic Generation of Pseudo Continuous LoDs for 3D Polyhedral Building Model. In: *Innovations in 3D Geo Information Systems*, Springer Verlag, Berlin.

Serra, J., 1982. *Image Analysis and Mathematical Morphology*. Academic Press, London.

Thiemann. F, Sester, M., 2004. Segmentation of Buildings for 3D-Generalisation. In: *Working Paper of the ICA Workshop on Generalisation and Multiple Representation*, Leicester, UK.

Thiemann. F, Sester, M., 2006. 3D-Symbolization using Adaptive Templates. In: *Proceedings of the GICON*, Wien, Austria.