# LEVEL OF DETAIL GENERATION OF 3D BUILDING GROUPS BY AGGREGATION AND TYPIFICATION

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## ABSTRACT

The real-time visualisation of 3D city models requires the representation of the buildings in different levels of detail (LoD). This LoDs should be generated automatically by specific generalisation procedures. In this article we propose two approaches which extents cartographic generalisation algorithm for the application to 3D building groups generalisation. The problem of generalisation of object groups leads directly to the topic of aggregation and typification. Typification denotes the process of replacing a number of objects in a group by a smaller number of new objects, while leaving the main visual structure unchanged. We describe a typification approach which is able to detect grid like building structures to preserve this structure when reducing the number of involved objects. For the aggregation of 3D building groups we describe an approach based on the 2D aggregation program CHANGE.

## INTRODUCTION

The fast visualisation of large 3D city models requires the representation of the buildings in different levels of detail (LoD). This LoDs should be generated automatically by specific generalisation procedures. Nowadays the main focus of research in 3D building generalisation is on the generalisation of single buildings (Thiemann 2003, Forberg 2004, Thieman and Sester 2004, Kada 2005). However less research activities can be found on the topic of aggregation and typification of 3D building groups. Typification denotes the process of replacing a number of objects by a smaller number of new objects. Simplifying each building by itself is one big step to reduce the number of surfaces to be displayed, but we can continue to reduce the number of surfaces if we take into account that the visible distance between buildings depends on the viewing distance. That means we have to aggregate building geometries if they are too narrow to distinguish between them. The result of the aggregation is a reduced number of building objects and yet another reduction of the number of building surfaces. Current methods to generate different LoDs like edge collapsing, vertex clustering or wavelet transformations work well for all kind of singular objects. The main drawback of all this approaches is that they ignore the structure of architectural data, which is very important for the visualisation of large city models. The institute of cartography and geoinformatics (ikg) at the university of Hannover has experience since a long time in map generalisation of building ground plans by rule based approaches (software CHANGE) and least square adjustment approaches (Sester 2000). In this work we describe an extension of these 2D approaches to 3D objects, which is based on the aggregation of 2D projections of the 3D objects. For typification we can directly adopt approaches from 2D map generalisation. We describe a typification approach based on the so called *relative neighbourhood graph* (RNG) which is usable to detect grid structures in building groups.

## TYPIFICATION

Generalisation is needed in order to limit the amount of information on a map by enhancing the important information and dropping the unimportant one. Triggers for generalisation are on the one hand limited space to present all the information and on the other hand but also the fact that different scales of an object are needed in order to reveal its internal structure. Typification is a generalisation operation that replaces a large number of similar objects by a small number – while ensuring that the typical spatial structure of the objects is preserved. Consider e.g. a set of buildings in a city: when looking at this spatial situation at a different scale or resolution, the typical distribution and structure of the buildings should still be preserved. In general there are two classes of typification approaches:

- typification with structural knowledge and
- typification without structural knowledge.

Approaches with structural knowledge try to detect geometrical structures in the object groups which should be preserved by the generalisation process. Typification for linear structures is proposed by (Regnauld 1996). Based on a minimum spanning tree (MST) clustering groups are detected; then the relevant objects within these groups are replaced by typical exemplars. This approach for building typification is motivated by the phenomenological property of buildings being aligned along streets – thus a one-dimensional approach is feasible. Another approach which tries to find linear building structures is described in (Christophe and Ruas 2002). In (Anders and Sester 2000) we describe an approach to detect two dimensional structures, but in contrast to the following described algorithm we don't consider the inner structure of the found cluster. The above described clustering is applied to buildings, thus delineating buildings clusters, and their respective densities (or mean distances, respectively). After clustering, the number of objects within the clusters has to be reduced. The reduction factor can be derived using e.g. the black-and-white–ratio, which is to be preserved before and after generalization, or Töpfer's radical law. The problem now is to decide *which* object has to be removed. This question is decisive, since the removal of one object results in gaps.

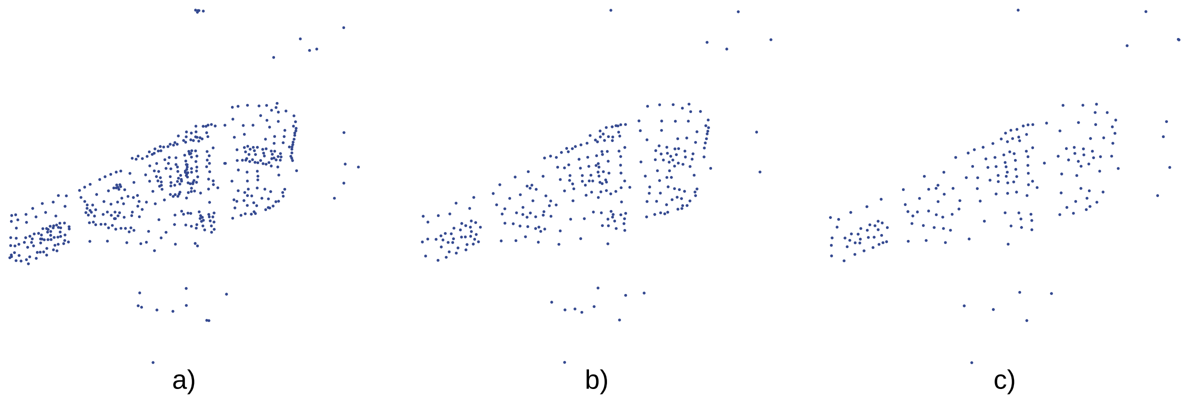
a) b) c)

Figure 1: Reduction of a larger data set (a): reduction to 60% (b) and 40% (c)

Approaches without explicit structural knowledge try to preserve the overall distribution and structure. (Müller and Wang 1992) use mathematical morphology to typify natural areal objects. Their principle is to enhance big objects and reduce small ones – unless they are important. (Sester and Brenner 2000) describe an approach based on Kohonen Feature Maps. Kohonen Feature Maps are self organising maps which try to preserve the original structure by moving the remaining objects in the direction of the removed one to minimise a certain error measure. In most cases this approach produces excellent results (Figures 1). The drawback of the approaches without structural knowledge is that dominant structures, like linear or grid structures are often destroyed. In cases of regular structures like grids, the approach presented in this paper will be needed (Figure 2).

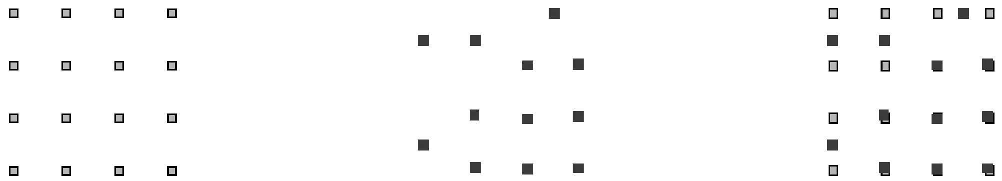
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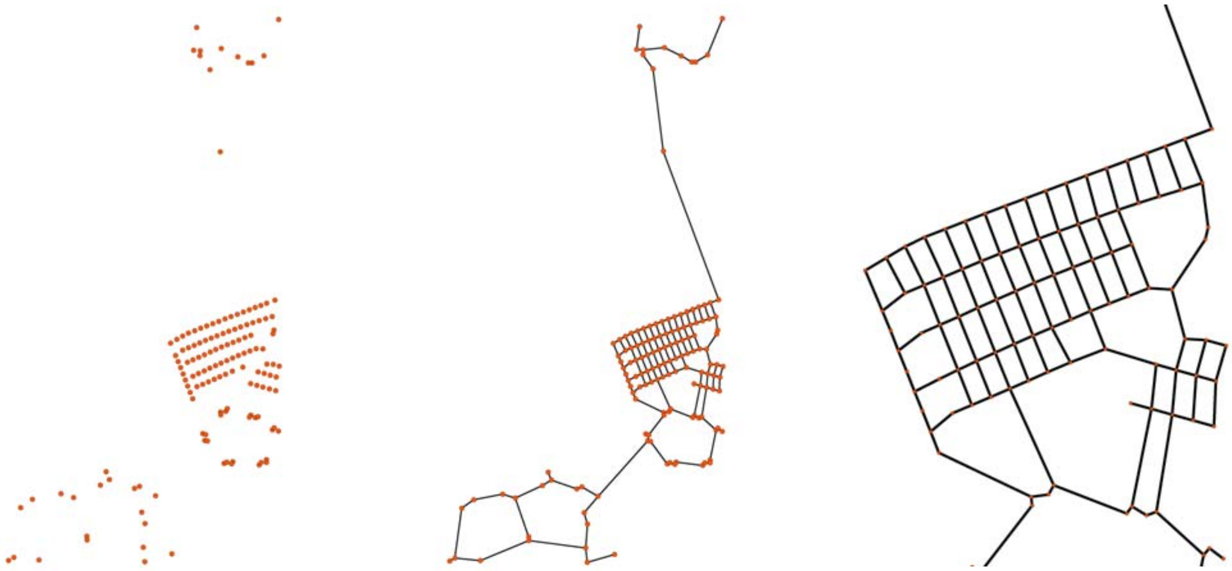
Figure 2: Regular grid structure of objects, which cannot be preserved: initial situation (a), result (b), overlay of initial situation and result (c).

## Grid Detection

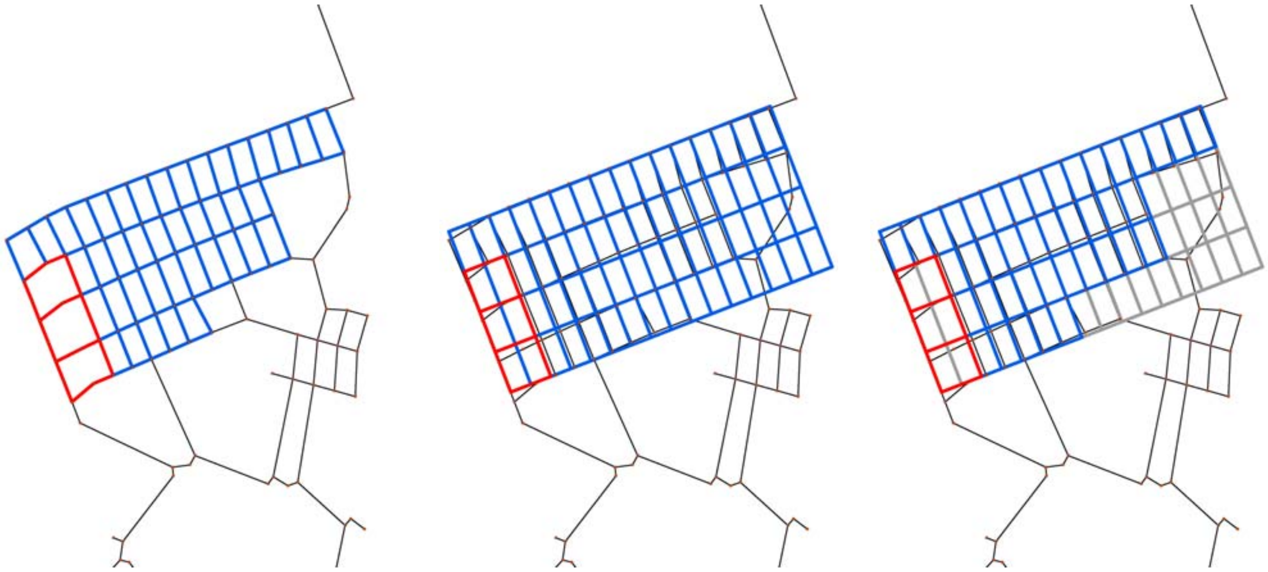
Our approach is using structural knowledge in terms of grids. With grids we mean regular lattice-like layout of buildings. More precisely the grid layout of the ground plan centroids (figure 3a). In a grid structure every building belongs to two linear structures which has to be preserved if possible. Like (Regnault 1996) we are using a neighbourhood graph to detect the grid structures. In place of using a minimal spanning tree (MST) we are using the relative neighbourhood graph (RNG) (Toussaint 1980). RNGs capture very well the inner structure of point sets, especially for the detection of grid like graph structures (figure 3b). The MST is better useful for pure linear structures because in regular grid structures (equal distance between points) there is no unique MST. The MST for instance is a subset of the RNG. A general introduction to the subject of Neighbourhood graphs is given in (Jaromczyk and Toussaint 1992) and (Anders 2004).



a) b) c)

Fig. 3: a) Building centroids. b) The associated RNG. c) Section of the RNG in b)

Built settlements based on development schemes frequently show a straight-line orientation. Groups of such linear structures can have a grid structure (Figure 3a). A grid is characterised by a set of mostly parallel lines, which are crossed by a second set of parallel lines. Frequently the sets of parallels intersect themselves approximately right-angled, this is however no compelling characteristic of a grid. Further characteristics of grid structures are rectangular or parallelogram-similar shape of the grid surfaces, straightness of the parallel line set, the convexity of the surfaces, a relatively constant side length relationship as well as a similar area of the rectangles. In practice the grid structures show rarely such "optimal" or ideal properties. Nevertheless the above mentioned characteristics can be recovered in the data with appropriate deviations. According to the characteristics pointed out above we use an algorithm described in (Heinzle, Anders, and Sester 2005). Starting point for the algorithm are so called cross-nodes, at which four edges are crossing almost at right angle. Polygons belonging to such cross-nodes are potentially candidates for a grid if they meet the above mentioned different criteria. Briefly described the similarity of a grid polygon candidate to its neighbour polygons is regarded, the surface size of the grid polygons are compared, and the convexity of the surfaces is examined. When we consider the example RNG shown in figure 3c) this algorithm finds two grid structures (Figure 4a).



a) Detected irregular grid structures. b) Regular grids c) Unused grid elements in grey.

Fig. 4: Detected grid structures (red grid 1and blue grid 2) and grid cleaning.

## Grid Cleaning

The above detected grids are of course not perfect regular (Figure 4a). However our grid model describes perfect regular and complete grids which means in detail that we consider an oriented (m x n)-matrix with m rows and n columns. We think that complete regular grid models are better useful for generalisation purposes. The origin of the grid is the lower left node. The orientation of the grid is determined by the minimal enclosing rectangle (Freeman and Shapira 1975, Toussaint 1983) of all points (building centroids) belonging to the detected grid. The number of rows and columns can be derived directly from the graph of the detected grid structure. The rows and columns are distributed along the minimal enclosing rectangle. The result of this cleaning is shown in figure 4b). In this example we have found a 4 x 2 grid and a 5 x 17 grid. In our grid model it is also stored which grid nodes are not used, which means there is no associated building centroid. The grey lines in figure 4c) visualise the unused part of the detected blue 5 x 17 grid structure.

## Grid Reduction

The cleaned grid structures are the input to the typification process. The reduction of elements in a grid is a discrete problem where we can not remove simply single centroids. If we would do that the grid structure will be destroyed. In the case of grid reduction we can only reduce the number of rows and columns. The reduction of the rows and columns is not solvable in a unique way. The left image in figure 5 shows the reduction to 40 percent of the number of rows and columns by a simple sampling process starting at the origin of the grid. Figure 6b) shows the result with unchanged centroid positions. In general after the sampling the distance between the centroids in row and column direction should be adjusted equally. That was not done in the presented figure 6 because in this work the focus was on grid detection. If the enclosing area of the grid should remain one needs a symmetrical sampling process which starts from both sides of the rows and the columns (see right image in figure 5). The result of this approach is shown in figure 6c). Figure 6a) shows a reduction about 25 percent of the rows and columns where both grid structures from figure 4 are still visible. After the sampling process the determined structure can be moved and scaled to fit the desired generalisation constraints.

We think the described approach will be very helpful for the segmentation of point sets in irregular and regular structured areas. For the irregular areas typification processes like the described one by (Sester 2000, Sester and Brenner 2000) are very well appropriated. In the case of regular structures other approaches have to be used to leave the dominant regular structure unchanged.

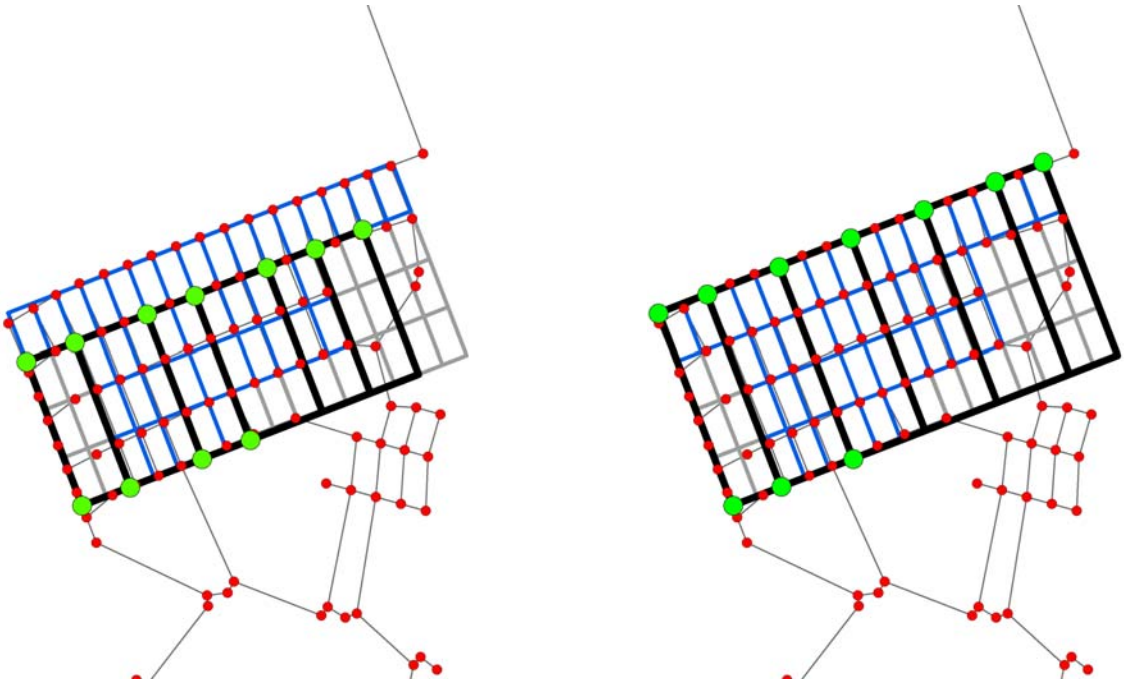
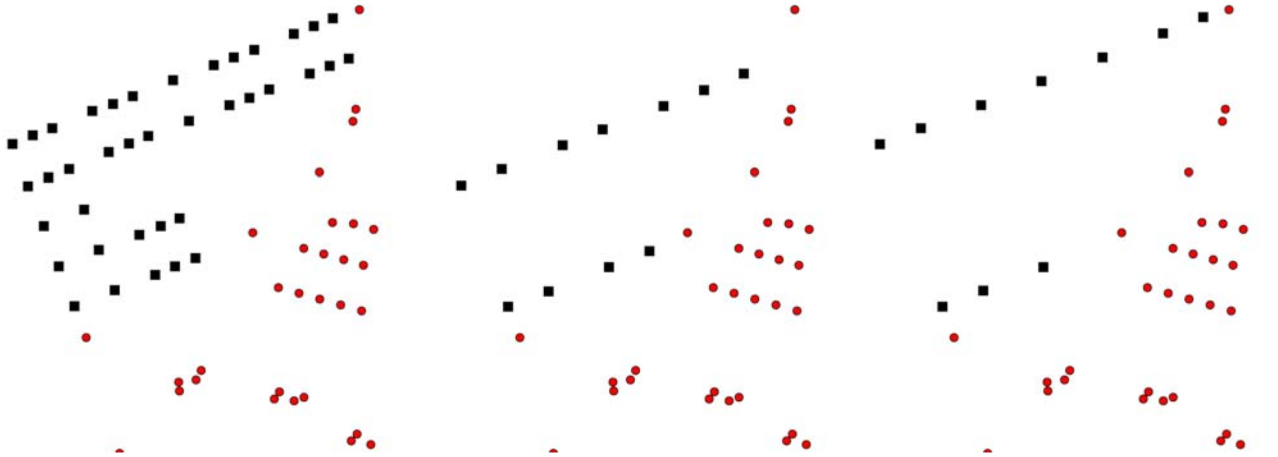


Fig. 5: Two possible samplings of grid 2.



a) 25% reduction of rows and columns by symmetrical sampling. b) 60% reduction of rows and columns by simple sampling. c) 60% reduction of rows and columns by symmetrical sampling.

Figure 6: Sampling results of the detected grid structures.

## AGGREGATION

The aggregation and simplification of 2D geometries is a well known problem in cartography. At our institute the program CHANGE was developed to generalise building ground plans for topographic maps in the scale from 1:5.000 up to 1:25.000. CHANGE aggregates and simplifies ground plan polygons and prevents the main architectural structure as far as possible (Figure 7). In case of real-time visualisation of large city models one has to generate different LoDs to reduce the number of geometry objects to be displayed without losing the architectural structure. That means one has to generalise the ground plans and the skylines of building groups in an appropriate way. In general the roof structures in large cities can be very complex. The two examples in figure 8 show that this generalisation task is a big challenge.

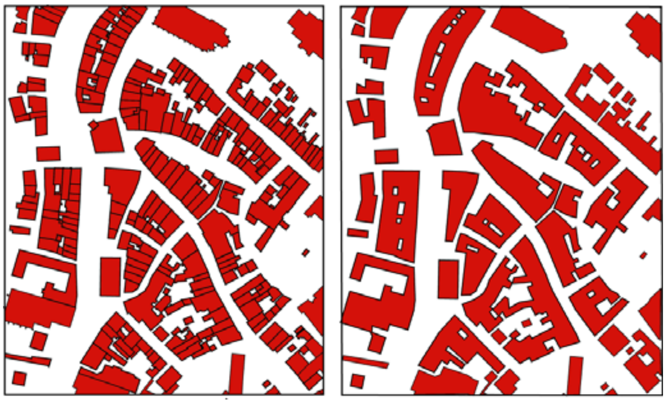


Fig. 7: 2D Ground plan aggregation and simplification with the program CHANGE. Left original data and right result.

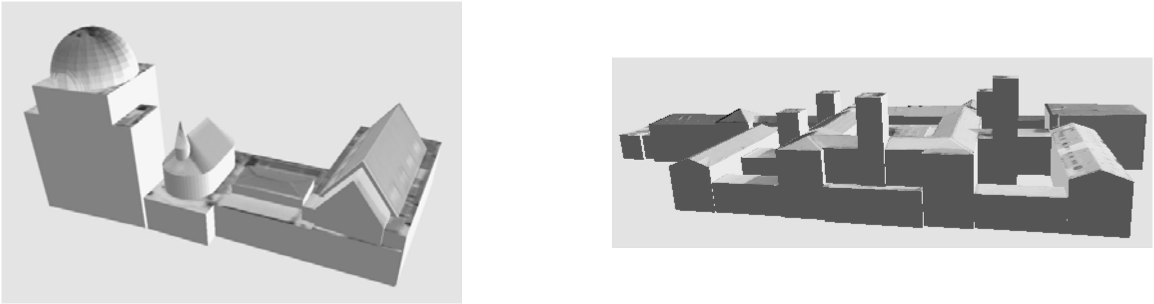
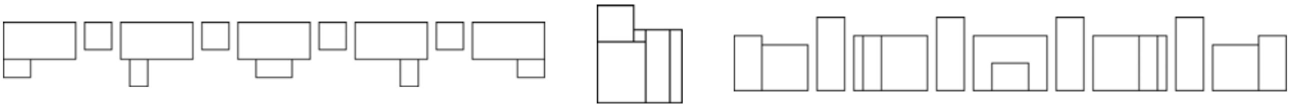


Fig. 8: Two examples for complex roof structures of building groups.

In the following we describe a first simple approach for the 3D generalisation of building groups. In the case of linear building groups (Figure 10) we use the program CHANGE to aggregate and simplify 3D building geometries by applying the following approach:

1. Compute the minimal bounding box of the building group using all points of the building geometries (Barequet and Har-Peled 1999).
2. The length, width, and height of the bounding box defines the three projection-directions L, W, and H.
3. Create the orthogonal projection (OP) along length (OPL), width (OPW), and height (OPH) (Figure 9).
4. Use the program CHANGE to generalise the three projections (Figure 11).
5. Extrude the 2D geometries OPL, OPW, and OPH along W, L, and H (Figure 12).
6. The generalised 3D building group is computed by the intersection of the extruded geometries (Figure 13).

This approach shows that we can reduce the generalisation problem of 3D building groups to the well known 2D problem. The achieved results are very promising, but of course there are some drawbacks in this simple approach. If the overall structure of a building group is very unsymmetrical the result will be not very well. In our approach the structure of the projected geometries specify the structure of the 3D generalisation. That means details behind the projection plane are getting lost. Therefore the result depends on the chosen projection direction, which is not so critical for symmetrical structures.



a) b) c)

Fig. 9: 2D building projections. a) Ground projection OPH, b) Side projection OPW, c) Front projection OPL.

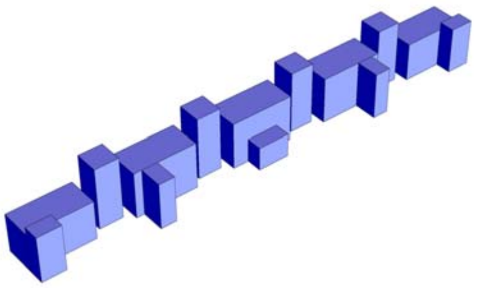


Fig. 10: 3D Building group.

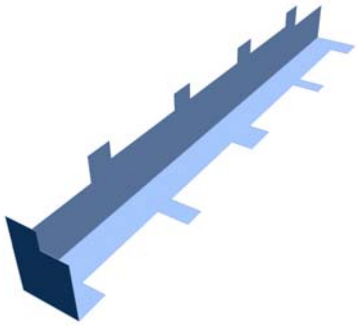


Fig. 11: Generalised projections from figure 9.

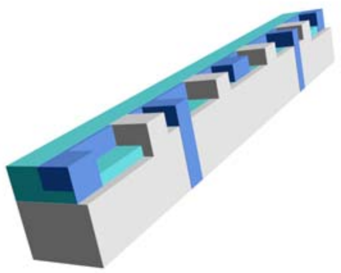


Fig. 12: 3D extrusion of the generalised projections.

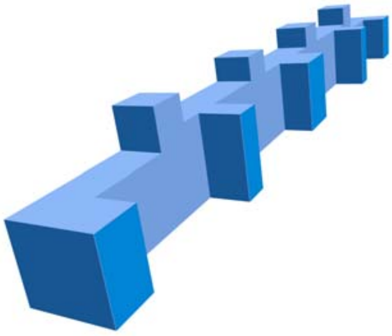


Fig. 13: Intersection of the extruded projections.

## CONCLUSION AND OUTLOOK

We have mentioned that cartographic generalisation methods like aggregation and typification are also very important for the real-time visualisation of 3D city models. In this work we have shown that the relative neighbour graph is very well applicable to detect grid like structures. In the current work we have considered only the spatial alignment of buildings. In future we will extend this approach to 3D grid structures. In this 3D grid structures the third dimension will represent important properties of a building. Such properties could be for example the building height, roof type, or building type. That will allow us to preserve not only the spatial alignment, but also other typical architectural properties of building groups after the generalisation. We have also shown that we can use 2D generalisation programs like CHANGE for 3D generalisation by an appropriate projection of the 3D building geometries. It has also shown that this approach is useful only for linear building groups, which have a symmetrical structure along the projection directions. Otherwise the asymmetrical structure can get lost by this approach. However we think the loss of asymmetrical structures is not so important for the visualisation of generalised background buildings. For now we can handle only flat roofs. The appropriate handling of more complex roofs in the aggregation process is an important problem for future work.

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## BIOGRAPHY

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