

# GENERALISATION OF BUILDING GROUND PLANS USING HALF-SPACES

Martin Kada, Fen Luo

Institute for Photogrammetry (ifp), Universität Stuttgart  
Geschwister-Scholl-Str. 24D, 70174 Stuttgart, Germany  
forename.lastname@ifp.uni-stuttgart.de

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## ABSTRACT:

In this paper, a new approach is presented for the simplification or rather generalisation of building ground plans that are represented as 2D line segments. It is based on half-space modelling and cell decomposition, techniques from the field of computer graphics. As it is important to preserve the overall characteristics of the buildings, the lines are geometrically simplified with regard to geometric relations like orthogonality and parallelism. These characteristics allow for an easy recognition of buildings even on small displays of mobile devices. Such equipment has become a tool for our everyday life in the form of mobile phones, personal digital assistants and GPS assisted navigation systems. Although the computing performance and network bandwidth will increase further, such devices will always be limited by the rather small display area that can be used to communicate the spatial information. This means that an appropriate transformation and visualisation of building data as presented in this paper is essential.

## 1. INTRODUCTION

With the widespread availability of mobile devices and network connectivity, new applications have emerged in recent years. Very popular examples are the navigation systems that are bundled with personal digital assistants (PDA) and also become standard equipment for cars. Although the computing performance and network bandwidth will further increase, such systems will always be limited by the rather small displays to communicate the spatial information that is needed by the user. Increasing the screen resolution does not improve the situation. It might lead to higher quality images of the rasterised vector data, but small structures will still be too small to recognize and will only disturb the viewer in perceiving the necessary situational information. This means that even though the technical requirements can easily be fulfilled, the focus must be on the appropriate transformation and presentation of the data.

The work presented in this paper is the simplification of 2D building ground plans. Major work has already been done in this field, which is generally known as cartographic generalisation. As building ground plans have special characteristics, their generalisation differs considerably from common line simplification. Even though algorithms have been proposed for raster data (Su et al., 1997) (Camara et al., 2005), most work has been done for vector representations where the ground plan is defined as a polygonal line. (Mayer, 1998) presented an approach in which scale-space-theory was extended to vector data in order to simplify building outlines.

The generalisation of lines is the geometrical simplification with regard to geometric relations like orthogonality and parallelism of the line segments. It is also very important that such algorithms preserve the overall characteristic of the building so that they can still be easily recognized by the viewer. Well known algorithms like (Staufenbiehl, 1973) or (Sester, 2001) formulate explicit set of rules for the detection and simplification of small structures. Other approaches use methods from pattern recognition to replace the original ground plan data by a standard shape (Meyer, 1989) (Rainsford and Mackaness, 2002).

A common problem is however, that these algorithms depend more or less on rectangular line segments, which is a property

not guaranteed for all real world buildings. So a new approach is presented in this paper for the generalisation of building ground plans represented as 2D line segments. The approach is based on half-space modelling and cell decomposition, techniques from the field of computer graphics. In half-space modelling, a rectangle is e.g. generated by trimming the infinite space using four straight lines. The lines would also be called half-space primitives. Assuming the normal vector of the straight line points out of the object, the rectangle or building ground plan is on the negative side of all four lines. The concept can be taken further for more than four lines to model any type of convex shape. If a concave shape is to be build, the resulting ground plan object is not on the negative side of all lines anymore. The cutting generates a set of fragments, or in our case we call them cells, for which we need to determine which subset belongs to the resulting shape.

## 2. ALGORITHM

The basic idea of the generalisation algorithm is as follows: if all lines from the ground plan are used as half-space primitives, the resulting set of cells has the same shape as the input model (Figure 1 top). So the number of half-space primitives must be reduced somehow to achieve a simplification (Figure 1 bottom).

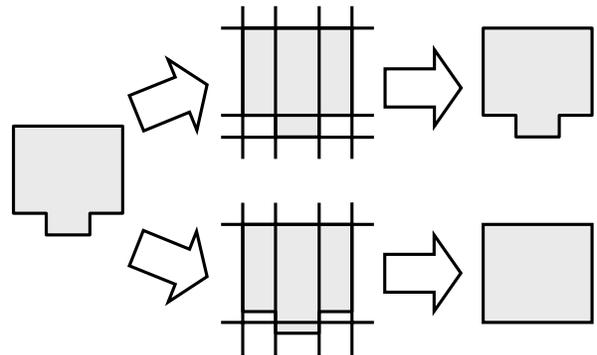


Figure 1. 2D building ground plan (left), cell decompositions (middle) and final ground plan (right).

### 2.1 Half-Space Generation

The reduction of the half-space primitives is the first step of the algorithm. Initially, each half-space is aligned with one or more line segments that lie on the same straight line. Then the half-space primitives are merged with the help of buffers and by pair-wise comparison of the straight lines. If the distance between both straight lines are under a tolerance value and they are almost parallel, then the two straight lines are merged together. The result of the merge is a buffer region in between the two parallel straight lines. If there are short line segments of the building ground plan that lie inside that buffer region, then those line segments are also included into that buffer without consideration of their orientation (Figure 2 middle). Protrusions and small structural elements are therefore included in those buffers and the number of half-space primitives is reduced. This process is repeated until there are no more candidates that can be merged anymore and the result is a minimal set of half-space primitives. For each line buffer, a new half-space primitive is now generated by averaging the location and orientation of all the included line segments (Figure 2 bottom). Thus, the new half-space primitive approximates part of the building ground plan.

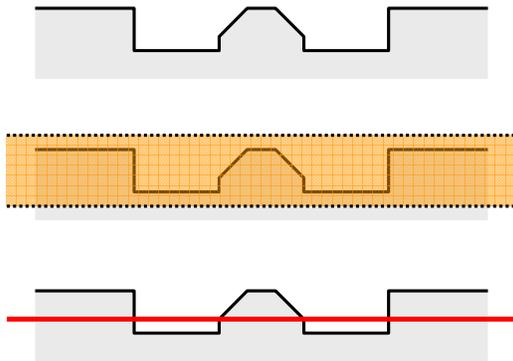


Figure 2. Section of a building ground plan (top), the straight line buffer region (middle) and the resulting half-space primitive (bottom).

In order to keep the number of half-space primitives small, line segments with opposite orientation, which is determined by their normal vector, are linked to the same half-space primitive. The benefit of this approach is that opposing line segments under a certain threshold distance will be made coplanar or even merge together (see Figure 3).

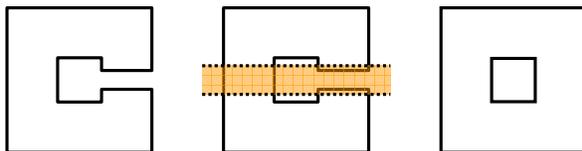


Figure 3. Line segments with opposite directed normal vectors are linked to the same half-space primitive and therefore merge together.

To limit the number of half-space primitives, all buffers that include lines with a total length shorter than the generalisation threshold are removed from further processing.

As right-angles and parallelism need to be preserved in the generalised building ground plan, the half-space primitives are analysed accordingly. If the angle of the straight lines from two or more half-space primitives is found to be below a certain threshold, these primitives are made rectangular or parallel, respectively.

### 2.2 Cell Decomposition

After the line equations of the half-space primitives have all been determined, they are then used to generate a cell decomposition of the building model. For this purpose, an infinite 2D space is subdivided brute force by the half-space primitives (see Figure 4). In practice, an infinite space is unsuitable, so a solid two times the size of the building's bounding rectangle is used as a substitute. The resulting cells are convex 2D polygons.

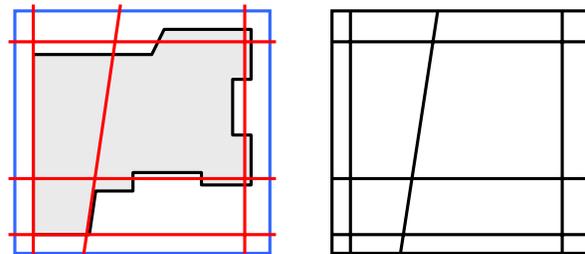


Figure 4. Building ground plan with red half-space primitives (left) and the resulting cell decomposition (right).

### 2.3 Cell Identification

From the decomposition process, it is not possible to identify the cells that belong to the generalised ground plan. Therefore, cells must be differentiated in building and non-building cells in the subsequent step. For each cell, a percentage value is calculated that denotes the fraction of building to non-building space. To simplify the process, the value is only approximated: a set of 2D points is equally distributed in the minimum enclosing rectangle of the cell (see Figure 5). Points that lie outside the cell are discarded. The remaining points are tested for inclusion in the original ground plan. Then the fraction of the points inside the ground plan and the overall number of points inside the cell are computed. If this value is under 50%, which denotes the overlap of the cell and the building ground plans, then the cell is discarded. Cells with a high value are considered to be important for the generalised ground plan and therefore kept.

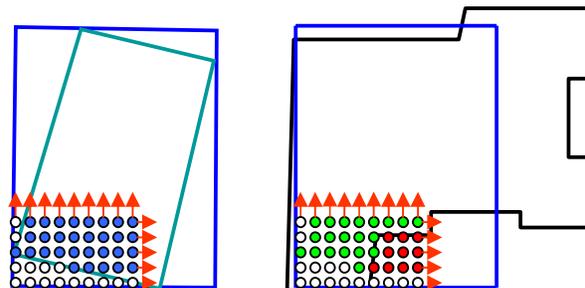


Figure 5. Points inside a cell (blue) are differentiated in points inside (green) and outside (red) the ground plan.

### 2.4 Ground Plan Generation

Once the building cells have been identified, the shape of the simplified ground plan is generated by a union operation on all remaining cells. As the cells do not intersect one another, the operation is as simple as gluing the cells together (see Figure 6).

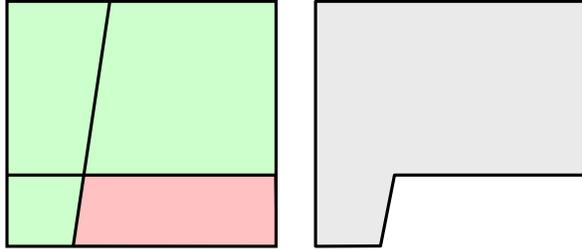


Figure 6. Non-building cells (red) are discarded. Building cells (green) are glued together to form the shape of the generalised ground plan (grey).

However, sometimes small elements are classified wrong and do disturb the appearance of the ground plane. This happens especially for very small cells. These wrong elements can be identified by looking at two consecutive line segments of the generalised ground plan. If the distance between the line points are under the generalisation criteria, then both line segments are removed and replaced by a new line segment (see Figure 7).

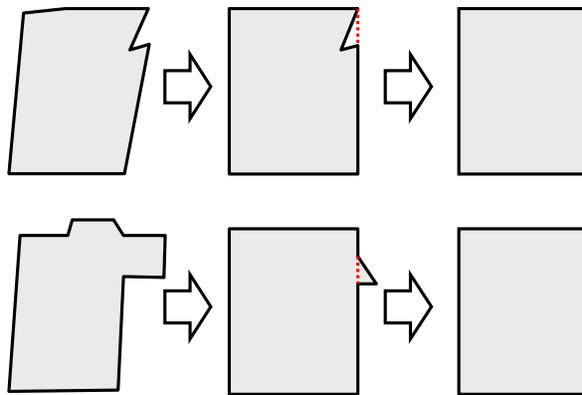


Figure 7. A replacement takes place if the connection of two consecutive lines (red dotted line) is shorter than the generalisation threshold.

### 3. RESULTS

The algorithm has been implemented for individual building objects with C# using ArcObjects in order to directly import and export ground plans from the ArcGIS shape files. We have tested it with a dataset of 1305 building ground plans from the city centre of Stuttgart. The urban area includes a wide area of different shapes. As can be seen in the following figures, the algorithm shows good results even for very complex shapes. However, for roughly 2% of the objects, incorrect ground plans were produced. Figure 8a-d shows a section of the generalised vector map with generalisation thresholds of 2m, 5m and 10m.



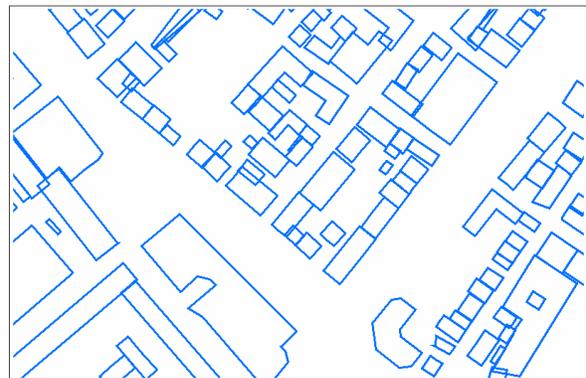
(a)



(b)



(c)



(d)

Figure 8. Original (a) and generalised ground plans at 2m (b), 5m (c) and 10m (d) generalisation threshold.

The complexity, measured in number of vertices, could be reduced significantly for the data set without disturbing the appearance of the ground plans. For example, the ground plan of the prominent New Palace of Stuttgart has 601 vertices while the simplified version only has 20 vertices left. Nevertheless, the characteristic of the original shape can still be recognized very well (Figure 9). Also see Figure 10 for close-up views of more results. Although no code optimisations were done, the processing of the test data, which included loading and saving, took less than a minute.

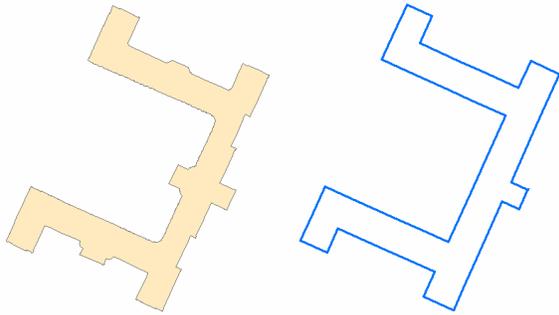


Figure 9. Original (left) and generalised (right) ground plan of the prominent New Castle of Stuttgart.

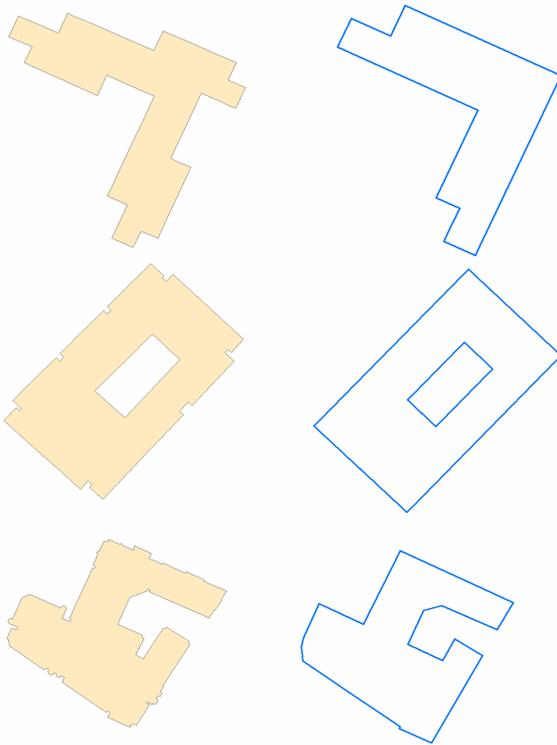


Figure 10. Example building ground plans in their original (left) and generalised (right) shape.

#### 4. CONCLUSION

We have presented a new generalisation approach for 2D building ground plans, which is algorithmically simple, needs

no explicit simplification operators and is not limited to certain shapes. Also, no further information like the orientation of the building is needed. The implementation proved to be stable and fast, so that interactive applications are possible. The geometric simplification is controlled by an easy to understand generalisation parameter, which acts as a buffer size for the generation of the half-space primitives.

However, there is still room for improvement. Due to the isolated processing of the single building ground plans, the resulting objects do sometimes intersect. This suggests that all ground plans of a building block should be processed at once. Also, the algorithm is unable to preserve curved lines as only straight lines are used as half-space primitives. So these building features are not preserved very well in the generalised building ground plans.

#### 5. ACKNOWLEDGEMENT

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