A generic approach for simplification of building ground plan

Hongchao Fan and Liqiu Meng

International Graduate School of Science and Engineering
Department of Cartography, Technische Universität München
Arcisstr. 21, 80333 Munich, Germany
{fan, meng}@bv.tum.de

Abstract
In cartography, a number of methods for the simplification or generalization of building ground plans have been developed. They are mainly focused on preserving and enhancing the properties of buildings like right angles or parallelism. Few methods can handle ground plans of buildings with complex geometrical forms, i.e. non-rectangular, non parallel shapes, long narrow angles. This paper presents a generic approach which can simplify ground plans with arbitrary shapes. The algorithm is implemented and tested for a large data set. The test shows our approach can provide good results by giving a predefined threshold. Moreover, the algorithm is very efficient.

1. Introduction

The simplification of ground plan is a well-established operation in cartography: the details of ground plan get less and less differentiable with the decreasing spatial scale. Therefore, ground plans have to be simplified. On the other hand, ground plans might contain much data redundancy due to the used techniques for data acquisition, for example, when they are extracted from LIDAR data (Neidhart and Sester, 2008).

Since Staufenbiel (1973) proposed a rule-based approach for the simplification of 2D building ground plan, a number of algorithms have been made available in this research field. Most of algorithms (e.g. Lamy et al. 1999, Rainsford and Mackaness 2001, Regnauld 2001, Van Kreveld 2001) were developed which allows the removal of line segments under a predefined length by extending and crossing their neighbouring segments according to some criteria, i.e. minimum length of a facade. For instance, Sester (2000, 2005) proposed a two-step procedure: (i) removing the minimal forms by applying rules i.e. a mere intersection of neighbouring faces; (ii) maximizing the similarity between the simplified building and the original form using least-squares adjustment. In this second step certain characteristics of the buildings, e.g. rectangularity and parallelism or size can be preserved or even emphasized.

Kada and Luo (2006) used the concept of half space to drastically reduce the complexity of building ground plans. In their approach the overall appearance of the original building ground plan can be good retained. However, artefacts such as self intersections occur sometimes. Haunert and Wolf (2008) proposed to simplify ground plans using graph algorithms and implemented their algorithm that strives for a heuristic solution. In addition, Bayer (2009) developed an automated (or semi-automated) tool for building simplification based on the recursive approach. In his approach Bayer tried to keep the area of the simplified ground plan unchanged, while the shape characteristics of ground plans cannot always be preserved.

In fact, the main objective of simplification of ground plans is the preservation of building characteristics (Sester, 2005). Sester and her colleagues proposed effective algorithm for this issue (Sester, 2000; Sester and Brenner, 2004, Sester 2005). However, in their approach so far, only the rectangular structure is considered. In the reality, the structure of ground plan reveals a vast diversity and may contain many non-rectangular shapes. Even long narrow angles can appear in the structure of a ground plan.

In our current research work, we attempt to generalize 3D buildings using a three-step approach: simplifying wall elements, generalizing roof structures, and then reconstructing the 3D building by intersecting the wall and roof polygons (Fan and Meng, 2010). In the first step, wall elements are simplified by simplifying building ground plans. For this purpose, a generic algorithm has been developed with the intent on handling various ground plans, including the abovementioned complicated shapes.

The process begins with a pre-process for removing the non-characteristic points in footprints. Then the shortest side of a ground plan is compared with a given threshold. It will be removed if it is below the threshold. The gap will be filled depending on the spatial relation of its immediate neighborhoods. If they are parallel, the longer one of the immediate neighborhoods has to be extended to intersect with the neighborhood of the shorter one. If they are not parallel, let them intersect at first. The intersection angle is then compared with an angle threshold. As a result, long narrow angle will be removed if it is smaller than the angle threshold. In this way, the ground plan is simplified.

The paper is structured as follows. Section 2 presents our algorithm of simplification for ground plans. Section 3 demonstrates a number of generalization results and gives evaluations.

2. Algorithm for Simplifying Building Ground Plans

The whole process is composed of two stages: (i) pre-process for the data of the ground plans, and (ii) simplification of ground plan. These will be described in this section respectively.

2.1 The pre-processing

Ground plans of buildings can be acquired using a variety of terrestrial and non terrestrial techniques. Among others, aerial photogrammetry, aerial laser scanning including LIDAR technology, terrestrial measurement and official cadastral information systems have been widely applied. The ground plans that are automatically derived from the data of the abovementioned techniques may contain many non-characteristic or redundant points. For example, many points are collinear or nearly collinear, as shown in Figure 1.

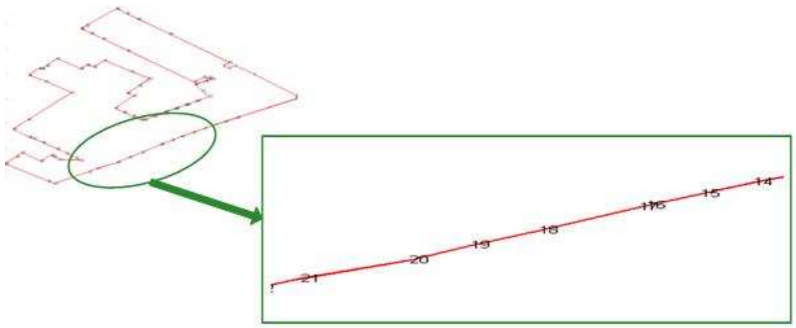


Fig.1. Original ground plan with redundant footprints

The non-characteristic points can be removed as following: (i) for the point P_n, a buffer zone is created with the line $\overline{P_{n-1}P_{n+1}}$ as axis and $2 \cdot \varepsilon$ as the width of the buffer zone (Figure 2); (ii) if the point P_n is located inside of the buffer zone, i.e. the intersection of the red line in Figure 2, it has to be removed; otherwise (i.e. the intersection of the green line in Figure 2), the point P_n will be retained.

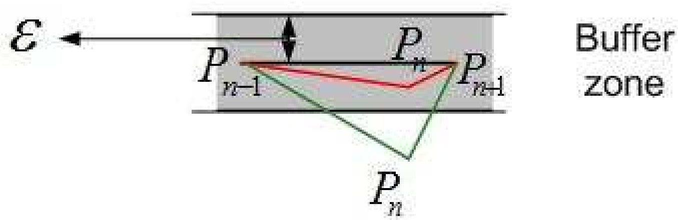


Fig.2. Removing the point located inside of the buffer zone, whereby the width of the buffer zone $2 \cdot \varepsilon$ can be predefined for the given data.

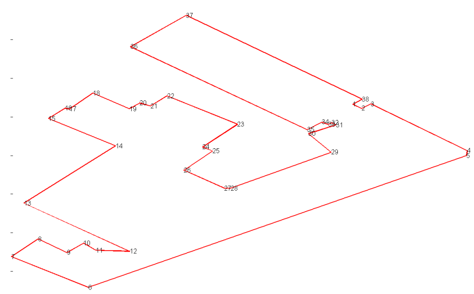


Fig.3. A footprint after removal of non-characteristic points

Figure 3 reveals a cleaned footprint. In comparison with the original one (Figure 1), it is composed of 38 points while the original one is composed of 91 points. The width of the buffer zone is defined as 0.4m. In this pre-processing all the vertices of the ground plans are remained.

2.2 The algorithm of simplification

Prior to the process of simplification lengths of all sides of the ground plan are calculated. First of all the shortest side S_n is identified. If S_n is smaller than the given threshold which is corresponding to a minimum length T_s just visible at a given scale, the simplification operation will be triggered and the two immediate neighbors S_{n-1} and S_{n+1} of S_n are checked in terms of the following two cases:

Case 1: S_{n-1} and S_{n+1} are parallel

In this case, their lengths are compared at first. If S_{n-1} is shorter than S_{n+1}, the side S_{n-2} should be then intersected with S_{n+1}, thus introduce a new vertex P_{in} which becomes the new end point of the side S_{n-2} and start point of S_{n+1}. At the same time, S_n and S_{n-1} have to be removed. Figure 4 illustrates the above described operation with two typical examples.

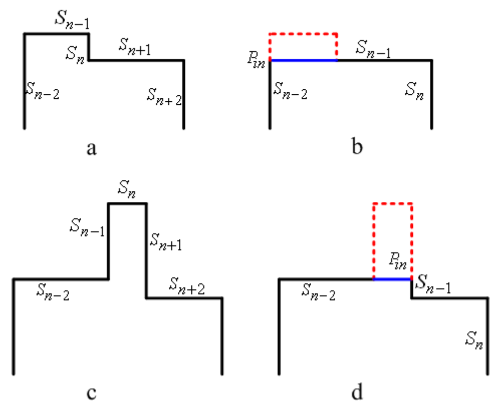


Fig.4. Different parts of a ground plan a) and c) and their simplification results b) and d) after the first iteration

If S_{n-1} is longer than the side S_{n+1}, the new vertex P_{in} is introduced by intersecting S_{n-1} with S_{n+2}, which becomes the new end point of S_{n-1} and start point of S_{n+2}. At the same time S_{n+1} and S_n have to be removed. Figure 5 shows the process with two different examples.

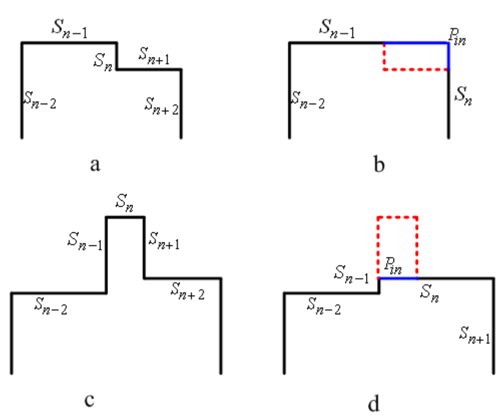


Fig.5. Different parts of a ground plan a) and c) and their simplification results b) and d) after the first iteration

Case 2: S_{n-1} and S_{n+1} are not parallel

In this case S_{n-1} and S_{n+1} must be intersected at P_{in}. The operation to be deployed depends on the topology of P_{in} in relation to S_{n-1} and S_{n+1}:

- If P_{in} lies on S_{n-1} or S_{n+1}, it becomes the new end point of S_{n-1} and start point of S_{n+1}. S_n has to be removed (see Figure 6a -d).

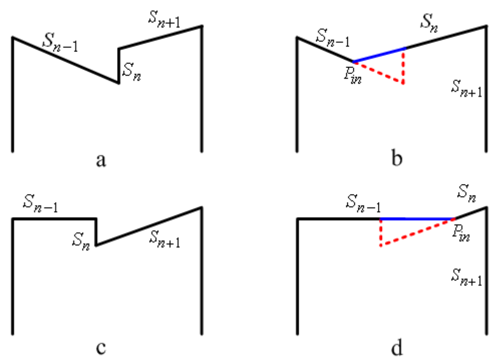


Fig.6. The shortest side is removed by intersecting its flanking neighbors

If P_{in} lies on neither S_{n-1} nor S_{n+1}, the resulted angle α_n with the vertex P_{in} has to be compared with a angle threshold w_s.

Normally, $\alpha_n > w_s$. Then the intersection point P_{in} is the new end point of S_{n-1} and start point of S_{n+1} (Figure 7a and 7b). S_n should be removed.

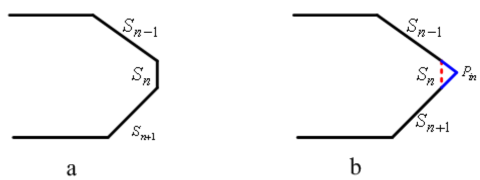


Fig.7. Wide angle as the simplification result

Sometimes the intersection angle might be smaller than the threshold (Figure 8b). In this case, the midpoint of side S_n is set as the new end point of S_{n-1} and start point of S_{n+1} (Figure 8c).

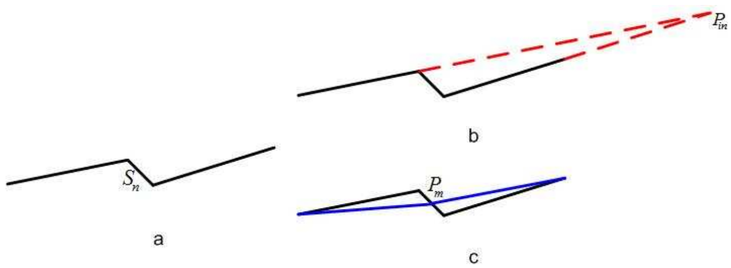


Fig.8. Removal of a sharp angle caused by removal of a short side

After the treatment of the currently shortest side of the ground plan the polygon is newly arranged and the same procedure will be repeated till no side lies below the threshold.

3. Quality assessment by measuring shape similarity

In order to evaluate the results of the algorithm presented in Section 2, we introduce the polygon distance function for the similarity measurement, whereby building ground plans have to be transformed into tangent space.

3.1 The tangent space representation

Traditionally, there are two ways to represent a closed polygon: (i) by giving a list of vertices or (ii) by giving a list of line segments. Alternatively, a polygon can be represented using a list of angle-length pairs, whereby the angle at a vertex is accumulated tangent angle at this point while the corresponding length is the normalized accumulated length of the polygon sides up to this point. Let C be the polygon on the left of Figure 1. The tangent angle at a vertex is $\theta_1 = \varphi_1$. Then $\theta_{i,(i>1)}$ can be calculated as $\theta_i = \theta_{i-1} + \varphi_i$. The right of Figure 1 shows the change of tangent angles (y-axis) along the normalized accumulated length of the polygon sides (x-axis). From this point of view, the tangent angle can be treated as a function of the normalized accumulated length $T_C(l)$. It can be called tangent function or turning function (Arkin et al., 1991).

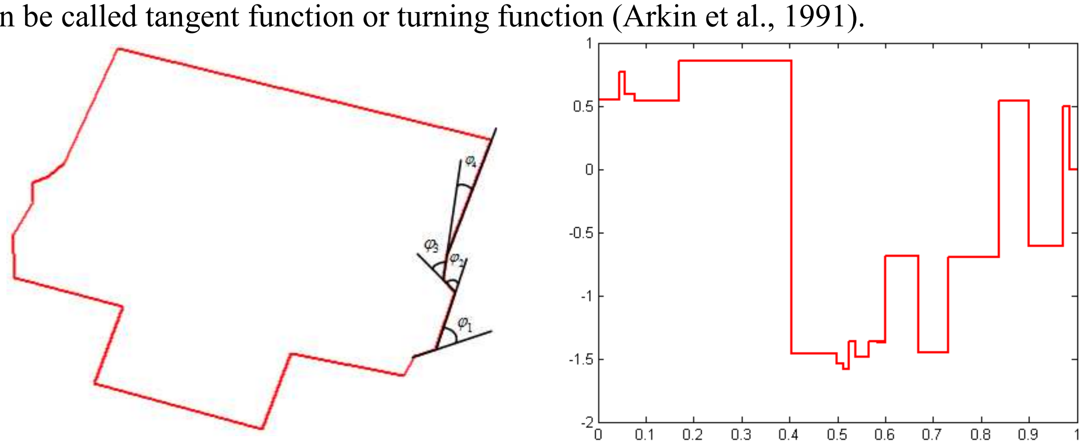


Fig.9. Illustration of tangent space representation of polygon

The function $T_C(l)$ measures the angle of the counter-clockwise tangent as a function of the normalized accumulated length l. The cumulative angle increases with left hand turns and decreases with right hand turns. This kind of representation is invariant to rotation, because it contains no orientation information. Furthermore, it is invariant to scaling, since the normalized length makes it independent to the polygon size.

3.2 The similarity measure

Similarity measures can be derived based on the $L_2 - norm$ of the shape features. In this paper, the similarity of two polygons is defined as the distance between their tangent functions.

$$d(A,B) = \|T_A - T_B\|_2 = \left(\int_0^1 (T_A(s) - T_B(s))^2 ds\right)^{\frac{1}{2}} \tag{1}$$

As abovementioned, the tangent function is invariant to rotation and scaling. In other words, the rotation and scaling are not considered in Equation 1. However, for the quality assessment in ground plan simplification, whether the size can be preserved is an important factor. For this reason, a factor is added using the ratio of the perimeters between the two polygons.

$$S(A,B) = \frac{\max(L_A, L_B)}{\min(L_A, L_B)} \cdot d(A,B) \tag{2}$$

where L_A and L_B are the perimeters of polygon A and B respectively. In order to avoid the translation of the tangent angle in relation to the other one, an identical point pair of the two polygons has to be found out and set as reference point for the calculation of the tangent angles. Note that $S(A,B)$ denotes actually the dissimilarity between A and B. The smaller $S(A,B)$ is, the more similar are the two polygons. In the case A is identical to B, there is $S(A,B) = 0$.

4. Implementation and experimental results

The above presented algorithm has been implemented using Matlab (version Matlab 7.4). The platform is a PC with Inter(R) 3.33GHz Xeon(R) CPU, 4.00GB RAM (3.49GB usable), and Microsoft Windows 7 Professional x86 (32bit).

The algorithm for simplifying building ground plan has been tested for large dataset in Munich. Totally, there are 64698 ground plans in our test bed - the city of Munich. The computation time for the whole dataset varies depending on the defined threshold. We tested the algorithm by setting different thresholds. Table 1 lists the thresholds (in meter) in our test and their corresponding computation time (in second). The average computation time for a single ground plan is about 0.006 second.

Table 1. Thresholds and the required computation time

Threshold	1m	2m	3m	5m	10m	15m	20m
Computation time	336.59 s	361.33 s	367.31 s	373.83 s	395.67 s	392.04 s	389.82 s

Figure 10 shows a ground plan with a complex geometric form and a series of simplification results with different thresholds.

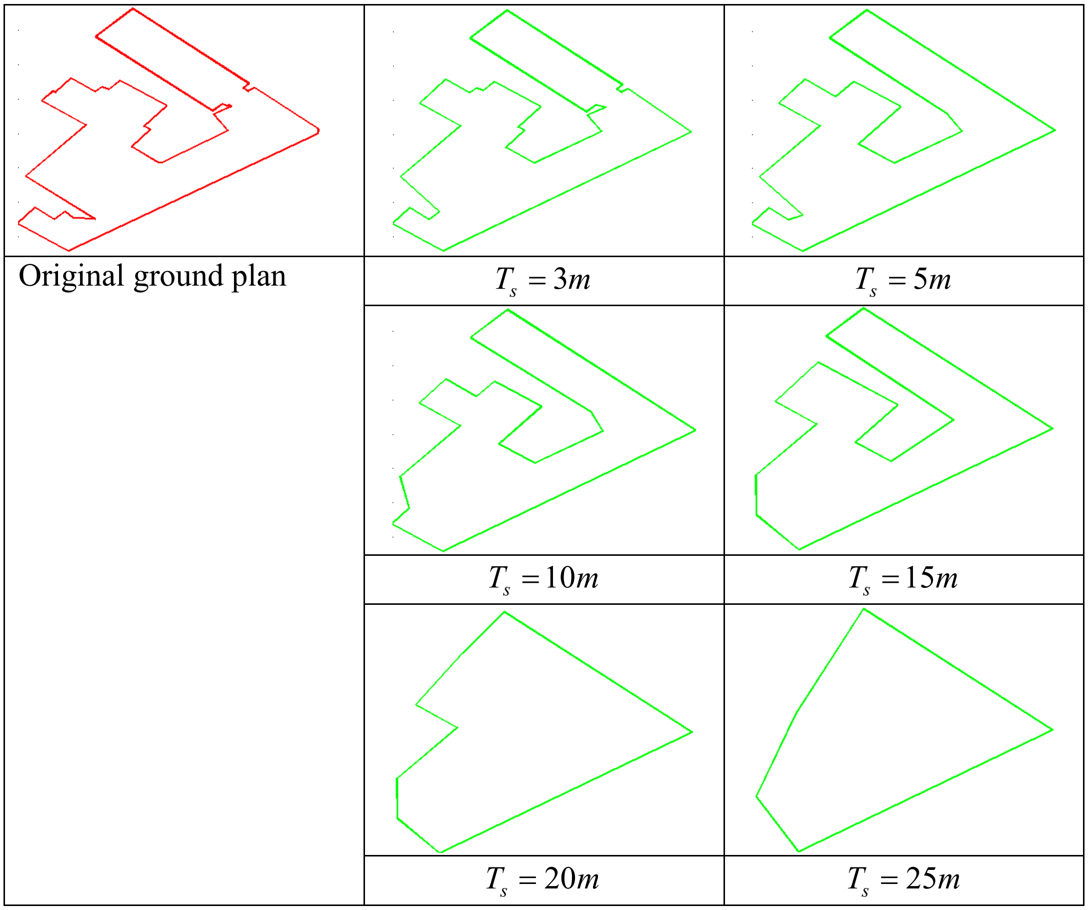


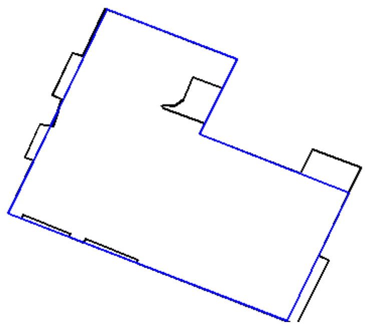
Fig.10. A building with a complex geometric form and the simplification results with different thresholds

Transforming the original building ground plan and the simplified ones into tangent space, then their similarities can be calculated according to the algorithm in Section 3.2. The similarities between the simplified building ground plans and the original one are listed in Table 2. It is obvious, that the similarity decreases when increasing the threshold. It reflects the fact that the larger the threshold is, the more detail of the building ground plan is removed.

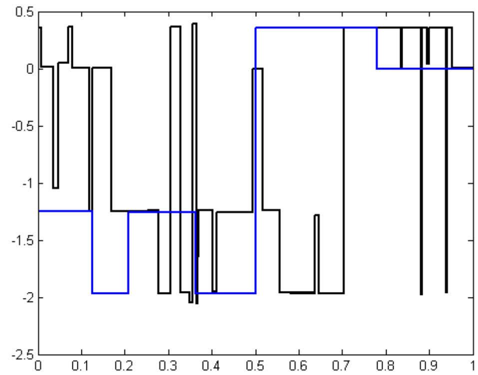
Table 2. Similarities between the simplified ground plans and the original one

Simplified ground plan with threshold:	$T_s = 3m$	$T_s = 5m$	$T_s = 10m$	$T_s = 15m$	$T_s = 20m$	$T_s = 25m$
Similarity to the original one	0.2468	0.6568	0.8422	0.8463	1.9081	2.0140

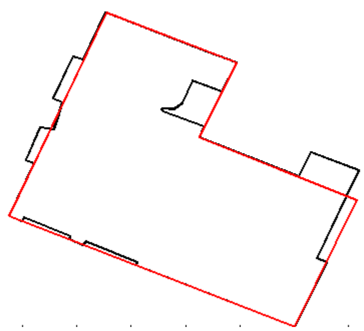
Besides, the similarity measure was conducted for evaluating the results using our algorithm in comparing with the results of a manual simplification (Figure 11). In Figure 11 an example building ground plan is represented in black color. The blue polygon (Figure 11a.) is the result of our algorithm, and the red, green ones are resulted using manual simplification. Their corresponding similarities to the original one are represented on their right respectively. The values of the similarities indicate that our algorithm is better than the other two simplifications.



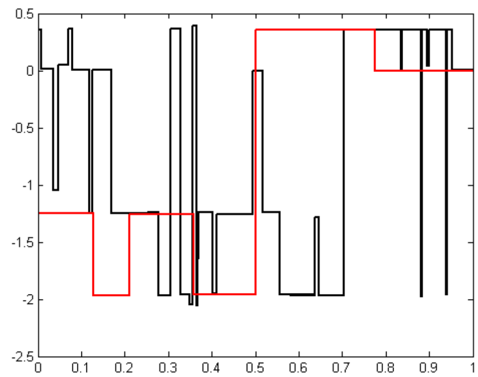
a



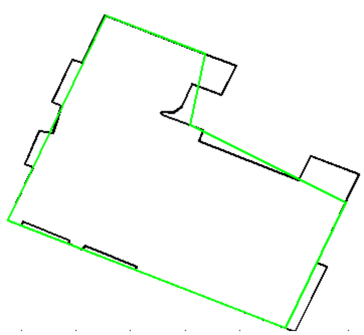
b. S = 1.4504



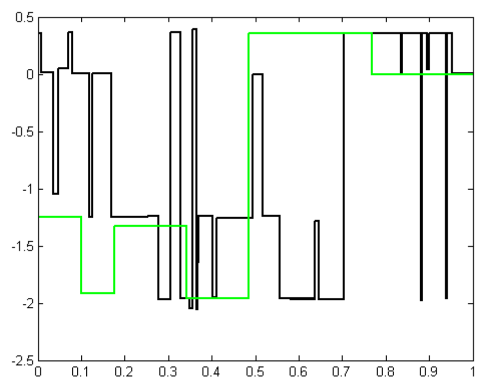
c



d. S = 1.4839



e



f. S = 1.5320

So far, our approach has not considered the generalization of ground plans with their neighboring ones. Therefore, ground plans with smaller sizes are not removed after the simplification, because they might be merged with their neighboring ground plans. In the nearest future, we will embed further generalization operations such as aggregation, typification etc. into our simplification algorithm.

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