EXTRACTION OF BUILDING GROUND PLANS FROM LIDAR DATA

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ABSTRACT:

The goal of this research is to extract and delineate building ground plans from LIDAR data. Our approach consists of three steps: first of all, the raw point cloud has to be classified into terrain points and off-terrain points. Secondly, the off-terrain points (the potential buildings) have to be aggregated to form connected building blobs. Those blobs that exceed a certain size and have certain characteristics (e.g. consisting of planes) are supposed to be building candidates. For them, in a third step the outline is simplified. This is a generalization task, which has to take the characteristics of buildings into account to produce a meaningful 2D building shape. In the paper, these steps are described in detail. The focus lies on the different possibilities to generalize the building ground plans.

1. INTRODUCTION

1.1 Motivation

The airborne laser scanning delivers a dense point cloud (approx. 10 points/m²). Buildings can be recognized easily in this data. The aim of our work is to automatically detect and reconstruct the buildings from this data.

In one of our projects the task is to determine 2D building ground planes. These ground plans can be used to detect changes in existing maps. So areas that require updates can be identified.

In another project we have to determine building volumes and the area of the outer surface. One possibility is to combine the LIDAR data with the cadastral map. But the aim is to use only LIDAR data. So the ground plans have to determined by the data itself.

1.2 Related Work

In the literature, some approaches for delineating buildings from laser scanner data have been reported. Most of them refer to the reconstruction of the 3D-geometry of buildings. From them, the outline of the ground plan can be determined. Maas & Vosselman (1999) present two approaches for this: the first is to use geometric moments to determine the main orientation parameters for gable roof buildings. For other kinds of buildings they propose to segment and intersect planar faces. In order to generalize the outline they use the direction of the ridge line as an approximation for the main direction of the building (modulo 90 degrees). This ridge line is determined as a horizontal intersection between roof faces. Gerke et al. (2001) use an recursive cut of rectangles from a minimum enclosing rectangle in order to fit a rectangular outline to the jagged building outline determined from laser scanning data. A similar approach has been realized by Dutter (2007). She starts with an MER and determines relevant deviations from the rectangle lines. This is done recursively, thus enabling different shapes of buildings like L, T or U-shaped outlines. Shan & Sampath (2007) use straight lines in the main direction of the buildings to approximate the shape and least squares adjustment for the adaptation to the original boundary points.
In cartography, methods for the simplification or generalization of building ground plans have been developed (e.g. Staufenbiel 1973, Lamy et al., 1999, Lee 1999, Sester, 2005). All try to eliminate too small edges, protrusions and insets of the buildings, while preserving and enhancing the properties of buildings like right angles or parallelism. These methods, however, cannot be directly transferred to the problem of simplifying outlines determined by laser scanner data analysis, as those outlines are only coarse approximations of the real building; they are typically jagged and potentially also spoiled with outliers.

2. CLASSIFICATION AND SEGMENTATION OF POINT CLOUDS

2.1 Point classification

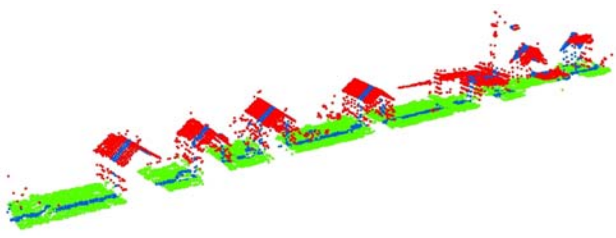

Figure 1: Small part of a LiDAR point cloud. The points for one profile are selected (blue).

In this approach airborne LIDAR data is used to determine building ground plans. As a first step the buildings have to be detected in the data. Sometimes the points are already classified in ground and off-terrain points. Unfortunately the classification is not always available, and also sometimes not reliable. So our process starts with the classification of the points. The implemented method (Abo Akel et al., 2004) divides the points into small stripes (approx. 3m) in x- and y-direction. The heights of the points of one stripe are considered to depend only on the x-coordinate or the y-coordinate respectively.

A 2D polynomial is fitted into the stripes. In the first calculation the weights of all points are the same. When the polynomial is determined new weights for the points are set. The weights of points beneath the polynomial function stay 1. The weights of the points above the polynomial function decrease with increasing height difference. With the new weights a new polynomial is determined. The calculation of the polynomial and the new weights is repeated until the changes of the polynomial is below a given threshold.

Figure 2: Side view of the selected profile (blue) and the adjusted polynomial after one iteration (red) and five iterations (green).

Afterwards, the height of the points are compared with the polynomial. In our case we are only interested in buildings. So only points above a certain threshold (in our case 2.5m) above the polynomial are classified as off-terrain. As there are polynomials in x- and y-direction every point is classified twice. Only the points that are classified as off-terrain twice are considered to be off-terrain, and thus building candidates (see Figure 3). Points that are classified different in x- and y-direction often can be found at steep slopes.

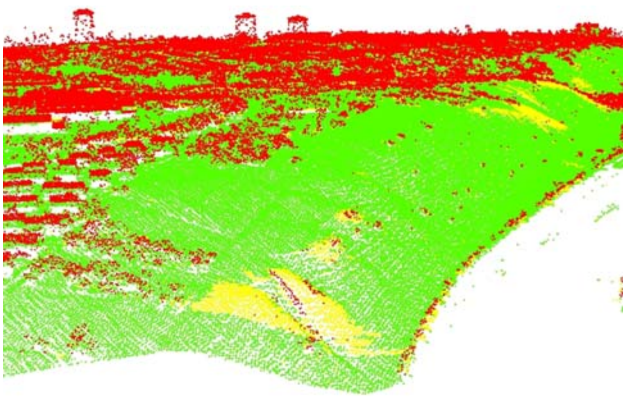

Figure 3: Some points (yellow) at the slope are classified different in x- and y-direction.

The off-terrain points in Figure 4 are points on buildings but also on trees. Compared to buildings trees cover only small areas. So one idea is to eliminate trees due to the small size.

2.2 Segmentation

After the points have been classified, points that belong to one building have to be identified. This is done by a segmentation. First the points are connected by a Delaunay-Triangulation using TRIANGLE (Shewchuck 1996). The triangulation establishes the neighbourhood relation between the points. Then the points are segmented in a region growing process: A triangle which is not yet classified is taken first. If at least one point is a terrain point the triangle is classified as terrain and added to the segment 0 (indicating the terrain). If all three points of the triangle are classified as off-terrain the triangle starts a new segment. Iteratively, the triangles next to the actual segment are tested. If all the points are off-terrain the triangle is added to the segment. Otherwise the triangle is added to segment 0. A segment is finished, when no further neighbouring triangle is available. The whole process stops, when all triangles have been assigned to a segment.

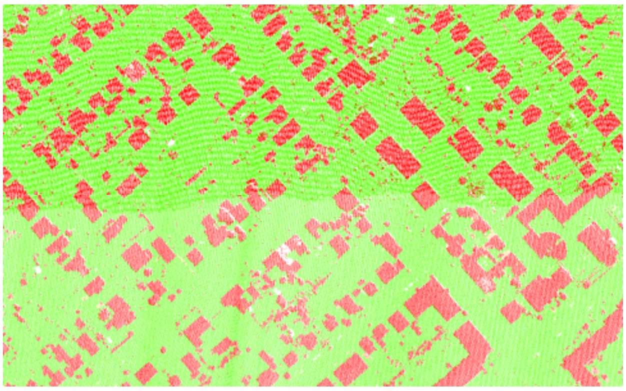

Figure 4: Points classified into off-terrain (red) and terrain (green).

The triangles of one segment are merged to create the boundary of the segment. The boundary represents the building ground plan. Unfortunately the boundary typically contains many points and is jagged (see Figure 5). So in the next step the boundary has to be simplified and generalized (see Section 3).

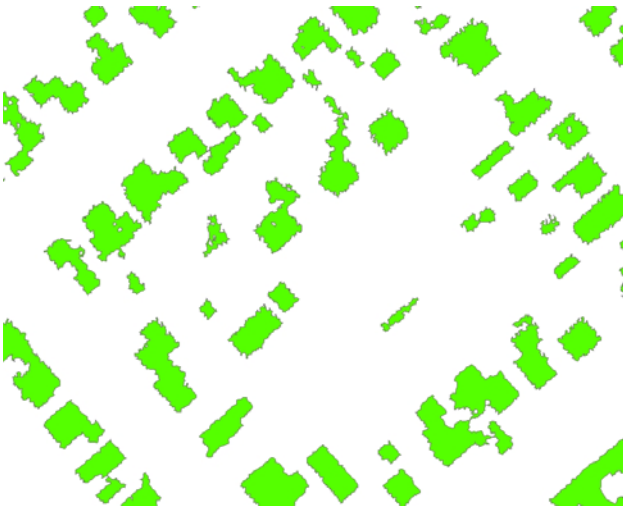

Figure 5: Segments created by dissolving triangles for every segment.

With the described region growing method some difficulties may occur. Areas with trees may form a segment similar to a building segment. Besides trees near buildings may connect building segments to one segment.

To avoid this the region growing has to be improved. The idea is that points on trees vary in height. Points on buildings are more homogeneous. So the improved method uses additional criteria to stop the region growing.

If the points of a triangle differ in their height then the triangle is excluded from the region growing. In Figure 6 these triangles are shown in yellow. In this way the trees in the lower right part can be removed. Besides building parts with different heights can be separated.

Buildings measured with airborne sensors can be characterized by their roof which are mainly composed planes. This can be used as another criterion. One idea is to compare the normal vectors of the triangles. However the normal vectors of triangles on one roof plane can vary. Especially the normal vectors of small triangles differ from the normal vector of the appropriate roof plane. So the segments have many small holes (see Figure 6).

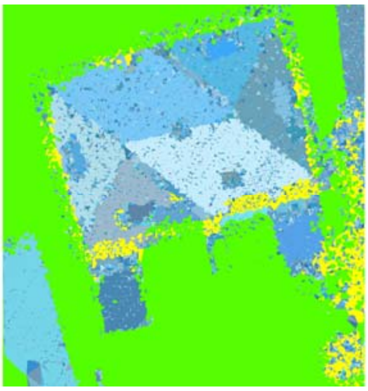

Figure 6: Region growing with height difference and normal vectors.

A better solution is to determine the plane equation for a segment and only add another triangle if the distances of the points are below a given threshold. This approach is able to identify single roof planes (see Figure 7).

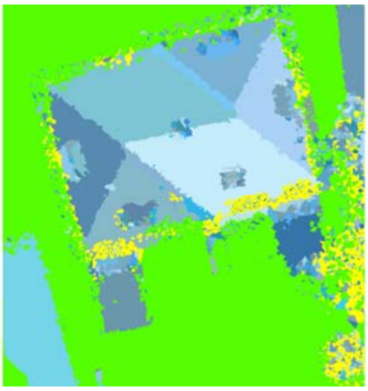

Figure 7: Region growing with height difference and plane equations.

3. SIMPLIFICATION AND GENERALIZATION OF SEGMENT BOUNDARIES

For the generalization of building ground plans several methods have been proposed in the literature. The problem is, however, that these approaches start from correct building ground plans, that have to be transformed to a representation in a smaller scale. So they start with a real building ground plan at a given resolution consisting of an adequate point sampling. This is not the case in our problem: here, the boundary is composed of too many points, also, the general characteristics of the shape are not necessarily given.

To improve the representation of the ground plan different methods are implemented and tested

- line simplification with Douglas Peucker-Algorithm (Douglas & Peucker, 1973); extension of this algorithm including least squares adjustment of lines to the original points.

- graph based method with shortest path search
- Approximation of ground plan with straight lines using RANSAC, followed by least squares adjustment

3.1 Using Douglas-Peucker algorithm as approximation

The line simplification with the Douglas-Peucker algorithm is good to reduce the number of points. But the results are not satisfying because right angles are not retained. Also, it is constraint to the original points. This is a disadvantage, as the original outline is typically an approximation between the boundary points. Thus, although Douglas-Peucker is very well suited to reduce the number of points, it is not able to reconstruct the correct shape of the buildings.

Therefore, we propose a variation of the Douglas Peucker algorithm. Instead of representing the simplified boundary by the recursively selected extreme points, straight lines are fitted to the original points on the boundary between two extreme points. Consecutive adjusted straight lines are intersected. The whole process therefore works as follows: In order to initialize the recursive process, firstly a straight line is adjusted to all points of the boundary. Then the polyline of the boundary is subdivided into two parts at the two points with the maximum distances to the straight line (points P1 and P2 in Figure 8). The partition is repeated recursively until the most distant point is within a given buffer around the straight line. When all lines are determined the points of intersection for every pair of successive straight lines can be calculated and they form the new boundary points of the generalized building.

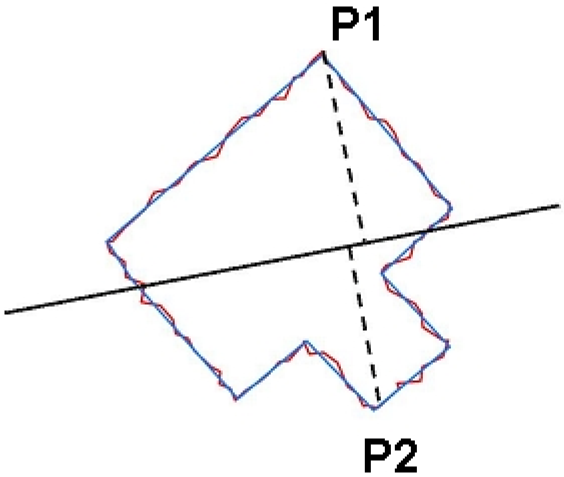

Figure 8: Subdivision of the boundary (red) at the points that have the greatest distance to the adjusted straight line.

Figure 9 shows an example of a larger area. For most of the buildings the results are good. But some buildings have very small angles. Also, self-intersections may occur. An additional drawback is that the extreme points must not necessarily lie on a building corner. This can happen due to the jaggedness of the outline. An improvement will be to include right angle and straightness constraints in the least squares adjustment (similar to the approach described in subsection 3.3).

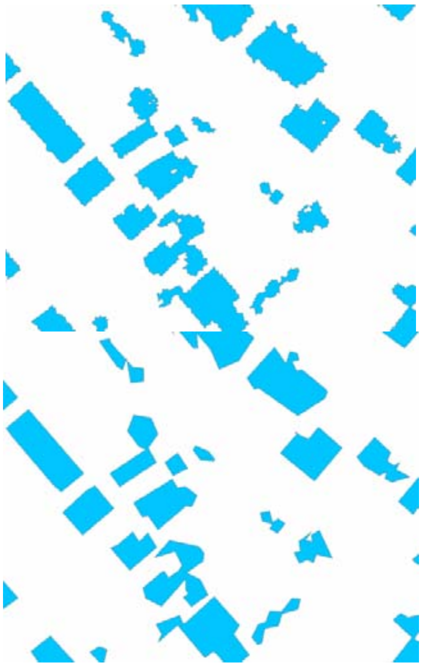

Figure 9 : Example of a larger area: original building outlines (top); adjusted straight lines (bottom).

3.2 Graph-Based approach for generalization

The next method is graph-based (Chen et al., 2005). First of all the points of the segment boundary become the nodes of the graph. The edges of the graph are directed. These directed edges represent the connection between a pair of points. The points of the segment boundary are ordered clockwise. Accordingly the to-node of an edge is a point that lies behind the point of a from-node.

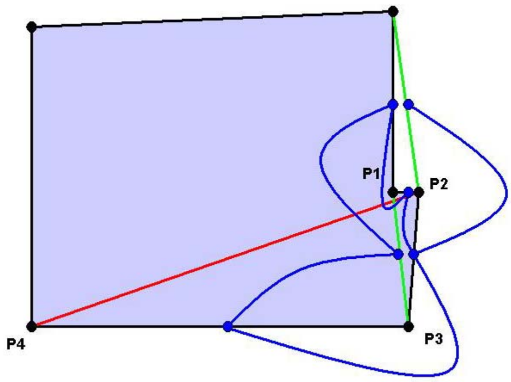

Figure 10: Original boundary (black) and allowed shortcuts (green), an invalid shortcut (red), combination of two shortcuts (blue).

In a first step every point is connected to any other point of the segment boundary. This connection is only accepted as a valid shortcut, if all the points between the start and the end point are lying within a pre-specified distance threshold. In this case, this shortcut is inserted as an edge into the graph. In Figure 10 the connection between P1 and P3 is valid, as the distance to P2 is low; however, the connection between P2 and P4 is not accepted, as the distances of the intermediate point P3 from the line is too high.

As threshold for the maximum distance the values of 0.25m, 0.5m and 1m are used. In the case of 0.25m and 0.5m the number of valid shortcuts is small. So the generalization effect a is poor. With a threshold of 1m the result of the generalization is better.

The graph can be used to find the shortest cycle. The weights of the edges can be set equal to the length of the connection lines. Then the result is a polygon with the minimum perimeter. If all edges have the same weight, the result is a polygon with a minimum number of points.

The described method only reduces the number of points. A characteristics of building ground plans are right angles. To retain and emphasize right angels it is necessary to evaluate combinations of two successive shortcuts. A good combination encloses a cutting angle of nearly 90 degree.

In order to include this angle constraint, a second graph is created. In this graph the nodes are the shortcuts. Two nodes are connected with an edge if the two corresponding shortcuts share an end point (see blue connections in Figure 10). The weight of the edge depends on the angle between the lines.

To emphasize right angles combinations of shortcuts with an angle that differs more than 15 degree get a higher weight as a penalty.
One possibility for selecting the weights is to multiply the length of the shortcuts with a value greater than one. Different values have been tested. A value near one delivers a result similar to the polygon with the minimum perimeter; using a high value has the effect that the right angles are emphasized too much (Figure 11). Thus, the multiplication is not the best solution.

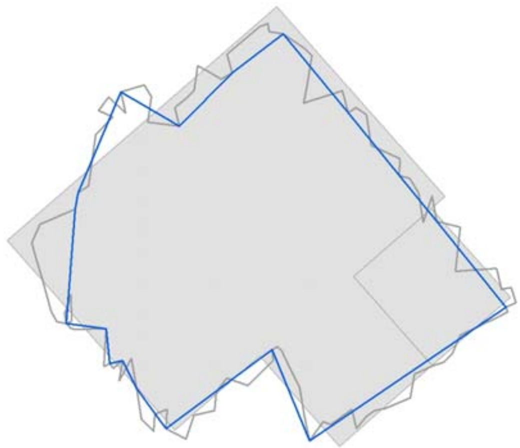

Figure 11: Multiplication with a value greater 1. Right angles are overemphasized (left).

Another possibility is to add a constant to combinations where the angle differs more than 15 degrees. A value of 1m was used. A shortcut that skips a correct corner point receives a penalty of 2m. So in the end it is better to include the corner point. The second possibility preserves important corner points (see Figure 12). Still, however, the proposed method is only based on the original building points. An extension of this approach, that allows intersections of lines, and thus the inclusion of new object points is presented by Haunert & Wolff (2008).

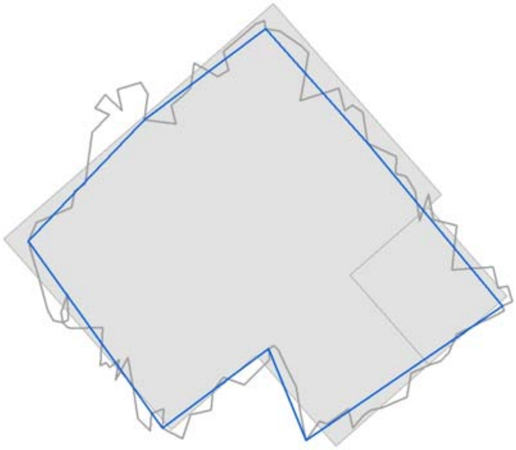

Figure 12 : Addition of a constant value.

3.3 Generalization using RANSAC and Least Squares Adjustment

This approach tries to approximate the outline with a set of straight lines. This approach is motivated by the fact that buildings are man-made objects and mainly consist of straight lines that are linked using additional constraints concerning rectangularity and parallelism. We firstly extract straight lines with RANSAC (Fischler & Bolles, 1981), then these lines are adjusted to the original building outline using additional constraints that take the building characteristics into account, similar to Sester (2005). RANSAC is a method that is able to find a model in a data set in a high presence of noise.

Random Sampling of Straight Lines: Randomly, two points of the outline are selected and a straight line is set up connecting them. If enough consecutive points of the outline are found that fit to that straight line, then this hypothesis is accepted. The points constituting this line are eliminated from the outline and the process is repeated until a high degree of the outline points are assigned to straight lines.
In Figure 13 the result for the detection of straight lines is shown: on the left hand side the original building is shown, on the right the straight lines generated by the RANSAC process are shown.

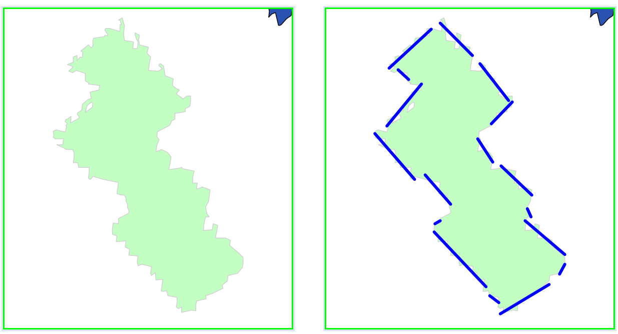

Figure 13: Original Object (left), approximation with straight lines adjusted to original points (right)

Combination and Adjustment of Straight Lines: In a next step, these straight line segments have to be combined to form a meaningful building outline. Meaningful means that typical buildings mainly consist of parallel and rectangular facades. The task is therefore, to connect adjacent straight line segments using parallelism and rectangularity as constraint. This can be formulated in terms of a Least Squares Optimization process. In Least Squares Adjustment the unknown information is determined by a set of observations. A function is set up that describes the observations in terms of unknowns, leading to the so-called functional model. The stochastic model describes the accuracy of the observations. The Least Squares Adjustment finds the optimal solution by minimizing the corrections of the observations.

In the process, the constraint equations between consecutive straight lines are set up (for more details see (Sester & Neidhart, 2008)). Depending on the angle between two consecutive lines, either a 90 degree constraint is set, or a 180 degree constraint, or the angle is left as it is. In this way, rectangularity and parallelism are enforced, however, if they are not present in the data, also other angles are allowed.

Figure 14 shows the result when processing a larger area with buildings.

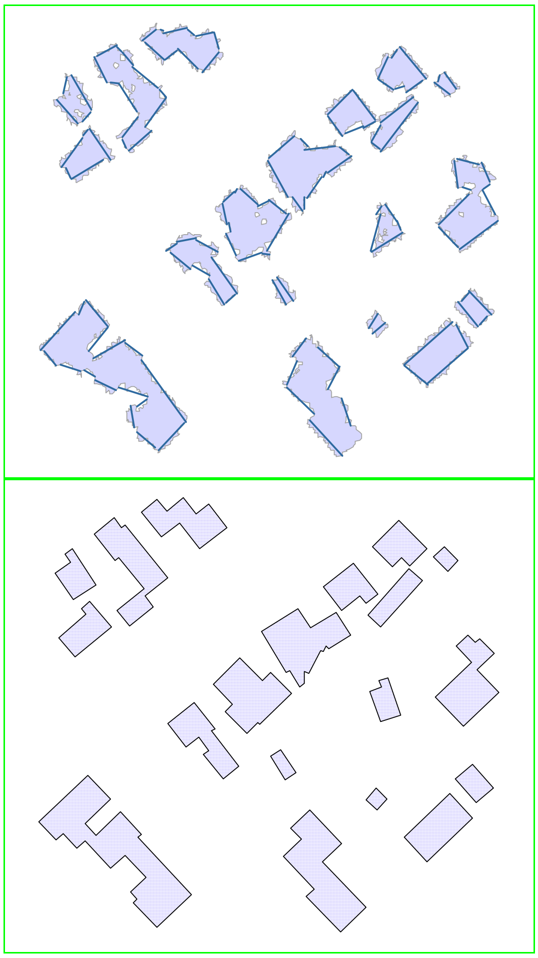

Figure 14: Example of a larger area: original building outlines and straight lines (top); adjusted straight lines (bottom).

The following example (Figure 15) shows that rectangularity and parallelism are not enforced, when there is no indication in the data for it.

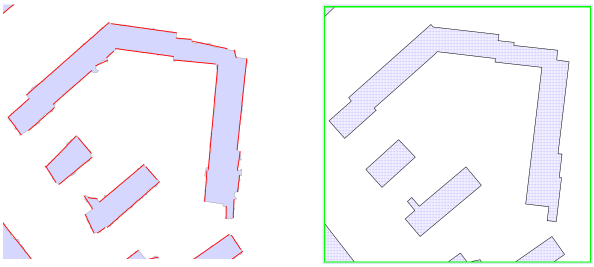

Figure 15: Example with non-rectangular buildings

Due to the random generation of the straight lines, there is a certain degree of non-determinism in the whole process. I.e. when the algorithm is run several times, (slightly) different results may occur. To date the quality of the results has not yet been thoroughly investigated, however, manual intervention and correction seems to be necessary only in approx. 10% of the buildings.

4. CONLCUSION AND FURTHER WORK

The result of the graph-based method already achieves good results. But the angles are not exact right angles. The problem with all the point-reduction approaches is that the final ground plan can only consist of a subset of the original points, i.e. if a building corner is not given, it can never appear in the final shape. Therefore, approximations of the shape have to be taken into account. This is done in the RANSAC approach. It yields satisfying results, as long as there is enough support for building facades (straight lines) from the data.

In the future, we plan to integrate the Douglas-Peucker-like approximation method with the Least Squares approach. In this way we expect to reduce the randomness from the whole process.

Another idea to improve the ground plans is to use 3D information from the original point cloud (see also Maas & Vosselman, 1999). Especially the normal vectors of a roof planes give hints about the direction of the boundary lines in the ground plan. They are either in slope direction or perpendicular to the slope direction.

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