

3D BUILDING MODEL GENERATION FROM AIRBORNE LASERSCANNER DATA BY STRAIGHT LINE DETECTION IN SPECIFIC ORTHOGONAL PROJECTIONS

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ABSTRACT:

The paper describes a novel approach for the generation of 3D building models from airborne laserscanner data, which is based on the detection of straight lines in specific 2D projections of the data. First, the main roof ridge directions of a building are determined. Based on these ridge directions, hypotheses on the roof orientation are generated. The whole point cloud is rotated by the roof orientation and orthogonal projected into a 2D space perpendicular to the roof orientation. Roof edges show up as straight linear point clusters in this 2D projection. These lines representing projections of roof faces are extracted by a line tracing technique. They provide information about inclination and width of the roof faces. Subsequently rotating the points of each roof face around the z-axis and tilting it by its inclination produces another 2D projection containing lines representing the roof face's length. The technique was tested on a sample of 200 buildings. They were reconstructed with the approach and evaluated for their correctness and geometric accuracy.

1 INTRODUCTION

1.1 Motivation

The topic of building model reconstruction from airborne laser scanner data has become more interesting in the past years. Examples of the various application fields are the generation of 3D-city models for city planning or virtual city tours as well as the acquisition of information for geographical information systems (GIS) and their derived products. Furthermore, building modelling can be used for the revision of cadastral maps.

For this reason one searches for methods with which buildings can be modelled automatically from laserscanner data (see Figure 1-1) as reliably and effectively as possible. Considering the increasing point densities and accuracy of the laserscanner data, it is also of interest to develop methods which are scalable in a way that they produce a level of detail that depends on the density and quality of the data.

Under these criteria different approaches had been developed for building model reconstruction. Methods, which are based purely on laserscanner data, can be differentiated into model-driven approaches such as [Maas 1999] and numerous data-driven approaches. The data-driven approaches have been realised by using for instance a segmentation procedure e.g. [Rottensteiner 2002] or a region-growing-based method e.g.

[Gorte 2002]. Another data-driven approach, which is parameter-based, was introduced by [Vosselmann 1999].

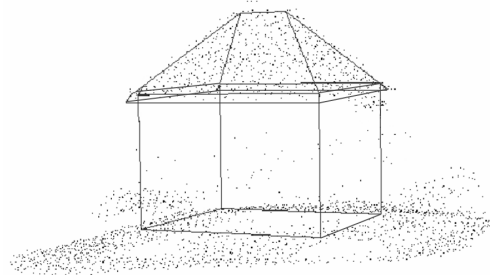


Figure 1-1: Comparison of the derived building model with the original building

The disadvantage of the known model-driven approach is in the fact that it is, in comparison to others, inflexible regarding the building's ground plan. Many segmentation-based approaches are based on raster data, enabling the use of standard image processing software tools. Region-growing based approaches have the advantage that the detected roof planes fit very well into the laser scanner points. They may however be sensitive to errors or gaps in the data

The additional use of ground plan information has the advantage that the position and extension of a building are known. This replaces error-prone segmentation methods, and it simplifies the modelling of a building substantially.

Nevertheless, the method presented here is a generic method based purely on laserscanner data, exploiting and proving the potential of this data.

1.2 Goal and idea

The goal of the here described method is the automatic reconstruction of building models from raw airborne laser scanner data without any additional information. In addition to a virtual 3D model of the reconstructed building, the ground plan of the building will be generated. The chosen procedure is a coarse-to-fine method, generating a rough building model in a first stage and then successively refining it by an analysis of the point cloud.

The basic idea of the chosen procedure is a simulation of the behaviour of a human operator when analysing a point cloud in order to recognise a building. This procedure is characterised by the rotation of a point cloud into specific projections. Most information is received by the view of the gable of a building. In Figure 1-2 it is demonstrated that roof faces are reduced to lines if projected onto a plane parallel to the gable.

From this line of sight the roof type as well as the number, the inclination and the width of roof areas can be recognized. This information is used in the method to detect roof faces. For this purpose, the orientation of the building is determined and the data points are projected onto the appropriate vertical plane. In these projections, lines are searched, which represent roof areas. These lines are finally extended to roof areas and grouped to a building model. Detecting roof planes is thus reduced to a two-dimensional parameter space, what reduces the complexity and ensures a more efficient performance of the algorithm.

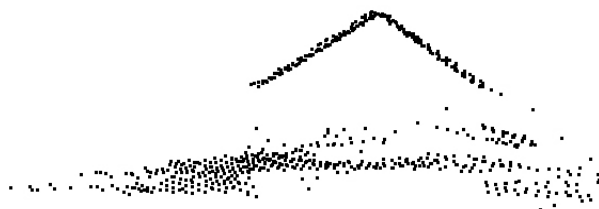


Figure 1-2: A building's point cloud projected onto a plane parallel to the gable side of the building

2 DATA SET

The described method was tested on three different data sets, which differ by their point density and the kind of the buildings:

The first data set is an alpine area in Switzerland. The point density amounts to approximate one point per square meter. The area is characterised by single houses and simple roof morphologies. It predominantly contains simple or combined saddle roofs. A special peculiarity of the buildings in this data set is that they are partly built into the slope and possess large roof overhangs. The latter is to be taken into account for the determination of ground plan information. 229 buildings of this data set have been chosen to determine the effectiveness of the developed modelling procedure.

The second data set includes the city of Freiberg which is on rather flat terrain in Saxony/Germany. This test area is characterised by a high density of buildings including various large and complex buildings as well as different roof shapes. The point density amounts to 3-5 points per square meter.

The accuracy of both data sets is estimated ± 30 cm in position and ± 20 cm in height. In both cases the raw irregularly distributed laserscanner data were used. Segmented point clouds of the data set contain an individual building, some surrounding ground points as well as points of adjacent vegetation. The point density of the data sets results from several highly overlapping flight strips.

As a third data set an area within the city of Dresden (Saxony/Germany) was used. This dataset contains rasterised data with a point distance of one meter. It serves as a comparison of the modelled buildings with data obtained by classical terrestrial measurements.

3 METHOD

3.1 Model

The variety of the existing roof shapes places different requirements on an algorithm for building model reconstruction. Not all details and shapes, which arise in reality, can be modelled. Therefore it is first necessary to develop a certain model conception of a building. For this purpose initial considerations have to be made, which roof shapes arise most frequently and which common characteristics are valid for the majority of the buildings.

It is assumed that buildings consist of plane surfaces. Thus, the algorithm can be based on the search for straight lines in 2D-projections. The fundamental roof shapes, which should be modelled with the available algorithm, are gable roofs, pent roofs and hipped roofs as well as combinations of these basic shapes. A first assumption is that buildings possess maximally two main directions that are orthogonal to each other. The normal vectors of all roof faces should be orthogonal to one of the main directions. The main directions of the building are defined by the orientation of the ridges and/or by the orientation of the building edges. In order to model more complex buildings, such as buildings with combined roof shapes, it is necessary to make further assumptions. A building can possess multiple ridges of different height. They are parallel or orthogonal to each other. Besides, it is taken that the lower eaves (the gutter) is parallel to the ridge and the ridge is parallel to a horizontal plane. The walls of a building are plane vertical surfaces and are attached to the eaves, under consideration of a

certain roof projection. Opposite roof faces, which intersect in a ridge line, do not necessarily have the same inclination.

3.2 Overview

The basis for the developed algorithm is a segmented laser point cloud, which represents a potential building in each case. The individual point clouds are processed one after the other by means of the following algorithm:

- Read laser scanner points and reduce coordinates to barycentric coordinates
- Elimination of alleged bottom points
- Determination of the azimuth of the ridge direction and rotation of the data points by the azimuth around the z-axis
- Projection of the laser points in the z-x and z-y-plane
- Search for lines in these projections and determination of the extension of the roof faces, which are represented by the lines
- Determination of the roof face outlines
- Blending the roof faces, which were obtained from the different projections
- Determination of the walls
- Determination of the ground plan polygons and visualisation of the building as VRML model

3.3 Determination of the ridge direction

As the method is based on the principle of line detection in projections of the point cloud orthogonal to the direction of the ridge of the roof, the first step of the modelling procedure is the determination of the main directions of the buildings. Potential ground points are eliminated by analysing a height-bin histogram. The minimum of laser points in the height layers within the range of the walls can be used as a criterion for the separation of potential roof points from ground points.

With the remaining points that are classified as roof points, the search for the ridge direction of the building takes place. The main ridge direction is then given by the azimuth κ (see Figure 3-1 a).

The principle used is based on the investigation of the orientation of the points in individual height layers of the point cloud. Not only the upper height interval containing ridge points shows the orientation of the building, but also the lower height layers of the roof contain this information. The idea is to search for lines within the points of each height layer. Within the range of the roof the dominant direction of the detected lines corresponds to one of the two main directions of the building. In contrast, the distribution of points in height layers of vegetation has a random character.

The most pronounced direction of the detected lines is the one that is accepted as the main roof direction. The point cloud is now rotated by the angle κ around the z-axis, so that the main direction (the main roof ridge) of the building runs parallel to the y-axis (see Figure 3-1 b).

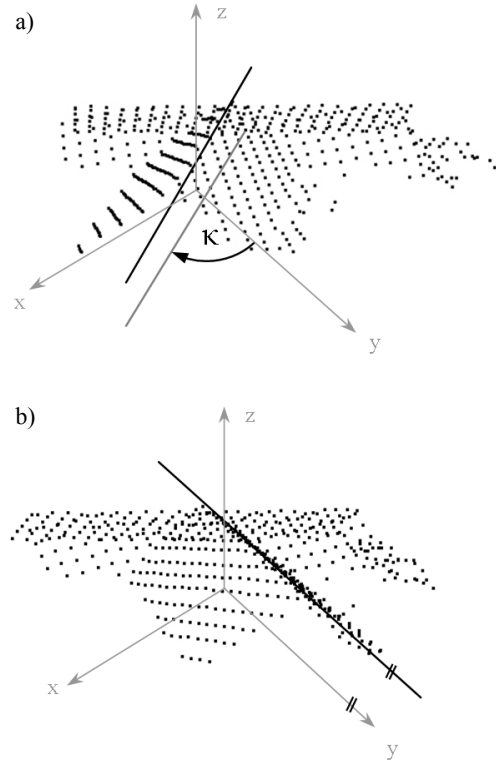


Figure 3-1: a) roof ridge direction; b) rotated point cloud

3.4 Detection of roof faces in projections

In the next step the points are projected onto vertical planes, defined by the detected azimuth direction. First the data is projected onto the z-x-plane. Points, which lie on a roof plane with a normal vector parallel to the projection plane, are displayed as a line in the projection plane.

In the projection, lines that represent roof planes are intersected and their end points are determined. In dense datasets it may be necessary to thin out the points on the line to warrant a proper performance of the line detection procedure. On this basis, knowing the start and the end points of the lines, the inclination and the width of the roof areas represented by the lines are given (see Figure 3-2).

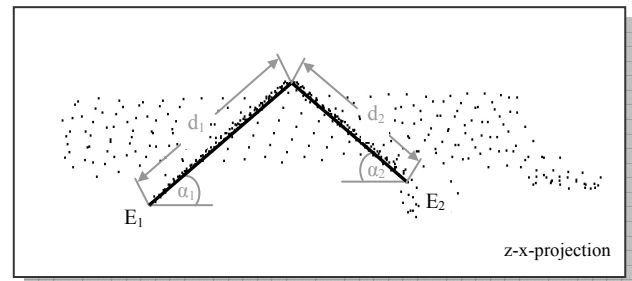


Figure 3-2: Inclination and width of detected roof faces

The individual lines should now be extended to planes. The z- and x-coordinates of the corner points of the plane polygon are known by the endpoints of the lines seen in Figure 3-2. The y-coordinates of these corner points can be derived using the following approach: All points that belong to a line are rotated by the slope angle of the line (e.g. line E_1 by angle α_1). After that, the points are projected onto the z-y-plane. The points form a line in the z-y-projection. The y-coordinates of the corner points of the plane polygon can be obtained at this stage. The plane's polygon is then complete. Each line in the z-x-projection is treated individually in the same way.

The outline of each detected roof face is now described by a three-dimensional rectangular polygon (see Figure 3-3).

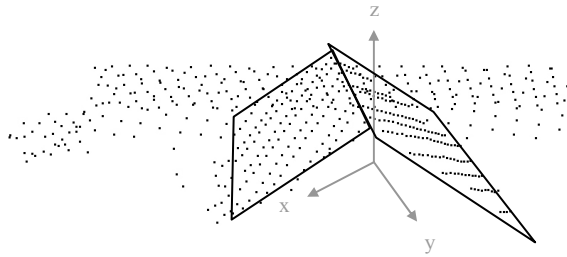


Figure 3-3: Extension of lines to roof faces

The roof areas might not be optimally described with this rectangular shape. Figure 3-4 a) shows an example of a roof area with cut-outs.

In order to determine these cut-outs, all points are determined that belong to a roof plane. These points are rotated by the inclination angle α of the plane into a horizontal position. Doing so, only the x and y coordinates of the plane's points have to be analysed. The cut-outs of the respective roof plane are detected via a binning strategy and a comparison of the points within the plane. The polygon is extended accordingly (see Figure 3-4).

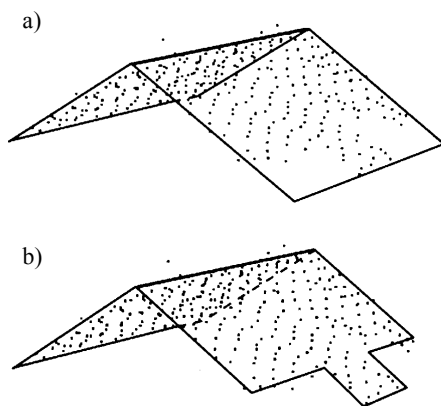


Figure 3-4: Modelling of cut-outs: a) roof face with cut-outs; b) complete roof polygon

As it is presumed that a building may possess two orthogonal main directions, a further projection of all data points onto the z-y-plane is performed. For this second projection the same procedures are applied as for the projection onto the z-x-plane. As an example, Figure 3-3 depicts a combined saddle roof with t-shaped outline and four roof planes. Two of the surfaces are found in the first projection (z-x-projection), the other two in the second projection (z-y-projection).

3.5 Reconstruction of the building model

As a result of the evaluation of both projections the three-dimensional polygons of all detectable roof planes are now extracted. Those planes that have been detected in the same projection are already intersected. This is why the endpoints of connected lines as shown in Figure 3-2 are the same.

After the detection of the roof planes some post-processing might be necessary. On the one hand, false surfaces can be present under the detected surfaces. The reasons are e.g. ground points, which were not removed from the data set. Therefore, all detected surfaces are examined whether they represent a roof plane or not. Planes, which are recognised as false surfaces, are removed. On the other hand, the following problem may arise: In case of two roof planes intersecting at the ridgeline, the two upper horizontal lines are on one line. The end points of these lines, however, do not coincide and have to be shifted in that way that the eaves fit in a vertical plane.

In many data sets planes are found that originate from different projections. In these cases, the surfaces are intersected as well. Now, the modelling procedure of the building's roof is finished (see Figure 3-5).

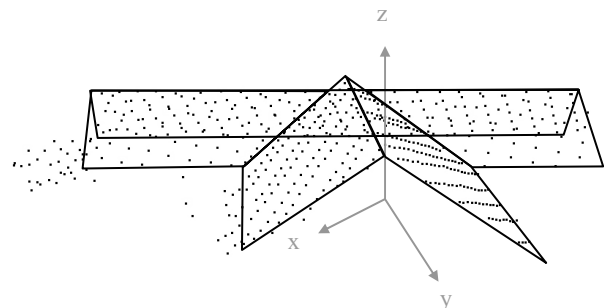


Figure 3-5: Intersected roof faces

To complete the building model, polygons are determined, which describe the walls of the building. Thereby, a certain roof overhang is assumed and the walls are engaged accordingly. The height of the lower edges of the wall polygon is the mean height of the ground points that have been eliminated. By projecting the walls onto the x-y-plane the outline of the building is created. The corner points of the ground plan polygons are now determined.

The polygons are grouped to a polyhedral building model and visualised as a VRML model (see Figure 3-6).

4 RESULTS

4.1 Assessment

The quality of the modelling results of the described technique depends on the data quality and the complexity of the building, which is to be modelled. In the following, the results are classified as correctly modelled buildings, partially correctly modelled buildings and incorrectly modelled buildings. The main reasons for incorrectly modelled buildings are:

- Gaps in the point clouds
- Strong dispersion of the points due to certain roof characteristics or by height misalignment in case of multiple flight strips
- Buildings that are built into the slope and false surfaces that result from this situation
- Very small buildings with only few points
- Small pitch roofs

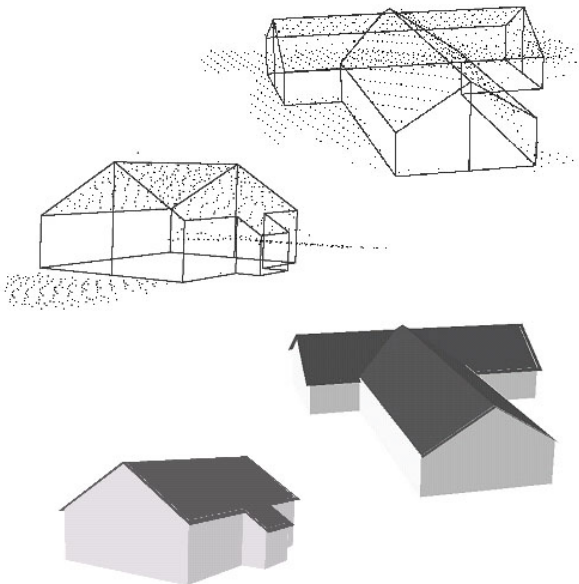


Figure 3-6: As VRML models visualised buildings

For the determination of the correctness of the buildings generated with the proposed method the Swiss data set was used. The probe contains a total of 229 point clouds, 29% of the point clouds were not modelled, 9% of the buildings were modelled with small errors, and 62% of the buildings were modelled successfully.

The procedure is characterised by a short computation time. The computation time of one point cloud with about 300 points is in average 0.1 seconds using a Pentium 4 (1.6 GHz) and 256 MB RAM.

4.2 Analysis of the modelled details

The level of detail in the modelled buildings depends on the relationship of the feature size to the point density of the laser scanner data as well as of the set parameters of the thinning procedure. The practical testes have shown that a minimum of ten points per plane is required, in order to be able to find a line representing the plane. In addition to the detectability of

planes, the definition of the plane outline becomes rather vague if only few points represent a plane.

With a point density of approximate one point per square meter (Swiss data set) this means that only surfaces with a minimal size of approximately ten square meters can be modelled. A larger point density (data set of Freiberg) does not necessarily mean an increase of the detail recognizability, since the data in this case are also thinned out more in the current implementation of the method.

The procedure tends to a certain generalization. Smaller details such as dormers or chimneys are usually not modelled. Still, the method is less susceptible to strong dispersions in the laser data or insufficient strip adjustment between individual flight strips.

4.3 Comparison with terrestrial measurements

To determine the geometric accuracy of the modelled buildings the coordinates of all corner points of the modelled building were compared to terrestrial measurements for these points. The mean difference between the modelled and measured corner points is $\pm 0.46\text{m}$ in position and $\pm 0.25\text{m}$ in the height. The accuracy in height is better than the position accuracy. This is due to the better height accuracy of the laser points. For the position accuracy of the modelled corner coordinates the major restriction is posed by the point density (average point distance approximate 1 m).

5 CONCLUSION AND OUTLOOK

The method is suitable for the modelling of the most important basic building types as well as for simple combinations of those. Advantages of the procedure are to be seen in the effective computation and small sensitivity to sub-optimality in the laser scanner data. A wide range of point densities can be processed. A disadvantage of the method lies in the necessity of thinning out data for proper line detection and the loss in small detail associated with it.

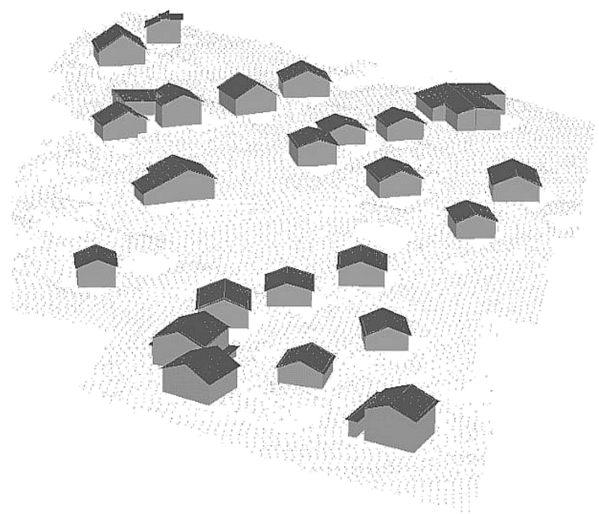


Figure 5-1: Example of reconstructed building models in a virtual village

A further disadvantage is the restriction to buildings with only two orthogonal main directions. This may be overcome by the projection of the point clouds in smaller angle increments than 90°. Besides this, a number of further extensions can be envisaged to improve the applicability of the method:

In addition to the search for lines, circles or other linear elements might be searched for in the projections. In this way possibly curved roof members could be reconstructed.

In order to be able to evaluate more complex buildings it should be considered to split buildings into smaller primitives, as suggested by [Brenner 1998]. The method might also be combined with further segmentation steps, by which points are selected that belong to surfaces of same orientation. This sub-segmentation could be used to accomplish a projection only with the associated points, allowing the detection of lines in single projections. Beside these improvement steps, the method offers itself for a combination with other building reconstruction techniques.

6 ACKNOWLEDGMENTS

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