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TARGET GRAPH MATCHING FOR BUILDING RECONSTRUCTION

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ABSTRACT:
We present a building reconstruction approach, which is based on a target graph matching algorithm to relate laser data with building models. Establishing this relation is important for adding building knowledge to the data. Our targets are topological representations of the most common roof structures which are stored in a database. Laser data is segmented into planar patches. Topological relations between segments, in terms of intersection lines and height jumps, are represented in a building roof graph. This graph is matched with the graphs from the database. Segments and intersection lines that do not fit to an existing target roof topology will be removed from the automated reconstruction approach. For the geometric reconstruction our approach is flexible to use information from data and/or model. For specific object parts it might be better to use model constraints as the data might not appropriately represent the object. As our approach combines data and model driven techniques, we speak of an object driven reconstruction approach. We present our algorithm using airborne laser scanner data with about 15 pts/m^2. Existing 2D map data with scale 1:1000 has been used for selection of building segments, for outlining flat building roofs and to reconstruct walls.

1. INTRODUCTION

1.1 Background

Over the last years, laser scanner systems improved in terms of higher pulse rates (Roth and Thompson, 2008) and laser range performances (Wehr, 2008). As a direct consequence, also the products increased in terms of quality and point densities. This reflected on the user side where there has been a huge growth of demand for detailed DTM's and 3D geo-information. In Denmark and in The Netherlands, national mapping agencies started to build up national DTMs with 0.5 to 10 points per square meter respectively. When such detailed height products become standard for whole countries it is of high interest to develop automated methods that can handle national datasets. In this paper we will not focus on handling large data sets, but deal with a specific automated process, in this case 3D building reconstruction. On a project bases, manual or semi-automatic approaches probably will produce the fastest and best result. Upgrading 2D maps to 3D models on a national scale is a task that preferably will be done as automatic as possible. Despite the progress that has been made in the past, when handling more detailed input and output data other research problem raise and new solutions are needed.

1.2 Research problem

Oude Elberink (2008) describes several problems when reconstruction buildings from detailed laser scanner data. The main problems mentioned are data driven problems. Lack of returned laser pulses and lack of extracted features such as lines and segments, will result in incomplete building models. The author proposes to integrate building knowledge to the data.

Model driven approaches intend to avoid many of the data driven problems. Valid building shapes are combined in order to reconstruct a valid 3D model. Typical model driven problems are that the limited number of building shapes is not capable of reconstructing complex buildings. Related problem is that the final model does not necessarily have to have the real shape of a building, to look correct, although for several applications this does not have to be a problem.

1.3 Proposed methodology

We propose a target based graph matching algorithm that relates model information with data features. These features are segments and intersection lines, which are topologically matched with roof models from a database. Now, we are able to both add building knowledge to the data features and add flexibility to the roof shapes.

2. RELATED WORK

Rottersteiner and Briese (2002; 2003) present an approach that analyses roof segments and looks for intersections and/or step edges between two segments. Geometric constraints are added and tested in an overall adjustment process. Brenner (2000) is looking at neighbouring segments to form logical sequences of segment patches along the map outline. If a certain sequence is logical these segments are accepted for further reconstruction. Later, in (Brenner, 2004) the author describes how to use weak primitives in the geometric reconstruction, assuming the topology is correct. Dorninger and Pfeifer (2008) reconstruct 3D buildings from airborne laser scanner data as single data source. The authors describe the process in detail from begin till end. Building knowledge is incorporated in terms of regularization of the roof outline and several assumptions during the model generation. They mention segmentation as one of the crucial steps as each segment represents one roof patch. (Durupt and Taillandier, 2006) describe a fast algorithm to reconstruct 3D roofs from DEMs and cadastral maps. Their approach is limited to roof faces that connect to gutters and they expect a strong relation between map direction and roof orientation. Milde et al. (2008) propose a formal grammar to get valid building models after connecting primitive building shapes. Finding these shapes is proposed on a similar manner as presented in (Verma et al., 2006), who describe a graph matching algorithm for building reconstruction. They allow sub-graph matching: a sub-graph of the building data may match with a simple building shape from the database. This way, a complex building can be built from multiple simple building shapes. The opposite direction, matching the building (sub-)graph with a sub-graph of (simple) roof shapes from database, is not taken as usable match result. Parts of the building graph that do not match with the database shapes are considered as rectilinear shaped objects. This implies that the authors expect the building graph to be free of errors. The authors conclude that their approach can be improved by adding more building shapes. Most of the authors start with the assumption that roof faces are planar. Exception to this list is (Filin et al., 2007), in which the authors describe a method to detect and reconstruct curved surfaces by using NURBS.

Our contribution to the research field of building reconstruction is that we integrate data driven and model driven approaches. We use the flexibility to reconstruct what is in the data, but incorporate building knowledge from a data base to exclude illogical combinations and to repair gaps when data is missing. Map data is used for selection of roof segments and are taken as location for walls. We do not rely on direct relations between roof orientation and wall direction, as this will limit our possible solutions (Oude Elberink, 2008).

3. FEATURE EXTRACTION

3.1 Segmentation of laser scanner data

An important step in the processing chain from laser data towards building models is segmenting the laser data. As our goal is to build models consisting of planar faces, we segment the data into planar patches. Automatic approaches strongly depend on the success of this segmentation step. Several parameters have to be set to define assumptions how to optimally segment the data. These assumptions are made on spatial appearance of objects in the laser data, such as minimum size and smoothness of expected objects, and how well laser points can record these objects. If locally these segmentation parameters do not fit the actual situation, over- and under segmentation can occur. Although our aim is to segment the data as good as possible, we have to accept that these "errors" can be present.

3.2 Intersection lines and step edges

Intersection lines and step edges are important features in our approach. Not only do they give an approximate location for boundaries of roof faces, they also indicate neighbourhood relations between two segments. These relations are labelled according to the way how two segments spatially intersect, as indicated in Table 1. In section 4 we describe how we can use the topological relation between two segments.

3.2.1 Intersection lines

Lines have been determined for which both segments have points within a specified distance. Setting the distance parameter is not done for the whole data set, but for each intersection line individually. The distance is a function of the median point spacing of those two segments: twice the median point spacing of the less dense segment of the two segments. Also the minimum length of intersection lines has been made dependent on the density of the data. Again we take twice the median point spacing. Higher density data can better represent short ridge lines than coarse segments. Setting parameter values by analysing data locally is an important aspect in automated processing. It reduces the highly arbitrarily influence of an object being acquired in a single, double or triple coverage. Shorter lines are removed in this step.

3.2.2 Step edges

Rottensteiner and Briese 2003 detect and reconstruct step edges by looking at height differences between two neighbouring segments, and regularizing the direction of the step edge. In this step we only detect step edges. The geometric reconstruction of step edges is considered in a later stage. We detect step edges by analysing 2D and 3D relations between two segments. If the segments connect in 2D but are separated in 3D we keep the topological information that these two segments connect through a step edge.

Label	Description	Situations
1	Intersection line between segments with opposite normals	Gable, middle of hip/gambrel roof types,
2	"" with same normals	Gambrel
3	One horizontal, one tilted segment	Mansard
4	One segment inside other segment, horizontal intersection plus height jump edge(s)	Dormers
5	Tilted, convex	Hip roof types, pyramid shapes
6	Tilted, concave	L-shapes, sub objects on gable roof
7	Height jump edges	Height jumps

Table 1 Labelling of topological relations according to appearance in object space.

4. TOPOLOGIC RECONSTRUCTION

One of the main tasks in building reconstruction is to get the correct topology of the building. It is important to realise that features found in the data are results of a chain of stochastic processes and deterministic assumptions. This makes the exact position and even the existence of a feature uncertain. In fact, this holds for every data driven approach.

4.1 Target based sub-graph matching

We integrate model and data driven approaches by a matching algorithm that relates information from a database to features found in the data. This matching relates the topology between segments to topological relations between roof faces from a database. In other words, we do not take intersection lines between segments as input, but its dual region adjacency graph (RAG). Using topological descriptions of roof faces for building reconstruction has been described earlier by Ameri and Fritsch (2000) and Verma et al (2006). Our approach is an extension of this earlier work, as we include additional attributes to each of the adjacency relations.

4.2 Roof topology graphs

Based on the intersection lines and height jumps, a roof topology graph is constructed. Each node in the graph represents a laser segment. Graph edges represent the topological relation between two segments as described in 3.2. Each graph edge inherits the label value of its corresponding intersection line or step edge.

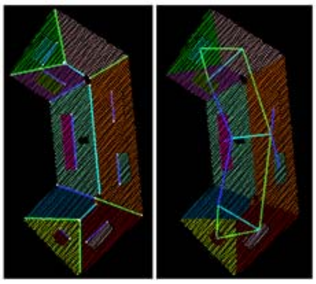


Figure 1 Labeled intersection lines (left) and roof topology graph (right).

As can be seen in Figure 1 taking the topological relations instead of geometrical relations avoids problems with disconnected intersection lines.

4.3 Target graph

In our database we describe a limited number of roof shapes, which in this paper we call targets. Similarly to data features, targets can be described in terms of topological relations. These relations are labelled according to the same definitions as the data (Table 1) and stored in target graphs, see Figure 2.
Matching between data and model takes place on these roof topology graphs and target graphs. As the label of the edges is taken into account, this is called a labelled graph matching algorithm.

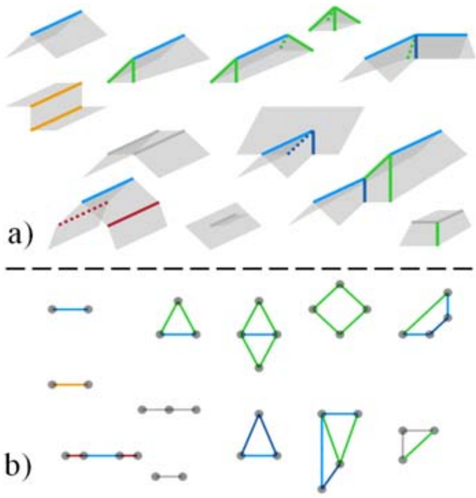


Figure 2 a) Target shapes and b) their labelled graph representation. Graph edges represent topological relations between roof faces.

4.4 Results of matching

In this paper, a matching result is the assignment of a target graph to corresponding segments and intersection lines. For each target, multiple match results can be stored if that shape appears more than once. Logically, each segment and intersection line can be part of more than one target graph.

4.4.1 Complete matching results

A complete matching results stands for a full relation between all nodes and edges of a target with segments and intersection lines in the data. In case of Figure 1, the summary of complete matching results would be, three gable roofs, two half hip roofs, two L-shaped roofs and seven dormers. Note that there is redundancy as segments and intersection lines might have matched on multiple targets. Verma et al. (2006) avoids redundant information by starting with the most complex target and stops when a full match is found.

4.4.2 Incomplete match results

Our approach also records incomplete matching results. This means that if segments and/or intersection lines are missing, we still may record a partly match. Note that this implies that multiple match results will be stored. To give an example, half hip roofs will also partly match on the hip roof target. To avoid unnecessary processing time, we only process incomplete match results for segments that are not part of any complete match result. Figure 3 shows an example of two segments that is only part of incomplete matching results. These segments are matched partly on a gable-shaped dormer, because the other side of the dormer was missing.

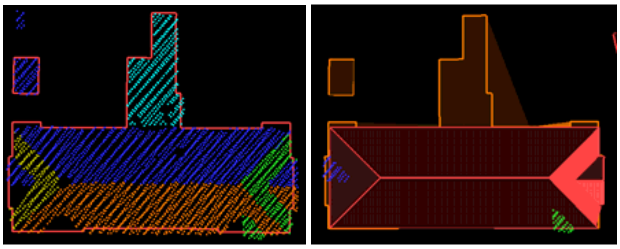


Figure 3 Segmented laser data and map data (left), segments on incomplete matches superimposed on a 3D model (right).

Obviously, the matching algorithm produces a great amount of statistical information, such as number of accepted targets, segments and lines. Here we only present a small number of statistics, specifically the number of segments and lines that did not correspond completely with a target. As can be seen in Table 2, between 4 and 11 % of data features only match partly on a target.

Test dataset	1	2	3	4
# buildings	60	220	230	100
# laser segments	550	1610	798	981
# segments not in complete match (%)	35 (6%)	68 (4%)	71 (9%)	35 (4%)
# intersection lines + step edges	623	1527	494	1253
# intersection lines not accepted (%)	55 (9%)	75 (5%)	52 (11%)	78 (6%)

Table 2 Statistical information on number of all - and not accepted - segments and lines.

These incomplete matching results will be transferred to an algorithm that proposes shapes of the missing segments, by taking constraints from the target shapes. This algorithm falls outside the scope of this paper, and will be published in future articles.

4.5 Combining the match results

Our approach presented here, actually works from a bottom-up perspective: we accept intersection lines from complete match results. Together with the topology of accepted lines and segments, we can connect end points of intersection lines with each other. For each segment, all accepted intersection lines are connected. This is done by extending intersection lines to object points that are intersected by more than two planes. Note that the shape of each roof can be more complex than the target shapes. For object points that are intersected by three planes, extension of three intersection lines is unambiguous as they intersect in one point. However, if four planes should intersect in one point, we have to force one plane to intersect the other three in the same point. Our implementation is such that the three largest segments define the intersection point, and the smallest segment is slightly adjusted.

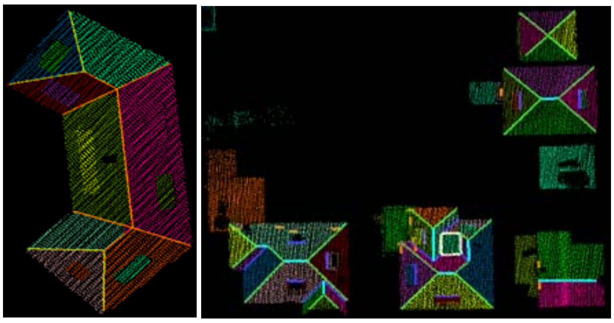


Figure 4 Topologic reconstruction of intersection lines to target topology.

The exact location of the end points of the intersection lines has to be determined. Extra lines have to be inserted to make a closed polygon around each roof segment. Intersection lines only define part of the bounds of each roof face. Normally the intersection lines represent the inner bounds, but the outer bounds such as eaves and gutters still have to be reconstructed. In the next section we will focus on the geometric reconstruction of those missing features.

5. GEOMETRIC RECONSTRUCTION

The main task is to produce closed polygons for each roof face, and to combine closed polygons to a closed 3D building model. At this point of processing, it still can be decided if the final model will be more model-driven or data driven. For both processing directions the matching results is helpful.

5.1 Object driven reconstruction approach

As we combine properties both from model driven and data driven approaches, depending on how well an object can be captured by the data, we propose to call it object driven reconstruction. In the following a summary is given on the assumptions made on input data, output objects and processing steps.

5.1.1 Laser segments assumptions

Outer boundaries of laser segments such as convex or concave hulls are noisy and not reliable, in the geodetic sense of the word. This means that, unless the segment is intersected by another segment, the boundary is not controlled by other information than the arbitrarily location of laser points at the edge of a segment. As this cannot be taken as fixed roof edge, assumptions have to be added to generalize the outline. Dorninger and Pfeifer (2008) and Vosselman (1999) generalize the outer boundary of individual segments by enforcing orthogonality or parallelism to a dominant direction. Although this might work in most of the situations, in this paper we want to explore alternatives that do not rely on the outer boundary of individual segments.

5.1.2 Assumptions on intersection lines

Directions and position of accepted intersection lines are supposed to represent directions and positions of ridges. Object points connected by two or more intersection lines are fixed. Object points connected to one horizontal line (such as end points of a gable intersection line) might be extended along the intersection line to the map (partition) line.

5.1.3 Eaves and gutter lines

Tilted eaves connecting to horizontal intersection lines are created perpendicular to the intersection line, or parallel to the map outline, see Figure 5. Map data represent locations of building walls, and cannot be taken as gutter location for tilted planes. Gutters are made horizontal. They take the height of the lowest laser point in the segment. However, gutter heights are changed if:

- The lower part of the segment is noisy. Histogram analyses are done to check if the lower part of the segment is sensitive to a few laser points. If this is the case, the lowest 5% of the segment is removed, and the histogram analysis is repeated.
- Gutter heights at segments that have matched on the same target are made equal if the height is within a threshold (default: 0.5 m).
- Gutter heights of segments of the whole building are made equal if the height is within a threshold (default: 0.5 m).

This means that object points are either fixed by:

- intersection of 3 or more planes;
- heights of other points in the same target or building;
- extension to map outline, or map partition.

5.2 Use of 2D map data

Using existing 2D map data in the reconstruction process has been described as helpful, (Brenner, 2000; Vosselman and Dijkman, 2001). As our point of departure is that we could use both 2D map data and laser data to reconstruct 3D buildings, we describe the value of 2D map data. An important assumption is that 2D map data of buildings detect areas of interest, and helps detecting roof faces in laser scanner data. Map polygons represent horizontal information of walls, instead of outer edges of the roof. This knowledge is used in detection and reconstruction phase:

- Our detection method is based on a segment-in-polygon algorithm. If a planar segment (partly) falls inside the polygon, all laser points of that segment are taken as potential building roof points.
- The location of the map does not represent the outline of the 3D model exactly for all objects. We can use the map outline as an approximation, which we have to adjust to the roof outline if we can determine the roof outline better by other data sources. However for flat segments touching the map outline, we propose to take the map outline as location of that roof part.

In specific situations intersection lines will be extended to the map out line. Situations were we can make use of map data are shown in Figure 5. Intersection lines of gable roofs end near the map outline. The user can decide in the target database or with Boolean parameters during the processing whether these intersection lines should be extended to the map outline or not. It can also be decided to extend to the map outline only for lines that end inside the map polygon. This makes sense if overhanging parts are accepted at this location of the building.

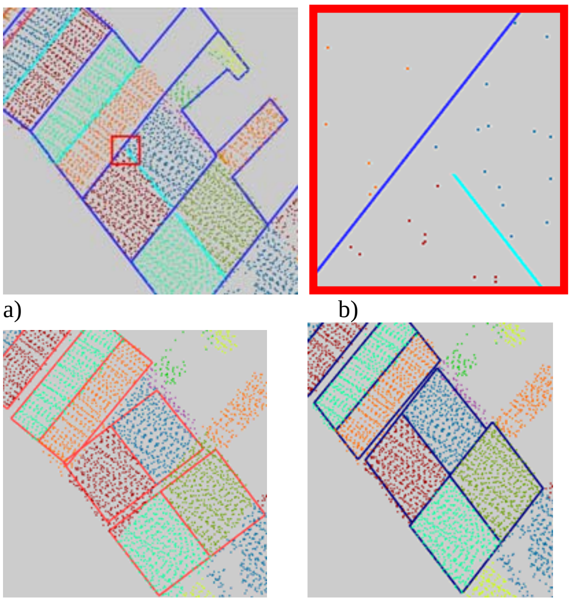
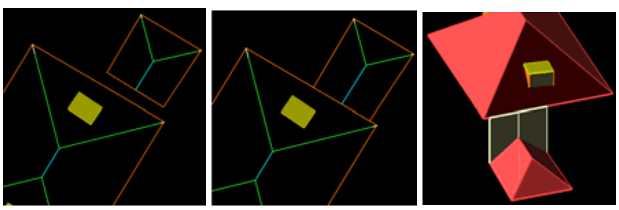


Figure 5 a) Map outline, segmented laser data and intersection lines, b) zoomed in on red squared box of (a), c) reconstruction of eaves by taking perpendicular direction to intersection line d) and adapting eave direction to direction of map outline.

If an intersection line is extended to the map outline, the eaves at both sides are adjusted to the local direction of the map outline. Figure 5 shows an extreme example where the direction of the map outline differs about 15° from the perpendicular direction. It can be seen that the roof face is better reconstructed if the direction of the map outline is taken (d) instead of the perpendicular direction (c).

5.3 Step edges

The geometric reconstruction of step edges needs some extra attention. As described in 3.2.2 step edges are detected because of a vertical height difference between two segments. Therefore in 3D models their appearance can best be described by a vertical face. This vertical face is bounded by an upper and lower segment. These segments might have been reconstructed individually in the object driven approach described before. The location of the vertical face depends on the location of the edges of the reconstructed segments. We propose to take the location of the higher edge, as occlusion might affect the location of the lower segment. So, lower edges of the step edge will be snapped to the location of the higher edge, as visualized in Figure 6.



a) b) c)

Figure 6 a) Reconstruction of individual roof parts, b) extended roof edges of faces that connect through step edges, d) reconstructed step edge.

6. RESULTS OF 3D BUILDING MODELS

6.1.1 Correct situations

Figure 7 shows a suburban area where assumptions of our reconstruction method are correct. Roof parts are large enough to have at least 20 laser points in a segment. The fact that all buildings in the scene can topologically be built from the target graphs, plus the complete segmentation and intersection result, produces a complete building model.

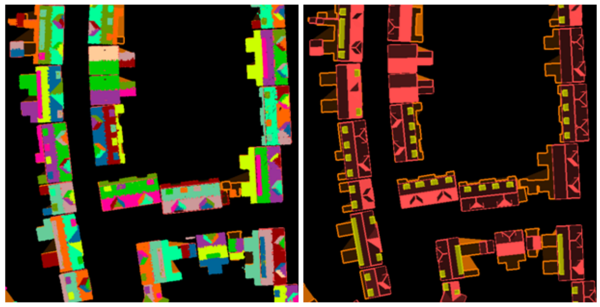


Figure 7 Segmented laser data of suburban area (left), reconstructed buildings (right).

Walls are reconstructed at locations of map outlines and step edges. As we allow roofs to extend the map outline, 3D buildings include overhanging parts, as can be seen in Figure 8.

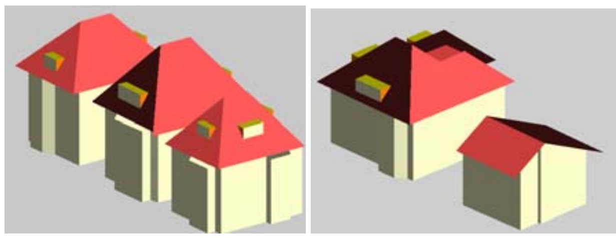


Figure 8 Reconstruction of overhanging parts. Walls are reconstructed at location of map outline.

6.1.2 Problematic areas

In this section a brief analysis is given to situations that were not reconstructed properly in an automated way. Assuming the gable roofs' eaves to follow a line perpendicular to the intersection line to the lowest height of the segment, is not always correct, see Figure 9. Instead, following a generalized segment outline as proposed by Dorninger and Pfeifer (2008) and Vosselman (1999) would give better results in these occasions. As mentioned in 4.5 our approach presented here only handles complete match results. This means that if intersection lines or segments do not fully match with one of the targets, these features are not incorporated in the geometric reconstruction.

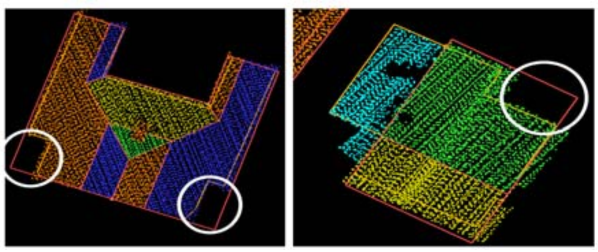


Figure 9 White circles indicate incorrect assumption on gutter reconstruction.

On the left in Figure 10 laser segments are shown that are left out from the reconstruction, superimposed on the model reconstructed from the accepted laser segments. This object is definitively a too big challenge to reconstruct automatically, at the moment.

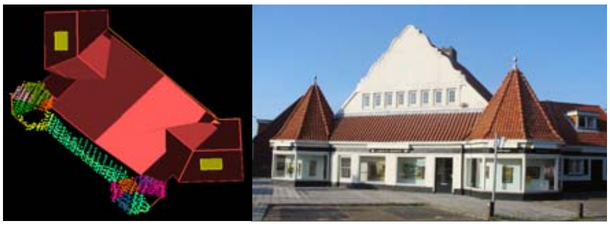


Figure 10 Challenging situation: roof faces are slightly curved and steep, roof shape is irregular and not in target database.

7. CONCLUSION & OUTLOOK

When reconstructing the topology of a building roof, laser data provides information on what could be roof part (in terms of segments) and how these roof parts connect (in terms of intersection lines and height jumps). The advantage of using a target based matching approach is that the algorithm filters out intersection lines that do not fit to a target model. The matching also transfers database knowledge to the data. This knowledge can be in terms of deciding what the optimal height for a gutter is, or what other constraints affect the data. In the geometric reconstruction phase, laser data provides geometry to roof face orientation and ridge directions. Although our object driven approach combines strong elements from laser data with strong parts of model driven approaches, there are still problems to be solved. Problematic areas are found in cases where both laser data and model information are weak. This occurs at complex roof structures where data is missing or erroneous and the roof shape is not in the data base.

Future work includes a detailed quantitative description of the quality of automatically reconstructed models. This quality assessment contains several aspects such as number of laser points (not) used, assumptions made during the process and RMS values in 2D and 3D on reference data.

In this paper we only have described the automated geometric reconstruction of complete matches. Reconstructing incomplete matches is of great interest to be able to fill data gaps and improve the completeness of 3D building models. Future work will describe the (semi-) automated reconstruction of those roof parts.

REFERENCES

Ameri, B. and Fritsch, D., 2000. Automatic 3D building reconstruction using plane-roof structures, ASPRS Congress, Washington DC, accessed (14/03/2009): www.ifp.uni-stuttgart.de/publications/2000/pub2000.html.

Brenner, C., 2000. Towards fully automatic generation of city models. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXIII, part B3: pp. 85-92.

Brenner, C., 2004. Modelling 3D Objects Using Weak CSG Primitives. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXV, part B3: pp. 1085-1090.

Dorninger, P. and Pfeifer, N., 2008. A Comprehensive Automated 3D Approach for Building Extraction, Reconstruction, and Regularization from Airborne Laser Scanning Point Clouds. Sensors, 8(11): 7323-7343.

Durupt, M. and Taillandier, F., 2006. Automatic building reconstruction from a digital elevation nodel and cadastral data: an operational approach. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVI, part 3: pp. 142-147.

Filin, S., Abo Akel, N. and Doytsher, Y., 2007. Detection and Reconstruction of Free Form Surfaces from Airborne Laser Scanning Data. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVI, part 3/W52: pp. 119-124.

Milde, J., Zhang, Y., Brenner, C., Pluemer, L. and Sester, M., 2008. Building Reconstruction using Structural Description based on a Formal Grammar. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVII, part 3B: pp. 227-232.

Oude Elberink, S., 2008. Problems in Automated Building Reconstruction based on Dense Airborne Laser Scanning Data. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVII, part 3A: pp. 93-98.

Roth, R. and Thompson, J., 2008. Practical Application of Multiple Pulse in Air (MPIA) LIDAR in Large-Area Surverys. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 37, part 1A: pp. 183-188.

Rottensteiner, F. and Briese, C., 2002. A New Method for Building Extraction in Urban Areas from High-Resolution Lidar Data. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXIV, part 3A: pp. 295-301.

Rottensteiner, F. and Briese, C., 2003. Automatic Generation of Building Models from Lidar Data and the Integration of Aerial Images. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXIV, part 3/W13: pp. on CD-ROM.

Verma, V., Kumar, R. and Hsu, S., 2006. 3D Building Detection and Modeling from Aerial LIDAR Data, IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'06). IEEE Computer Society, Washington, DC, USA, pp. 2213-2220.

Vosselman, G., 1999. Building Reconstruction Using Planar Faces in Very High Density Height Data. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXII, part 3/2W5: pp. 87-92.

Vosselman, G. and Dijkman, S., 2001. 3D Building Model Reconstruction from Point Clouds and Ground Plans, ISPRS Workshop Land Surface Mapping and Characterization Using Laser Altimetry. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Annapolis, USA, pp. 37-43.

Wehr, A., 2008. LIDAR: Airborne and terrestrial sensors. In: C.B. Li (Editor), Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences; 2008 ISPRS Congress Book. Taylor & Francis Group, London.