ON THE QUALITY OF OBJECT CLASSIFICATION AND AUTOMATED BUILDING MODELLING BASED ON LASERSCANNING DATA

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ABSTRACT:

In this paper, techniques for an automated extraction, classification and modelling of 3D objects will be presented. They use solely laserscanning derived digital elevation models as data basis. Trees, buildings and terrain objects are detected and classified. Firstly, a special region growing algorithm segments 3D objects on the terrain surface. Object specific features are extracted inside these segments and used for classification by means of a fuzzy logic approach. Subsequently, a quality analysis is based on classification rates which are compiled in a confusion matrix. For geometric modelling of buildings a generic approach is used where buildings are approximated by (oblique) planes. The intersection of neighbouring planes leads to building edges and corners. The quality analysis of these building models is separated into positioning and height accuracy. First experimental results are presented.

1. INTRODUCTION

Airborne laserscanning has become operational in the last years and meanwhile it is used for numerous applications due to its high point density and accuracy. An object oriented classification of these laserscanning data is important for most applications, e.g. for the extraction of terrain models as well as for the modelling of 3D objects like buildings or vegetation. In our approach the detection, classification and modelling of objects is based exclusively on the laser data itself without additional information like GIS data or spectral images. This is necessary for specific application in a disaster management tool where our system has to be able to acquire data also during night time and poor weather conditions. Furthermore, time restrictions and the amount of data require a high degree of automation of the analysis process. Therefore, a main aspect of our approach is the obtained quality of classification and building modelling, e.g. for generation of city models (as reference data) or further change detection after earthquakes. At the moment raster data (1.0 m pixels size on ground) are used, provided by TopoSys (Germany).

2. DETECTION OF 3D OBJECTS

To detect 3D objects, a digital terrain model (DTM) is derived from laser raster data (Figure 1) which form a digital surface model (DSM). Many filtering techniques for the extraction of terrain points can be find in literature (e.g. Weidner & Foerstner, 1995; Kraus & Pfeifer, 1997; Vosselmann, 2000).

We use an approach developed at our institute, the *convex-concave hull* (v. Hansen, Voegtle, 1999). As initial status for the following extraction procedure a convex hull containing the local lowest points (e.g. in a TIN structure) is determined. For each triangle of the convex hull those points above that triangle are extracted which fulfil specific distance and curvature conditions. Out of these the most suitable one is taken to subdivide that triangle into 3 new ones. This procedure is continued for each triangle till no more acceptable points can be found. Therefore, a very fine triangulation – consisting of convex and concave parts – is created as an suitable approximation of the terrain (Figure 2).

This DTM is subtracted from the original DSM to obtain a normalised DSM (nDSM) which is used for segmentation of 3D objects.

$$nDSM = DSM - DTM \tag{1}$$

In such a nDSM only 3D objects on the surface of the Earth will remain, e.g. buildings, trees but also extreme terrain edges or cliffs (Figure 3).

A special region growing algorithm (Steinle & Voegtle, 2001) is used for segmentation of 3D objects of significant size and height (Figure 4).

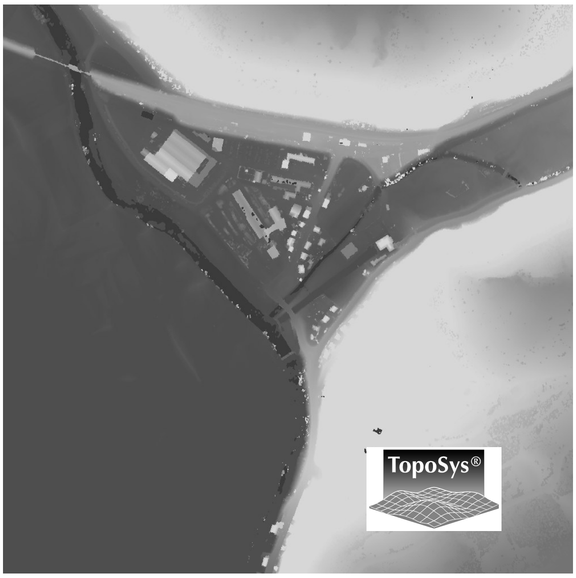

Figure 1. Original laserscanning raster data (DSM), pixel size 1m, test area 'Fridingen' (1 km x 1 km)

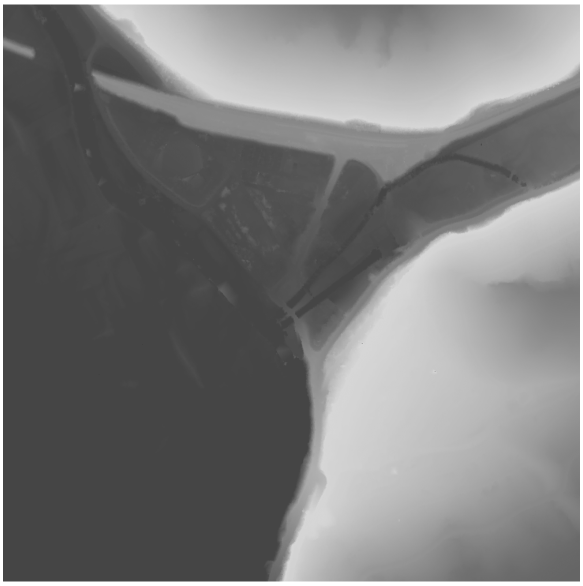

Figure 2. DTM derived from original raster data by filtering

Figure 3. Normalised DSM

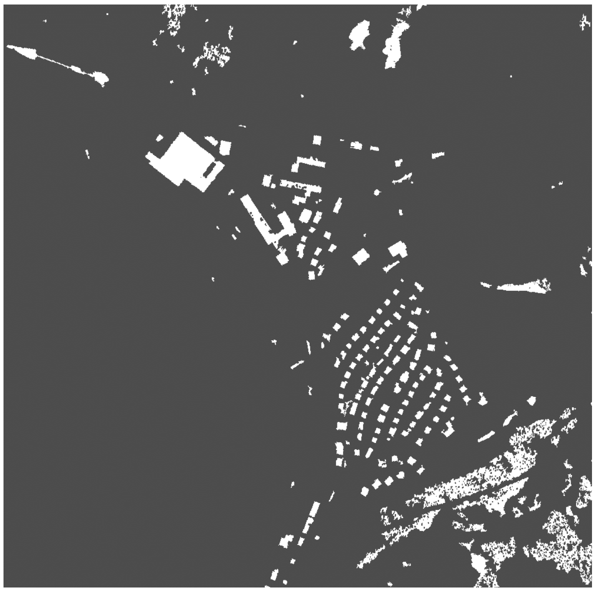

Figure 4. Segmented 3D objects

3. CLASSIFICATION OF 3D OBJECTS

3.1 Feature Extraction

The classification process starts by extracting object specific features inside the separated segment areas. The following parameters have proved to be suitable to distinguish the main object classes *buildings*, *vegetation* (trees, bushes etc.) and *terrain objects*:

- Gradients on segment borders
- Difference of first and last pulse value
- Shape
- Height texture

Significant gradients on the border of segments contribute mainly to the discrimination of buildings/vegetation objects on one hand and terrain objects on the other hand. In contrast the differences of first and last pulse values allows the discrimination of vegetation and buildings. Additionally in most cases the shape of buildings is smoother than that of vegetation or terrain objects. Experience has shown that commonly used shape parameters like *roundness*, *compactness* etc. fail for the above mentioned object types and therefore, new ones had to be defined, e.g. *parallelism of long segment contour lines* determined by the deviation of line directions. Usually, at buildings borders relatively long and parallel contour lines can be extracted (in contrast to vegetation and terrain objects). Therefore, the parallelism of the longest 4 or 5 lines can be used as specific shape measure for these objects. As parameters to describe *height texture* for discriminating building(roofs) and vegetation only those can be used which determine deviations from oblique planes. Therefore, the well-known Laplace operator (Maas, 1999) and local curvature (Steinle & Voegtle, 2001) has been chosen in this context.

Figure 5. Height texture / border gradients (detail)

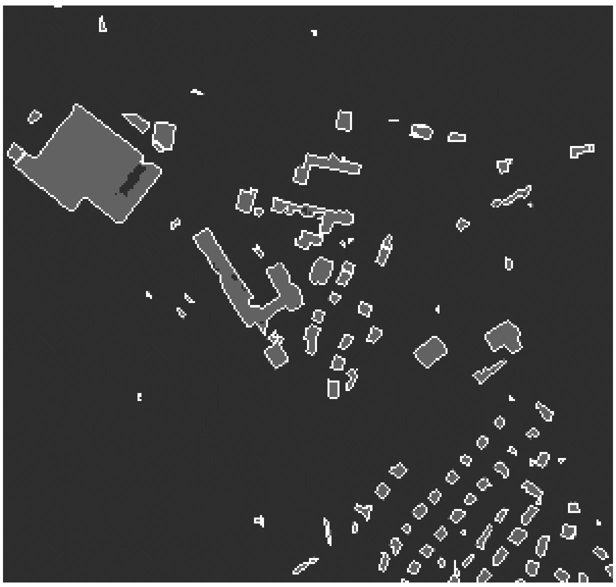

Figure 6. Extracted contour lines for shape analysis (detail)

Exemplary, the parameter height texture and segment contour lines for determination of shape parameters are shown in Figure 5 and 6 respectively.

3.2 Fuzzy Logic Classification

A method based on *fuzzy logic* has been chosen to classify 3D objects because most of the above mentioned features are not normal distributed. The procedure consists of two main parts. First a so-called fuzzification has to be carried out, i.e. for every parameter mentioned in chapter 3.1 membership functions have to be defined for every class during a training phase. As an example the membership functions of feature *border gradients* is shown in Figure 7.

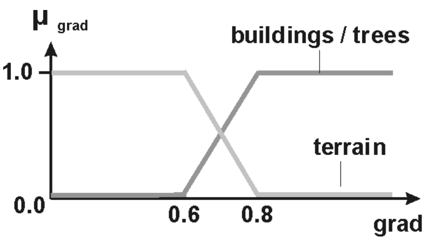

Figure 7. Membership function of feature *border gradients*

In a second step the determined membership values have to be combined to get a final decision (inference process). In this project we have tested two different methods, a structure of logical operators and a weighted sum approach. The latter has shown better results and therefore, it shall be shortly explained. The resulting value for class j is calculated by the sum of the membership values $\mu_{i,j}$ for each parameter i (mentioned in chapter 3.1) concerning an individual weight factor w_i. The weights for parameters *height texture* and *shape* depend on the segment size (Figure 8).

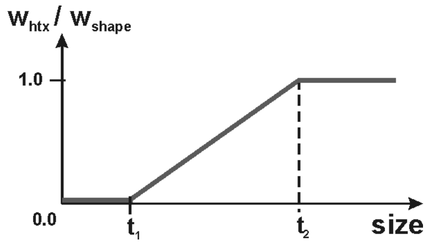

Figure 8. Weighting function for *height texture* and *shape*

Investigations at our institute have shown that for instance small buildings may have a high texture as well as small bushes may have relatively smooth surfaces in laserscanning data. A similar characteristic can be seen concerning the shape of small objects. Suitable values t_i have been determined during training phases in different test areas ($t_1 = 20\ m^2$, $t_2 = 250\ m^2$).

Finally, every segment is assigned to the class of highest value. Figure 9 shows the result for a rural test area with sharp terrain edges and cliffs, Figure 10 for urban area in flat terrain.

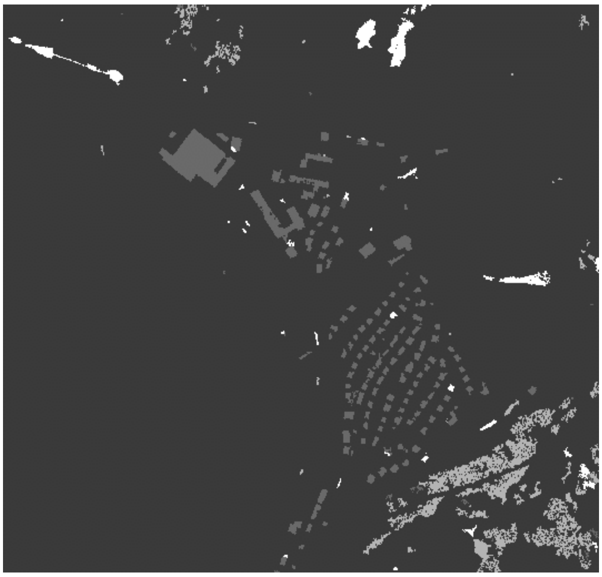

Figure 9. Classification result for test area ‘Fridingen’ (dark grey: buildings, light grey: trees, white: terrain objects

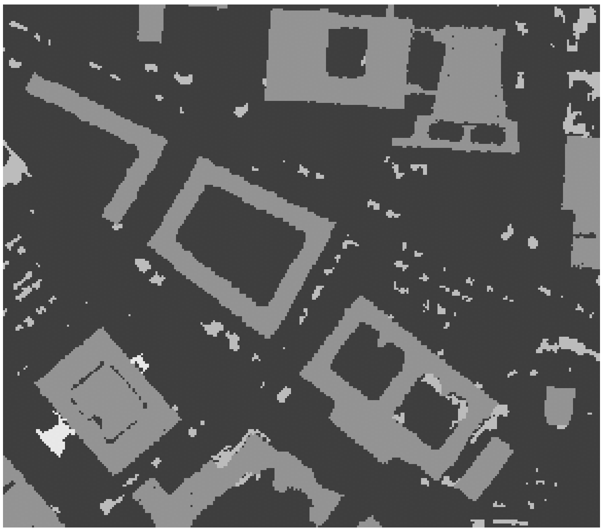

Figure 10. Classification result for test area ‘Karlsruhe’ (dark grey: buildings, light grey: trees, white: terrain objects)

The classification result is compiled for the first example by a confusion matrix (Table 1). The overall classification rate is 92.6%. The classification of terrain objects has proved to be problematic, especially if these areas contain forest. So our results confirm the experiences of (Csaplovics et al., 2003).

Usually large buildings and forest areas can be classified with high reliability mainly based on border gradients and difference between first and last pulse values. Small buildings covered only by a few pixels lead in some cases to misclassifications. For the second example the classification rate is even better (95.8%) because last pulse date were used in order to detect and model buildings exclusively. These data contain only few vegetation objects and due to the flat surface of the Earth no terrain objects exist in this area (with exception of two ramps beside a building).

	buildings	trees	terrain
buildings	**92**	5	3
trees	6	**94**	0
terrain	2	11	**87**

Table 1. Confusion matrix for test area ‘Fridingen’ (classification rates in [%])

4. MODELLING OF BUILDINGS

Modelling of buildings is based on the results of the detection and classification process.

According to the further application, the attempt is to model the buildings geometry very close to their representation in the data and not to generalise them strongly for achieving the fulfilment of a restrictive conceptional model. The modelling is done using an analytical modelling methodology (compare Foerstner, 1999), assuming buildings to be polyhedrons. Therefore, the basic and most important features to extract from the height data are oblique planes, i.e. the roofs top planes.

They are extracted using a special region growing algorithm. The seed regions are small areas wherein all neighbouring pixels are quite homogenous regarding their heights. A mathematical plane equation is computed and neighbouring points are tested if they belong to this plane. A homogeneity predicate is calculated for each regarded point, including it into the determination. If the adding of this point into the calculation of the plane leads to a significant decrease of the homogeneity measure the membership probability of already recognised plane members decrease significantly, too. Therefore, this point is rejected (further details of this technique can be found e.g. in (Voegtle & Steinle, 2000)).

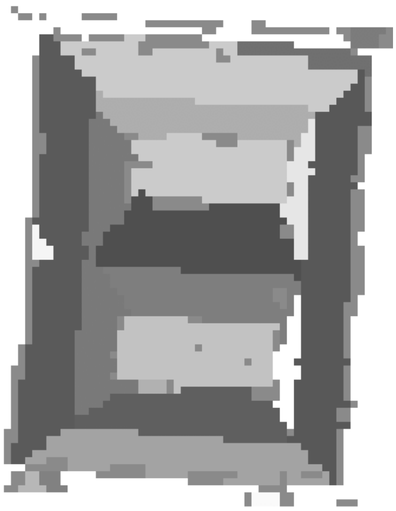

Figure 11. Segmented roof planes for a building

Once a 3D object is segmented into planes (Figure 11), topological relations are examined, i.e. primarily the neighbourhood of planes is analysed. In a first step, the analysis is done in a 2D representation of the segmented object, i.e. mathematical morphology is carried out on a label image to extend all segments and analyse their overlapping areas. Neighbouring planes are analysed at their common border lines regarding the occurrence of a significant height shift. For this purpose, the common border is split up in straight line parts. If high gradients occur at one of the partial lines, a vertical plane and its topological relations are inserted.

In the next step the planes are intersected according to the detected neighbourhoods, i.e. the building edges are computed. In the following step these edges are intersected, according to the topological relations between the planes they had been derived from. This results in computed building corners connected by the building edges (Figure 12).

As can be seen in this figure these intersections must not lead in every case to a common corner point. This is the influence of uncertainties in determination of the planes caused by measurement errors of laser points and remaining errors of segmentation process. Because of the requirements of disaster management (acquisition of damaged buildings) no geometrical restrictions had been introduced, but for other applications it is possible to merge closely neighboured points, e.g. such lying inside a snap circle.

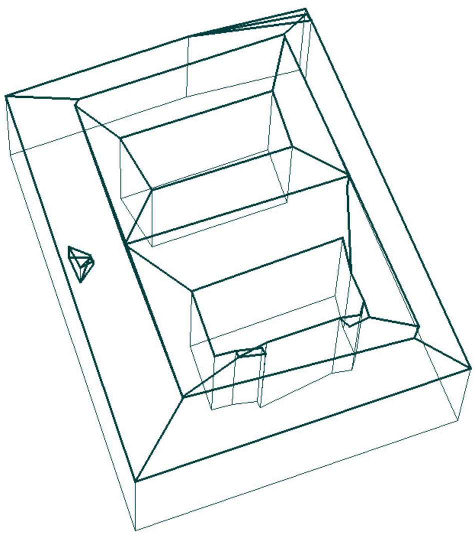

Figure 12. Extracted building edges and corner points by intersection of vertical and roof planes

In a last step this building model is supplemented by vertical planes which are introduced at the building borders (more details see (Voegtle & Steinle, 2000); (Steinle & Voegtle, 2001)). These contour lines are determined at subpixel accuracy by analysing the maximum gradients (e.g. Busch, 2001) and calculating an adjusted straight line.

5. ACCURACY OF BUILDING MODELS

The resulting accuracy of building models derived from laser-scanning data is influenced by different factors. The most important ones are measurement accuracy of laser points, rasterisation effects, segmentation errors of planes and generalisation effects of modelling buildings by planes.

At the moment no generally accepted measures can be found for accuracy assessment of 3D object models. Therefore, we decided to separate positioning accuracy (σ_{xy}) and height accuracy (σ_z). For our quality assessment reference models of buildings in test area ‘Karlsruhe’ were generated by means of geodetic measurements of the main contour lines of the roof structures with an accuracy of $\sigma_{xyz} = \pm 0.05$m. Only these parts of buildings can be acquired by airborne laserscanning and, therefore, only these should be taken for accuracy determination. Distances between various building models derived from laserscanning data and their corresponding reference models were calculated as accuracy measure.

5.1 Positioning Accuracy

Concerning raster data a method using distance transformation – a special image processing tool – has been reported by (Ragia, 2000). But due to our vector based models this approach is not suitable. Therefore, two different methods had been developed to determine positioning accuracy based directly on the analysis of (building)roof contour lines:

- discretisation approach
- area based approach

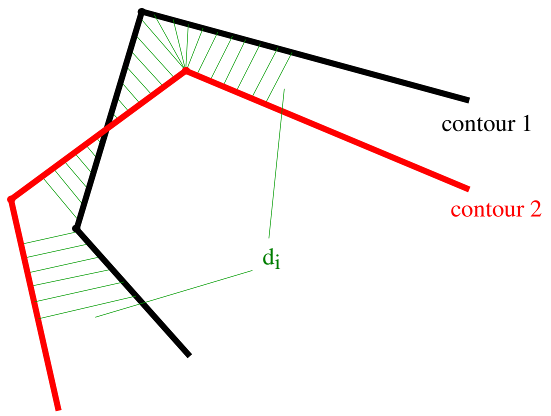

Figure 13. Discretisation approach by pointwise determination of shortest distances d_i

For the first method contour lines of one model (e.g. the laser model) were discretized by points of equal distances (discretisation length). For each point its shortest distance to the other contour line (e.g. the reference model) is calculated (Figure 13). An overall accuracy measure can be determined by the mean value of these distances (e.g. Kunz et al., 1997; Bruegelmann, 2000).

For the second method the non-overlapping areas of the two contours are subdivided in quadrangles and triangles respectively. Calculating their areas A_i and corresponding centrelines c_i representative distance values d_i can be determined (Figure 14).

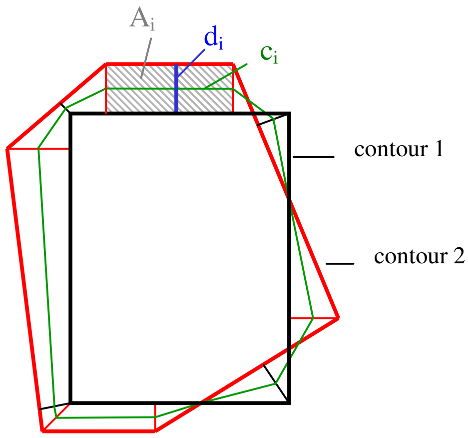

Figure 14. Area based approach for positioning accuracy analysis

The disadvantage of the first method is that slight differences between the resulting distances may occur, dependent on the calculation of distances from contour 1 to contour 2 or vice versa, which is not valid for the second method. First experimental results of both methods including 8 reference buildings and their related laser models derived from first pulse and last pulse data resp. are compiled in Table 2.

	first pulse	last pulse
method 1	1.19 ± 0.29	1.26 ± 0.18
method 2	1.19 ± 0.28	1.28 ± 0.19

Table 2. Positioning accuracy of laser derived building models (mean distances [m])

With both methods nearly the same results are achieved. The dimension of few more than 1 m corresponds to the pixel size of the laser data.

The mean distance values for first pulse and last pulse models are of similar dimension, but first pulse models are systematically larger, last pulse models systematically smaller than the related reference models due to the known characteristics of laserscanning (Steinle & Voegtle, 2000).

For investigations of the influence of orientation errors caused by dGPS/INS a best fit of the laser model contours was performed by minimising the described distance values in terms of the reference model (Table 3).

	first pulse	last pulse
method 1	1.18 ± 0.29	1.20 ± 0.20
method 2	1.16 ± 0.27	1.18 ± 0.21

Table 3. Positioning accuracy of laser derived building models (mean distances [m]) after best fit

The mean distance values show no significant decrease, therefore, no effect of orientation errors can be verified. A relevant improvement of laser model accuracy will be achieved by fusion of first and last pulse results. Due to the mentioned systematics of first and last pulse models a mean contour line can be determined by means of centrelines analogous to method 2. The mean distance values of this new (combined) contours are significantly smaller than that of the original contours (Table 4).

	mean contours
method 1	0.65 ± 0.13
method 2	0.65 ± 0.13

Table 4. Positioning accuracy of laser derived building models (mean distances [m])

5.2 Height accuracy

For determination of height accuracy also the discretisation approach was applied analogous to the positioning accuracy. Taking into account that positioning errors leads to pseudo height errors not caused by the elevation measurement, a best fit of positioning is performed before calculating the height differences between laser data derived and reference models. Inside a bounding box around these two model contour lines a point grid is defined to calculate the height differences dz_i at the knot points in the common area as accuracy measure (Figure 15). First experimental results are compiled in Table 5.

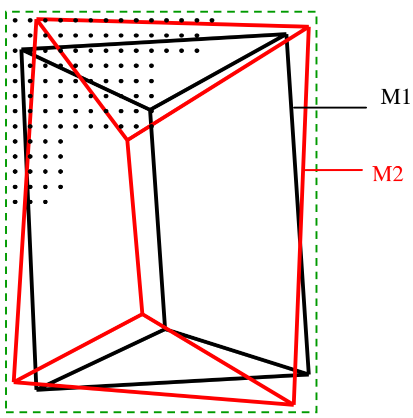

Figure 15. Discretisation approach for height accuracy analysis

	first pulse	last pulse
discretisation approach	0.42 ± 0.18	0.31 ± 0.15

Table 5. Height accuracy of laser derived building models determined by using the discretisation approach (mean height distances [m])

The values of Table 5 were found analysing some building models with different roof types. Nevertheless, the data basis was not very large, so further investigations are necessary to confirm the results.

6. CONCLUSION

This paper described approaches for extracting and modelling objects in urban areas. The suitability of these methods were proved by a quantitative rating of the results. The accuracy analysis was carried out separately for the positioning and height components, as well for first as last pulse data.

First experiences could be presented, the results are promising and proved the general suitability of the extraction and modelling techniques.

Nevertheless, these first results have to be validated by extending the investigations to additional building types and urban structures. As well other approaches for the accuracy analysis should be tested and compared, e.g. statistical based classification methods.

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