AUTOMATIC DETECTION OF BUILDINGS FROM LASER SCANNER DATA FOR MAP UPDATING

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ABSTRACT:

Automatic interpretation of laser scanner data for building detection and map updating was studied. Digital surface and terrain models (DSM and DTM) and an intensity image were created using a helicopter-borne TopEye system recording with 2–3 pulses per m^2. The DSM was segmented into homogeneous regions using a region-based segmentation method, and the segments were classified as \`building´, \`tree´ or \`ground surface´. Height differences between the DSM and DTM, textural characteristics of the DSM and intensity image, and shapes of the segments were used in classification. Building segments were compared with an old building map and further classified as \`new building´, \`enlarged building´ or \`old building´. Similarly, building segments derived from the old map were classified as \`detected´, \`partly detected´ or \`not detected´. Comparison with an up-to-date building map shows that about 80% of all buildings in the study area were detected from the laser scanner data. For buildings larger than 200 m^2, the detection percentage was about 90%. Pixel by pixel comparison of the classification result with the reference map shows that 90% of pixels covered with buildings in the map were correctly classified. 85% of building pixels in the classification result were buildings in the reference map. The accuracy measures of the pixel-based comparison also include errors caused by small location differences between the data sources. According to visual evaluation, the most important changes between the laser scanner data and the old map, e.g. new buildings, were detected in change detection. The most problematic buildings for automatic detection were small buildings surrounded by trees.

1. INTRODUCTION

Laser scanner data has proved to be a promising data source for various mapping and 3D modelling tasks. One of the most important application areas is extraction and modelling of buildings to create 3D city models. Several studies related to the topic have been published during recent years (e.g. Haala and Brenner, 1999a, 1999b; Maas and Vosselman, 1999; Morgan and Tempfli, 2000; Vögtle and Steinle, 2000; Vosselman and Suveg, 2001; Fujii and Arikawa, 2002; Rottensteiner and Briese, 2002). The building extraction and modelling process can typically be divided into two steps: building detection and building reconstruction. At first, buildings have to be distinguished from the ground surface and other objects, such as trees. After this, 3D models of buildings can be created.

Methods for building detection are often based on step-wise classification of the data to eliminate objects other than buildings. Some methods use aerial images in addition to the laser scanner data (e.g. Haala and Brenner, 1999b; Vögtle and Steinle, 2000). Classification can be pixel-based, but segmentation is normally applied in some stage of the process to obtain regions. Segmentation of laser scanner data has been studied by e.g. Geibel and Stilla (2000) and Gorte (2002). The building detection stage can be avoided if an up-to-date map is available as a basis for building reconstruction (see e.g. Haala and Brenner, 1999a, 1999b; Vosselman and Suveg, 2001).

Murakami et al. (1999) studied the use of laser scanner data in change detection of buildings. They used simple comparison between DSM data sets acquired at different occasions. Use of laser scanner data in 'upvaluation' of map information to transfer 2D building data into 3D data was discussed by Hofmann et al. (2002).

The goal of our study is to investigate the feasibility of laser scanner data for updating of large-scale city maps and to develop automatic methods for the work. In the first stage of the updating process, which is discussed in the present article, the aim is to automatically recognize buildings from laser scanner data and to detect changes compared with an existing 2D building map. The results should provide a preliminary updated 2D building map that presents approximate building polygons associated with attribute information showing if the building has been built, removed or changed after the map was made. This preliminary updated map could then be used in further processing steps that can include verification of the changes, exact location and modelling of the buildings, updating of a map database and finally creation of a 3D city model. These further processing steps can be manual, semi-automatic or fully automatic.

Results of a previous study (Matikainen et al., 2001) showed that planimetric and height precisions high enough for large-scale mapping of buildings can be obtained with high-pulse-rate laser scanners. Promising results were also obtained in automatic building detection by using a region-based segmentation method and a simple classification procedure based on laser scanner data and an aerial colour image. The present article discusses results obtained when the study was continued in a larger study area, the building detection procedure was improved and change detection compared with an existing building map was included in the process.

2. STUDY AREA AND DATA

2.1 Study area

The size of the study area is 2.0 km^2, and it is located in Otaniemi, Espoo, about 10 km west from the city of Helsinki. More than 50% of the area is campus area with mainly university and office buildings. Most of these buildings are large and have complex shapes. The terrain is relatively flat. The rest of the area is residential area with apartment houses and some small houses. The residential areas have a varying topography with small hills. The study area is not very densely built-up. Coniferous and deciduous trees and small forests occur between buildings. The area has an irregular shape because most of it is surrounded by sea. In data processing a larger rectangular area (about 1.8 km x 1.8 km) had to be used. Sea and other areas outside the selected 2.0 km^2 study area were excluded from the analysis by using a mask.

2.2 Laser scanner data

The laser scanner data were acquired with the Swedish TopEye system from a helicopter on 5 September, 2002. The flying altitude was 200 m, resulting in a point density of about 2–3 points per m^2. The pulse modes of the laser points were only echoes, first (of many) echoes or last (of many) echoes. Digital surface and terrain models (DSM and DTM) in regular raster format were created from the laser-measured points. An intensity image was also formed. The pixel size of the models and the image was 0.60 m x 0.60 m.

The dataset used in creating the DSM and intensity image consisted of a list of points with X and Y coordinates transformed to the Finnish coordinate system, orthometric height, and intensity of the returned pulse. To create the DSM, each pixel was assigned the maximum height value occurring within the pixel. Separation between first, last and only echoes or points originating from different measurement strips was not made. Height values for pixels without measured values were obtained by using linear interpolation based on a Delaunay triangulation. To create the intensity image, each pixel was assigned the intensity value corresponding to the maximum height value within the pixel. Interpolation was performed in the same manner as for the DSM.

The DTM was created with TerraModeler and TerraScan using originally 15 144 044 laser points. Laser points were first classified into class ground using only echoes and last echoes. Classification of the ground is iterative creating a triangulated surface model (Soininen, 2003). Classification starts selecting local low points and controlling initial point selection with the maximum building size parameter. Triangles in this initial model are below the ground with only the vertices touching the ground. Then the model is moving iteratively upwards when new laser points are added to it using terrain angle, iteration distance and iteration angle. The triangulated surface model was created after having classified the laser points. The triangulation is constructed in a way that there is one triangle under every XY location inside the surface area. Error points have been filtered from the model. In the triangulated model the maximum triangle size was 50 m. The triangulated surface model was exported into a 0.6 m by 0.6 m grid.

2.3 Maps

Two digital map datasets were used in the study. The first one (referred to as map 1 in the following) contains buildings of the Topographic Database obtained from the National Land Survey of Finland. Information in this data corresponds to situation in 2000, and the map was used as an ‘old’ map to be updated. The other dataset (map 2) was obtained from FM-Kartta Oy and contains buildings and forest areas. Buildings of map 2 are also based on the Topographic Database, but some changes and updates have been made to it, and the map corresponds to situation in 2001. Buildings of map 2 were used as reference data in estimating the accuracy of building detection results. Both of the maps are relatively new but not completely up-to-date because some new buildings have been constructed in the area both in 2001 and 2002. In map 2 there are thus some buildings that are missing in map 1, and in the laser scanner data there are some buildings that are also missing in map 2. Areas with new buildings not presented in map 2 were excluded from the analysis when estimating the accuracy of the classification results. This was conducted by using a manually defined mask.

A small part of the study area was selected as a training area for development of classification rules. Buildings of map 1 (in this part of the area map 1 was up-to-date and had good correspondence with the laser scanner dataset) and forest areas of map 2 were used in rule development. When estimating the accuracy of the building detection results, buildings of the training area were excluded from the analysis.

The map data were originally in vector format. For the study, they were converted into raster format with 0.60 m x 0.60 m pixels. The pixels corresponded to pixels of the DSM and DTM.

3. METHODS

3.1 General

The building detection and change detection procedure used in the study can be divided into three stages:

- Segmentation of the DSM into homogeneous regions using a region-based segmentation method.
- Classification of the segments to distinguish building segments from other segments and formation of new segments in which each building is represented by one segment.
- Detection of changes between the old building map and building segments found from the DSM. To facilitate processing, the old map was first segmented to obtain a segmentation in which each building of the old map is represented by one segment.

Each of the stages is described in detail in the following. In segmentation and classification, the eCognition software (Definiens Imaging, 2003) was used. Change detection was performed in Matlab (MathWorks, Inc.) using segmentation and classification results exported from eCognition.

3.2 Segmentation

The applied segmentation algorithm (Baatz and Schäpe, 2000; Definiens Imaging, 2002) is based on bottom-up region merging and a local optimization process minimizing the growth of a given heterogeneity criterion. The heterogeneity criterion can be defined as a combination of colour and shape heterogeneity. Heterogeneity criterion based completely on colour information, which in this case corresponds to height, was used in the study. The segmentation method has earlier been applied for laser scanner data by e.g. Matikainen et al. (2001), Schiewe (2001, 2003) and Hofmann et al. (2002).

3.3 Classification

Our earlier method for classifying DSM segments into buildings and other objects was based on two stages. At first, segment was classified as `tree or building´ if the difference in the mean height between the segment and the segment with the lowest mean height within a square neighbourhood was over a given threshold value. This classification rule was based on the assumption that the lowest segment represents a ground segment. Buildings and trees were then distinguished from each other on the basis of an aerial colour image. An aerial image was not available now, but on the other hand, the intensity information from laser scanning was available. It also appeared that the previous algorithm could not distinguish trees and buildings from ground well enough in hilly areas. Changes to the procedure were thus needed.

In the first stage of classification, the DTM was used. Difference between the mean height of the segment in the DSM and in the DTM was calculated, and if this difference was over 2.5 m, the segment was classified as `tree or building´.

Segments in the training area (see Section 2.3) were used to find good rules for separating buildings from trees. Segment was used as a training segment for building or tree if over 80% of it belonged to building or forest in the map. Several segment attributes that can be exported from eCognition were analysed. These included mean values and standard deviations of height and intensity, size, various shape attributes, as well as various texture attributes calculated from the height or intensity values inside the segment. Histograms and plots of the attribute values in the two classes were formed. The following three attributes were selected for classification: 1) Grey Level Co-occurrence Matrix (GLCM) homogeneity of height (texture measure), 2) GLCM homogeneity of intensity and 3) average length of edges in a ‘shape polygon’ created on the basis of the segment. Histograms of these attributes for the training segments are shown in Figure 1. The GLCM homogeneity of both height and intensity is normally higher for building segments than for tree segments. The average length of edges is also typically higher for building segments than for tree segments.

Fuzzy membership functions for recognizing buildings were formed based on the distributions of the attributes. For example, when the average length of edges increases from 3 to 7, the membership to class building gradually increases from 0 to 1. The three membership values for each segment were combined by calculating their mean value. Classification rule defined for trees was simply ‘not building’. A segment thus became classified as building if its final membership value to class building was over 0.5, otherwise it became classified as tree.

After classification, a classification-based segmentation was performed such that all neighbouring segments classified as buildings were merged into the same segment. Each building segment thus corresponded to one entire building, which was advantageous for change detection. This step was needed because buildings with different height levels became divided into several segments in the first segmentation. Ground and tree segments were not changed. Finally, the new segments were classified. Ground segments were recognized on the basis of the previous result. For buildings and trees, the rules described above were applied again. By this means, a membership value to class building, calculated on the basis of the three attributes, was obtained for each building segment.

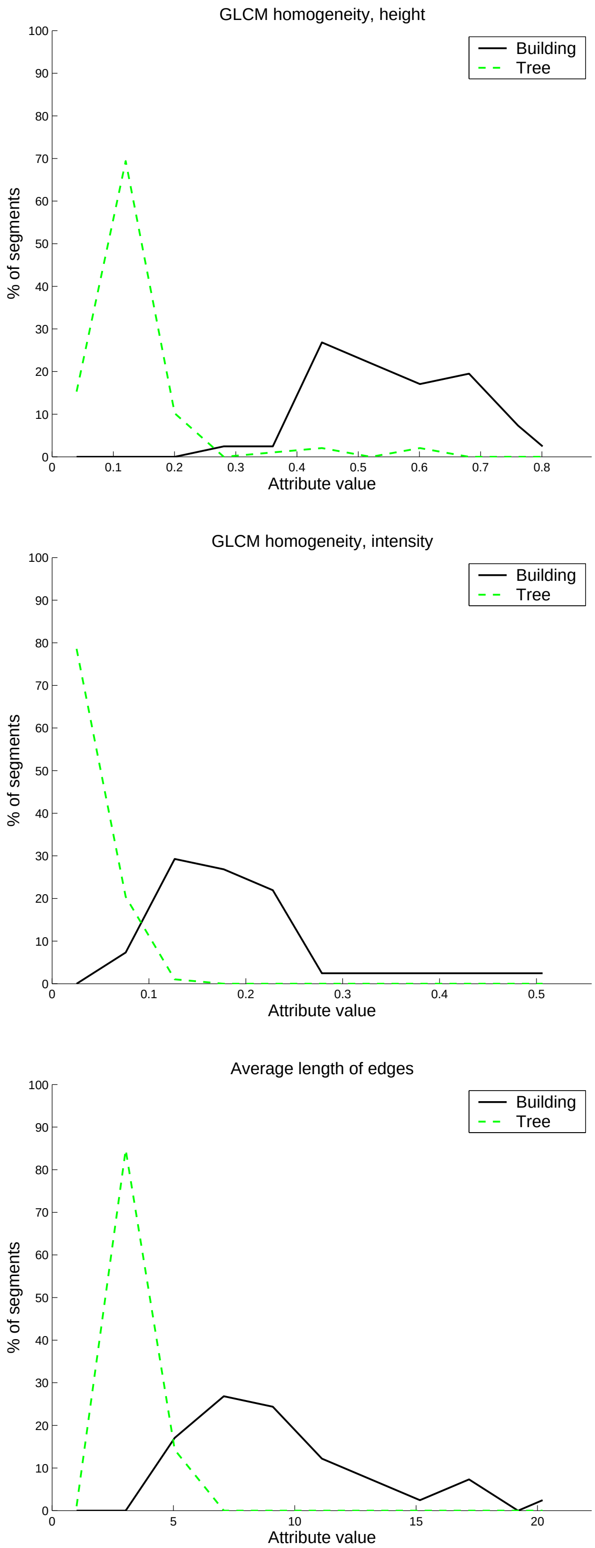

Figure 1. Histograms of attribute values for building segments and tree segments.

3.4 Change detection

The map data in raster format were segmented in eCognition to form segments that correspond to buildings of the map. Each building is represented by one segment. This was made to facilitate comparisons between buildings in the map and in the classification result. In the original vector map data many buildings were divided into several polygons.

Simple rules were created to detect changes between the old building map and the building segments found from the laser scanner data. At first, building segments detected from the laser scanner data were divided into four classes using the building map:

- Less than 10% of the building segment is covered with buildings in the map –> New building
  - Membership value to building in classification was over 0.75 –> Certain detection
  - Membership value to building in classification was 0.5 – 0.75 –> Uncertain detection
- 10 – 80% of the building segment is covered with buildings in the map –> Enlarged building
- Over 80% of the building segment is covered with buildings in the map –> Old building

Similarly, buildings of the old map were divided into three classes on the basis of the building detection result:

- Over 80% of the building is covered with buildings in the classification result –> Old building detected
- 10 – 80% of the building is covered with buildings in the classification result –> Old building partly detected
- Less than 10% of the building is covered with buildings in the classification result –> Old building not detected

The final change detection results thus consist of two separate segmentations with associated classifications:

- Old building segments derived from the map and classified as \`detected´, \`partly detected´ or \`not detected´.
- New segments derived from the laser scanner data and classified as \`building´, \`tree´ or \`ground surface´ and building segments further classified as \`new building, certain detection´, \`new building, uncertain detection´, \`enlarged building´ or \`old building´.

In the study, the segmentation results were treated in raster format, but they are also available as vector polygons. The results can be used as input data in further steps of map updating.

4. RESULTS

Segmentation and classification results for part of the study area are shown in Figures 2 and 3, respectively. Figure 4 shows change detection results for the entire study area. It is a combination of buildings presented in the old map and buildings detected from the laser scanner data. At first, new and enlarged buildings from the classification result were plotted. Buildings of the old map were then overlaid. The figure thus shows the shape and location of old buildings as they appear in the map and the shape and location of new buildings as they were detected from the laser scanner data.

Figure 2. Segmentation result overlaid on the DSM. The size of the subarea shown in the figure is 450 m x 540 m.

Figure 3. Classification result (Light grey: building, Dark grey: tree, Black: ground surface). The size of the subarea shown in the figure is about 1.1 km x 1.3 km.

To obtain information on the accuracy of the results, buildings detected from the laser scanner data were compared with buildings of map 2. Buildings used as training objects in rule determination and new buildings not presented in map 2 were excluded (see Section 2.3). The comparison was first made by comparing the classification result with the raster map pixel by pixel. Two measures were calculated:

- Interpretation accuracy = $\frac{n_{CB\,\&\,MB}}{n_{MB}}100\% = 90.0\%$ and
- Object accuracy = $\frac{n_{CB\,\&\,MB}}{n_{CB}}100\% = 85.4\%$,

where $n_{CB\,\&\,MB}$ is the number of pixels labelled as buildings both in the classification result and in the map, n_{MB} is the total number of pixels labelled as buildings in the map, and n_{CB} is the total number of pixels labelled as buildings in the classification result. The accuracy measures thus show that 90.0% of the area covered with buildings in the map was classified as buildings, and 85.4% of the area classified as buildings was covered with buildings in the map. It was also calculated that 5.0% of the area covered with buildings in the map was classified as trees and 5.0% as ground surface.

In addition to the pixel-based accuracy estimation, building-based comparisons were made to find out the percentage of buildings correctly detected (corresponds to interpretation accuracy). The reference map was segmented to obtain building segments each of which represents one building in the map. Building was considered as detected if more than a given percentage of its area was labelled as building in the classification result. Comparisons were made with different threshold values. Additionally, comparisons were made separately for large and small buildings (threshold value 200 m^2). Buildings detected from the laser scanner data were analysed in the same manner using the reference map to find out the percentage of correct buildings, i.e. buildings that were also presented in the map (corresponds to object accuracy). Some of these comparisons were also made by considering only 'certain' buildings, i.e. buildings that had a membership value over 0.75 in classification. The results are presented in Table 1.

Table 1. Percentage of buildings correctly detected from the laser scanner data.

Buildings of the reference map (Interpretation accuracy)				
Building size (m^2)	Percentage threshold *)	Minimum membership	Total number of buildings	Percentage of buildings correctly detected
All	80%	–	259	**75.7%**
	70%	–	259	**80.3%**
> 200	80%	–	202	**85.6%**
	70%	–	202	**91.1%**
0 – 200	80%	–	57	**40.4%**
	70%	–	57	**42.1%**
	50%	–	57	**49.1%**
Buildings of the classification result (Object accuracy)				
All	80%	0.50	238	**60.5%**
		0.75	177	**74.6%**
	70%	0.50	238	**73.1%**
		0.75	177	**88.1%**
> 200	80%	0.50	195	**71.3%**
	70%	0.50	195	**84.1%**
0 – 200	80%	0.50	43	**11.6%**
	70%	0.50	43	**23.3%**
	50%	0.50	43	**34.9%**
		0.75	9	**55.6%**

*) Percentage threshold shows the required overlap for buildings of the map and buildings of the classification result.

To evaluate the quality of change detection results, some known changes between the old map (map 1) and situation in 2002 were analysed visually. These were found by comparing map 1 with map 2 and the laser scanner data. List of the changes and description how they were detected from the laser scanner data are given in the following. The list does not include all changes in the area, but it includes the major changes:

- Five new buildings: all were detected as `new building, certain detection´.
- Five enlarged buildings: three were detected as `enlarged building´, two were classified as `old building´. The enlarged parts of these two buildings were included in the building segments in classification, but they covered less than 10% of the buildings. The change detection rules thus classified the buildings as old buildings.
- Nine small houses were incorrectly located in the old map. Eight of these were detected as buildings in classification. In change detection, four were classified as `new building, certain detection´, two as `new building, uncertain detection´ and two as `enlarged building´. The building segments from the old map were classified either as `not detected´ or `partly detected´.
- One large building complex was presented as three building polygons in the old map. Two of these were incorrectly located. The building segment obtained from the laser scanner data was classified as `enlarged building´. The incorrectly located building segments of the old map were classified as `partly detected´.

5. DISCUSSION

Segmentation results were mainly satisfactory and the location of segment borders correct when compared visually with the DSM. Trees growing beside buildings, however, caused problems. They were often connected with the buildings.

Classification results were relatively good as shown by the accuracy measures. 90% of building pixels in the reference map were correctly detected as buildings, and 85% of building pixels in the classification result were buildings in the map. These measures also include errors caused by displacements between the map and the laser scanner data. Displacements can occur due to inaccuracies in the laser scanner data and its preprocessing or inaccuracies in the map. Many of the buildings that were not detected were small buildings surrounded by trees. In segmentation they were connected into same segments with trees.

The building-based accuracy estimates (Table 1) show that 80.3% of all buildings in the reference map were correctly detected if an overlap of 70% was required for correct detection. With an overlap requirement of 80%, the detection percentage was 75.7%. For small buildings, an overlap of 70 – 80% is a strict requirement. Even a small displacement between the laser scanner data and map can decrease the overlap area remarkably. On the other hand, small buildings are also more difficult to detect than large ones. For buildings larger than 200 m^2, the detection percentage was about 90% (91.1% with an overlap of 70% and 85.6% with an overlap of 80%). For the smallest buildings (under 200 m^2), the detection percentage was clearly lower. With an overlap of 50%, it was 49.1%.

Accuracy estimates in the lower part of Table 1 show that 73.1% of all building segments detected from the laser scanner data were correct detections, i.e. buildings that were also presented in the reference map. This estimate was obtained by using an overlap of 70%. With an overlap of 80%, the percentage was 60.5%. Larger buildings were correct buildings more probably. For buildings larger than 200 m^2, the percentage of correct buildings was 84.1% with an overlap of 70% and 71.3% with an overlap of 80%. According to the accuracy estimates, small buildings were often false detections. With an overlap requirement of 50%, the percentage of correct buildings was 34.9%. The membership value obtained from classification

Figure 4. Change detection results for the entire study area (2.0 km^2). Map data © The National Land Survey of Finland, permission number 49/MYY/03.

gives useful information on the reliability of building detection. When only certain buildings (membership to building over 0.75) of the classification result were considered, the percentage of correct buildings clearly increased. For all buildings it was 88.1% with an overlap of 70% and 74.6% with an overlap of 80%. For the smallest buildings, the percentage of correct buildings increased to 55.6% (overlap 50%). Visual inspection of the remaining 'false' detections of small buildings (four buildings) revealed that two of them were buildings, one was part of a building and one was possibly a large vehicle. The buildings were presented differently in the map. It is worth noting that differences between buildings in the map and buildings detected from the laser scanner data occur e.g. due to generalization of objects in the map. These differences affect the accuracy estimates, especially for the smallest buildings.

In change detection, the most important changes, e.g. new buildings, were detected as described in Section 4. It is also interesting to note that segments incorrectly classified as buildings in classification were typically labelled as `new building, uncertain detection´ in change detection. The membership value to building for these segments was lower than for real buildings. In the future, further development of the change detection method is needed. For example, small location differences between buildings in the map and buildings in the classification result should be distinguished from real changes, such as enlargement of a building. Many buildings were now classified as `enlarged building´ due to small location differences or problems in segmentation (connection of the buildings with trees).

The displacement problems could be reduced by advanced matching techniques (object-to-object matching), where buildings detected from the laser scanner data are matched with corresponding buildings in the map and then possible changes are detected by comparing the size and shape of the buildings. Segmentation results might be improved by using more advanced heterogeneity criteria, e.g. based on surface slopes. Use of aerial imagery with visible and infrared channels could also be useful, especially for distinguishing buildings from trees. Combination of the building polygons presented in the map and the new building polygons determined from the laser scanner data is also needed to further automate the updating process.

6. CONCLUSIONS

Automatic segmentation and classification of laser scanner data for building detection and map updating was studied. Classification results were compared with an old building map to detect changes. The results of the study include segments derived from the laser scanner data and classified as `building´, `tree´ or `ground surface´ and building segments further classified as `new building, certain detection´, `new building, uncertain detection´, `enlarged building´ or `old building´. The results also include old building segments derived from the map data and classified as `detected´, `partly detected´ or `not detected´. Comparison of the results with an up-to-date reference map shows that about 80% of all buildings in the study area were detected from the laser scanner data. For buildings larger than 200 m^2, the detection percentage was about 90%. Pixel by pixel comparison of the classification result with the reference map shows that 90% of pixels covered with buildings in the map were correctly detected as buildings in classification. 85% of building pixels in the classification result were buildings in the reference map. The accuracy measures of the pixel-based comparison also include errors caused by small location differences between the data sources. The most problematic buildings for automatic detection from the laser scanner data were small buildings surrounded by trees. In change detection, the most important changes, such as new buildings, were correctly detected. The results can be used as input data in further steps of map updating.

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