

KNOWLEDGE-BASED BUILDING DETECTION BASED ON LASER SCANNER DATA AND TOPOGRAPHIC MAP INFORMATION

Alexandra D. Hofmann¹, Hans-Gerd Maas¹, André Streilein²

¹ Institute of Photogrammetry and Remote Sensing
Dresden University of Technology
Helmholtzstr.10
D-01062 Dresden, Germany
Alexandra.Hofmann@mailbox.tu-dresden.de

² Swiss Federal Office of Topography
Section Photogrammetry and Remote Sensing
Seftigenstrasse 264
CH-3084 Wabern, Switzerland

KEY WORDS: Segmentation, building detection, airborne laser scanning

ABSTRACT:

Laser scanner data is being increasingly used to obtain topographical and object height information for mapping and GIS tasks. Valuable information can be derived of the terrain and objects of a region. Different methods have been published to segment laser scanner data in order to extract information. This paper aims to discuss the extraction of buildings to transfer 2D building data into 3D building data of a higher accuracy. For this study, only laser scanner data and scanned topographical maps are to be used. The study can be divided into two parts: segmentation and detection. Firstly, the region-based segmentation method is used to delimit objects. Then a scanned topographic map, filtered and converted into a vector format, is utilised to locate already recorded houses. Buildings not contained in the map could be found by combination of segment attributes. The study shows promising results – more than 95% of the buildings were detected.

KURZFASSUNG:

Laserscannerdaten werden im zunehmenden Maße zur Informationsgewinnung von topographischen und Objekthöhen für Karten und Geoinformationssysteme genutzt. Sie bieten wertvolle Informationen zu Gelände und Objekten. Jedoch ist es immer noch schwierig und es benötigt weiterer Daten wie digitale Katasterinformationen oder Grundpläne, um passende Informationen aus den Laserscannerdaten zu extrahieren. Dieser Artikel behandelt das Thema Gebäudeextraktion aus Laserscannerdaten mit dem Ziel der Datenaufwertung topographischer Karten. Als Hilfsmittel steht nur eine gescannte topographische Pixelkarte zur Verfügung. Die Analyse besteht hauptsächlich aus zwei Arbeitsschritten: der Segmentierung und der Detektion. Zuerst wird eine nachbarschaftsbasierte Segmentierungssoftware angewendet, um Objekte zu begrenzen. Anschließend wird eine modifizierte topographische Pixelkarte als Vektordatei zum Detektieren bereits aufgenommener Gebäude verwendet. Noch nicht registrierte Gebäude sollen danach mit einer Kombination verschiedenster Segmentattribute identifiziert werden. Dieses Prinzip der Informationsextraktion verspricht gute Erfolge – mehr als 95% der Gebäude der Testgebiete wurden erkannt.

1 INTRODUCTION

The application of laser scanner data has expanded rapidly during the last decade. They are well known as an information tool in many environmental applications such as urban modelling (Palmer 2001, Haala and Brenner 1997), disaster management (Steinle and Voegtle 2001), or flood modelling (Cobby et.al. 2001). Other applications, such as mapping of corridors and electrical transmission lines, have been presented by Wehr and Lohr (1999). Laser altimetry data has been also discussed with regard to building extraction (Forlani and Nardinocchi 2001, Gülch 2001, Hyypä and Hyypä 2000, Lee and Schenk 2001, Maas 1999, Stilla et.al. 2001, Vosselman and Dijkman 2001). Existing building information has been used for building reconstruction as well (Brunn and Weidner 1997, Haala 1999, Hug and Wehr 1997, Vosselman and Suveg 2001). Vice versa, it also seems that laser scanner data could be very useful regarding the upvaluation of map information.

Upvaluation of map information, in the sense of transferring 2D building data into 3D building data of higher accuracy, is a current topic of interest, since many applications such as urban modelling are based on this information. Now it is of special interest to find a method to obtain 3D information of objects as fast and accurate as possible. This paper aims to demonstrate the steps we have made by using laser scanner data for upvaluation of map information in sense of building reposition and modelling. Auxiliary media used, included simple filter methods and scanned topographical maps as they are available for the public.

The main idea of this study is to use the raster pixel map as a basis to obtain the majority of the buildings in the laser scanner data set and so to have a direct relation between the found buildings and their position on the map. Those buildings not recorded on the map, can be found by using the unique characteristics of buildings. The analysis is composed of two

main steps: the segmentation and the detection of buildings. A segmentation software segments the height data. The vectorised object segments as well as the digital map are the inputs for a GIS software. The buildings are detected by combining the map information and the segment attributes.

2 STUDY AREA AND DATA SET

Two study areas, each with 7km², in the region Gruyères, Switzerland were chosen – a rural mountainous area and a flat urban region. The rural study area mainly consists of residential areas with mainly single-family houses in a typical regional style. For the urban study area, the city Bulle was picked out. Bulle contains beside single-family and multi-family residential units also commercial and light industry areas.

The laser scanner data is first pulse data with a mean point distance of 1.2m. It was acquired in early 2001. The scanned topographic map was a small-scale map (1:25,000) from 1995. Due to generalisation effects, planimetric discrepancies of up to 12 metres can occur between the map and the laser scanner data set. An aerial (false) ortho photo, from 1998, was used to check the results.

In the beginning of the study, some statistical data was generated to confirm the main idea explained above. The rural study area contains 820 buildings derived from the DSM. In the pixel map, about 93% of the buildings are recorded. Due to generalisation effects, 3% of the houses are insufficiently positioned, that means that the centre of the building in the pixel map is more than four metres apart from the building in the laser scanner data. This needs to be considered in the analysis. The urban study area had 1630 houses in spring 2001 of which 9% are not recorded in the map and 3% are insufficiently positioned.

3 SEGMENTATION OF OBJECTS AND THEIR FEATURES

3.1 Data Preparation

Before the segmentation could be performed, data editing and formatting had to be done. The laser scanner data was interpolated into a regular grid and saved as an image with 1m² raster cells in order to be processed with raster oriented image processing tools. The pixel map required the most editing. The situation information such as houses, streets, or lettering was extracted. A morphological filter was applied, to mainly reduce this information for houses. The procedure consisted of an opening filter followed by a dilating filter. Thus, the extension of the houses is shortened, but this will not effect the analysis. Some parts of the map text are still in existence and need to be excluded from the analysis.

3.2 Segmentation

Most methods applied for the segmentation of laser scanner data interpolated to a regular grid, were purely pixel-based methods (e.g. Oude Eleberink and Maas 2000). The goal of the approach shown here was to extend these methods to region-based methods in order to improve the quality of the segmentation.

The presently available region-based segmentation software eCognition 2.1, usually used with image data e.g. in (Neubert

and Meinel 2001), was utilised. Image analysis with eCognition is based upon contiguous, homogeneous image regions, which are generated by an initial image segmentation. The image content is represented as a network of image objects. The segmentation algorithm of eCognition is based on the so-called “bottom up region-merging” technique. Thus, starting with the pixel level, each pixel is joined with its most similar neighbour pixel. In a number of steps, these two-pixel-objects are enlarged to bigger pixel groups until a certain heterogeneity value (scale parameter) is reached. These pixel groups (segments) are optimised considering the homogeneity criterions color and shape. With these three parameters (scale, color and shape) the user can influence the segmentation process. (Definiens Imaging 2001)

Referring to laser scanner data, it is supposed that objects, having a different height in comparison to their surroundings, are assigned into one segment and the surroundings into another.

The segmentation performed with eCognition requires some experience. As the scale parameter, which is a measure of heterogeneity, determines the size of segments, the user has to check carefully whether the segmentation was successful. The correct scale parameter can only be found empirically. The homogeneity criterions are easy to set, given that the height information is the only relevant one. Hence, the color is high weighted and the shape is neglected. Weighting the shape parameter would result in segments of similar shape and area. However, only buildings are supposed to be compact and rectangular, not their environment or vegetation. The shape of the segments is used in the later classification. Thus, weighting the shape parameter would complicate the classification.

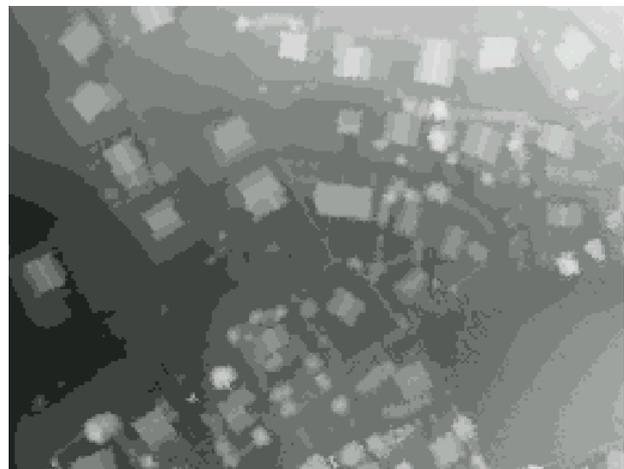


Figure 3-1. Example of laser scanner data (1m raster)

The experience shows that segmenting pure laser scanner data (Figure 3-1) does not always produce the desired result. The reason is the smooth transitions of the objects to their neighbours such as houses and trees that stand close together. Therefore, attempts were made to modify the laser scanner data to improve the segmentation result. No pleasing solution was found. To comprise the ortho photo and / or the pixel map directly in the segmentation was not valuable as planimetric discrepancies, mentioned in chapter 2, pervade the data sets. The segmentation statistic presented in Table 3-1 indicates that up to 85% of the buildings were segmented according to the features form. Passable segmentations occurred when trees

stand close to buildings or buildings have been built on slopes. Only few buildings were not segmented at all.

	Correct	Passable	Not segmented
Rural area	78	13	9
Urban area	85	10	5

Table 3-1. Quality of the segmentation [%] of the laser scanner data



Figure 3-2. Segmentation result

The segmentation result is shown in Figure 3-2. To separate houses and trees that have been enclosed in one segment, sublevels were created. Sublevel means that smaller segments are calculated within the segments of the super level. For the sublevel, an aspect image of the interpolated laser scanner data is generated. (Equation (2)) ΔX and ΔY are the average elevation changes in the coordinate directions. Thus, areas with a high elevation change density have a strong textured appearance. They consist of many small segments. Whereas homogeneous areas ideally have only one segment. Referring to houses, it is assumed that there will be one segment per roof side. This information will also be used in the house modelling procedure, which is still under development.

$$aspect = \arctan\left(\frac{\Delta X}{\Delta Y}\right) \quad (2)$$

To each segment of every file in the project, eCognition supplies additional information, such as standard deviation, mean, minimal, maximal values and shape and neighbour information. These attributes are important parameters for the building detection. Hence, a slope and a laplacian filter image of the laser scanner data is added to the eCognition project in order to increase the information potential. The segmentation result of the height image and its sublevel (the aspect image based level), are converted into vector data with the attributes supplied by eCognition.

In a second eCognition project the modified pixel map is segmented. The segments, only representing buildings and parts of the lettering, are also exported as vector data. The next chapter will refer to it as the map-segment-file.

3.3 Results

Although both study areas have a different structure, the preparation for the segmentation process was the same. In matter of house segments, it is interesting that commercial, light industry, and multi-family residential areas are segmented well. Only the roof segments of multi-family residential areas appear to be insufficient. For single-family residential units the results of house and roof segments in both study areas are satisfactory and equivalent.

The mean and standard deviation values of the segments in the laplacian and slope image seem to be very useful in the detection analysis.

A disadvantage of the segmentation with eCognition is still the time-consuming generation and export of vector data. The segmentation process cannot be fully automated, as for each scene individual parameter settings are necessary. The scale parameters of the laser scanner data and aspect image segmentation are for example higher for city areas. Another condition for eCognition is that the images for a given project have to have the same dimension.

The segmentation based on the laser scanner data will be called the house-segment-file and the sublevel, the aspect based level, the roof-segment-file. Examples of both files are given in Figure 3-3 and 3-5. The darker polygons are the map segments. Comparing Figure 3-2 with Figure 3-3, several houses, not on the map or ortho photo, are visualised and segmented.



Figure 3-3. Example of house segments and map segments

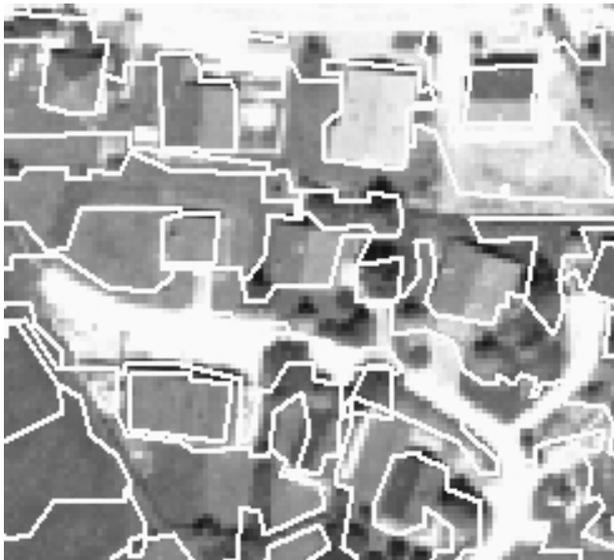


Figure 3-4. Zoom of the house segment example

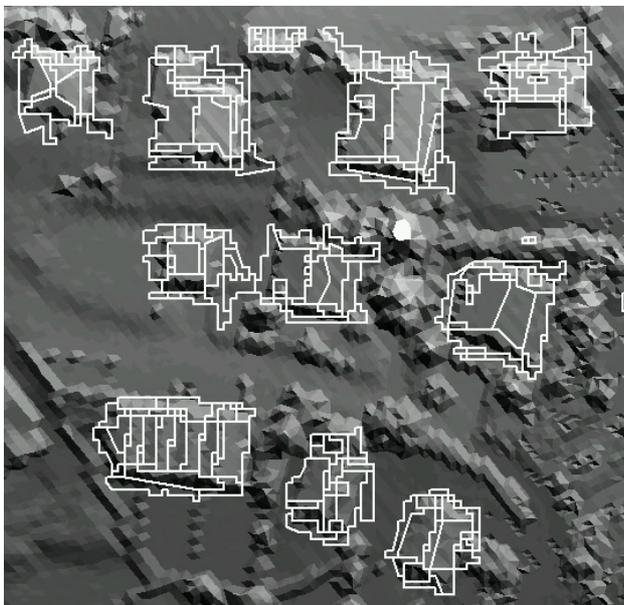


Figure 3-5. Example of aspect based roof segments

4 DETECTION OF BUILDINGS

In a next processing step, a GIS package is used to detect buildings in the segmented regions. The segments are analysed by their position, shape and attributes. Rules have to be found and complex relationships have to be recognised. To find as many houses as possible, several methods have to be combined. First, the houses recorded on the map are located in the roof-segment-file. Their centre coordinates are saved in a look-up table. Secondly, the house-segment-file is classified and centre coordinates of possible houses are compared to those in the table. Those not in the table will be added. Later the single segments are analysed whether they hold a building or not.

4.1 Detection by Map

For this part of the analysis, the modified and vectorised pixel map is utilised. Since the filter routine did not remove all no-

house information in the rural part, these superfluous segments have to be eliminated or at least reduced. Analysing the standard deviation values of the surrounding laser scanner data does minimize them. Those segments in the roof-segment-file, which are in a distance of four metres to the map segments, are selected. An ID is assigned to the roof segments according to their position to the map segments. After dissolving the roof segments, the following parameters are chosen to eliminate polygons that are located in field or forest areas and cannot represent houses: the average standard deviation of the laser scanner data per segment and the average of the slope values in a segment. The value of the average standard deviation of the laser scanner data is low for field and high for forest areas. Areas of small bushes have a mean average standard deviation for laser scanner data – a low average slope value will reveal them. In this step of the analysis, the laplacian values are not valuable, because of the size of the dissolved segments and the spatial resolution of the data set at hand.

The selected no-house polygons are excluded from the map-segment-file. About 48% of the no-houses map polygons are eliminated and all house segments are retained, which is most important. Table 4-1 presents the statistics of the pixel map derived polygons.

The procedure was not necessary for the urban study area, as the morphologic filter worked adequately.

	Number of buildings	Number of misplaced buildings	Other objects
Rural area	768 (93%)	26 (3%)	455
Urban area	1434 (91%)	41 (3%)	193

Table 4-1. Modified pixel map statistic

The remaining map segments are fed into in a routine, which selects all polygons in the roof-segment-file. To make sure that the planimetric discrepancies between map and laser scanner data do not prevent the selection of all roof segments of a building, all segments in the roof-segment-file that are within a certain distance of the map segments are selected. For normal houses – single-family houses – a distance of 2.5 metre is sufficient, whereas buildings larger than 300m² require a 4m buffer zone. The centre coordinates of the selected roof segments per map segment are stored.

The segments incorrectly marked as houses, will be thrown out of the analysis by the later house modelling we are still developing.

4.2 Detecting by Attributes

Houses not detected via the pixel map are to be found by analysing the house-segment-file. The procedure is comparable to a classification. The house-segment-file supplies valuable attributes for the classification such as mean value and standard deviation of the input laser scanner data, mean value and standard deviation of the aspect, slope, and laplacian image, and shape attributes such as area, border length, and main direction. In accordance with the attributes, each segment is signed as house-containing or no-house-containing.

Within the classification, the following assumptions and rules are made for rural regions:

- Buildings are not to find within forest or water areas
- Building segments are smaller than 6000m²

- The length/width rate is smaller than a certain value, determined by the longest building
- The standard deviation of laplacian values are within a certain range for buildings

Segments exceeding 6000m² usually represent field or branched street areas. The length/width criterion excludes long narrow segments, as they are to be found on grassland and streets. The standard deviation of the laplacian values of the segments is small for flat areas and high for undulating regions. To apply the laplacian value of a segment as a classification criterion works only with a good segmentation result. The building has to be entirely within a segment and the segment should not be too long-ranged around the building.

Urban areas subject to different conditions. Thus, the classification parameters have to be altered to:

- Buildings are not to be found within forest or water areas
- Buildings do not have higher neighbour objects than buildings itself, except they are situated on a slope – thus the relative border to higher neighbours in the laser scanner data segments should not exceed a certain value
- Building segments are smaller than 6000m²
- The length/width rate is smaller than a certain value, determined by the longest building
- The standard deviation of laplacian values are within a certain range for buildings

Similar conditions can be suggested for flat, rural regions. In general, the detection algorithm is more complex for urban areas since the variation of house types is bigger – big flat roofed buildings of light industry units and small steep roofed houses in residential areas. Specific shape attributes such as number of arcs were not used since the shape of house-containing segments is not consistent (e.g. to buildings attached trees).

The whole processing chain was optimised to detect as many buildings as possible. 2nd order errors were accepted as a problem to be solved in the following steps of classification and building model generation. Hence, the percentage of 2nd order errors is relatively large. The number of segments, which are wrongly classified as house-containing (second order errors), is much higher for the rural area than for the urban region. Table 4-2 contains the statistical figures. The reasons are the general characteristics of the locality such as vegetation and height differences. Since the detection mainly bases on the degree of the variation in height (laplacian values), urban areas are segmented more clearly. That means, in dense city areas, that the height differences between buildings and their surrounding is bigger as in rural areas. Especially commercial units: they usually do not have high vegetation areas at all – thus, the segments limit the buildings precisely.

	Classified correctly	2 nd order errors
Rural area	770 (94%)	1960 (340%)
Urban area	1553 (95%)	1114 (170%)

Table 4-2. Statistic of purely on height information based house segment classification

The exceptional high number of second order errors of the rural region can be easily reduced by an analysis of the local standard

deviation of the height information and the gradient values. About 40% of the 1960 second order errors could be eliminated.

Finally, the centre coordinates of the segments selected as houses in the house-segment-file are compared with those already recorded in the look-up table. If the coordinates differ by more than four metres from each other, the new ones are added. Segments wrongly classified as house-containing are nonetheless included in the house positioning and modelling process. Whether there is a house or not, is checked by the point distribution. The position and the new outline of the recognised building shall then be saved in a new vector file. It is also planned to create a model of each house.

In both building detection procedures, it is important, that no segment, which might contain a building, is eliminated. Each centre coordinate in the look-up table is assigned a percentage expressing the likelihood of containing a house.

With this method of detecting buildings, very good detecting quotes were achieved. In the urban area 99% and in the rural area 99.5% of the in 2001 existing buildings were detected.

5 RESULTS AND CONCLUSIONS

Based on the procedures described in the former chapters, 99% of the buildings in the study area could be detected in the laser scanner data. The pixel map proved to provide a good trigger for the detection of buildings in the laser scanner data and it also decreased the processing time. In addition, a number of buildings, which were not present on the map, could be detected purely on the basis of the laser scanner data. Due to planimetric discrepancies of up to 12 metres, which were detected between the map and the laser scanner data set, the final segmentation was performed purely on the basis of the laser scanner data, without the contribution of the map. The ortho photo was solely used for visualization and verification purposes. The problem of identifying segments, which do not contain houses, has to be addressed in future work on building model generation.

The use of eCognition proved to be rather beneficial in the detection and segmentation procedure as well as in the characterization of the segments used for classification. It has to be mentioned, however, that the current version of eCognition is rather slow in some operations, and that larger regions have to be subdivided into small tiles for successful operation.

6 FURTHER RESEARCH

Future work should first concentrate on the optimisation of the segmentation and detection procedures in eCognition and ArcView. Furthermore, methods for processing very large data sets have to be developed. Tests with more data sets from different sensors and in different regions have to be performed to prove the applicability of the developed processing schemes. Raw unfiltered first and last pulse data, preferably in combination with laser scanner intensity values, should be used as input into the detection and segmentation procedure.

Building modelling will be a major point of future research. A discussion of suitable data formats for storing 3-D building model information in a topographic landscape model and techniques for transferring these models into maps and other visualization tools will follow.

7 ACKNOWLEDGMENTS

This work was partly founded by the Swiss Federal Office of Topography. We thank the Swiss Federal Office of Topography for providing the laser scanner data set, pixel map as well as the ortho photos. The authors also thank the "Gesellschaft von Freunden und Förderern der Technischen Universität Dresden e.V."

8 REFERENCES

- Brunn, A., Weidner, U. 1997 'Extracting buildings from digital surface models' IAPRS, Vol.32, Part 3-4W2
- Cobby, D.M., Mason, D.C., Davenport, I.J. 2001 'Image processing of airborne scanning laser altimetry data for improved river flood modelling' *ISPRS Journal of Photogrammetry and Remote Sensing*, 2001(56), pp.121-138
- Forlani, G., Nardinocchi, C.: 2001 'Building detection and roof extraction in laser scanning data' IAPRS Vol.34
- Gülch, E. 2001 'New features in semi-automatic building extraction' ASPRS annual conference, St.Louis, Canada, April 23-27
- Haala, N. 1999 'Combining multiple data sources for urban data acquisition' Photogrammetric Week 1999 (Eds. Fritsch/Spiller), Wichmann
- Haala, N., Brenner, C. 1997 'Generation of 3D city models from airborne laser scanner data' EARSel Workshop, Tallin, Estonia
- Hug C., Wehr, A. 1997 'Detecting and identifying topographic objects in imaging laser altimeter data' IAPRS Vol. 32, Part3-4W2
- Hyypä, H., Hyypä, J. 2000 'Quality 3-Dimensional infrastructure models using airborne laser scanning' PJJ, Vol. 17, No.1
- Lee, I., Schenk, T. 2001 'Autonomous extraction of planar surfaces from airborne laser scanner data' ASPRS annual conference, St Louis, Canada, April 23-27
- Maas, H.G., Vosselman, G. 1999 'Two algorithms for extracting building models from raw laser altimetry data' *ISPRS Journal of Photogrammetry and Remote Sensing*, 1999(54), pp.153-163
- Neubert, M., Meinel, G. 2001 'Segmentbasierte Auswertung von IKONOS-Daten – Anwendung der Bildanalyse-Software eCognition aus unterschiedliche Testgebiete' AGIT, Salzburg, Austria, pp.108-117
- Oude Elberink, S., Maas, H.-G. 2000 'The use of anisotropic height texture measures for the segmentation of airborne laser scanner data' IAPRS, Vol. 33, Part B3
- Palmer, T.C. 2001 'Urban modelling from LIDAR data in an integrated GIS environment' ASPRS annual conference, St Louis, Canada, April 23-27
- Steinle, E., Voegtli, T. 2001 'Automated extraction and reconstruction of buildings in laser scanning data for disaster management' Third International Workshop on Automatic Extraction of Man-Made Objects from Aerial and Space Images, June 10-15, Ascona, Switzerland
- Stilla, U., Soergel, U., Thoennessen, U., Michaelsen, E., 2001 'Segmentation of LIDAR and INSAR elevation data for building reconstruction', Third International Workshop on Automatic Extraction of Man-Made Objects from Aerial and Space Images, June 10-15, Ascona, Switzerland
- Vosselman, G., Suveg, I., 2001 'Map based building reconstruction from laser data and images' Third International Workshop on Automatic Extraction of Man-Made Objects from Aerial and Space Images, June 10-15, Ascona, Switzerland
- Vosselman, G., Dijkman, S., 2001 '3D building model reconstruction from point clouds and ground plans' IAPRS, Vol. 34, pp. 37-43
- Wehr, A., Lohr, U., 1999 'Airborne laser scanning – an introduction and overview' *ISPRS Journal of Photogrammetry and Remote Sensing*, 1999(54), pp.68-82
- Definiens Imaging - eCognition Documentation 2001 <http://www.definiens-imaging.com/ecognition/index.htm>