Automatic Generation of 3D Building Models from Point Clouds

AUTOMATIC GENERATION OF 3D BUILDING MODELS FROM POINT CLOUDS

Vojtěch, HRON, Lena, HALOUNOVÁ

Department of Geomatics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29, Prague 6, Czech Republic

vojtech.hron@fsv.cvut.cz

lena.halounova@fsv.cvut.cz

Abstract

Point cloud is a product of laser scanning (terrestrial/airborne) or it can be derived from automatic image matching. Both techniques are very modern and progressive methods of non-selective collection of spatial data. The representation of buildings through point cloud is not appropriate for many applications. Handling with a set of data points, covering large areas is also very hardware consuming. For these reasons, it is suitable to represent individual buildings as spatial objects, called 3D models.

This paper is a review of fully automatic generation of 3D building models from point clouds. It compares the solutions of various academic institutes and analyzes current commercial software products that process this task. In this work, data point clouds collected by airborne laser scanning will be used as an input. A major influence on the generation of 3D building models have the density and quality of the point cloud, which are determined by scanning parameters. For this reason, various input datasets will be tested.

Keywords: 3D building models, point clouds, airborne laser scanning, LiDAR

INTRODUCTION

Spatial data are very popular and in demand nowadays. Due to its great popularity, this data type and high requirements for the accuracy and topicality lead to their more frequent acquisition. The acquired data have a great information potential. Manual interpretation of spatial information is in fact extremely time consuming and it is impossible to repeat it with the same result due to the human factor. Fully automatic methods of processing are used with increasing amounts of data that must be processed in shorter time periods. Current automatic techniques are still under development and can only partially exploit the potential of the data. The real potential of the data is usually unused. This issue is therefore a challenge for experts from a wide range of disciplines like remote sensing, photogrammetry or computer vision.

The most common form of spatial elevation data is a point cloud which can be obtained by active sensors like airborne laser scanning (ALS) systems which use the Light Detection and Ranging (LiDAR) principle. The spatial data can be also derived by image matching techniques using satellite or aerial images. Point cloud data represent the surface geometry by an object independent distribution of points with uniform quality, however, this form of representation is not appropriate for many applications. For more sophisticated tasks, a generalization and simplification of the digital surface model (DSM) is necessary. The generation of 3D building models is just such the case. The fields of application of 3D building models are quite various such as visualizations, urban planning, environmental monitoring (for example air pollution, propagation of road traffic noise etc.), propagation of electromagnetic waves for telecommunication applications and the generation of flood maps.

Image matching techniques are very popular and progressive methods nowadays, however, they are extremely dependent on the quality of input aerial images. Ground sampling distances (GSD) and overlaps between images have a major impact on the acquisition of high quality outputs. Most of the presented results were typically achieved by high quality input datasets with large forward and side overlaps between images and GSD under 10 centimeters. Data with these specifications can be collected relatively easily from small areas, but it seems that it will not be economic to collect such data for large areas for entire countries. This paper gives a review of the possibility of fully automatic generation of 3D building models from point clouds covering large areas. For this reason, point clouds collected only by airborne laser scanning will be used as input data in this paper.

RELATED WORK

The first important task in 3D building reconstruction is the identification of points describing the buildings. These points represent mainly building roofs and their parts in case they were collected from the air. The second important task is the segmentation and conversion of these roof parts into geometrically and topologically correct building models. These tasks are really challenging and most scientific papers solve this problem using other external sources of information like maps or even better ground plans. Building ground plans can be obtained from digital cadastral maps or GIS layers containing building footprints. This information can rapidly help for building reconstructions as no sophisticated algorithms must be used for the classification of raw point cloud (Haala, Brenner, 1997). The buildings are reconstructed on the position of their footprints and the shape of these footprints can be used for the exact determination of the buildings outer walls. The roof planes can be detected by using ground plan lines. The assumption is that the normal direction of roof planes is usually perpendicular to one of the ground plane lines (Haala, Anders, 1997; Jibrini et al., 2000; Vosselman, Dijkman, 2001). The shape of the building outline can be used for a decomposition of a building as a combination of simple roof elements (Haala et al., 1998; Brenner, 2000; Vosselman, 2002).

The combination of different data sources is a great idea for solving complex tasks. Many countries have digital cadastral maps and it is therefore possible to use ground plans for 3D city modelling. Unfortunately, additional data sources like digital ground plans are not available for every country. Supporting data can be also outdated in relation to the time of acquisition of elevation data or can come from untrusted sources. The use of maps is also problematic. The positions of buildings are known with some uncertainties due to map inaccuracy and generalization. These uncertainties are not higher than 0.5 m (Suveg, Vosselman, 2000), however, they strongly depend on the quality and scale of the maps. The original form of the maps (digital or paper) is also important.

Using ground plans can be often quite complicated. Ground plans are based on cadastral maps that register only the outer walls. A large number of buildings have different shapes of their ground plans and roof footprints. Modern houses have typically large roof overhangs over the outer walls. It is illustratively presented in Fig. 1.

Fig. 1. Left: Orthoimage of two buildings with roof overhangs (green line) over the outer walls (cyan line)
Right: Oblique image of the same buildings taken from the east

This problem is solved by the Czech Land Survey Office. The Czech Republic has an old cadastral map, which contains many errors as a result of many decades of a continuous operation. Most users want consistent and especially actual data sets. Now there is an effort to fix these errors using point clouds acquired by ALS for the new altimetry mapping. Automatic detection of buildings can be also used for updating and revision of the cadastral map and other derived products. Manual validation of millions of buildings is not feasible from the perspective of the whole country. It is also necessary to use a very sophisticated full-automatic solution which is independent on other sources.

In one approach, which is explained in detail (Nizar et al., 2006), a robust algorithm for the autonomous reconstruction of buildings from sparse LiDAR data was used. No prior knowledge and supplementary sources were needed in this paper. The classification of the point cloud into terrain and off-terrain points was done by a filtering process that uses global functions in the form of orthogonal polynomials. The iteration process was based on a fitted function that passes between laser points. In the subsequent iterations, the degree of the polynomial was decreased. The reduction of the polygon degree was done in accordance with an evaluation of the residuals. The assumption was that terrain points have negative residuals and off-terrain points have positive residuals. The final result was reached when the iteration did not change the shape of the terrain, so only the terrain points influenced the polynomial (Akel et al., 2004). Separated areas of off-terrain points were then filtered by size and height above the ground. Filtered points that created planes as roof parts were further grouped into segments and classified in unique roof faces. Between roof faces, topological relations were identified and from this information, an adjacency graph was created which was very useful for the determination of roof types. The crease edges between the roof faces were computed by the plane intersection. Boundaries of buildings were derived from their roof edges that were detected using the Hough Transformation. It was an approximate solution with lines that were geometrically incorrect, they were not parallel and rectangular. Extracted lines were also fixed using an adjustment with specific weights for roof edges according to their classification into three classes: horizontal crease edges, non-horizontal crease edges and border lines. The adjustment was not a destructive operation so it had no influence on topology. The generation of buildings was completed after the adjustment of their bounding lines.

This solution (Nizar et al., 2006) is much more sophisticated than the one that is described in (Haala, Brenner, 1997), where the shapes of buildings were determined by a segmentation of DSM in the raster form and a subsequent extraction of planar regions. The planar range image segmentation algorithm (Jiang, Bunke, 1994) was used because it was fast, essentially simple and scored very well if compared to other algorithms (Hoover et al., 1996). The algorithm is based on the segmentation of a regular DSM grid into straight 3D line segments which are used as a starting position for the region growing process. The main advantage of this algorithm is that it requires no *a priori* knowledge. However, the algorithm has a problem with the precise extraction of region boundaries. The author solved this problem by using ground plans. The problem was bypassed instead of being solved.

The following part of the text is dedicated to an analysis of commercial software, which is designed for the automatic generation of 3D building models.

METHODOLOGY AND DATA

The automatic generation of 3D building models will be tested in ENVI LiDAR (more detailed in ENVI LiDAR Help, 2012). Other commercial products are INPHO Building Generator, tridicon CityModeller and tridicon BuildingFinder. INPHO Building Generator and tridicon CityModeller allow the generation of 3D building models from point clouds and building footprints. Tridicon BuildingFinder generates building footprints and 3D buildings only from oriented aerial images. These software products have not yet been tested.

ENVI LIDAR

ENVI LiDAR (E3De in the past, further only the software) comes from Exelis VIS (Visual Information Solutions) that focuses on the development of software products for analysis and visualization of geo-information. A trial version of the software (version 3.2, January 2013) was obtained from the company ARCDATA PRAHA s.r.o., which is a distributor of Exelis VIS products for the Czech Republic.

The software is designed for automatic processing and interactive control of ALS data. The result of processing is a classification of raw point cloud into several classes (terrain, buildings, trees, power lines and poles). Classified data can be used for the creation of elevation models (DTM and DSM) and 3D models of buildings and vegetation that can be exported and used in other software products.

Input data can be in binary format LAS (LiDAR/Laser data exchange format) or ASCII. The software enables you to work with the georeferenced data in any projection and geodetic datum. The recommended density of the point cloud is greater than 1-2 points per square meter. The data processing runs completely automatically without the need of human intervention. The setup processing is done in the only dialog window with three tabs.

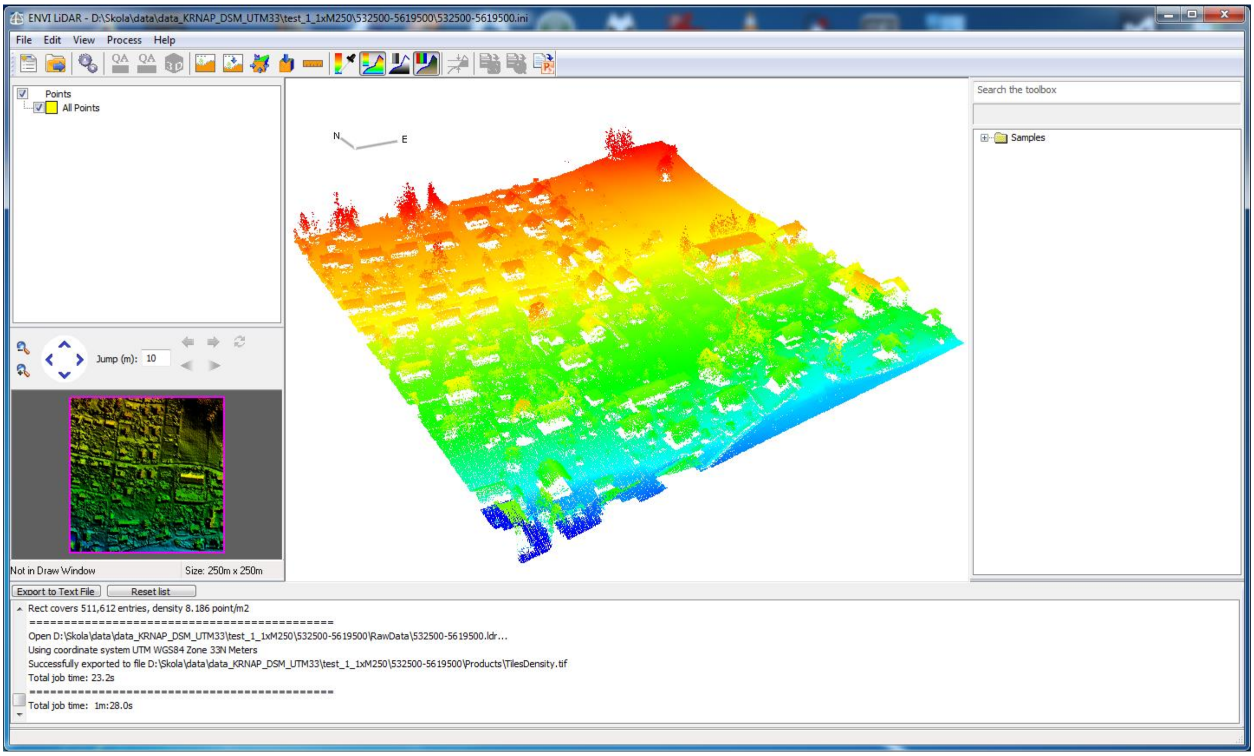

Fig. 2. Interface of the software and visualization of raw point cloud (colour hypsometry, perspective view)

Input data quality

Software testing was performed on three datasets with different densities of point clouds. The first and second dataset covered the identical area (part of the city Rokytnice nad Jizerou) and so their outputs can be compared to each other. Sample dataset attached to the software was a very dense point cloud and thus represents an interesting source suitable for precise modelling.

Table 1. Comparison of input data; # - dataset N^{o}

#	Owner of data	Area	Average density (p/m^2)
1	Czech Land Survey Office	Rokytnice nad Jizerou (Czech Republic)	1.2
2	Krkonoše Mountains National Park	Rokytnice nad Jizerou (Czech Republic)	8.2
3	ENVI LiDAR sample data	Kleinwolkersdorf (Austria)	21.8

Classification of point cloud

Fig. 3 (top) shows point clouds in the colour hypsometry in relation to the height of the terrain. The colour range is not created from absolute height values, but from relative heights of points above the ground. This type of visualization eliminates the height disparity of the terrain, which gives a better idea about objects on the ground (buildings and vegetation). Classification results are in Fig. 3 (bottom), where each class is displayed in a different colour.

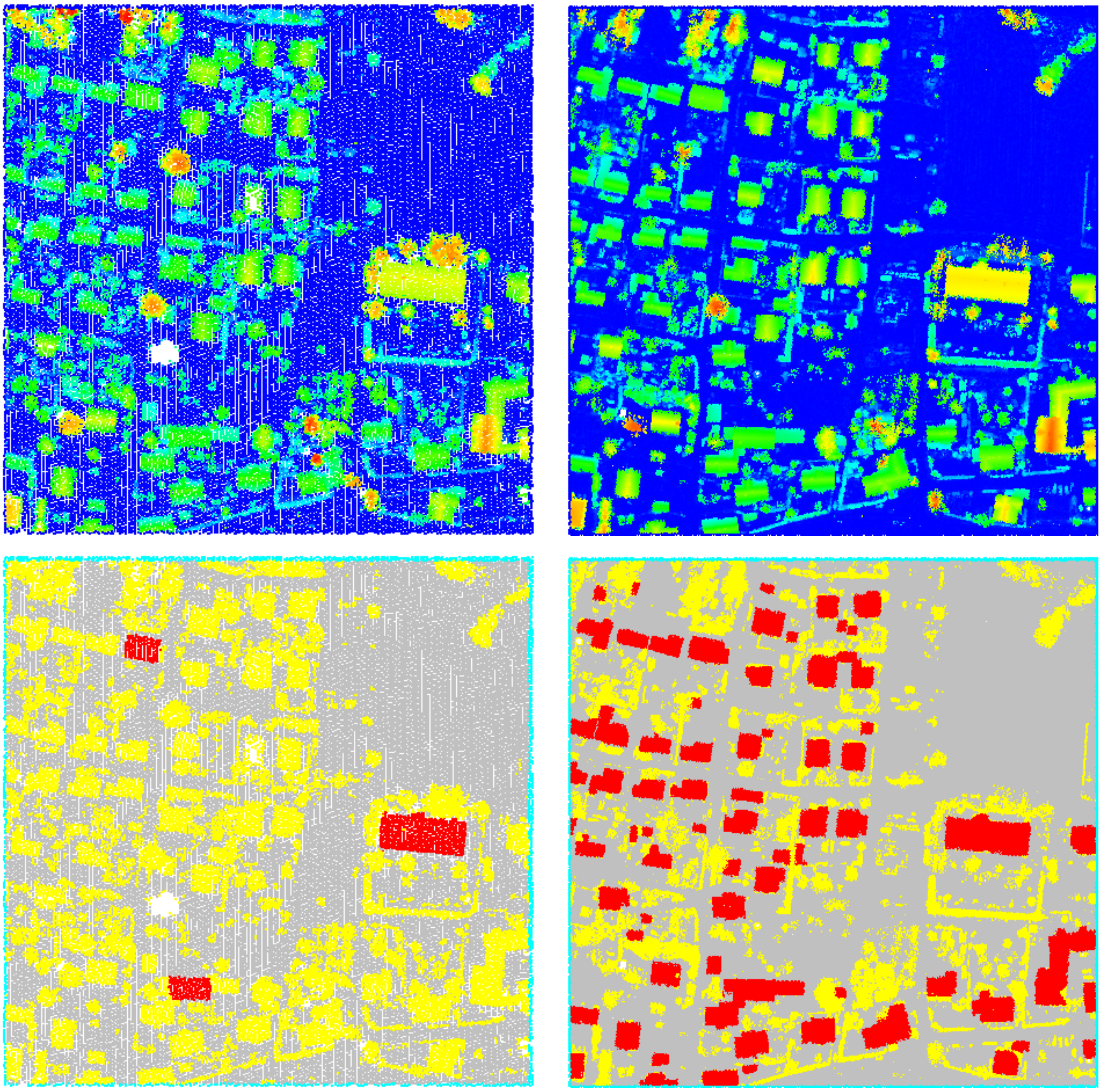

Fig. 3. Datasets: #1 - Czech Land Survey Office [left] and #2 - Krkonoše Mountains National Park [right].
Top: Raw point clouds (colour hypsometry in relation to the height of the terrain)
Bottom: Classified point clouds: terrain (gray), buildings (red), other (yellow), unprocessed (cyan)

Input datasets were classified into four classes (terrain, buildings, other and unprocessed). Fig. 3 shows that the terrain was identified correctly in both datasets, however, it does not apply to the buildings. In the first dataset, almost no buildings were found. This is due to the too sparse point cloud from this dataset. Points representing most of the buildings were classified incorrectly into the class other. The result of the classification of buildings in the second dataset is significantly better. All buildings have been identified. The class other contains only those points that represent vegetation (trees and shrubs) and small objects with low height (outhouses, greenhouses, fences, cars etc.).

The result of the classification of the sparse point cloud from the first dataset is not satisfying. Changes of the recommended setting did not lead to improved results. For this reason, the first dataset is not suitable for building modelling. The next part of the analysis considers only the remaining two datasets in Table 1 (#2 and #3).

The following Fig. 4 shows only a part of the test area. It is approximately the central part of the second dataset. The classification result can be evaluated easily by a visual comparison of the orthoimage (Fig. 4 [left]) and the classified point cloud (Fig. 4 [right]). A good classification is a prerequisite for the subsequent automatic generation of 3D building models.

Fig. 4. Detail of the second dataset: orthoimage [left] and classified point cloud [right]: terrain (gray), buildings (red) and other (yellow)

Creation of 3D building models

The automatic generation of 3D building models is based on the RANSAC (RANdom SAmple Consensus) method (Fischler, Bolles, 1981). The principle of this method is to find geometric primitives by interleaving planes through the point cloud. The software interleaves planes exclusively from the points that were classified into the class buildings. This approach reduces the amount of data that must be analyzed (Fig. 5).

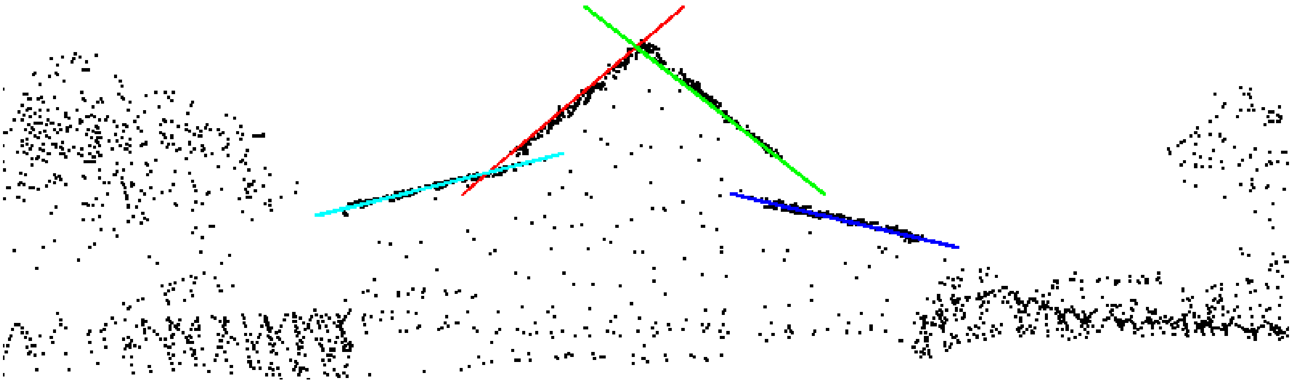

Fig. 5. Profile of the point cloud with interleaved planes through the roof faces

The created 3D models of buildings can be visualized as wire-frame objects or more realistic 3D objects covered by textures. The following figure shows a plan view of the wire-frame models of buildings (Fig. 6 [left]) and 3D view of textured models of the buildings (Fig. 6 [right]).

In the software settings, it is possible to define a desired form of the generated models. The models of buildings can be in the form of models with the real shape of the roofs (LoD 2 - Level of Detail 2) or box models (LoD 1 - Level of Detail 1) with a choice of the height (the lowest point on the roof, the average height of the roof, and the highest point on the roof).

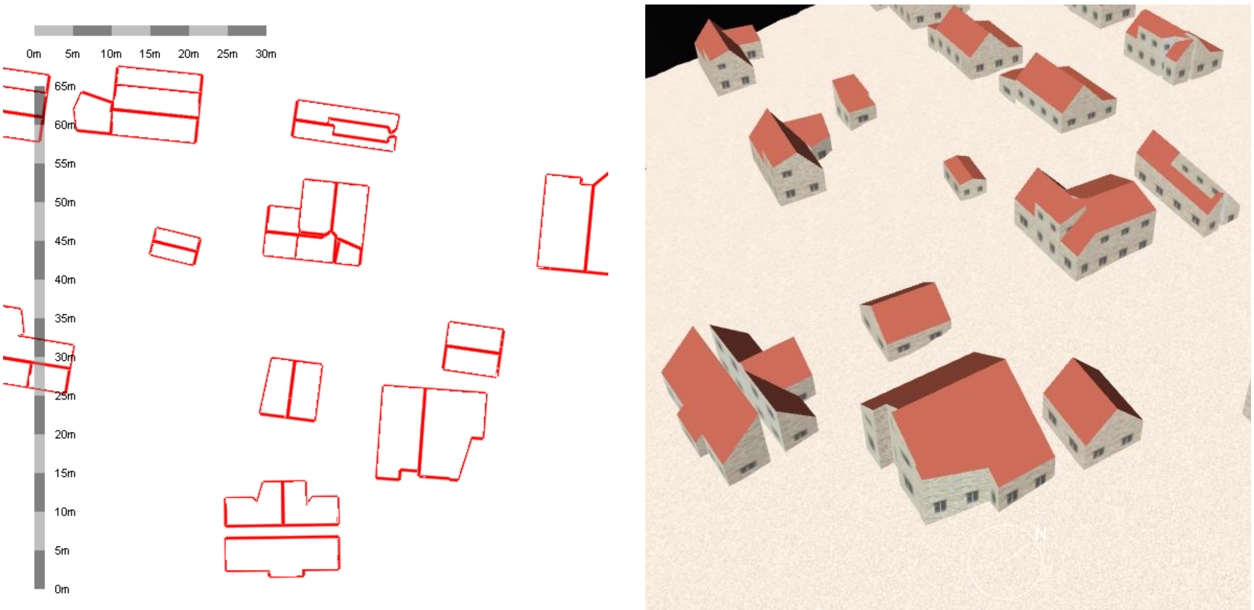

Fig. 6. 3D building models in LoD2 created from the second dataset, plan view of the wire-frame models [left] and 3D view of the textured models [right]

The quality of the created 3D building models with real shapes of roof (LoD 2) is not ideal. During the detailed inspection of individual buildings, it was discovered that the algorithm does not produce real building models. All buildings are composed of several smaller parts (irregular polyhedrons) that are adjacent or overlap each other. It gives an impression of real building models. Unfortunately, the software does not contain any knowledge base of buildings or roof shapes. For this reason, the building models are highly incorrect. Some buildings were split into smaller parts, although the building identification in the point cloud was good (see Fig. 6 - building down in the middle).

Fig. 7 demonstrates the result that can be achieved by using an extremely dense point cloud. In this case, the third dataset with point cloud density approximately 20 points per square meter was used. Fig. 7 [left] shows that the produced building model is composed of seven parts. It is not a single object. The building model is very accurate and does not contain any glaring errors, therefore the result can be regarded as satisfactory.

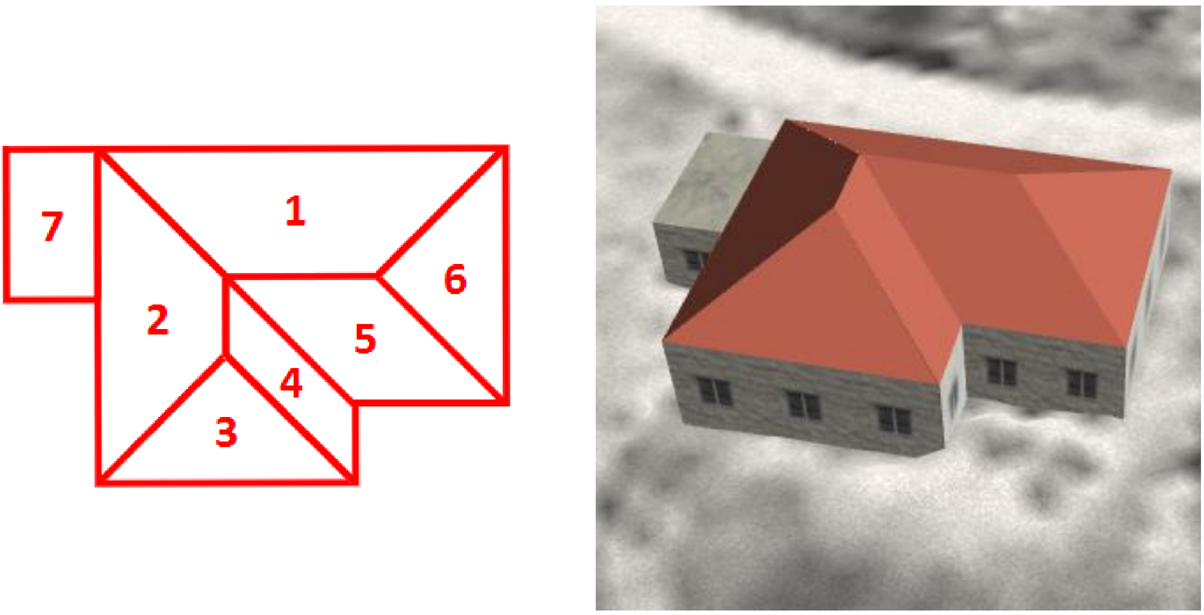

Fig. 7. 3D building model in LoD2 created from the third dataset, plan view of the wire-frame model [left] and 3D view of the textured model [right]

CONCLUSIONS

The software has a user-friendly graphical interface that is quite intuitive and allows users to view analyzed data in several options. Data processing is very well described in the Help section. The main advantage of this software is the possibility of automatic data processing, which is controlled by user-defined parameters. However, the description of the parameters is not very detailed in the Help of the software. Options are described in general and very tersely in the text. A user does not have sufficient insight into the internal functionality of the software.

The processes of the point cloud classification and modelling of buildings are very robust but they are not too sensitive to changes of optional parameters. This can be considered as an advantage and disadvantage at the same time. The modification of some parameters did not lead to the desired changes in the final result. For this reason, recommended settings were used in most cases. An implemented method analyzes the data locally and without the use of any knowledge base of buildings or roof shapes. The building model is created by a group of smaller parts (irregular polyhedrons). The software does not create real building models, but only groups of spatial primitives.

The main weakness of the software is its necessity to use high-quality input data. Processing of different data sets showed that for achieving high-quality building models, it is necessary to use a very dense point cloud as an input (20 points per square meter and more). Unfortunately, point clouds with this density are not typical. The missing knowledge base of building and roof shapes, and a poor control of the implemented algorithm make the processing of sparse point clouds difficult. Applying a sparse point cloud (up to 10 points per square meter) results in the creation of building models with a lower quality.

At the end of this paper, it should be mentioned that a detailed 3D city model consists of an accurate digital terrain model and high-quality 3D models of buildings and grown vegetation and all objects alongside roads. The data will become a normal part of the visualization of such space to allow designers to enlarge their data sources and geographic data for further processing and modelling. They will enable specialists to control and even improve conditions of the road traffic to be safer and passable. All these spatial data have a great importance for intelligent transportation, therefore they are quite important.

REFERENCES

Akel, N. A., Zilberstein, O., Doytsher, Y. (2004) A robust method used with orthogonal polynomials and road network for automatic terrain surface extraction from LiDAR data in urban areas. 20th ISPRS Congress, Istanbul, Turkey, 12-23 July, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 35 (Part B3), pp. 243-248.

Brenner, C. (2000) Towards fully automatic generation of city models. 19th ISPRS Congress, Amsterdam, Netherlands, 16-23 July, International Archives of Photogrammetry and Remote Sensing, 33 (Part B3/1), pp. 85–92.

ENVI LiDAR Help (part of the software installation), Exelis Visual Information Solutions. Document Version 3.2., c 2012, 2013-06-11.

Fischler, M. A., Bolles, R. C. (1981) Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography. Communications of the ACM, 24 (Number 6), 381-395.

Haala, N., Anders, K.-H. (1997) Acquisition of 3D urban models by analysis of aerial images, digital surface models and existing 2D building information. Integrating Photogrammetric Techniques with Scene Analysis and Machine Vision III, Orlando, FL, United States, 21-23 April, Proceedings of SPIE – The International Society for Optical Engineering, 3072, pp. 212-222.

Haala, N., Brenner, C. (1997) Generation of 3D city models from airborne laser scanning data. Proceedings 3rd EARSEL Workshop on LIDAR Remote Sensing on Land and Sea, Tallinn, Estonia, 17–19 July, pp. 105–112.

Haala, N., Brenner, C., Anders, K.-H. (1998) 3D urban GIS from laser altimeter and 2D map data. International Archives of Photogrammetry and Remote Sensing, 32 (Part 3/1), 339–346.

Hoover, A. et al. (1996) An experimental comparison of range image segmentation algorithms. IEEE Transactions on Pattern Analysis and Machine Intelligence, 18 (Issue 7), 673-689.

Jiang, X., Bunke, H. (1994) Fast segmentation of range images into planar regions by scan line grouping. Machine Vision and Applications, 7 (Issue 2), 115-122.

Jibrini, H., Paparoditis, N., Deseilligny, M. P., Maitre, H. (2000) Automatic building reconstruction from very high resolution aerial stereopairs using cadastral ground plans. 19th ISPRS Congress, Amsterdam, Netherlands, 16-23 July, pp. 16-23.

Nizar, A. A., Filin, S., Doytsher, Y. (2006) Reconstruction of buildings from airborne laser scanning data. Prospecting for Geospatial Information Integration, Reno, NV, United States, 1-5 May, American Society for Photogrammetry and Remote Sensing, 2, pp. 988-997.

Suveg, I., Vosselman, G. (2000) 3D Reconstruction of building models. 19th ISPRS Congress, Amsterdam, Netherlands, 16-23 July, International Archives of Photogrammetry and Remote Sensing, 33 (Part B2), pp. 538-545.

Vosselman, G. (2002) Fusion of laser scanning data, maps, and aerial photographs for building reconstruction. International Geoscience and Remote Sensing Symposium (IGARSS), Toronto, Ont., Canada, 24-28 June, pp. 85-88.

Vosselman, G., Dijkman, S. T. (2001) 3D building model reconstruction from point clouds and ground plans. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 34 (Part 3/W4), 37–43.