3D MODELLING OF TOPOGRAPHIC OBJECTS BY FUSING 2D MAPS AND LIDAR DATA

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ABSTRACT:

In the past few years the number of applications that use 3D information of topographical objects increased rapidly. With the growing demand for 3D topographic data the need for automated 3D data acquisition also grows. Height information can be extracted from airborne or terrestrial acquisition methods, but can also be modelled as implicit semantic information. Adding height information to existing features is insufficient; additional features have to be acquired and existing features might get an extra dimension (surfaces can be converted to volumes, etc). The challenge is to produce semantical, geometrical and topological correct 3D topography. In this paper we describe the steps to acquire 3D topographic information. Special attention lies on the user requirements of 3D models. These requirements have been accomplished by information analysis at four major geo-information organizations in The Netherlands. The four cases describe the wishes and requirements for 3D data and modelling. The most important acquisition task is the modelling of 3D infrastructure and 3D building models. In this paper we will focus on the modelling of 3D infrastructure in general, and specially the reconstruction of hidden infrastructural object parts. The developed method will be demonstrated with a 3D reconstruction of the complex motorway interchange 'Prins Claus Plein' near The Hague, The Netherlands, with multiple infrastructural objects crossing each other at different height levels. Although the focus in this paper will lie on the modelling of 3D infrastructure, the presented 3D map includes the modelling of topographic features completely covering the terrain.

1. INTRODUCTION

In the past few years the number of applications that use the 3D information of topographical objects increased rapidly. Examples can be found in location based services, virtual reality tasks, visualisation for city planning, etcetera. These applications require 3D topographic input data. Acquiring 3D topographic information is even more complicated than 2D data.

With the growing demand for 3D topographic data the need for automated 3D data acquisition also grows. 3D data acquisition and object reconstruction is conventionally performed using stereo image pairs. Photogrammetry is a classic, accurate and operational approach for 3D data acquisition (Tao, 2005). However, the automated reconstruction of buildings using only aerial images as data source has been proven to be a very difficult problem (Suveg and Vosselman, 2004).

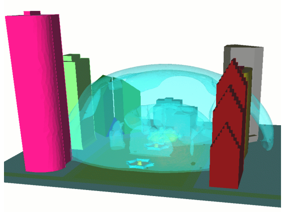

Figure 1 Example of a 3D modelling application.

The use of laser altimetry as data source for the (semi-) automatic reconstruction has been described by several authors (Brenner, 2000; Elaksher and Bethel, 2002; Maas, 2001; Vosselman and Dijkman, 2001), and shows great potential to reliable 3D surface modelling. Some of them use additional information, like 2D GIS data, in one or more steps of their methods.

Correctly combining height information with existing 2D maps has a great potential for a fast, accurate and highly automated acquisition of 3D maps. Several papers describe the advantage of using both laser data and 2D maps (Brenner, 2000; Haala et al., 1998; Hatger and Brenner, 2003; Hofmann, 2004; Koch, 2004; Rottensteiner and Briese, 2002; Vosselman and Dijkman, 2001). Topographic maps provide outlines, classified polygons and topologic and 2D semantic information. The purposes for integrating map data and laser data ranges from improving the filtering process for DTM generation by explicitly modelling 3D breaklines (Briese, 2004) to rapid acquisition of 3D city models for virtual reality applications (Haala et al., 1998).

In 3D maps it should be possible to acquire multiple topographic features at one and the same 2D location (e.g. tunnels, flyovers, etc). Height information can be extracted from airborne or terrestrial acquisition methods, but can also be modelled as implicit semantic information. Adding height information to existing features is insufficient; additional features have to be acquired and existing features might get an extra dimension (surfaces can be converted to volumes, etc).

When aiming for fully 3D models, the volume below and on top of the object surface has to be modelled. Not only does this mean that acquisition of multiple cartographic object types at one location is possible or necessary at interchanges, bridges etc, but it also means that vertical object planes have to be acquired. Existing 2D objects that indicate height information have to be revised. In [Penninga, 2005] a summary is given of some representations of height information: height contours, shadowing, hatches to indicate height differences at banks and dikes. If the user really can explore the third dimension some of these objects will become superfluous.
This research is a part of a project to develop methods for acquiring, storing, and querying 3D topographic data as a feasibility study for a future national 3D topographic database. Usage is therefore made of the current national 2D topographic database TOP10vector and the national elevation model AHN.

The topic of this paper is twofold. Special attention lies on the user cases of 3D models. These cases have been accomplished by information analysis at four major geo-information organizations in The Netherlands. The cases describe the wish and requirements for 3D data and modelling, added with a list of scientific activities to fill the gap between the wishes and reality. These user cases have been highlighted in chapter 2. Second issue is describing one of the first research activities: the modelling of 3D infrastructure. In this paper, chapter 4, we will focus on the modelling of 3D infrastructure in general, and specially the reconstruction of hidden infrastructural object parts.

2. USER CASES

In our research project we defined and analyzed four user cases. Each user case represents the 3D model requirements of one specific organization to perform their 3D modelling and visualization tasks.

2.1 Survey department of Rijkswaterstaat

Rijkswaterstaat is responsible for the maintenance of national highways and waterways, including bridges, dikes and the navigability of canals. Geo-information of these infrastructural objects has been acquired at several scales, using several spaceborne, airborne, terrestrial and hydrographical measurement techniques. Rijkswaterstaat focuses on improving the acquisition, storage and distribution of their geo-information data. To successfully offer their web based geo information services and applications, Rijkswaterstaat is looking for the optimal production of 2, 2.5 and 3D geo-information. Their focus is on the large scale topography of infrastructural objects and the medium scale landscape modelling and visualization.

2.2 Municipality Den Bosch

Den Bosch aims for the production of a large scale 3D GEO database to inform citizens and to support other departments for real estate taxes, city planning, noise modelling etcetera. Their main motive for acquiring 3D data is to model and visualise the “as-is” situation. Den Bosch has many situations with multiple land use, like shown in Figure 2. At the moment they have to store these multiple classifications in multiple 2D layers, which makes it hard to perform 3D modelling and visualisation tasks.

Figure 2 Multiple land use at one location: buildings on top of a canal.

Their list with 3D model requirements starts with the modelling of shapes of buildings, followed by the possibility to store and analyse multiple objects on top of each other. Research activities have been determined in the field of semi-automatic reconstruction of buildings, using high point density airborne and terrestrial laser scanner data together with a large scale base map (scale 1:1000). These activities will be carried in 2007 and 2008.

2.3 Water boards

For the inspection and maintenance of regional dikes, bridges and waterways, the water board needs up-to-date and reliable geo-information. For several applications, e.g. when combining topography with hydrological, geological and geotechnical information, it is necessary to use full 3D topographic information. At the moment most of the water boards use large scale 2D base maps and high point density laser data separately from each other. Integration has been done visually by the user: information from one source can be used to better interpret the other. Requirements for a 3D model is that breaklines, e.g. on top and at the bottom of a dike, are modelled with high precision. Breaklines are important features for the condition (shape and strength) of dikes. The reconstruction of breaklines from laser scanner data has previously been described in (Briese, 2004). Our research activities are planned for 2007 and will focus on the integration of existing 2D maps and high point density laser scanner data, using a full 3D model data structure (e.g. a TEN structure), as described in (Penninga, 2005).

2.4 Topographic Mapping Agency

The Topographic Mapping Agency of the Dutch Cadastre produces national 2D topographic databases from scale 1:10.000 to 1:250:000. Users can be found in several public and private sectors in the Netherlands. To come to meet the growing 3D desires of the users, the Mapping Agency would like to implement the third dimension to their products. They participate in this research project by providing data and by helping to translate user requirements into research activities.

In the remaining part of the paper we will focus on the user case of the Topographic Mapping Agency as described in 2.4.

3. DATA PROPERTIES

The Topographic Mapping Agency aims to integrate the third dimension into their medium scale (1:10.000) topographic map, called the TOP10vector. In this chapter a description is given of the TOP10vector and the laser data set used in this project.

3.1 Topographic map

TOP10vector is a digital 2D topographic database for usage at a scale around 1:10.000. It has been built up in a fully coded object structure. The databases has been built from photographs in a 1:18.000 scale and has an accuracy of 1-2 m. Small buildings like houses, are stored in a different layer and are not shown in Figure 3.

Figure 3 The study area in the TOP10vector database.

One property of the TOP10Vector is that a polygon can have more than one classification, including the information whether this class is visible from above or not.

3.2 Laser data

The national elevation model of the Netherlands (AHN) has an average point density of 1 point per 16 m² or better and a height precision of about 15 cm standard deviation per point. In the standard production process the laser data has been filtered, removing buildings, trees and outliers. This filtered dataset will normally be interpolated to a regular grid, and delivered in grid sizes of 5, 25 and 100 meter. However, in this project the original, unfiltered irregular point cloud has been used in order to use as much information from the point cloud as possible.
In the first step of data fusion it will be decided which parts of the laser data will be used to provide height information to which part of the 2D map. This is one of the most crucial steps in the automation of the reconstruction process. The easiest way to select the laser data is just to perform a points-in-polygon function, where the outlines of the grouped 2D objects act as polygons. In the ideal case this is enough to select the right points. However, in many cases not all laser points represent height information of the topographic object, but may indicate height of details of this object, e.g. a laser point can lie on a chimney instead of the roof, or on a car instead of the street. An important step of the selection is segmenting the point cloud, according to the rules and conditions of the object (group).

As described in more detail in (Oude Elberink and Vosselman, 2006), laser data has been filtered in a segment based approach to eliminate laser points on small objects like cars, light poles, traffic signs, and trees.

For the segmentation of the point cloud a surface growing algorithm is used with some modifications that allow a fast processing of large datasets (Vosselman et al., 2004). The surface growing method consists of a seed surface detection followed by the actual growing of the seed surface.

4. APPROACH

4.1 Surface modelling

Some aspects of the 3D reconstruction are independent of the data source. Important examples are the type of surface representations and object modelling. One way to represent the terrain given by a set of surface points is to construct a Delaunay Triangular Irregular Network (TIN). In (Verbree and Oosterom, 2003) a surface reconstruction method has been described, based on the Delaunay Tetrahedronised Irregular Network (TEN), which tessellates the 3D-space with non-overlapping, adjacent, tetrahedrons. In this part of the research the surface is represented in a TIN structure; at a later stage a TEN structure will be used to be able to model volume objects.

4.2 Data fusion

Laser data and 2D map data are integrated and processed in an object-based approach. For groups of objects rules for 3D reconstruction are being set-up. These rules have to ensure the geometrical, topological and semantical correctness of the 3D map. Adding height information to existing 2D features is not sufficient; additional features have to be acquired and existing features might get an extra dimension. Examples are given showing the automated generation of additional polygons at real 3D objects like viaducts and flyovers. Road objects at those locations will be converted automatically from surfaces to volumes, in order to get realistic 3D data.

In this research we recognise and model height discontinuities between objects that are adjacent in a 2D topographic database. For modelling the surfaces of the 3D topographic object a point cloud segmentation algorithm is used. This algorithm preserves height discontinuities, but eliminates small objects like cars and traffic signs that should not be included in the 3D topographic database. Filtering algorithms are also used to select the correct laser points for modelling the object surfaces.

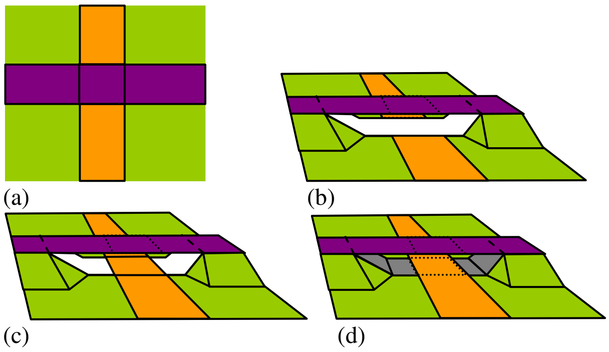

Figure 4 Creating new objects: interchange in 2D (a); height given to 2D features (b); connecting lower road parts (c); filling gaps (d).

Figure 4 illustrates four stages in the reconstruction process, starting with the 2D situation in (a) and ending with the 3D situation in (d). In (b) heights have been calculated at boundaries of visible objects, followed by the height determination of 'invisible' objects in (c). In the next part of this chapter we will describe the 3D modelling of existing object boundaries in 0, creating new parts that did not exist in 2D, but are necessary in 3D to get a tight surface model (4.4 and 4.5).

4.3 Modelling 3D boundaries

As shown in Figure 4a-b, edges that are straight in the 2D map do not need to be straight in the 3D model. To correctly capture the shape of the boundaries, the edges therefore need to be described by more points. For this purpose, points were inserted into the edges of the polygons at every 10 m. For all these points and the original map points the height needs to be determined from the laser data. Every map point belongs to two or more polygons. In each of the neighbouring polygons laser data is selected to calculate the height at the map point, see Figure 5. Laser data has been filtered to remove small objects like cars and traffic signs. By calculating multiple heights at every map point, height discontinuities can be detected and modelled. Several constraints have been introduced to get a topological correct model, see (Oude Elberink and Vosselman, 2006).

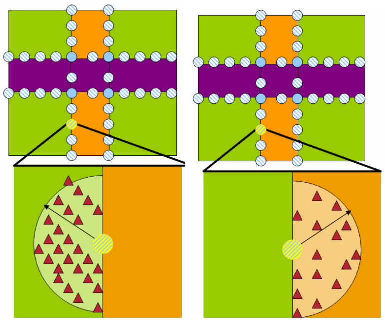

Figure 5 Calculation of map point height, from grass land (left) and road object (right).

In figure 6 results are shown for the modelling of 3D boundaries of a simple crossing. The 3D map points have been visualised as small red dots. Note that the density of map points is much higher in the 3D model than in the 2D map.

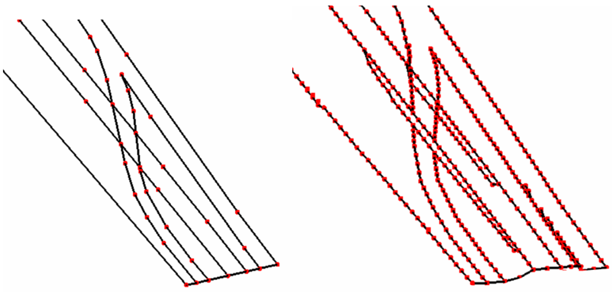

Figure 6 Oblique view on boundaries of crossing roads in 2D (left) and the 3D boundaries (right).

4.4 Connecting road parts

As we can see in Figure 4b gaps will occur when only modelling visible map features. Additional features have to be created under bridges and interchanges. The first step in filling the road gaps is the reconstruction of polygons marked as 'invisible', like in Figure 4c. Although it is likely that no laser points may be available, constraints in the model can fill the gap and connect two parts of the model in 3D. The modelling of the invisible polygons is accepted if the nodes successfully fit to potential neighbouring polygons. Successfully means that the reconstructed polygon is smooth and connect to neighbouring road parts. Planes have been fitted through laser points and 3D map points on those neighbouring road parts. At the centre point of the missing polygon, the height of each plane has been determined. If the heights of the planes at the centre point coincide within a certain threshold, the reconstructed polygon will be accepted. With this method also slanted 'invisible' roads will be reconstructed correctly.

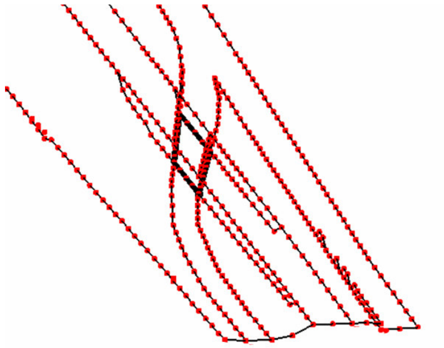

Figure 7 Polygon connecting two lower road parts, shown as bold polygon.

4.5 Completing surface model

After the previous step many other gaps remain at both sides of the 'invisible' polygons, as can be seen in Figure 4c. These can be filled by creating new polygons, which have the 2D shape (and topology) of the road polygons lying above them. The heights of the new nodes are determined by searching for map points at neighbouring polygons that lie on the ground surface. Doing so, these new polygons are connected to lower neighbouring polygons, like in Figure 4d.

Adding height to a 2D object not only means giving height to the boundaries of this object, but also to the surface of the object. Most of the terrain objects show some relief at its surface. Laser points lying on the terrain (i.e. not on buildings, roads, trees, water) are used as nodes in the surface TIN model. To get a smooth surface at road objects, map points at road boundaries have been used to generate a constrained TIN model, without adding laser points lying on that road. Trees and buildings have not been modelled in this part of the research project.

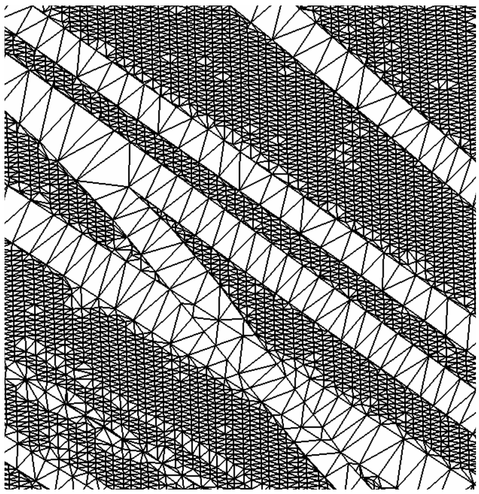

Figure 8 Constrained TIN model with roads and grass land.

5. RESULTS

5.1 Project results

In Figure 9 and in Figure 10 results are shown for the fusion of a medium scale topographic map (TOP10Vector) with laser data with a point density of one point per five m^2 (original dataset of part of the AHN). The developed method is demonstrated with a 3D reconstruction of the complex motorway interchange 'Prins Claus Plein', with multiple infrastructural objects crossing each other at different height levels.

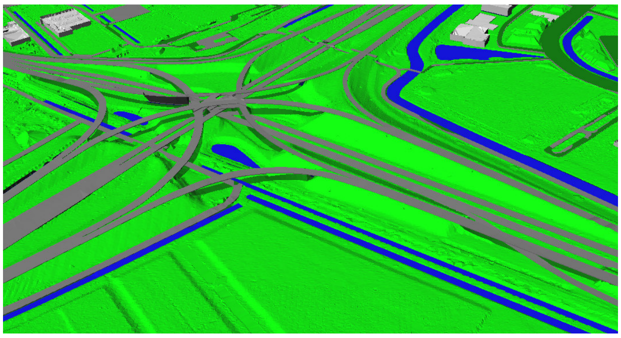

Figure 9 Reconstructed model of Prins Claus Plein.

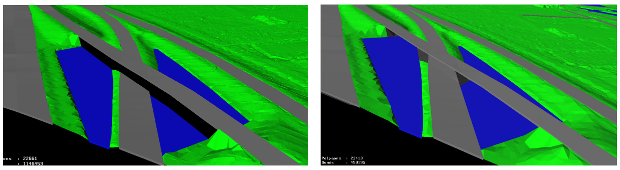

Figure 10 3D Modelling of existing polygons (left); with additional features (right).

The major disadvantage of the proposed method is the strong dependency on the quality of the 2D map. In Figure 11 five of many missing polygon edges are highlighted. Due to the lack of 2D edges, it is impossible to automatically reconstruct the accompanying 3D edges. In a later stage of the project a semi-automated approach will be introduced to be able to intervene in the reconstruction process.

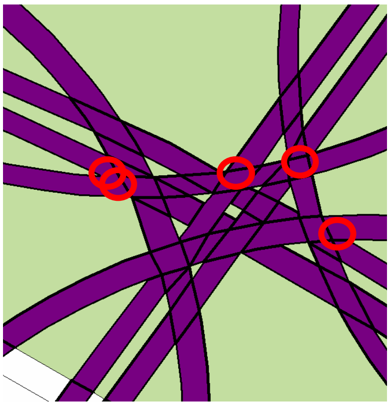

Figure 11 Several polygon edges missing in 2D map at complex interchange.

Another disadvantage is the possible time difference between the acquisition of the map data and in the laser data, resulting in two different recorded situations.

5.2 Applications

During the modelling of the scene the user can choose to derive several supplementary products. One side product can be a Digital Terrain Model (DTM), instead of a Digital Surface Model (DSM). Objects located above or on top of the surface can easily be left out when deriving a DTM from the laser point cloud. Doing so, this DTM excludes 3D objects like buildings, trees and interchanges but includes semantically correct break lines at topographic features; Figure 13 shows the DTM in which 3D objects have been filtered from the laser point cloud (Figure 12).

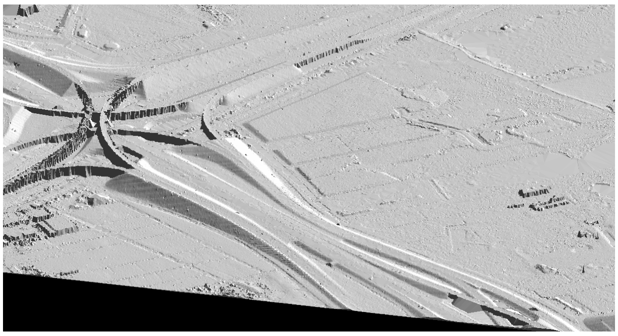

Figure 12 TIN of laser points at Prins Claus Plein.

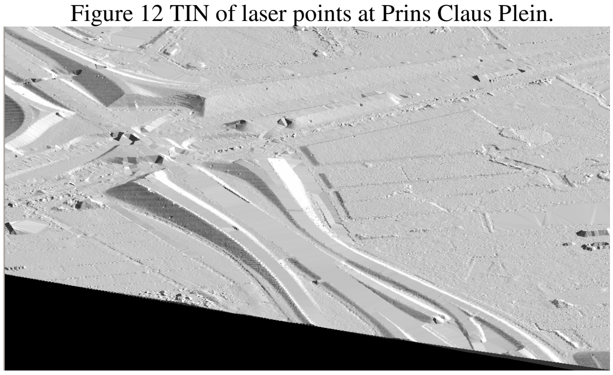

Figure 13 DTM of Prins Claus Plein, derived by filtering 3D objects.

Several producers of 2D topographic maps struggle with the implementation of the third dimension, as we have seen in user case 4 (chapter 2.4). One barrier is the increasing amount of data when adding laser points as nodes on the 3D surface, the other is the change of the products' topologic structure. The first step to implementation could be the determination of the height of map nodes, which can be derived from the 3D boundaries. By doing so, the topology of the map does not have to change, and the laser points have only been used to determine the height, but are not part of the end product. This 3D boundary product gives the user height information at nodes of the 2D map. However, when visualising 3D maps the 3D surfaces have to be triangulated. This implies a change of the topological structure of the product.
Several software packages can be used to further process 3D topographic objects. To give an eye-catching example, recently Google Sketchup became available for free, allowing basic handling and editing of 3D data for a large group of users. When exporting to Google Earth this 3D data can easily be visualised and distributed, as shown in Figure 14.

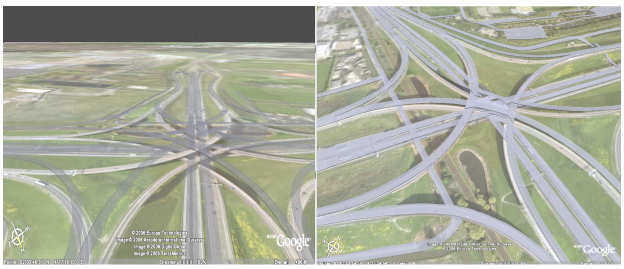

Figure 14 Road objects imported in Google Earth.

6. CONCLUSION & OUTLOOK

We have presented a method that recognises and models height discontinuities between objects that are adjacent in a 2D topographic database. A segmentation algorithm has successfully been used to connect laser points on smooth surfaces and remove small segments. First, the 3D boundaries have been determined by fitting planes to neighbouring dominant laser segments. Several connection rules have been applied to get a tight model at object boundaries. Several conditions have been applied to get horizontal lakes and smooth roads. At interchanges and flyovers additional boundaries have automatically been reconstructed to allow the reconstruction of 3D objects. We've added missing polygons to hidden objects to get a tight surface model.

Together with other research partners we are working on the modelling of volume objects in a TEN data structure. This gives the opportunity to reconstruct 3D models with 3D primitives instead of with 2D surfaces. Next, focus will be on the detailed reconstruction of buildings, by fusing higher point density laser data with large scale topographic maps.

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REFERENCES

Brenner, C., 2000. Towards Fully Automatic Generation of City Models, XIX ISPRS Congress. IAPRS, Amsterdam, The Netherlands, pp. 85-92.

Briese, C., 2004. Three-Dimensional Modelling of Breaklines From Airborne Laser Scanner Data, XXth ISPRS Congress: Geo-Imagery Bridging Continents. IAPRS, Istanbul, Turkey.

Elaksher, A. and Bethel, J., 2002. Reconstructing 3D Buildings From Lidar Data, Symposium 2002 Photogrammetric Computer Vision. IAPRS, Graz, Austria.

Haala, N., C. Brenner and Anders, K.-H., 1998. 3D Urban GIS From Laser Altimeter and 2D Map Data, ISPRS Commission IV – GIS Between Visions and Applications. IAPRS, Ohio, USA.

Hatger, C. and Brenner, C., 2003. Extraction of Road Geometry Parameters From Laser Scanning and Existing Databases, ISPRS working group III/3 workshop `3-D reconstruction from airborne laserscanner and InSAR data'. IAPRS, Dresden, Germany.

Hofmann, A., 2004. Analysis of TIN-Structure Parameter Spaces in Airborne Laser Scanner Data for 3-D Building Model Generation, XXth ISPRS Congress: Geo-Imagery Bridging Continents. IAPRS, Istanbul, Turkey.

Koch, A., 2004. An Approach for the Semantically Correct Integration of a DTM and 2D GIS Vector Data, XXth ISPRS Congress: Geo-Imagery Bridging Continents. IAPRS, Istanbul, Turkey.

Maas, H.-G., 2001. The suitability of Airborne Laser Scanner Data for Automatic 3D Object Reconstruction, Third International Workshop on Automatic Extraction of Man-Made Objects from Aerial and Space Images, Ascona, Switzerland.

Oude Elberink, S. and Vosselman, G., 2006. Adding the Third Dimension to a Topographic Database Using Airborne Laser Scanner Data (to be published), Photogrammetric Computer Vision 2006. IAPRS, Bonn, Germany.

Penninga, F., 2005. 3D Topographic Data Modelling: Why Rigidity Is Preferable to Pragmatism. In: A.G.C.a.D.M. Mark (Editor), Spatial Information Theory, COSIT, Ellicotville, USA, pp. 409-425.

Rottensteiner, F. and Briese, C., 2002. A New Method for Building Extraction in Urban Areas from High-Resolution Lidar Data, Symposium 2002 Photogrammetric Computer Vision. IAPRS, Graz, Austria, pp. 295-301.

Suveg, I. and Vosselman, G., 2004. Reconstruction of 3D building models from aerial images and maps. ISPRS Journal of Photogrammetry and Remote Sensing, 58(3-4): 202-224.

Tao, V.C., 2005. 3D Data Acquisition and Object Reconstruction for AEC and CAD. In: S. Zlatanova and D. Prosperi (Editors), Large-scale 3D Data Integration. CRCpress, Boca Raton, Florida, USA, pp. 245.

Verbree, E. and Oosterom, P.V., 2003. The Stin Method: 3D-Surface Reconstruction by Observation Lines and Delaunay TENS, ISPRS working group III/3 workshop `3-D reconstruction from airborne laserscanner and InSAR data', Dresden, Germany.

Vosselman, G., B. Gorte, G. Sithole and Rabbani, T., 2004. Recognising Structure in Laser Scanner Point Clouds, International Conference NATSCAN "Laser-Scanners for Fores and Landscpae Assessment – Instruments, Processing Methods and Applications, ISPRS working group VIII/2, Freiburg im Breisgau, Germany.

Vosselman, G. and Dijkman, S., 2001. 3D Building Model Reconstruction from Point Clouds and Ground Plans, ISPRS Workshop Land Surface Mapping and Characterization Using Laser Altimetry. IAPRS, Annapolis, USA.