Generation of a National Virtual 3D City and Landscape Model for the Netherlands

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Abstract

This paper describes the generation of a national three-dimensional (3D) dataset representing the virtual and landscape model. The 3D model is produced automatically by fusing a two-dimensional (2D) national object-oriented database describing the physical landscape and the national high-resolution height model of the Netherlands. Semantic constraints are introduced to correctly model 3D objects. Three areas from different regions in the Netherlands have been processed in order to develop, improve and test the automatic generation of a national 3D city and landscape model. Specific attention has been paid to exceptional cases that may occur in a nationwide dataset. Based on the test results, the Kadaster, the national agency in the Netherlands responsible for the production of nation wide geo-information, decided that it is feasible to produce a national 3D city and landscape model that fulfills the specifications that were defined as part of this study. Future research is identified to make the results further ready for practice.

1. Introduction

Over the past two years, a uniform approach for acquiring, storing and visualizing 3D geo-information has been explored in a pilot in the Netherlands. In this pilot, over 65 private, public and scientific organizations have collaborated to push the use of 3D information. The pilot project established the groundwork for a comprehensive national 3D geo-information program. A major result was a proof of concept for a 3D spatial data infrastructure (SDI) covering issues on the acquisition, standardization, storage and use of 3D data (Stoter et al., 2011).

Besides the need for a national 3D standard realized as City Geography Markup Language (CityGML) implementation (OGC, 2008; 2012a) (see Van den Brink et al., 2013), the pilot showed the need for a nationwide 3D city and landscape model. This model can serve as a reference for (new) 3D information in a 3D virtual world, and as a basis for 3D planning and management of public space. The 3D base model can be further refined when a project develops.

Many large municipalities have 3D data sets, but these are specifically required for the territory of the city and in various formats and resolutions. The pilot has shown promising results for generating a national 3D city and landscape model as a combination of 2D topography with high-resolution airborne Light Detection and Ranging (Lidar) data. This paper describes how those results are further developed to generate a national 3D topographic dataset covering the whole of the Netherlands. The work is collaboration between the University of Twente, the Delft University of Technology, and the Kadaster, the national agency in the Netherlands responsible for the production and provision of nation wide geo-information. Three areas from different regions in the Netherlands have been processed in order to develop, improve and test the automatic generation of a 3D dataset. The test areas include complex interchanges, buildings above roads, bridges, urban areas and forested areas.

This paper describes the applied methodology (including the choices that were made), the results, findings and remaining challenges to obtain a first version of the national 3D dataset in 2012. As our goal is to generate a nationwide 3D dataset, our procedure has to pay specific attention to manage large datasets and to handle any situation. It means that the design should fulfill five main conditions, i.e. our procedure should:

1. Be fully automatic;
2. Deal with inaccuracies in both datasets;
3. Create valid 3D geometries;
4. Completely cover the country;
5. Handle all – including special – situations.

In addition, since the dataset is intended as a foundation for the 3D Spatial Data Infrastructure (SDI), the interest is not only in the generation of the 3D data but also in the maintenance and dissemination of the 3D dataset.

The structure of the paper is as follows. After a description of related work (Section 2), Section 3 presents the specifications of the 3D dataset that represents the virtual city and landscape model. The proposed 3D reconstruction methodology covering the five conditions is presented in Section 4. Section 5 presents results, followed conclusions and identification of future research and developments in Section 6. In the extended version (Oude Elberink et al., 2013) published by ASPRS, more details on special situations and the dissemination of 3D models are described.

2. Related work

The research attention on automated generation of 3D information from a combination of 2D topographic vector data and high resolution Lidar data is not new. Two main reasons justify this combinatorial approach. Firstly existing 2D datasets contain information about the types of object to generate (i.e. building, road, water etc.)

that increases the possibilities to automatically generate 3D information. Secondly the 2D topographic datasets often contain rich semantics, such as functionality of objects, which is difficult to obtain from automated acquisition techniques.

Previous research on this topic is reported in (Haala et al., 1998). They describe the combination of detailed Digital Surface Models (DSM) and 2D topographic objects to reconstruct urban objects such as buildings and trees. To enhance the boundary representation of objects, Koch and Heipke (2006) introduce semantic rules when fusing a DSM with 2D map data. These rules ensure a logical and consistent 2.5D representation (i.e. height surface representation) of the topographic objects. Oude Elberink and Vosselman (2009a) propose an extension of these semantic rules to real 3D, to ensure that actual 3D objects, such as bridges and interchanges can be represented realistically.

In recent years the density of point clouds, either generated from Lidar data or aerial imagery, has increased up to several points per square meter. The increasing point density is considered important in 3D reconstruction algorithms because it allows for a more detailed and reliable description of objects. Even more important for national mapping agencies is the national coverage of such datasets.

3. The 3D dataset

This section presents the two source datasets (Section 3.1 and 3.2) and explains the specifications of the 3D object-oriented topographic dataset that were defined as part of our study (Section 3.3).

3.1 Source data: the 2D topographic dataset

In the Netherlands, two 2D topographic vector data sets are candidates for extension into 3D: the large-scale base dataset, modeled according to Information Model Geography (IMGeo) and the national topographic vector map at scale 1:10,000. The first data set is the object-oriented version of the large-scale base map of the Netherlands, with a scale of approximately 1:500 (1:1000 in rural areas). The new version of the model IMGeo has recently been established and nationwide coverage of IMGeo data (in 2D) is expected to be ready in 2015. Providers of the IMGeo data are municipalities, provinces, agencies responsible for the railway and high way network infrastructure (Prorail and Rijkswaterstaat), and Kadaster. The second candidate source dataset for extension in 3D is an object oriented topographic dataset at scale 1:10,000 (called TOP10NL) available for the whole country since 2006 and maintained by the Dutch Kadaster.

Although IMGeo has been fully prepared for extension into 3D by integration of the information model with the OGC CityGML standard (Stoter et al 2011; Van den Brink et al, 2013), we selected TOP10NL as the most suitable candidate for a nationwide 3D base dataset. This has several reasons. Firstly TOP10NL data is available nationwide while 2D IMGeo data will only be generated in the coming

Figure 1. TOP10NL data of the test area in Amersfoort.

years. Secondly, TOP10NL is less detailed than IMGeo and therefore better suitable for fully automatic 3D object reconstruction since fewer details are required (therefore less special cases). Despite fewer details, we are of the opinion that the resulting dataset generated from TOP10NL is appropriate for a nationwide dataset (i.e. acceptable performance for nationwide applications), and that it can be further refined when applied in future projects. Finally for an automated workflow it is essential that the data have been acquired in a standardized manner. Since TOP10NL has only one data provider, the data are homogenous for the whole country and the nice side effect is that the 3D result will be a consistent national 3D dataset. Consequently it was decided that for the moment, 3D TOP10NL is the best option to generate and disseminate a nationwide 3D base dataset.

The main classes in TOP10NL (see Figure 1) are: Road, Land Use, Water, Railway, Layout Element, Registration Area, Building, Geographical Area, Functional Area, and Relief.

The land use, road and water objects that can be seen from above form a complete partition of the country, without any gaps or overlap. Consequently, buildings, and also functional and geographical areas, overlap with other objects. In addition infrastructure objects can cross (i.e. overlap in 2D). This is modeled using two attributes assigned to infrastructural classes with polygon geometry (Water and Road): a 'type of infrastructure' attribute, which models whether the infrastructure object is a connection or a crossing and the 'height level' attribute. This last attribute models the relative order of objects where a value of '0' indicates that the object is on top of a stack of two or more objects (i.e. visible from above). All objects at height level '0' constitute the planar partition.

3.2 Source data: the Lidar dataset

3D TOP10NL is generated by combining the TOP10NL vector data with the national height model of the Netherlands (called AHN, see (AHN, 2012)), which is
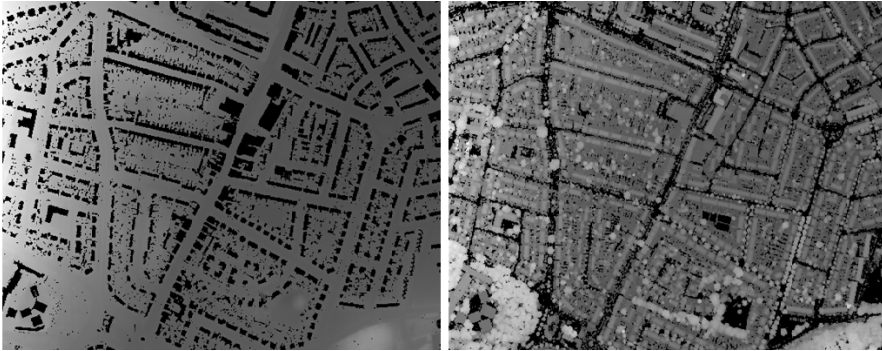
Figure 2. Lidar (AHN) data: ground points (left) ranging between 5 m (dark grey) and 22 m (white) above means sea level (MSL); and non-ground points (right) ranging from 5 to 48 meters above MSL. Black areas do not contain laser points because points are either removed during the filtering or because these are areas with water.

acquired by airborne Lidar systems. The first version of AHN (with a density of at least one point per 16 square meters, and in forests one point per 36 square meters) was completed in 2003. In the period of 2009 – 2012, the second version of the data set is acquired with an average point density of 10 points per square meter. Currently a third version, possibly enriched with pulse count information, is being considered.

The AHN data set has been acquired, assessed, filtered and stored in a standardized manner, in terms of specifications on point densities, overlapping areas and quality reports. A useful property of the height model is the filtering step that separates points on ground and points on elevated objects such as trees and buildings, as shown in Figure 2. The companies that acquire the data also filtered the data and therefore the AHN point data is available as two products for any customer. In our procedure we use the second version of the AHN (i.e. AHN-2) data, which includes both the ground and non-ground points. Notice that the dataset is also available as a grid (different resolutions are available) but we use the original samples.

3.3 Specifications of the 3D TOP10NL dataset

The aim of 3D TOPNL is to have a 3D version of the 2D vector map covering the whole country. Consequently the map objects should still be available in the 3D model but now with the 2.5D (i.e. height-surface) and 3D (i.e. volumetric) repre-sentations. Not all TOP10NL classes are relevant or suitable for an extension to 3D, for instance functional land use (e.g. zoo, cemetery) and point based features (e.g. striking objects) are not. We therefore selected the most appropriate classes, which are road, water, geographic land use and buildings.

The type of 3D representation that is generated (i.e. 2.5D or 3D) depends on the class. Following the characteristics of the TOP10NL objects, we decided to obtain volumetric geometries (3D) for buildings and height surface geometries (2.5D) for
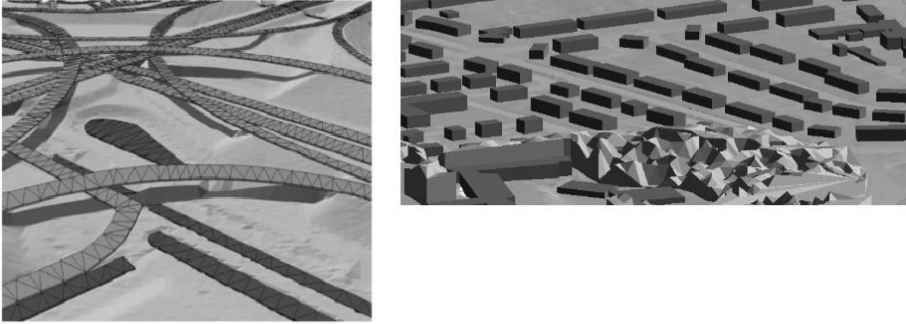
Figure 3. Multi-level infrastructural crossings (left) and a urban scene including forest areas (right).

the other objects (road, water and land use). Multi-level infrastructural crossings are represented through surface geometries that connect in space (Figure 3, left).

'Forest' (which is a type of geographic land use) is a specific case, since the AHN data contains two products at those locations: the point data at the terrain level and point data representing the heights of the trees. To represent both types of information in the resulting dataset, we create a height surface from the tree heights that we extrude downwards to the terrain level, see Figure 3, right. Both types of height (tree heights and terrain heights) are relevant information at those locations.

4. Methodology for the generation of a nationwide 3D dataset

This section presents the methodology and engineering choices to generate a nationwide 3D dataset. It is organized according to the five main conditions that we should fulfill, introduced in Section 1:

1. Fully automatic reconstruction (Section 4.1);
2. Dealing with inaccuracies in both datasets (Section 4.2);
3. Creation of valid 3D geometries (Section 4.3);
4. Covering a large area, i.e. a complete coverage of the country (Section 4.4);
5. Handling all -including special- situations (Section 4.5).

4.1 Automatic 3D generation process

The procedure to obtain the 2.5D and 3D representations from TOP10NL object builds on the work of Oude Elberink and Vosselman (2009a). The 3D generation of polygon boundaries is a two-step procedure: firstly heights are assigned to polygons following specific rules (section 4.1.1); secondly information on neighboring polygons is used to refine the height values (section 4.1.2).

4.1.1 Polygon based processing

The 2.5D and 3D representations are generated using the 2D geometry, the accurate 3D point-based surface description of the airborne Lidar data that fall within

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the object and specific characteristics of the TOP10NL object class identified by us, such as "roads are continuous surfaces", "water is flat", "terrain can have height variance within each polygon".

Per object polygon, Lidar points are selected and processed using the 3D modelling constraints of every object class, see Table 1. Ground points have been used for the generation of the classes 'Road', 'Terrain' and 'Water', whereas non-ground points are used to assign Lidar data to 'Building' and 'Forest' polygons.
The surface description within the polygon depends on the object class. Water and road objects are constructed by producing a constrained TIN using the 3D coordinates of the boundary. In terrain polygons, Lidar points are added to allow a more detailed height description within the surface.

Class	Lidar data taken from	3D Representation type / Semantic constraint	Initial height of object points on boundary	Surface description
Water	Ground	Horizontal plane	All object points are set to average height	Determined by triangulation of boundary object points
Roads	Ground	Locally planar	Each object point is determined by height of local fitted plane	Determined by triangulation of boundary object points
Terrain	Ground	May vary locally	Each object point is determined by height of local fitted plane	Lidar points are inserted inside polygon, followed by constrained triangulation
Buildings	Non-ground	Horizontal plane, LoD 1	All object points are set to average height	Determined by triangulation of boundary points
Forest	Non-ground	May vary locally	Each object point is determined by height of local fitted plane	Lidar points are inserted inside polygon, followed by constrained triangulation

Table 1. Class based constraining of processing Lidar points within polygons.

In general, the basis of our approach is a series of point-in-polygon operation, meaning that all Lidar points within a polygon are assigned to that polygon. However, for multiple reasons, some points may not be appropriate for further processing. One reason is a possible planimetric offset between map and Lidar data: the offset causes that object boundaries in TOP10NL do not correspond to the object structure of the Lidar points. In Figure 4 an example shows an offset of more than 2 meters between a bridge boundary in the topographic vector data and the corresponding Lidar points. For a correct reconstruction of the bridge only the Lidar points on top of the bridge should be selected, thus excluding the points at the water surface level.

Theoretically, it could be decided to tolerate a maximum offset between the datasets. However, our experiences show that offsets occur of up to 2 meters, specifically since the 2D data set is acquired (and therefore generalized) at midscale (i.e.
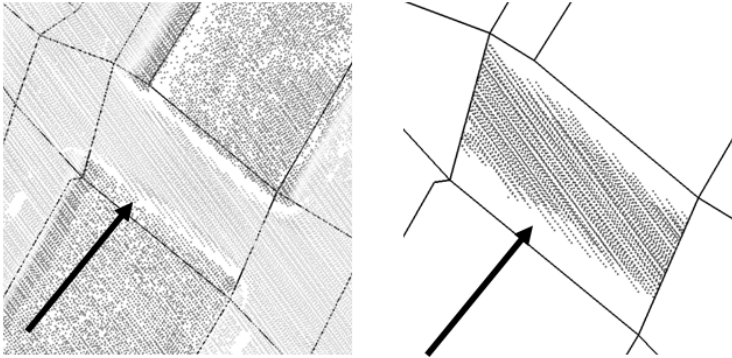
Figure 4. Discrepancy between bridge boundary in the topographic dataset and Lidar data, indicated by black arrow (left). Lidar points for further processing of the bridge polygon (right) are selected for further processing.

1:10,000). Our automatic modelling approach is designed such that it can deal with these inaccuracies. The Lidar data is segmented into locally planar surface patches. Subsequently, the program checks the most frequent segment number in a radius of 5 meters. Those points are assigned to the polygon for further processing and others are excluded. In the example of Figure 4 only the points at the bridge are selected and the points at the water surface are excluded in the 3D generation of the bridge.

The unique ID number of the original topographic object is kept during the reconstruction process. It means that per topographic object, it is known which original Lidar points have been selected and how the further processing was performed.

4.1.2 Including neighborhood relations

The next step in the 3D reconstruction procedure refines the initial heights that are assigned to the polygon boundaries using the 2D neighbor relationships. The final height of a boundary point depends on which height was determined for the neighboring polygon at the same location. Figure 5 shows that the planar partition in the 2D vector map assures that each object point connects to two or more polygons.
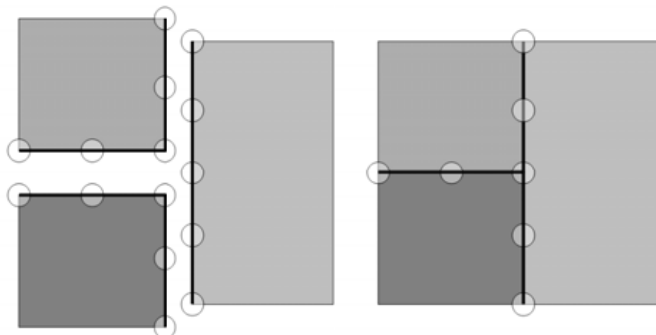

Figure 5. Initial height calculation based on single polygon processing (left). Final height calculation by considering neighbor relationships (right).

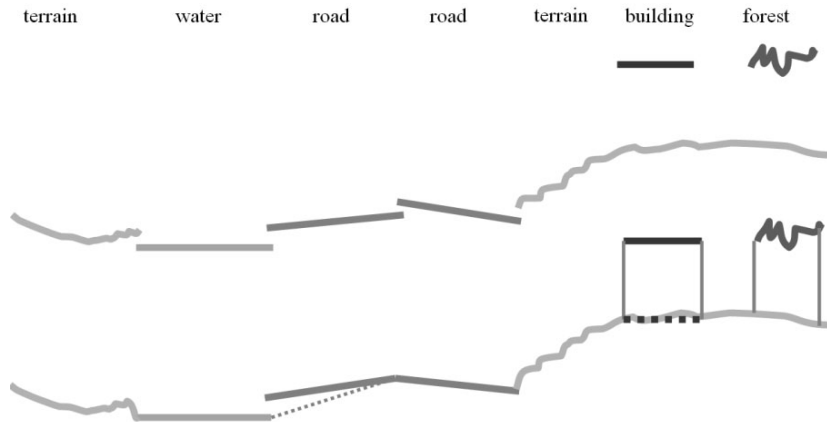terrain water road road terrain building forest

Figure 6. Schematic profile visualizing the initial height (top) and final height (bottom) depending on neighbor relationships from Table 2. Additional polygons are shown as dotted lines.

Depending on the classes of both neighboring object polygons, specific constraints (see Table 2) are applied and the final 3D boundaries are created accordingly, see Figure 6.

Table 2 lists the possible relationships and their constraints. Per object point the classes of the adjacent polygons are identified and heights are adjusted accordingly. For example object points that connect to water polygons will always keep the height of the water polygon. If terrain polygons are adjacent to this water polygon the corresponding boundary of the terrain will be 'pulled' to the water height. Vertical "walls" are added to objects from the classes 'building' and 'forest' (which is a specific type of land use). These "walls" extrude the polygons downwards to the height at the terrain, i.e. at the height of the Digital Terrain Model (DTM).

	Water	**Road**	**Terrain**	**Building**	**Forest**
Water	Both keep own height	Both own height, create additional polygon below road	Take water height	Both keep own height, create wall in-between	Both keep own height, create wall in-between
Road		Average if close in height	Take road height	Both keep own height, create wall in-between	Both keep own height, create wall in-between
Terrain			Take average of both heights	Both keep own height, create wall in-between	Both keep own height, create wall in-between
Building				Both keep own height	Both keep own height
Forest					Both keep own height

Table 2. Modeling constraints based on neighborhood relationships.

The generated "walls" get the class label of the above ground objects, e.g. building or forest. The lowest DTM height that is located below a building is taken as a constant height for the ground height of the building. Consequently, the floors of buildings built on a hillside are approximated. An extra floor polygon is added to the building, to make it a solid block object. These additional polygons are shown as dotted lines in Figure 6.

We have considered generating buildings with roof shapes instead of building blocks, based on large-scale 2D building geometries available in the building register (BAG, 2012) as proposed in (Oude Elberink and Vosselman, 2009b). But experience showed that this is not an appropriate solution. Firstly, because the 2D large-scale building objects of the building register do not fit with TOP10NL data. The geometrical differences between the two data sets is mainly caused by different acquisition methods: TOP10NL is obtained from aerial photographs and applies (little) generalization; while the building objects in the building register are obtained form terrestrial measurements. Another problem for generating the roof shapes is that this cannot be done fully automatically in all cases, which is an important prerequisite for a nationwide dataset. Finally, the high details of the roofs do not fit with a 1:10,000 representation of 3D data.

4.2 Revealing the inaccuracies in the result

To be able to use the 3D data in a correct manner, it is important to provide accuracy measures of the constructed data. Therefore at the end of the 3D generation procedure, the program calculates and analyzes the differences between heights of the original Lidar points and the 3D model (Figure 7), based on (Oude Elberink and Vosselman, 2011). Green Lidar points in Figure 7, right bottom are within 20
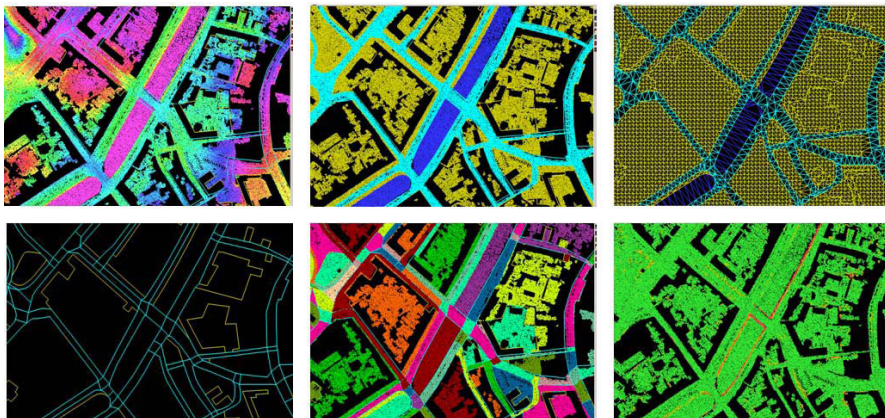

Figure 7. Overview of the complete workflow. Left: input data, Lidar data (top) and topographic data (bottom). Intermediate processing results (middle): Lidar points colored by class label (top) and object (bottom). Results (right): triangulated 3D model colored by class label (top), quality indicator (bottom), Lidar points within 20 cm to the 3D model are colored green; red points are further than 50 cm from the 3D model.

cm to the 3D model, the yellow points are between 20 cm and 50 cm (these hardly existing in this area), points that are further away are red. Any systematic behavior in residuals between the two is an indication that either the two data sets, AHN and TOP10NL, do not match or the assumptions do not hold for that particular object. Main reason for discrepancies is the time difference between production of the TOP10NL vector data and AHN data. To increase the accuracy, the user can select polygons with a certain percentage of Lidar points that show large residual values. If necessary, these polygons can be adjusted manually to obtain higher accurate data.

4.3. Reconstructing valid 3D geometries

Our methodology to reconstruct the 3D TOP10NL dataset ensures that the 3D volumetric geometries generated for buildings and forests are *geometrically* valid. While different definitions of a valid 3D object are used in different disciplines, we focus on the definition given in the ISO 19107 standards (ISO, 2003) and implemented with Geography Markup Language (GML; OGC, 2007). A GML Solid is defined as follows: "The extent of a solid is defined by the boundary surfaces as specified in ISO 19107:2003. gml:exterior specifies the outer boundary, gml:interior the inner boundary of the solid" (OGC, 2007). In the case of the 3D TOP10NL dataset, no inner boundaries will be created (since extrusion is used), but a solid will be represented by its boundary surfaces. The criteria for a valid 3D geometry are the following: (1) a solid should be 'watertight', i.e. there should be no gaps in its boundary; (2) it must be simple: no self-intersection of the surfaces is allowed; (3) each surface should be planar; (4) the normal of each boundary surface should point 'outwards'. These rules have been taken into account when developing the reconstruction algorithm, and the resulting solids are valid.

Ensuring valid solids has many advantages. First, it facilitates their use by others and their processing with other tools (such as the DataBase Management System Oracle Spatial 11g) as users will not face problems when importing them and converting them to other formats and representations. A tool to convert CityGML datasets to Keyhole Markup Language (KML) could for instance not function properly if the surfaces of the buildings are not planar. Second, it permits users to use the 3D model for spatial analysis. While at this moment 3D models are mostly used only for visualisation, we believe that in the near future they will be used for analysis in different domains. CityGML already has Application Domain Extensions for noise modelling, flood simulation and for utility networks (OGC, 2012b). Other examples of 3D analyses are disaster management (Kolbe et al., 2008), urban planning (Yasumoto et al., 2011) and 3D cadastre (Stoter and van Oosterom, 2005). That is also why we aim at an object-based 3D model and not at a relief description of the terrain possibly overlaid with a topographic map.

It should be noticed that in our current implementation each extruded building-footprint becomes a valid solid, but the buildings as a whole are not *topologically consistent*. Indeed, two adjacent buildings will have duplicated surfaces that might not have their vertices at the same location. The solution to that problem is to con-
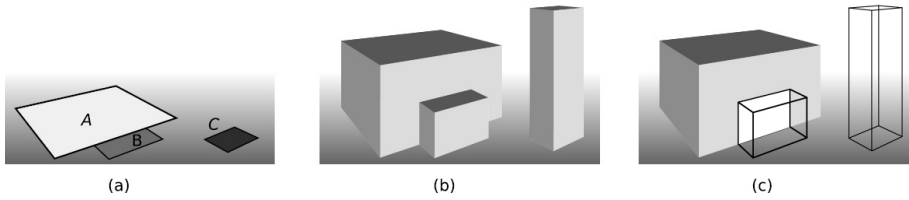
Figure 8. (a) Polygons in the plane. (b) Polyhedra obtained by extrusion of the polygons. (c) To be topologically consistent the front polygon of the polyhedron as extrusion of A should be modelled with two polygons. (Figure from Ledoux and Meijers, 2011).

sider topological relations in 2D when extruding (see Figure 8, Ledoux and Meijers, 2011), but we have not included that in the implementation yet.

4.4 Nationwide processing

The 2D version of TOP10NL is a seamless product, and that is also the goal for the 3D version. The developed procedure assigns height values to each polygon, also taking into account the information from the neighboring polygons. To make the procedure that uses the very large AHN point dataset possible and efficient, at this moment we resort to a simple solution: we split the input datasets into tiles of about 1kmX1km, and each tile is processed separately. The AHN dataset is already tiled in that way (it is stored this way), and we perform the tiling on the vector map of TOP10NL (notice that we are not splitting polygons, but we simply perform a selection of the polygons intersecting the 1kmX1km tile).

4.5 Special cases

Applying the procedure described in Section 4.1 to the different test areas identified specific situations that needed to be solved. These situations including bridge buildings over roads, interchanges, lack of laser points and height variations within a building block, are discussed in detail in Oude Elberink et al (2013).

5. Experiments and results

Three areas from different regions have been processed to refine and test the automatic generation of a 3D dataset of that area. In the test, datasets were copied to disk and the regions of interest were cropped. In Figure 9 part of an urban scene is
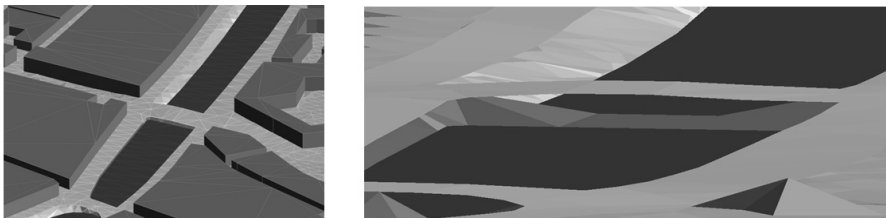

Figure 9. 3D Model of an urban scene (left), including real 3D objects such as bridges (right).
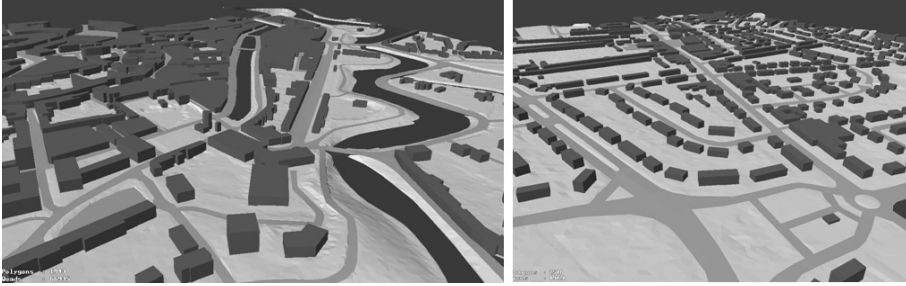
Figure 10. 3DTOP10NL of Middelburg (left) and Amersfoort (right).

presented to show the ability of the program to correctly reconstruct bridges, even in the case of a discrepancy between topographic data and Lidar data (as shown in Figure 4).

Overview of part of the cities of Middelburg and Amersfoort are shown in Figure 10. As the processing time depends on the number of polygons, number of neighbor relationships and complexity of the scene, it is of interest to analyze the differences in processing time for each step per test area.

Processing has been done on a standard desktop computer, containing an Intel Core duo CPU, running at 3 GHz and 3GB of RAM memory. Table 3 shows that most time is spent on fusing the datasets, i.e. assigning polygon information to Lidar points and vice versa, and on the 3D boundary generation of ground objects. The latter step includes the checking of the height of the neighboring polygons, which is a time consuming step.

	Size of datasets (number of polygons, number of Lidar points)	Fusing topo-graphic data and Lidar (minutes)	3D boundary generation (minutes)	3D surface reconstruc-tion (minutes)	Total processing time (in minutes), and minutes per object
Amersfoort (ground)	659, 5.3 Million	50	131	7	188, 0.29 per object
Amersfoort (non ground)	2707, 5.5 Million	70	11	1	82, 0.03 per object
Middelburg (ground)	814, 4.8 Million	79	132	4	215, 0.26 per object
Middelburg (non ground)	362, 2.9 Million (reduced by factor 3)	59	3	1	63, 0.17 per object
The Hague (ground)	670, 6.9 Million	263	117	6	386, 0.57 per object
The Hague (non ground)	941, 2.5 Million (reduced by factor 3)	34	2	1	37, (0.04 per object)

Table 3. Performance in terms of processing time per step.

To decrease processing time, we implemented a Lidar data reduction by factor 3 for non-ground objects, e.g. for producing the building blocks. Our argument is that for producing building blocks (i.e. one height for each building) it is not necessary to keep a point density of 10 points per square meter. Our experiences confirm this assumption. Further increase of processing performance is work in progress.

6. Conclusion and future work

This paper presents the work carried out by the University of Twente, the Netherlands Kadaster and the Delft University of Technology to produce a nationwide 3D city and landscape model at midscale (approximately 1:10,000) based on TOP10NL vector data and high resolution Lidar data. The methodology is described as well as the choices that were made.

Regarding the specifications of the resulting 3D dataset (i.e. what should be its content?), it was decided that the 3D dataset contains a 2.5D representation of the terrain-, the water- and the road-objects, and a block-representation for the buildings (volumetric objects). Complex interchanges such as viaducts and bridges are represented by a combination of several 2.5D representations of the particular infrastructure objects.

Based on the test results, the Kadaster has decided that it is feasible to produce a nationwide 3D city and landscape model that fulfills the specifications that were defined as part of this study. At the same time, the results of different projects have shown that a nationwide 3D dataset would foster different applications in 3D. The fact that TOP10NL data is, since the 1st of January 2012, open and freely available makes the urge to make it also available in 3D even bigger.

Therefore in a follow up research project the results for the three test areas are being applied to other areas to obtain a data set for the whole country. Specific attention is being paid to make the 3D reconstruction procedure efficient as well as to maintain and disseminate the 3D data. To get feedback on the 3D product early in the process, the current results have been made available for the wide public. Future research has been proposed and granted to enhance the quality of automatically generated 3D building models with roof shapes. As the 2D largescale building objects (available for the whole country) are open data, the highly detailed 3D building data could be delivered as an additional product.

Another challenge is the management and the processing of the huge Lidar data set, which is estimated to contain around 200 billions elevation points. At this moment simple text files are managed, and that does not help applications such as ours to scale to the whole country. One solution is to store all the data in a database management system: Oracle Spatial 11g has support for point clouds (Finnegan and Smith, 2010) and we plan in the near future to use it (or an open-source alternative, if available).

For further research on automatic interpretation of Lidar data, it is of high interest to store and analyze this massive fusion process of 2D data and Lidar data. This can be used for obtaining knowledge on behavior of Lidar data in relation to specific classes, objects or complete regions, such as the differences between relief structure of terrain polygons in the west (clay area) and the east (sandy areas) of the Netherlands. This knowledge could potentially improve the 3D reconstruction process, as it provides statistical input for optimizing parameter settings during the selection and further processing of Lidar data into 3D information.

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