

CONSTRUCTION OF THE 3DTOP10

INTEGRATION OF COUNTRYWIDE PLANIMETRIC DATA AND LASER ALTIMETRY DATA TO SUPPORT 3D-VISUALISATION AND ANALYSES

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ABSTRACT

This paper describes a method to integrate two of the main geo-information products of the Netherlands, the TOP10vector (topography) and the AHN (height), into one multipurpose description of the road and railway infrastructure. By paying special attention to the modelling of bridges and viaducts it is possible to derive both a 2D presentation (like an ordinary map) and a high-end 3D-visualisation from this so-called 3DTOP10.

Special attention is given to the methods used to integrate the infrastructural objects into a ground-level constrained TIN-model. The objects in the TOP10vector are adjusted for a 2½D (TIN) representation. The overlapping bridges and viaducts are modelled in a separate top-level constrained TIN. The height-value of the vertices of these ground level and top-level TINs are computed from the overwhelming amount of laseraltimetry height-points, as available in the AHN. There exist some limitations and restrictions, which make fine-tuning on special cases still necessary. The automatic construction performed on large data sets gives satisfying results. With this method of integrating the data sets it is possible to model all infrastructure of the Netherlands in a dual-layered TIN datastructure.

1 INTRODUCTION

The Dutch topographic digital data-files are built up by the Topographical Service (TDN) on the basis of aerial photographs and land surveys. These files are internally used to produce a wide range of topographic maps (from TOP10vector - scale 1:10,000, to TOP250vector - scale 1:250,000) and other special map products. Although these files can be used in GIS environments, the main purpose is still to produce planer maps. The data structure is therefore completely two-dimensional. Special cases, like viaducts, bridges and other crossings are dealt with in the attribute coding (whether or not visible from above, high-rise or low-rise buildings) and specific cartographic symbols are used for dikes, slopes and inclines. For many GIS-applications, like transeiver positioning for telecommunication or the development of new road or railway infrastructure this global height description of the TOP10vector is insufficient. The planimetric precision is good enough, but these applications require a more complete 3D-representation of topographical objects.

One way to achieve this is to use the original height data, which is input for the 'Actual Height model of the Netherlands'. This so-called AHN is most used in the format of a regular DEM with a cell-size of 5 meter, derived (interpolated) from the 62.500 points per square kilometre (average) measured with laseraltimetry. Geodan Geodesie is one of the main contractors for this kind of measurements in the Netherlands. Laseraltimetry is a 'blind' surveying technique as a result of which each height point is unclassified. The height precision depends on the reflection of the surface. For 'hard topography', like roads, this precision is better than 15 cm.

Different methods of combining laseraltimetry data with the TOP10vector are already in use. One of them assigns one characteristic height-value to each TOP10vector polygon. This height-value can be the maximum, minimum or average of the overlapping AHN-points. All objects become blocks with different heights. Especially for roads this gives

unsatisfying results, because there will be thresholds from one road to the other. A second method of combining the two data sets is to drape the TOP10vector over the AHN-DEM. This kind of combination is only practical for visualisation-purposes, and won't really give an integrated result.

Concentrating on the road and railway infrastructure, this paper presents methods in which the laseraltimetry data can be integrated with the TOP10vector. In this way it becomes possible to create an integral 3D model of the infrastructure of the Netherlands, the so-called 3DTOP10. In fact this model will be structured as two 2½D surfaces, one for the 'ground-surface' and one for the parts which will be included to model the bridges and viaducts in a proper way. The data structure used is a Triangular Irregular Network (TIN). This structure makes it possible to derive both a 2D presentation and a full 3D presentation. In this way the 3DTOP10 can contribute to 'ordinary' map-making as well as to high-end 3D-visualisations and calculations.

For this purpose the rail- and road-objects derived from the in total 675 TOP10vec data-files (which cover 6.25 km x 10 km each) has to be combined with the spatial overlapping laseraltimetry points. The 3DTOP10 will be constructed by means of these two data sets without adding additional surveying data. To realise this, the following problems have been tackled:

- Classification of the 'blind' measured laser points based on the objects in the TOP10vector;
- 3D-definition and reconstruction of objects in the TOP10vector;
- Adjustment of the data structure of the TOP10vector to make it suitable for 2½D representation;
- Inclusion of the 3D objects, like viaducts, as a separate 2½D surface.

This paper will pay special attention to the selected methods and techniques for the construction of the 3DTOP10.

2 DATASETS USED

Objective of this research is the integration of two existing data sets. The two data sets have their own right of existence. They were not made for the purpose of combining and are therefore also not optimised for this. Available features and attributes in the data have to be used for an optimal integration. First the topographic data set is discussed and after that the height data set.

2.1 TOP10vector

The producer of the TOP10vector, TDN, has been making the map series 1:10,000 since 1952. An example of this map is given in figure 1. The monochrome map forms also the basis for the full colour map 1:25,000. In 1990, it was decided to switch from analogue map production to digital database production. The actual production of the database 1:10,000 started in 1991. This new product is called TOP10vector. TOP10vector is a digital topographic database in vector-format, which can be used in the scale-range 1:5,000 - 1:25,000. Analogue maps at scales 1:10,000 and 1:25,000 are derived from the database. TOP10vec is currently maintained in a four-year cycle.

In the early nineties, it was difficult to set up the specifications for a product like TOP10vector. User-requirements could not be formulated because experienced digital data-users did not exist. Therefore, three main starting points were formulated:

- TOP10vector should be kept simple in order to be useful for as many users as possible;
- TOP10vector should be compatible with as many hard- and software-systems as possible, especially GIS;
- The maps 1:10,000 and 1:25,000 should be produced directly from TOP10vector.

As a result, TOP10vector contains all map features that appear on the maps 1:10,000 and 1:25,000. To comply with the second starting point, it was decided to structure the vector data in a topological way, which facilitates the use of the data in GIS. It was also decided to produce TOP10vector in a CAD-environment, in this case Microstation-software running on Intergraph-workstations, because the geometrical objects and their attributes can be produced efficiently in

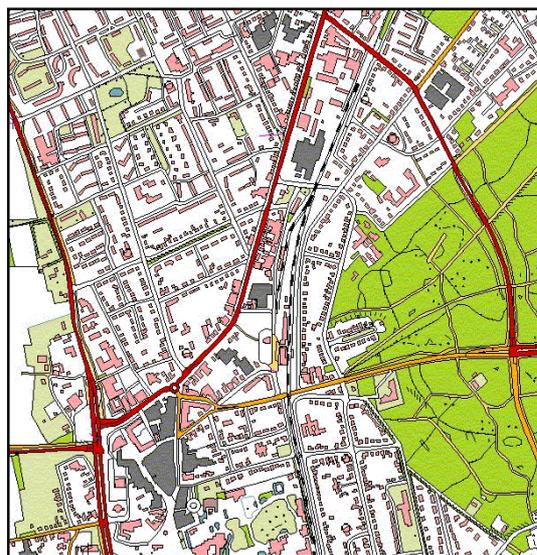


Figure 1. Example of a TOP10vector map

this environment. No relational attribute database would be used. This decision needs more clarification, because some other national mapping agencies have decided to produce their databases in a GIS-environment. The philosophy behind TDN's decision is that all kinds of GIS, containing user-specific objects and attributes, have to be supported. Therefore, data interchange is crucial and not the data production-environment. Secondly, TDN itself does not have the intention at this moment to query or analyse its data. TDN focuses on map production, which does not require a GIS.

Although TOP10vector is produced in a CAD-environment, a few attributes can be stored, mainly to describe the features in the database. TOP10vector contains coded points, lines and areas. Multiple coding is applied in order to store the necessary attributes. These attributes are stored within the applicable geometric features. The data is structured in a topological way: all areas are closed and left/right information is added as attribute data.

One TOP10vector-dataset covers an area of 62.5 km². The term data set is preferred over database and is defined as the collection of all topographic files covering one map sheet 1:10,000. A data set consists of the following files: BASE-file (BAS) - Coded point and line features, topologically structured (roadsides, ditches), plus centroids, representing the area code (forest, grassland); SYMBOLS-file (SYM) - Point features together with their cartographic representation, like post-office, bridge; PATTERNING-file (PAT) - Line features together with their cartographic representation, like row of trees, height differences; BUILDINGS-file (BLD) - Closed polygons representing individual buildings; and the AREA-file (AREA) - Closed polygons, computed from the BASE-file. The AREA-file is fully derived from the BAS-file. Through the centroids and their bounding lines, areas are built which are stored as closed polygons with the area codes copied from the centroids.

TOP10vector is a 2D-dataset. All co-ordinates are stored as (x, y)-pairs. TOP10vector does not contain contour lines. Only two types of height information are given:

- The sequence of piling of topographic networks at crossings: the features underneath are coded as such, which assures the network topology of the feature type (roads, railroads, and water). For example a bridge has two codes: one for the road type and one for the water underneath.
- Cartographic line symbols to visualise height differences in the terrain: hatches are automatically generated from line codes. The line codes may be attached to existing topographic lines (for example a slope at a road edge) or as an independent feature (for example a slope in the field). The slopes are subdivided in a few categories, which are all visualised in a different way.

TOP10vector is currently used in several 2D GIS-applications. However, some applications really need 3D-data, for example landscape architecture, water management and planning of telecommunication networks. TOP10vector has therefore to be extended with the third dimension.

2.2 AHN

The AHN is measured with the use of airborne laseraltimetry. Airborne laseraltimetry is an appropriate technique to measure the height of a huge area in a relatively short amount of time. Geodan Geodesie was the first company in the Netherlands that applied laserscanning technology on an operational basis as early as 1994. Since then a number of projects in the Netherlands and abroad has been performed for applications as diverse as water management, coastal zone management, 3D city modelling for telecommunication applications, forestry and many others. Geodan Geodesie is also one of the contractors for the AHN project. From an airplane a resolution of 1 point/m² is possible and with a helicopter a resolution up to 5 points/m² can be established. Geodan Geodesie does not only acquire and process the laseraltimetry data, but software development and consultancy aimed at usage of the data in a GIS environment and visualization of the data are important activities as well. This reaches from derived height products as contour lines to the creation of complete visual reality environments. Having a countrywide Digital Elevation Model as AHN available, the integration of this data within models opens up new applications. An important application for the Netherlands is the integration of 3D topographical data within waterflow models to assist water managers in solving the problems they are faced with.

The Survey Department of the Ministry of Public Works, Transportation and Water Management has contracted different private companies, Geodan Geodesie among others, in order to generate the AHN with the use of airborne laseraltimetry. The AHN is a countrywide height model with a density of at least 1 point per 16 m². For the accuracy of the topography a standard deviation of 15 cm maximum with an average error of 5 cm maximum is applied.

Three height products are derived from the AHN. A basic file, standard derived products and special height products. The special height products are e.g. special file-formats or combinations with other geographical data. Standard derived products are regular DEMs with a cell-size of 5 meter, derived (interpolated) from the laser measurements. From this DEM with a cell-size of 5 meter a DEM with a cell-size of 25 meter is derived. The basic data file is an ASCII-file with

all the measurements. For all measurements a x, y and z- co-ordinate is stored. There are two basic files, one with all the measurement on ground surface and one with all other points (e.g. vegetation, buildings). In built-up areas not all vegetation and buildings points are left out of the ground surface-file. For the integration of the AHN with the TOP10vector the non-interpolated basic files are used.

3 REALISATION

Before integrating the two data sets to a 3-dimensional topographic model, the TOP10vector has to be adjusted to make it suitable for triangulation. To do this, first of all, all the infrastructural works have to be put together in one layer. The railways are line-objects and have to be converted to polygons. Also the slope patterning in the TOP10vector, which are just graphics, are modelled as slope polygons and added to the layer.

If there is one layer with all required objects, that layer has to be made suitable to construct a 3D model. Because most GIS-software can handle only 2½D topographic data and no real 3D models, the data has to be modelled as two 2½D data sets, a 'ground surface' and a 'top surface' for bridges, flyovers and viaducts. Combined, those two data sets do not make a real 3D model, but they can handle two different objects above each other like viaducts. Visually it will look like a 3D model. To make this possible the infrastructure layer has to be adjusted where there are viaducts. The infrastructure that crosses the other will be put in a 'parallel' layer. This layer will have exactly the same structure as the other one, but will only contain the polygons that, at viaducts, crosses other polygons.

After the TOP10vector data is prepared for 3D-modelling, it is ready for calculating and assigning height to the objects.

3.1 Integrating Infrastructure

As mentioned before, the TOP10vector is a data set in which minor and major roads are represented as polygons and railways as lines. For each road-object there is a separate polygon, which, at viaducts, results in two identical polygons on top of each other. They belong to different roads. The railways have to be put together with the roads in one layer and they have to have the same structure as the roads. As a result of this they have to be converted into polygons. Where they go underneath or over a road or other railway, the layer has to consist of two identical polygons with different attributes. (Figure 2)

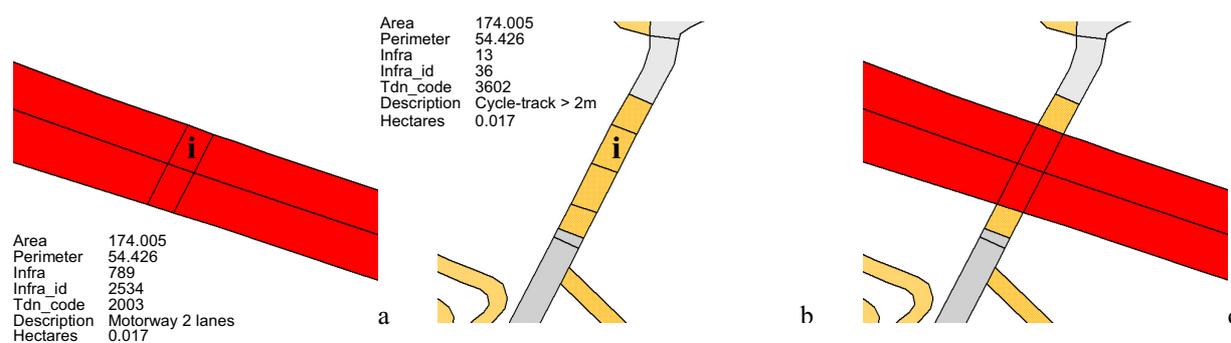


Figure 2. A motorway (a) is crossing a cycle-track (b). For each object there is a separate polygon with attributes. In the TOP10vector (c) the polygons overlap each other.

To make polygons of the railways, the most intuitive approach is to just buffer the lines. The polygon object should have the same attributes as the line object, so each line should be buffered separately. The problem with buffering each line separately is that the polygon-borders from following lines do not automatically match. Therefore all lines are first merged to one line object and then that line is buffered. In this way one polygon is created that represents the railways. Next this polygon is split into individual parts with the attributes of each particular line-object. In case of viaducts, also the road polygons have to be adjusted so that there are no polygons intersecting with other polygons (at viaducts the overlapping polygons are exactly the same).

The patterning in the TOP10vector is applied to create an easy-to-read and attractive map. From this patterning a slope object will be made that is tangent to road and railway objects. Slope-polygons are constructed by using the patterning itself and lines in the TOP10vector that are present where there is slope patterning. From all the patterning the points are calculated that are 'on the other side' from the slope (in most cases the lower side). These points are connected to the slope-line that is present. To make a 'clean' polygon all the points have to be in a particular order before the polygon is created. The first patterning-point that is connected to the slope-line is the point with the shortest distance to

the last vertex of the slope-line (Figure 3). The next vertex in the slope-polygon is the patterning point that is nearest to a certain position. This position is the projection on the slope-line of the point between the last added vertex and a predicted position of the new vertex. The reason for the use of this predicted point is to avoid the slope-polygon to cut off a sharp turn in the road. When there are no patterning-points left, the last vertex is connected to the first vertex of the slope-line.

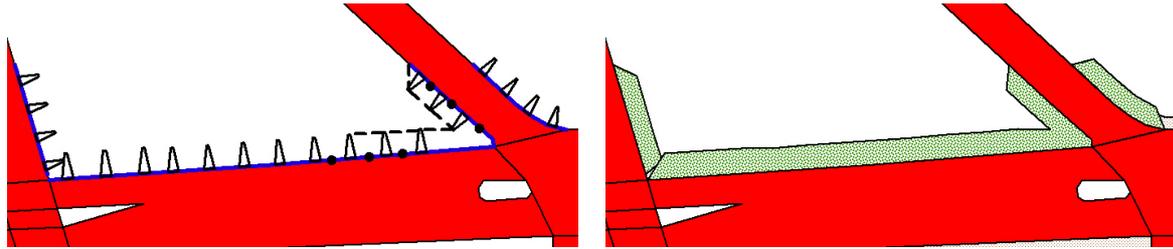


Figure 3. Building of the slope-polygons. a) the dots are the points from where the next vertices are selected b) the new slope-polygons are added

When there is no slope a verge of the road is constructed. To construct verge, the road is buffered. The Douglas-Peucker algorithm simplifies this buffer before it is added to the layer as an object.

3.2 Adjusting Viaducts

To make a 2½D model, it is not allowed to have two polygons with the same planimetric co-ordinates and a different height value. Simply said, it is not possible to have 2 z-values at one x, y co-ordinate. This means that, at viaducts, the object underneath (ground-object) has to be separated from the object above (top-object). Therefore the choice has been made to have one basis surface with all data, except the top of viaducts. The second surface will only consist of those tops. These surfaces are made from two different layers.

The TOP10vector uses codes to identify objects. These codes have four digits; the first three are for the identification of the object and a fourth digit gives extra information. A '2' as fourth digit means that the object cannot be seen from above, which, of course, is the case for the objects underneath the viaduct. All the visible objects, coded '3', belonging to a viaduct should have completely the same polygons as the invisible ones. Using this code makes it possible to select all the top-objects of the viaducts and move them to a new layer.

With no intersecting polygons in the layer, it still is inappropriate for 2½D surface-modelling. The corners of the viaducts have vertices that belong to both the top-road and to the road on ground level (Figure 4). These roads have different heights and having two heights at one point is not possible. A solution can be found by enlarging the top-object in the second layer and by reducing the road over the viaduct (over road) with the same amount so that this road is not tangent to the road on ground level.

Before this can be realised, the top-road (road that is on top of the viaduct) has to be determined. In the identification of the objects in the TOP10vector one cannot determine if a road or a railway, tangent to a viaduct, is a top-road or the road underneath the viaduct (ground road). If both objects in the viaduct have different identification (the first three digits are different), one can assume that the road with the same identification, as the invisible object in the viaduct, is the ground road. This is the case in figure 2, where the invisible object is the cycle-track and the top-object is the motorway. The other road should have the same identification as the visible viaduct-object. In case of a road crossing of the same type of object it is not possible to determine which road is above the other using only the TOP10vector polygon-layer. From the boundary layer of the TOP10vector it is possible to derive the top- and ground road

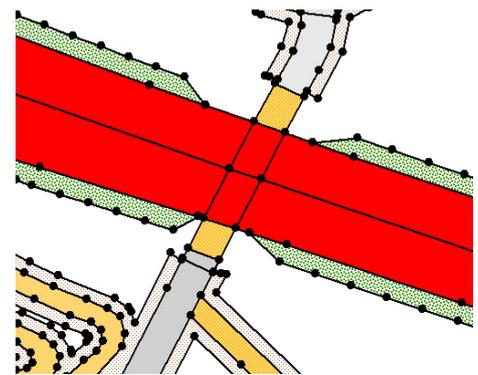


Figure 4. Vertices of the polygons

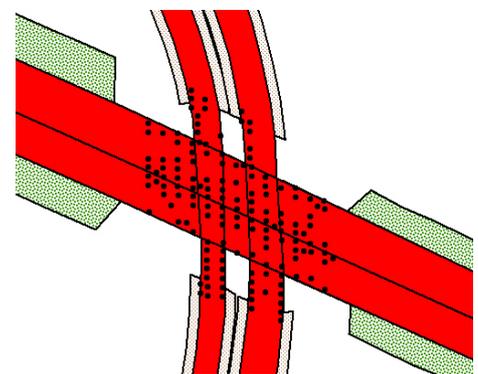


Figure 5. Determining the over road with use of laser points. Points 'on' and near the object are used for calculating height.

at viaducts on the condition that a new layer is brought in. It can also be determined using the height measurements from the AHN. From all points that have x and y co-ordinates inside the viaduct object, a height for the over road can be calculated. For all the adjacent objects an approximate height can be calculated by using laser points 'on' the object close to the viaduct (Figure 5). The objects that have a calculated height that is a few meters lower than the height calculated for the viaducts are assumed to be under roads (roads under the viaduct).

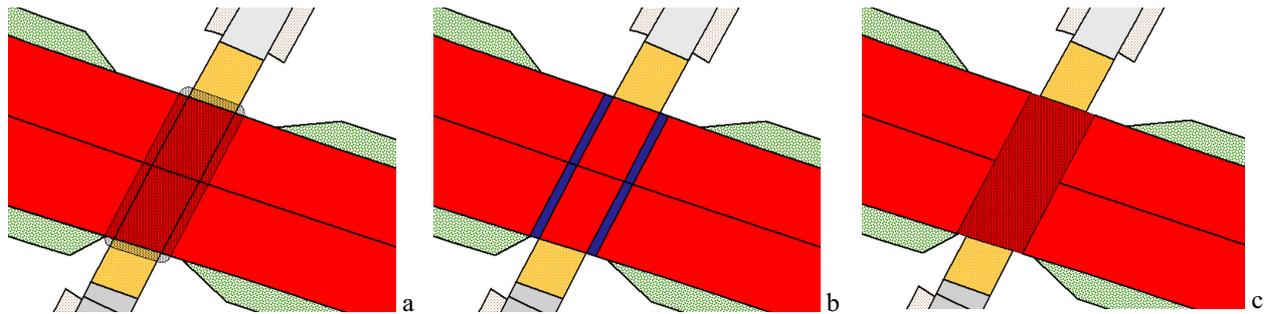


Figure 6. Adjustment of viaducts. a) buffer of the viaduct polygons ; b) intersection polygons that act as wall on the side of the viaduct; c) increased top-object

Now the over road and under road are distinct, the layer is fit for adjustment of the viaducts. To do this, first the viaduct polygon is buffered (Figure 6). For each over road the intersection with the buffer is made. This intersection polygon is subtracted from the over road and added to the top-object. The intersection polygon is also added to the basic layer to act as wall on the side of the viaduct.

All tangents of object are on the same height level now and consequently must have exactly the same height.

3.3 Assigning height

The entire infrastructure is now suitable for an easy height assignment. There is a basic layer for the 'ground surface' and one for modelling the viaducts, bridges and flyovers. There are no intersecting objects and all connecting polygons have no sudden height change at their boundary.

A planimetric polygon is build from a 2D vertices list. To make the objects 3D all those vertices should have a z coordinate. For calculating this height, use is made of the ground points of the AHN. For each vertice the points are selected that are within a distance of 15 meters of that particular vertice. From these points again a selection is made. Only the points that are within the objects the vertice belongs to are selected. From these points, the heighest and lowest values not included, an average is calculated (Figure 7). This average is assigned to the vertice as z-value. In case there are not enough laser points selected, first the distance of 15 meters has to be increased. In case there are still not enough points to calculate a representative height, also the 'vegetation' points are used. Especially a lot of laser points near viaducts are classified as 'vegetation'. According to the product definition of the AHN points on the viaduct itself belong to the 'vegetation'. For the viaducts, the ground surface gets its height from the calculated vertices of the roads connected to the object. In the

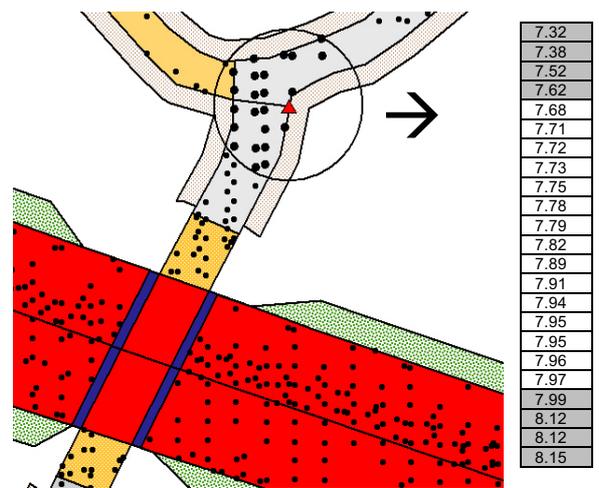


Figure 7. Calculating the height of polygon vertices with the laser points, z average = 7.82m

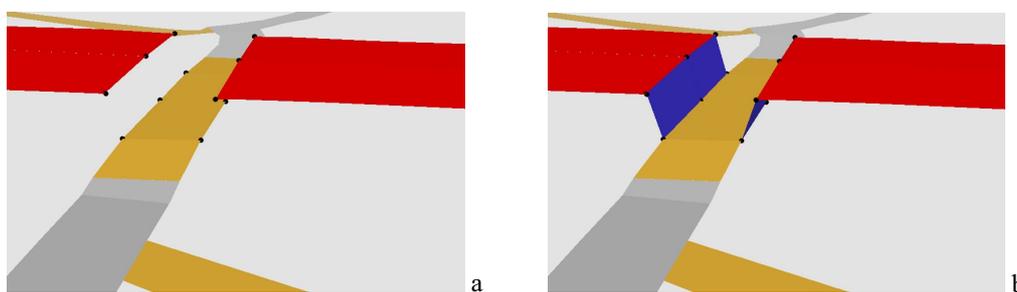


Figure 8. a) 2 1/2 D polygons of road object, b) Viaductwalls are fitted between objects

end all infrastructural objects are converted to 2½D polygons and the viaduct walls are fitted between the objects. (Figure 8). All the vertices of the walls have common vertices in roads and viaducts that are already calculated.

For converting the slope-objects and the verge, the calculated vertices are needed. The side of the slope-object touching the road has got the same vertices as the road. Consequently also the 3D vertices have to be the same. For the other side of the slope the height is calculated with the ‘ground’ laser points outside the slope (Figure 9). The verge has also one half of the vertices in common with the roads. The height assigned to the other half is the height of the nearest road vertex. This implies that the verges have approximately the same height as the road it is parallel to.

One of the 2½D surface, the ‘ground surface’, is finished. The second surface only consists of the top-objects of viaducts. These objects have vertices that connect to the over roads. The height of these vertices of course should be the same as the vertices of the tangent with the over road, so that the object exactly connects to the first surface without difference in height (Figure 10b).

Two 2½D surfaces are finished now and ready for a Constraint Delaunay Triangulation. The constraint is that all the boundaries of the polygons in the surfaces should be treated as hard breaklines and should keep the height assigned by the vertices that build the boundary.

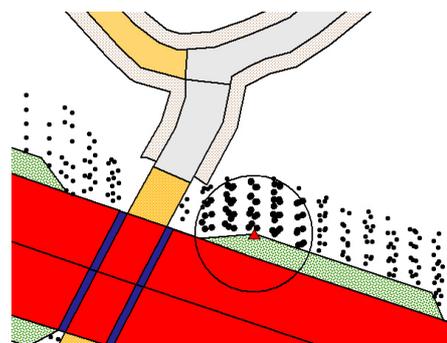


Figure 9. Calculating height of the slope-object

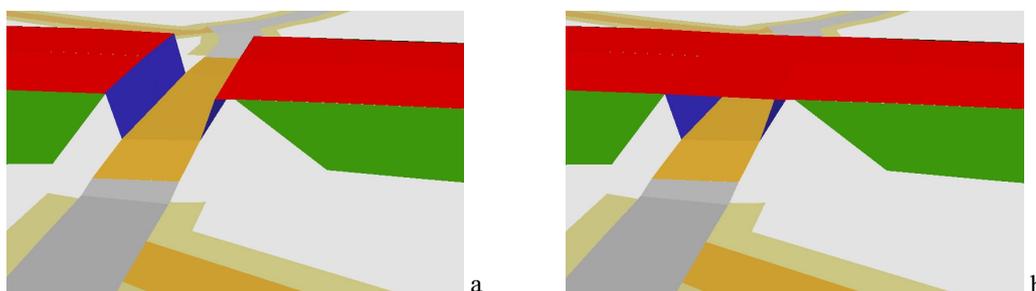


Figure 10. a) All 2½ D polygons of the groundsurface b) The ground- and topsurface in one view

3.4 Limitations and restrictions

There are still some imperfections in the algorithms but they can all be solved.

A consequence of the way height is calculated (taking the average of more laseraltimetry measurements) is that all extreme points on a road are less extreme. So on a top of a viaduct the assigned height is a few centimetres lower than the actual height.

Because not all infrastructure data in the TOP10vector is in the same layer, some problems arise from integrating the layers into one. Sometimes the height-information from the AHN indicates that both infrastructural-objects are not on the same level, while the TOP10vector indicates they are. To prevent these inconsistencies, which lead to non-realistic situations in the 3D model, the objects from different layers do not connect to each other in case of an uncertain situation.

Deriving the top- and ground road from the height measurements from the AHN does not work for 100%. In some very small viaducts (e.g. crossing of two cycle-tracks) there are not always enough representative measurements. To make this classification work at all viaducts it is recommended to use also the TOP10vectorboundary-layer.

Sometimes service roads are not on the same level as the road. Because the service and major road in TOP10vector are modelled as two connected polygons, they are, in the 3D model, also connected in height. This causes the road to slope towards the service road. Narrowing the service road and creating a side trip between can be a solution for this. By narrowing this road the two roads do not connect anymore, so they both can have their own height.

3.5 Implementation

The complete realisation in its whole is done in Avenue scripts of ESRI's ArcView, with the extension 3D-Analyst. This makes it possible to store a z-co-ordinate for every vertice used to define a spatial feature. With this 3D geometry representation the objects are 3D polygons. These 3D polygons are input for the constrained Delaunay Triangulation. Visualisation is done in the 3D-scene viewer of ArcView.

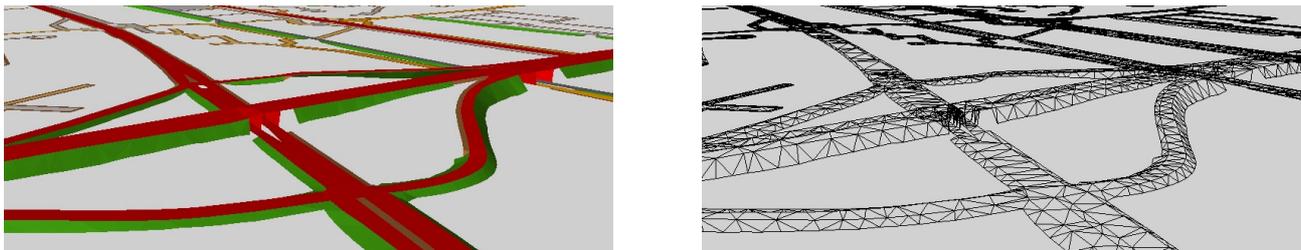


Figure 11. Full rendered example of viaduct near Nijmegen and constructed dual-layered TIN

4 CONCLUSIONS

The approach as described in this paper to integrate the TOP10vector (topography) and the AHN (height) into an integrated, multipurpose, 2½D structure is straightforward and gives very promising results. The implementation has focussed on infrastructural objects like road and railways. Special attention is given to the methods used to integrate these infrastructural objects into a ground-level constrained TIN-model. The overlapping bridges and viaducts are stored in a separate top-level TIN. The height-values of the TIN-vertices are calculated out of a selected set of the AHN-laseraltimetry height-points. The resulting 3DTOP10 is a dual-layered TIN that gives a smooth representative surface of the infrastructure.

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