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Article

# Towards a National 3D Spatial Data Infrastructure: Case of The Netherlands

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**Keywords**: national 3D standard, 3D GIS, 3D SDI, CityGML

**Summary:** This paper presents a research project in The Netherlands in which a large number of stakeholders collaborated on a 3D test bed, use cases and a test area to push ahead 3D developments and applications in The Netherlands. The pilot has realised a proof of concept for a 3D Spatial Data Infrastructure that addresses issues ranging from 3D data acquisition, definition of a 3D standard, maintenance of 3D data and use of the 3D data in specific applications. An important result is the 3D standard NL, compatible with international (i. e. CityGML) and national standards on 2D and 3D geo-information. The major contribution of this research is that the main building blocks of a 3D SDI (needs, data, test bed and standards) are studied in coherence to ultimately realise a shared approach to 3D for a whole country.

**Zusammenfassung:** *Auf dem Weg zu einer 3D-Geodateninfrastruktur: Der Niederländische Ansatz.* Dieser Artikel stellt ein Forschungsprojekt aus den Niederlanden vor, bei dem sich eine große Zahl von interessierten Gruppen zusammengefunden hat, um über ein 3D-Testbed, viele Anwendungsfälle und ein gemeinsames Testgebiet die Untersuchungen zu 3D-Geodaten und den darauf aufbauenden Anwendungen voranzutreiben. Das Projekt hat die Machbarkeit einer 3D-Geodateninfrastruktur nachgewiesen und dabei die 3D-Datenerfassung, die Definition von 3D Normen und Standards, Fortführung von 3D-Daten und Nutzung von 3D-Daten in unterschiedlichen Anwendungen untersucht. Ein wichtiges Ergebnis war die 3D-Norm-NL, die auf internationalen, d. h. konkret CityGML, und nationalen Normen und Standards für die 2D- und 3D-Geoinformation aufbaut. Der überragende Beitrag des Forschungsprojekts ist aber die gleichzeitige Analyse der wichtigsten Bausteine einer 3D Geodateninfrastruktur, nämlich Anforderungen, Datengrundlage, Testbed sowie Normen und Standards, um auf dieser Grundlage später die 3D-Geodaten für einen ganzen Staat aufzubauen.

## 1 Introduction

In the past ten years technologies for creating and managing 3D geo-information have matured while costs of generating 3D geo-information have significantly been reduced. Yet many (governmental) organisations hesitate to introduce 3D into their everyday processes. This is partly because there is no common approach for 3D geo-information and partly because knowledge of 3D technologies is still very scarce and not easily accessible to newcomers. Much relevant knowledge is only available at data providers and software vendors level which make it difficult to get an independent advice. On the other hand, the demand is not always clear which makes it hard for data providers and software vendors to offer demand-oriented products and services.

Despite the slow progress of 3D in practice, it is clear that 3D applications are important and will become even more important in the near future. The world is 3D and consequently a 3D approach has better potentials for managing and planning public spaces (for example


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underground and aboveground data can be integrated). Also a 3D approach allows better environmental predictions such as flood-, air- and noise-simulations (see Stoter et al. 2008). Therefore, the Kadaster (Dutch national cadastre and mapping agency), Geonovum (the National Spatial Data Infrastructure executive committee in The Netherlands which develops and manages the geo-standards), the Netherlands Geodetic Commission (initiates fundamental and strategic research in geodesy and geo-information in The Netherlands) and the Dutch Ministry of Infrastructure and Environment initiated a pilot to advance the use of 3D in The Netherlands. In this pilot (run between March 2010 and June 2011), more than 65 private, public and scientific organisations collaborated to analyse and push ahead 3D developments in The Netherlands.

Being an absolute necessity to realise such a push-ahead, a 3D standard NL based on contributions from many different 3D experts and stakeholders was established. For this purpose use cases were defined and executed on a 3D test bed. In addition large amounts of test data were made freely available for all participants in the pilot. Finally the established Dutch 2D standardisation framework was studied for extension into 3D while aligning to the international OGC CityGML standard, driven by experiences of the use cases and the test bed.

The establishment of a national standard for 3D geo-information can be considered as one of the main results of the pilot. However, the ultimate aim was to realise a proof of concept for a 3D Spatial Data Infrastructure (SDI) by studying the main building blocks of a 3D SDI (needs, data, information architecture and standards) in coherence, to define a common 3D approach for a whole country. This is the topic of this paper. The technical details of the development of the national 3D standard are reported in Van den Brink et al. (2011). It should be noted that the research did not focus on the individual techniques for generating, handling and exchanging 3D data, which has received considerable attention in past research.

A proof of concept (POC) for a national 3D SDI may be seen as a solution limited to one specific country. However, the process that established this POC, which includes a national 3D standard extending CityGML, contains many generalities which are of interest for other countries. In particular, because experiments on CityGML extensions and on the integration with existing 2D data sets are new. Therefore, other countries can learn from the process that led to the proof of concept of the 3D SDI as described in this paper.

This paper is organised as follows. The methodology of the research is described in section 2. Section 3 summarises the main findings and conclusions per Work Package. Section 4 closes with the main findings and conclusions and formulates recommendations to further push ahead 3D developments in practice.

## 2 Methodology of 3D Pilot NL

The pilot had quite ambitious goals: The creation of a test bed based on use cases related to a predefined test area in order to find consensus on a 3D standard NL which should lead to a breakthrough in 3D. This required a 3D standard NL that optimally relates provided 3D information and technology to the demand. Therefore, well-defined 3D requirements were needed from the start. However, (new) users may not be aware of all potentials of 3D techniques. Therefore, they may be better capable of formulating their requirements when 'confronted' with the technical possibilities during the research process. This has been a guiding principle of the methodology of the 3D pilot, which is further described in this section.

The motivation to establish a 3D standard NL in a pilot setting is twofold. Firstly, a testing environment was required to structure the knowledge in the wide domain of 3D and to show to new users the potentials of 3D techniques. This was driven by the notion that 3D techniques are more developed than currently applied in practice. Secondly, establishing a 3D standard NL requires wide support of many stakeholders. The involvement of those stakeholders in the development process of the standard within a pilot setting would be essential to obtain this support.

In January 2010 more than 45 organisations responded to the call for participation. Because the pilot received a lot of attention during its course, the number of participating organisations grew to about 65 (the list of participants is available at Geonovum 2011e). Those organisations consisting of (large) municipalities, provinces, universities, main GIS and DBMS vendors, 3D data suppliers, engineering companies etc. have played a major role in the pilot. The 3D pilot participants are not limited to The Netherlands, e. g. there are participants from Germany and Belgium. In addition several organisations work beyond the Dutch borders and included their international counterparts. Also, the (interim) results of the pilot have been discussed at various international workshops. See for example Stoter et al. (2010a), Verbree et al. (2010), and Stoter et al. (2011).

In order to realise the pilot objectives with so many contributing organisations four related work packages (WPs) were defined, each one equipped with its own WP leader (see Fig. 1). In this way all participants could contribute their expertise while pursuing their individual interests and, at the same time, jointly realising the aims of the pilot. An optimal alignment of the participants' interests was also driven by the fact that no budget was available for individual contributions. Intermediate results were exchanged and aligned during plenary sessions which were organised every six to seven weeks.

The four WPs that have run in parallel and in an integrated manner are:

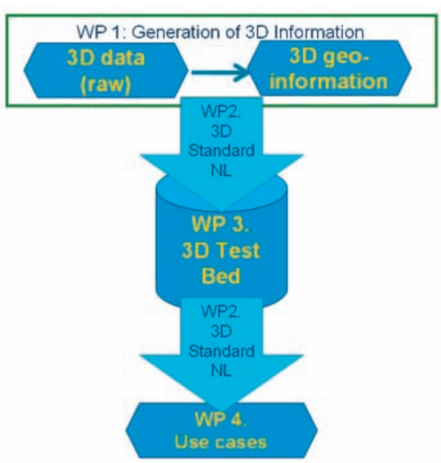



**Fig. 1:** Overview of the four work packages in the 3D pilot.

## WP 1. Generation of 3D Information

Being the purpose of this WP, an inventory of the available 3D data as well as techniques for (automatically) generating 3D information from different sources such as 2D underground and aboveground data, laser point clouds, airborne and terrestrial measurements and 3D models created for construction applications (CAD/AEC/IFC) was created. This inventory would allow newcomers to learn what data is already available as well as how much it takes to build a 3D dataset conformant to the standard with available techniques. Furthermore, this activity made all test data on the selected test area (*Kop van Zuid, Rotterdam*) available for the other WPs.

## WP 2. 3D Standard NL

The aim of the WP "3D standard NL" was the development of the national standard on 3D geo-information driven by the findings of the other WPs and also by aligning to both national and international standards. The international standards of interest are both CAD and GIS standards. The national standards of interest are the domain information models defined by the Dutch model of base geo-information (NEN3610), for example IMRO (spatial planning), IMKL (cables and pipelines), IMBOD/IMBRO (soil and subsoil), IMWA (water), TOP10NL (mid and small scale topography) and IMGeo (large scale topography), see (Stoter et al. 2010b, Geonovum 2011a).

## WP 3. 3D Test Bed

The goal of the test bed was to provide a testing environment for conducting experiments with 3D technologies to all participants and to disseminate the experiences of the test bed within the pilot. Ultimately, the experience of the test bed should provide insight into what works, what is missing and what developments are still needed to implement 3D geo-information architectures.

### *WP 4. Use Cases*

The core of the 3D pilot was the requirements analysis of 3D geo-information and corresponding techniques by specifying and executing use cases. This has been done in close consultation with 3D data providers (WP 1) and the 3D test bed (WP 3). The experiences of the use cases were used to further develop the 3D standard (WP 2).

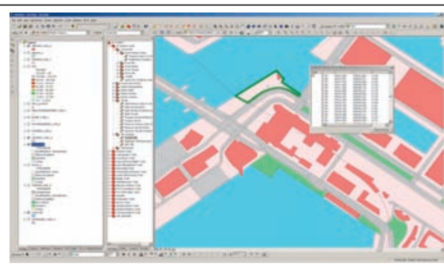
## 3 Main findings of the work packages

This section summarises the main findings per WP.

### 3.1 *Generation of 3D Information*

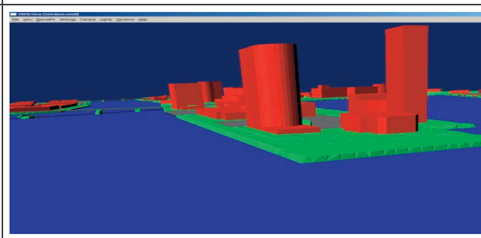
Many data suppliers have provided their (often specifically for the pilot acquired) 2D and 3D data of the test area '*Kop van Zuid*' in Rotterdam. Examples are: 2D topographical data at scale 1:500 and 1:10k, 3D geological data of the subsurface (voxels of 100 m x 100 m x 0.5 m), two high density laser point datasets (the Height Model of The Netherlands, called *Actueel Hoogtebestand Nederland* (AHN2), with a point density of 10 pts per $m^2$ and a dataset with 30 pts per $m^2$, acquired by Fugro for the Municipality of Rotterdam), a 2.5D large scale topographical dataset contributed by Rijkswaterstaat, Cyclomedia orthophotos and panoramic imagery, high resolution point data of terrestrial laser scanners integrated with panoramic photographs (Topcon Sokkia), pan-

All 3D pilot test data integrated in one environment, by Bentley



Assigning z-values to TOP10NL vertices by Kadaster

3D City model from laser point data, by IT-Pro-People (with Bentley software Terra Solid)



3D TOP10NL as integration of TOP10NL and laser point data, by ITC U Twente (Oude Elberink & Vosselman 2009)

CityGML buildings and trees by iDelft and Alterra


CityGML-LOD2 including trees by Toposcopie

**Fig. 2:** Examples of further processed data in the 3D pilot.

oramic video (Horus Surround Vision), recordings by Imagem etc.

These input datasets formed a rich starting point for 3D modelling activities of the test area. Several pilot participants have further processed these data in different types of 3D models. Some examples are shown in Fig. 2.

The main findings of this WP on 3D information generation can be summarised as follows:

- The 2D and 3D source data already available in The Netherlands in combination with data that can be obtained by additional acquisition offer rich potentials for building 3D geo-information.
- Currently no successful techniques exist for a fully automated generation of 3D information, other than using existing (2D) data and their semantics. It is expected that along with the establishment of a 3D standard the domain of 3D geo-information generation will change because people will stronger focus on the generation of 3D information.
- Laser scanning is a fast emerging technology, which contains a lot of potentials for building detailed 3D models (either in combination with existing 2D data sets or as an individual approach).
- The generation of relatively simple 3D models from 2D core spatial databases is the best starting point because of four technical reasons:
  - connection to existing datasets means connecting to existing application domains which provides a justification for the 3D information
  - existing datasets often contain rich semantics, which is difficult to obtain from automated acquisition techniques
  - existing datasets contain information about objects that increases the possibilities to automatically generate 3D models
  - the update process (or at least the update information) of existing datasets can be used for updating the 3D datasets
- From the perspective of a governmental organisation, the positioning of 3D geo-information in the organisation is not easy. The following guidelines may help:
  - seek contact with application domains
  - base the generation of 3D information on the intended uses which should also dictate the quality required (detailing, classification, semantics, geometry)
  - find a balance between acquisition of new data and use of existing datasets
  - acknowledge the file formats existing in the various application fields and realise interoperability through specific exchange formats
  - the need for a standard exchange format is evident and makes multiple use of single-acquired 3D information possible

**Tab. 1:** Comparison of 3D standards in CAD and GIS domains.

| Standard/Criterion | DXF | SHP | VRML | X3D | KML | Collada | IFC | CityGML | 3D PDF |
|---|---|---|---|---|---|---|---|---|---|
| Geometry | ++ | + | ++ | ++ | + | ++ | ++ | + | ++ |
| Topology | - | - | 0 | 0 | - | + | + | + | - |
| Texture | - | - | ++ | ++ | 0 | ++ | - | + | + |
| LOD | - | - | + | + | - | - | - | + | - |
| Objects | 0 | + | + | + | - | - | + | + | + |
| Semantic | + | + | 0 | 0 | 0 | 0 | ++ | ++ | + |
| Attributes | - | + | 0 | 0 | 0 | - | + | + | + |
| XML based | - | - | - | + | - | - | + | + | - |
| Web | - | - | + | ++ | ++ | + | - | + | 0 |
| Georef. | + | + | - | + | + | - | - | + | + |
| Acceptance | ++ | ++ | ++ | 0 | ++ | + | 0 | + | ++ |

- not supported; 0 basic; + supported; ++ extended support

## 3.2 *3D Standard NL*

The need for a 3D geo-information standard was evident throughout the whole pilot. This standard should align to available national and international 3D standards. After a comparison of the main 3D CAD and GIS standards (DXF, SHP, VRML, X3D, KML, Collada, IFC, CityGML and 3D PDF) the OGC standard CityGML (OGC 2008) proved to be the best starting point for a national standard on 3D geo-information, see Table 1.

CityGML provides the best support in terms of semantics, objects, attributes, georeferencing and operation via the Web. The OGC standard CityGML originated from the academia in Germany (University of Bonn, Technical University Berlin) and is often seen as an exchange format. But CityGML is also – and in particular – an information model for representing 3D spatial objects. CityGML distinguishes between thematic concepts, e. g. buildings, vegetation, water, land use, etc., at the geometric and at the semantic level. This conceptual model regards the features on every level of detail (LOD). A building object can vary from a simple block model (LOD1), a model including roof shapes (LOD2), a model

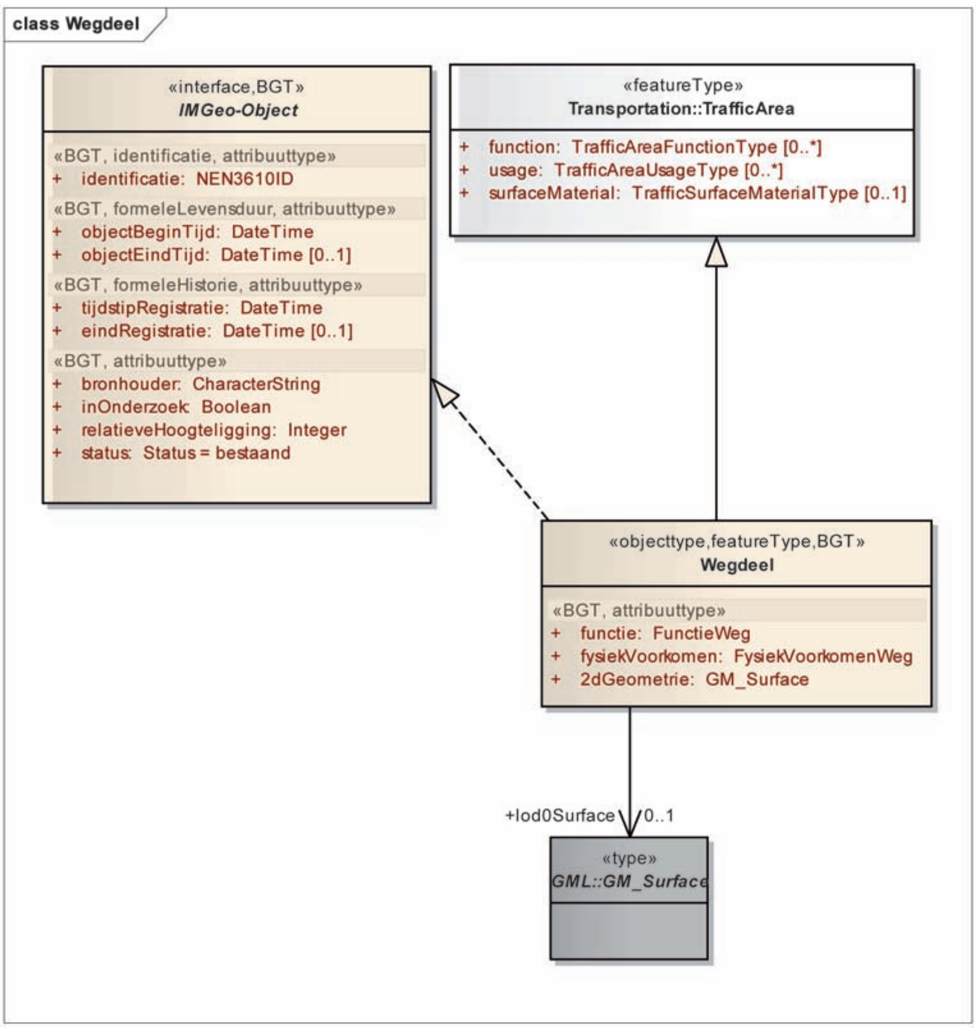



**Fig. 3:** Example – IMGeo modelling of *Wegdeel* as subclass of CityGML-TrafficArea (Van den Brink et al. 2011).

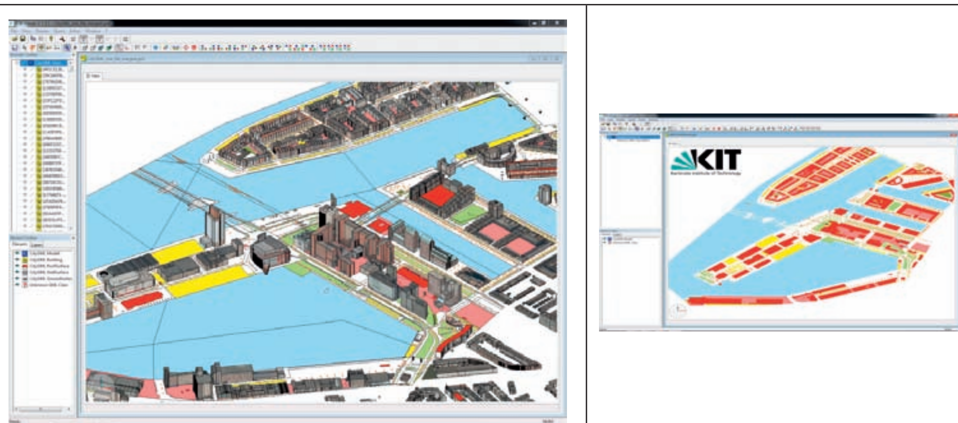
including windows, doors and other exterior features (LOD3) to a fully detailed interior model (LOD4) with or without texture information.

At the beginning of the pilot, participants were reluctant to use the CityGML standard. It was claimed that the standard would be too generic, that it does not contain detailed object definitions and that it does not support complex geometries supported in the CAD domain. Other problems are the focus on above ground objects, ambiguity about the LOD definitions (geometry- or semantic-based), the lack of relationship between the different LOD-representations and the lack of rules that ensure valid 3D geometry. Moreover, commercial systems had limited support for CityGML although this support improved during the pilot.

However, after a year of running the 3D pilot it became clear that, despite of these shortcomings, the connection to this standard ensures interoperability: that is, when Dutch geo-information is encoded in CityGML, this data is available to CityGML compliant clients.

Following the decision to use CityGML as a base for the standardisation of 3D geo-information in The Netherlands, the next step of this WP was to establish a CityGML implementation profile for The Netherlands. The realisation of this profile first focused on the Dutch Information Model on large scale Geo-information (IMGeo), since this model resembles CityGML the most. The main principle of the profile is the reuse of CityGML concepts as much as possible. Therefore, the agreements laid down in IMGeo were encoded in CityGML and additional classes, attributes, and attribute values were added if needed. See Fig. 3 for an example of the class *Wegdeel* (i. e. Road Parts; road segments that constitute a road*).* IMGeo *Wegdeel* class is modelled as a specialisation of the CityGML class TrafficArea, thereby inheriting its properties. The generic attributes of IMGeo are modeled via the stereotype <<interface>>, to avoid multiple inheritance. The stereotype <<BGT>> indicates the parts that are part of the legally established authentic registry of large scale geo-information (*Basisregistratie Grootschalige Topografie, BGT*). As can be seen, the only part which is not mandatory is Wegdeel.lod0Surface. The attribute Wegdeel.functie is equivalent to TrafficArea.function; the attribute Wegdeel.fysiekVoorkomen is equivalent to TrafficArea.surfaceMaterial. Further details of the CityGML implementation profile are described in (Van den Brink et al. 2011).

The CityGML implementation profile also contains further agreements of how to use CityGML for the Dutch context. These agreements solved most of the above mentioned shortcomings of CityGML (e. g. the lack of a precise LOD-definition and the lack of rules for the object definition). The model is designed in such a way that it supports both the



a | b

**Fig. 4:** Visualisation of CityGML-IMGeo encoded data: LOD2 (a) and 2D LOD (b).

'2D LOD' (a term that we have introduced for the integrated model) as well as the different LODs of CityGML. In May 2011 the proposed approach has officially been approved for the information model for large scale topography in The Netherlands. This close integration between an existing information model for 2D geo-information and CityGML is a major step for the use of 3D information and a unique achievement for standardisation in 3D.

To test the CityGML-IMGeo implementation profile IMGeo data and laser point data were combined to generate CityGML-IMGeo encoded data of the pilot test area. The result is shown in Fig. 4.

During the establishment of the model and sequential testing, deficiencies were identified both for IMGeo and CityGML which were used to formulate Change Requests (CRs) for both models. Examples of CRs for CityGML (submitted in August 2011) required to model every class at least in LOD0 (in current CityGML some classes only start at LOD1 such as Building, CityFurniture, TrafficArea) and to distinguish between function and physical appearance of Land Use (the current codes for 'function' is a mixture of both) (Van den Brink et al. 2011). Also a proposal for support of voxels in CityGML is under study based on the experiences of the 3D pilot. This proposal builds on the works of Tegtmeier et al. (2009) and Zobl & Marschallinger (2008).

Besides the IMGeo specific aspects, CityGML-IMGeo contains generic aspects that can be reused for extending other Dutch domain models into 3D when appropriate. To get a feeling for the possibilities, the WP 3D standard NL finally carried out a study regarding the matching of the concepts of the other Dutch domain models with CityGML. For this matching also several Application Domain Extensions (ADE) were considered, such as the extensions for Utility Network, Tunnel and Bridge. In the future, the planned ADE for cables and pipelines may be relevant (Becker 2010, Hijazi 2010).

## 3.3 *The 3D Test Bed*

The 3D test bed examined the techniques to support 3D information in general and CityGML in particular, based on the data made available by the participants of the Rotterdam test area. The Section GIS technology of the TU Delft implemented a specially designed test bed environment which could be used by all participants. Apart from a file-based data server for the test data, the test bed offered a DBMS implementation, i. e. the 3DCityDB. This database is an open source 3D geo-database, developed by the TU Berlin, that implements the CityGML data model in a relational database (Oracle Spatial 11g in our case) (TU Berlin 2011). The database was (and is still) available for all pilot participants to upload, validate and export CityGML data.

The feedback of the test bed experiences to the participants during the 3D pilot led to a better understanding of CityGML, as did the free CityGML course that this WP offered in March 2011 (recorded and available at (TU Delft 2011)). Therefore, the use of the 3DCityDB increased during the 3D pilot, which was also stimulated by better CityGML support by systems provided by companies such as Bentley, Esri and Intergraph.

The experiences of the test bed confirmed that a free interpretation of the use of CityGML LODs for both geometric and semantic level is possible and that the 3D standard NL should therefore make further arrangements in a CityGML implementation profile for the Dutch context. The WP 3D standard NL has taken over this suggestion, as described above.

Because CityGML does not directly enforce the validity of the 3D geometries, the test bed also studied a geometric validation tool (developed by the TU Delft) and the validation possibilities of Oracle Spatial. The tools check whether a 3D object is valid. This means that the faces of a volume do not intersect, the volume is waterproof (no openings) etc. (Ledoux et al. 2009).

Another important activity of the WP 3D test bed was the study of methods to generate CityGML encoded data (see also examples in Fig. 2). The experience with the 3D test bed showed that CityGML is increasingly supported in commercial software. This support allows to generate and export CityGML data. Several different approaches were demonstrated by the companies participating in the pilot. For example, Bentley Map is able to export CityGML files via an FME-based interoperability component, and recently a specific mapping of CityGML to Bentley XML Feature Modelling scheme has become available. With this scheme it is possible to build semantically and geometrically valid 3D CityGML objects from scratch and to manipulate them afterwards.

Another method for generating CityGML encoded data of buildings was the extrusion of 2D building "footprints" based on a height attribute of the LOD1 objects. A good example of this approach is the 3D data conversion tool from the company iDelft that was developed during the pilot. Other examples include ArcGIS and Toposcopie that offer tools to generate 3D building block models by a combination of 2D topography (large or midscale) and point clouds from laserscan data or photogrammetry. If the footprints of the buildings connect, it is also possible to generate topologically correct CityGML LOD1 data according to the method described in (Meijers & Ledoux 2011).

Most roof types for LOD2 data could be generated (semi-) automatically from laser point data by matching laser points with predefined roof shapes (see Fig. 2, example lower left by iDelft and Alterra) or by applying surveying methods combined with images (Toposcopie). A fully automatic generation of any LOD2 and LOD3 building objects from point clouds was not shown in the test bed for two reasons: The many complex roofs require internal lines for a border-definition. Those lines are not yet available. Combined buildings such as terraced houses require an a-priori object-definition to perform a correct processing of the laser data such as merge, split, and estimation.

Models of trees for LOD2 and LOD3 could also be derived from laser point data as done by Alterra, and ITC University of Twente (for examples see Fig. 2 and 5).

Another way demonstrated to generate CityGML data (manually) was the application of SketchUp (software for creating 3D models for use in Google Earth and other systems). This software has a plugin for CityGML, although this link is still not fully operational. The validation test on CityGML structure and scheme definitions usually happens when the CityGML data is imported into one of the available viewers, for example LandXplorer of FZK (Forschungszentrum Karlsruhe) (as in Fig. 4). If this visualisation looks good, then the CityGML data is deemed acceptable. Unfortunately, our tests have shown that CityGML viewers do not check for topologically and geometrically correct CityGML data. Such data is accepted and visualised though many of it was incorrect, for example some volumes were not waterproof, meaning that, the files sometimes had overlapping planes or gaps between objects that should connect to each other.

The 2.5D representations of CityGML (LOD0), i. e. Land Use objects were also tested. They can be generated through a constrained triangulation from laser points where the polygon boundaries are used as breaklines. In this way also the height variance within the polygon surfaces are represented.

## 3.4 *Use cases*

The use case studies were important in the 3D pilot: What applications need 3D information? Which 3D information is needed? What is the state-of-the-art of 3D techniques in relation to 3D needs? In order to answer these questions, six use cases were defined and executed in this WP. These are:

- 3D cadastre: recording of property items located above each other (see also Stoter & Ploeger 2003, Stoter & Salzmann 2003, Stoter & Oosterom 2005),
- generation, maintenance and distribution of 3D topography,
- applying voxel data for GIS analyses,
  - integration of voxels (3D grids) with 3D objects,
  - integration of surface and subsurface data,
- 3D data integration in construction processes: How to use design data (IFC/CAD/Collada) in GIS applications and how to use 3D geo-information in building information models (BIM)?
- 3D for spatial planning: generating 3D virtual environments based on architectural models for communication with citizens,
- 3D change detection (see also Vosselman et al. 2005).

Several 3D pilot participants have experimented with the use cases, see Fig. 5. To make the use cases easily available for the wide public, demos of the use cases are published on YouTube (see GEONOVUM 2011b).

Experience with the use cases confirmed that lacking knowledge about generating and using 3D data and techniques is often a bigger problem for 3D applications than the lack of technology itself. Technical problems did oc-

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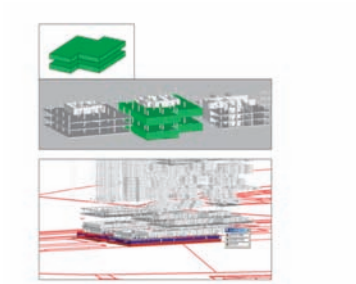
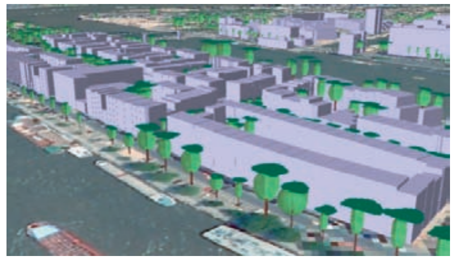
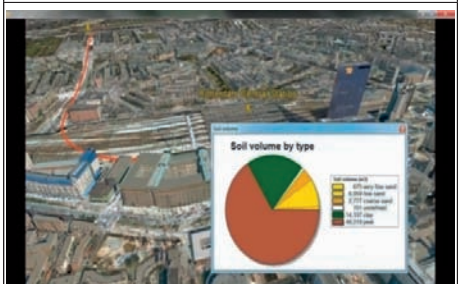
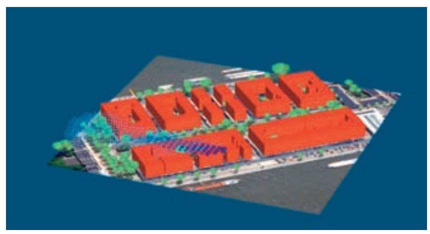
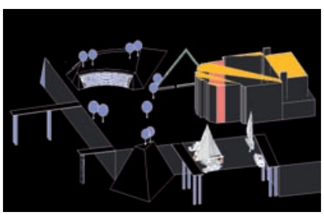
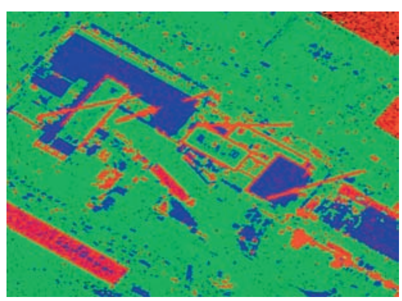
|  |  |
| 3D Kadaster (Dutch Kadaster and Bentley) | Tree model generated by Alterra for use case 3D topography |
|   |  |
| Calculation of soil volumes (voxels) at the location of a planned tunnel, by Esri and TNO | Realtime interactive airstream simulation with voxels, Alterra |
|  |  |
| Spatial planning objects in CityGML, Crotec | 3D change detection, NEO BV |
|   |  |
| Integrating design models in virtual environments , Gemeente Apeldoorn | 3D Change detection based on differences between two point clouds, U Twente |

**Fig. 5:** Selection of the executed use cases.

cur during the exchange of 3D data between software, because not always the original information (geometry and semantics) was maintained. Thus, the importance of an exchange format for 3D geo-information again proved to be evident.

Many of the use cases addressed the conversion from BIM information to 3D geo-information and vice versa (not shown in Fig. 5). These conversions go beyond the technical conversions as studied in Berlo & De Laat (2010), Bormann (2010) and El-Mekawy (2010). Instead, the efforts were focussed on the semantic issues of the conversions: How do concepts from the BIM domain relate to concepts in the GIS domain? Which information is specific for the two domains? How can the relevant characteristics be preserved in the conversion? How shall differences in the conceptual models in both domains be dealt with? How shall the different geometries in both domains, i. e. simple geometries in GIS and complex, parameterized geometries in BIM, be dealt with? These questions extend the work of Isikdag & Zlatanova (2009).

The experiences of the use cases on the BIM/GIS topic reinforced the different characteristics between BIM and GIS data. The integration of both types of data via a common exchange format is beneficial because BIM data can feed GIS data and GIS can serve as a reference for BIM data. However, integration should acknowledge the differences between both types of data. To start with, the object description of BIM and GIS, e. g. CityGML LOD4, differs significantly. In addition, GIS is characterised by the coverage of large areas, e. g. a complete city, and lower precision, while BIM is characterised by its local and very detailed approach, a limited number of construction models usually available in a city and high precision necessary for reliable construction calculations. Assuming that original BIM files may serve specific applications in the future, it is important to maintain both the original BIM source file and the simplified CityGML representation of the BIM file (in the city model).

## 4. Conclusions, main findings and recommendations

The aim of the research project presented in this paper was the advancement of 3D developments in The Netherlands by studying and applying 3D technologies on use cases and using these experiences to establish a national 3D standard to support a 3D SDI. After a year of collaboration with many stakeholders it can be concluded that the objective is achieved. The 3D pilot has shown the added value of 3D and what it takes to exploit this value. A typical example is the integrated planning and management of space above and under the surface. The findings of the pilot have shown that it is no longer the question if, but how 3D in The Netherlands should be organised and implemented in a 3D SDI. These conclusions can be drawn from several main findings. These will be summarised in Section 4.1. Section 4.2 formulates recommendations that follow from these findings.

### 4.1 *Main findings of the 3D pilot*

*3D is needed and feasible*

The 3D pilot has accomplished a focus on 3D geo-information developments in The Netherlands. At the beginning of the 3D pilot a small group of experts was aware that 3D technology is further developed than currently used in practice. But specific knowledge on how 3D could be applied in common applications was lacking. The extensive exchange of 3D knowledge and experiences between a large number of participants resulted in the consciousness of the feasibility of 3D within a wide public. The field of 3D geo-information has therefore become tangible and manageable, which is important for further 3D developments. The changing perception of the standard CityGML over time may illustrate the strong increase of awareness. The 3D pilot participants considered this standard as exotic at the start; at the end of the pilot there was a widely supported 3D CityGML-IMGeo profile. Also it became clear that 3D geo-information not only belongs to the traditional field of geo-information. Instead it requires close cooperation with other disciplines such as planning, design, and construction management to make 3D feasible and use its added value.

*3D standard NL is important and has been realised*

According to another finding the lack of a 3D standard considerably inhibits the use and exchange of 3D geo-information. Therefore, formalised agreements on a standard such as CityGML are essential. Even if this standard is not being considered 100% optimal it equips governmental organisations with the kind of 3D geo-information that they can build upon. At the same time it provides private industry a stable platform for innovative developments. The pilot provided a suitable environment to formulate user specific requirements for a diverse group of users which eventually led to the CityGML-IMGeo standard. This standard solved some of the issues of the generic standard CityGML. Without the pilot it would have been much harder to establish such an extended 3D standard.

*3D base dataset is required and feasible*

The pilot has shown the need for a nationwide 3D base (or reference) dataset. This dataset is needed for referencing (new) 3D information in the virtual model of the world and for providing a basis for 3D planning and management of public space. Many large municipalities have 3D datasets, which unfortunately are often restricted to the territory of the city and available in different formats and resolutions. Currently, only Google Earth is available on a country-wide scale, but has a limited representation of subsurface features - among other restrictions such as an unknown update status and an undisclosed accuracy. The pilot achieved promising results for generating 3D topography to be used as such a reference dataset, i. e. by a combination of 2D IMGeo data with AHN2 (both soon available nationwide) a 3D topographic base dataset can be quite easily generated. Also, a combination of TOP10NL and AHN2 showed potentials to rapidly and efficiently build a nationwide 3D base dataset at midscale.

*3D NL is organised*

One of the main results of the 3D pilot is the generation of an informal network in The Netherlands. This is valuable because further 3D developments ask for wide support as well as for an integrated approach of various expertises. The network is active on Twitter and LinkedIn (more than 400 members) which makes it easy to exchange and publish specific and generic 3D achievements within the 3D network of The Netherlands. This networking environment has appeared to be very powerful.

*The pilot approach was successful*

The collaboration of a large number of participants without any financial compensation can be considered as a good indication of the success of the pilot. It was also valuable that companies with more or less the same, and therefore competing, "businesses" were willing to share their knowledge. A major reason for the strong commitment of the participants was the overall goal being beneficent for all participants: pushing ahead 3D developments in The Netherlands. The result-oriented approach led to a close connection with practitioners and to a stimulating and motivating environment for collaboration.

The 3D pilot also received national and international attention, e. g. OGC has awarded the 3D Pilot NL with the OGC 3D award in September 2010. This was partly due to the various national and international publications and presentations.

*The lack of 3D knowledge is the severest bottleneck*

The execution of the use cases showed that a lack of 3D knowledge is a bottleneck for applying 3D. This is true for governmental organisations because they suffer from a lack of knowledge in the new domain of 3D. In addition, the pilot showed that 3D has many different fields of expertise. Structuring the knowledge within the broad field of 3D has been important for a wide support of 3D in The Netherlands. The intensive knowledge exchange resulted in several small partnerships among pilot participants (sometimes behind the 3D pilot scenes). Those partners have evoked 3D innovations (such as a better support of CityGML in commercial GISs and improved automatic object construction options).

In line with this finding, the five final reports of the pilot (one for each WP and an additional executive summary, see GEONOVUM 2011c) specifically aimed at filling knowledge gaps within the wider public. The reports are intended both to inform outsiders about what has been achieved in the pilot, but also to make various aspects of 3D accessible for newcomers to the field of 3D. In addition the pilot closed with a national symposium on 3D at which the acquired knowledge was presented to a wide public (GEONOVUM 20011d).

Besides generating new knowledge and merging existing knowledge, the findings of the 3D pilot identified a number of issues for further research. Examples include further developments in automatic generation of 3D information, updating 3D datasets, and maintaining 3D information. However, 3D topology and validation of 3D geometry needs further research attention. More attention should be drawn to the kind of 3D spatial operations that should be implemented, and to the broader use of the 3D information. As mentioned above, most of the use cases were focussed on the integration of data.

## 4.2 *Recommendations*

An important next step is the search for further agreements about the way of implementing and organising 3D in The Netherlands. In line with the findings and conclusions, some recommendations have been formulated. On one hand they cover aspects that can be picked up by the initiators of the 3D pilot (Kadaster, Geonovum, Ministry of I&M and NCG). On the other hand, some topics need further investigation and therefore require a similar collaborative and experimental environment as the 3D pilot.

Recommendations for the initiators of the pilot to take over the results and findings are:

- The established 3D standard NL needs maintenance and further testing on usability and technical aspects. In addition, experience with 3D IMGeo should be used to extend also other domain models with a notion of 3D if appropriate.
- The extention of the existing national 2D large and midscale reference datasets towards 3D requires further attention. This covers both, the implementation of successful 3D pilot results into practice as well as a business case study for providing such a 3D reference dataset supporting the Dutch SDI.
- The commercial companies should be encouraged to provide importers/exporters for the 3D standard NL.
- The accomplished network is important for further 3D developments in The Netherlands. Therefore, the network should be maintained and further expanded by a continued facilitation of the 3D test bed, maintenance of the Twitter and LinkedIn environment and organisation of regular knowledge sessions (as was done during the pilot).

The issues that require further elaboration in a pilot environment were derived directly from the observation that relevant knowledge is often lacking at the relevant organisations and that this hinders 3D developments. Therefore, more knowledge is needed to let governmental organisations as well as data-, technology- and service-providers better direct their 3D developments. Sometimes, this includes existing knowledge that still requires structuring in a collaborative environment. Sometimes it involves (new) knowledge that needs to be built in an experimental setting.

For several aspects the 3D pilot has built new capacities and organised existing knowledge, e. g. regarding the generation, management and implementation of 3D geo-information. But the pilot also identified capacity gaps that require additional knowledge building. Some topics that need further research attention in a pilot setting are:

*Successful 3D strategies for governmental organisations*

The introduction of 3D in governmental organisations is relatively new. The study of successful (technical) 3D strategies based on “good practices” may support the introduction of 3D in those organisations. These strategies regard the generation, update and management of the 2.5D and 3D data. In addition, example specifications for outsourcing 3D geo-information generation may be helpful as well as (more) examples of added value of 3D in governmental processes.

*Aligning to other disciplines*
An important part of a successful 3D strategy is the technical alignment with other disciplines such as design-, construction- and facility management-domains. Insight is required on how to balance between strict agreements on one hand and sufficient flexibility in the separate domains on the other hand.

*Organisational issues of 3D geo-information*
It is obvious that 3D requires a specific organisational approach within a governmental organisation, but the way how this best can be achieved remains open. Defining and executing use cases for municipal tasks may provide guidance how to best organise a 3D information infrastructure in such an organisation. How can optimal collaboration be accomplished between disciplines such as geo-information, planning, design, management and BIM? Often the benefits of 3D occur in other departments than those where the bill has to be paid. This causes another obstacle for organisations which plan to introduce 3D. This uncertainty about costs-benefits may be an obstacle and thus requires organisational solutions that can be studied with the help of dedicated use cases.

A new project group is currently working on these topics in a next phase (planned for September 2011 till June 2012). More than 100 participants have subscribed. The new project group will further work on the results of the first phase to make them ready for use in practice. Addressing the still open 3D issues in a collaborative and experimental setting where expertise of universities, industries and governmental parties are brought together, offers the optimal conditions for 3D being actually picked up by practice, as it was shown by the 3D pilot presented in this paper.

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