# A GENERIC APPROACH FOR 3D SDI IN THE NETHERLANDS

Jantien Stoter[1,2], Linda van den Brink[3], George Vosselman[4,5], Joris Goos[6], Sisi Zlatanova[2], Edward Verbree[2], Rick Klooster[7] , Leon van Berlo[8], Gerbrand Vestjens[9], Marcel Reuvers[3], Stefan Thorn [10]

[1] Kadaster, [2]TU Delft, [3]Geonovum, [4]University of Twente, [5]Netherlands Geodetic Commission, [6]City of Rotterdam, [7]Municipality Apeldoorn, [8]TNO, [9]Geodelta, [10]MSc student GeoInformation and Management
J.E.Stoter@tudelft.nl

**Abstract.** This paper presents a research project in The Netherlands in which a large number of stakeholders are collaborating on a 3D test bed, selected use cases and a test area to push 3D applications in the Netherlands. The project studies and realizes 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. The research results in a generic approach to 3D SDI in The Netherlands both at the national level and in specific organizations (for example a municipality) addressing the key aspects of such an SDI. Core of the proposed 3D SDI is the 3D standard NL, compatible with international (i.e. CityGML) and national standards on 2D and 3D geo-information. The innovation in this research is that the main building blocks of a 3D SDI (needs, data, test bed and standards) are studied in coherence to ultimately define a generic approach to 3D.

## 1 Introduction

The past ten years technologies for acquiring, generating, maintaining and using 3D geo-information have matured, while costs for 3D data and 3D geo-applications have been reduced significantly. Yet many (governmental) organizations are hesitating to introduce 3D application and technologies in their day-to-day processes. This is partly due to lacking knowledge of this new 3D domain within these organizations and partly due to the lack of a generic approach to handle 3D geo-information within the Spatial Data Infrastructure (SDI). At the same time we observe that 3D applications are indispensable for sustainable management of the densely built-up environment in the Netherlands.

This motivated a one-year research project (running from March 2010 until March 2011), called 3D Pilot NL, in which a large number of stakeholders (> 65!) from the private, public and academic domain are collaborating to push forward 3D developments in the Netherlands. The push is accomplished by structuring existing knowledge on 3D technologies, 3D standards and 3D applications available from people who are experts in different areas of 3D GeoICT. In the research these experts work closely together with potential users of 3D geo-information to further refine, develop and align available and new 3D technologies, 3D standards and 3D applications. The aim of the research is to realize a proof of concept for a 3D SDI both at the national level and in specific organizations (e.g. a municipality).

For 2D geo-information an SDI has been established in the Netherlands based on national and international agreements on geometry, topology, implementations in Database Management Systems, exchange formats, national semantic information models, services, clients etc. An important aspect of this 2D SDI is the national standardization framework in which both the geometry and semantics of geo-information are defined. This framework is built around the NEN 3610 information model of which the OGC and ISO/TC 211 compliant version was finalized in 2005. The aim of this model is to have common definitions for object classes in the geo-information domain at a generic level. Geo-application domains have built and are building their specific domain models on this generic model (see Figure 1). Examples are information models for physical planning (IMRO), for cultural historical objects (IMKICH), for cables and pipelines (IMKL), for soil and subsurface (IMBRO), for water (IMWA), for large-scale topography (IMGeo) etc. (Geonovum, 2011).

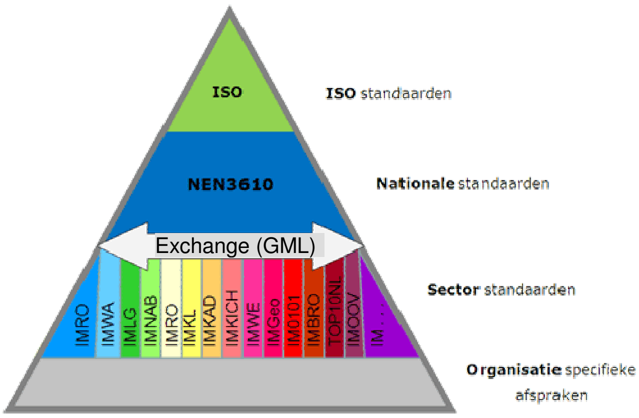



**Figure 1:** 2D semantic and geometry standardization framework in The Netherlands

This (2D) SDI has enabled the integration of geo-information from different sources and has also improved accessibility of geo-information by different types of clients in and across governmental organizations. The 3D research as presented in this paper aims at extending this SDI to also support 3D geo-information. The research questions are therefore: What kind of 3D base (i.e. reference) information is needed for a 3D SDI and what additional information is necessary for specific 3D applications? How can this information be generated as automatically as possible? How can 3D information be maintained in a centralized Database Management Systems (DBMSs) that can be accessed by different clients and different applications? How can standards on geometry and semantics be defined for the 3D data that supports the interoperability between DBMSs, services and clients?

In this research these issues are studied in an integrated manner because of their interdependencies. Based on selected and specified use cases the different aspects are being studied, varying from generating 3D information, defining and using 3D standards to maintenance of 3D data and use of 3D data in applications. For this purpose a 3D test bed was designed and implemented and a large amount of test data has been made available via this test bed. In addition the established Dutch 2D standardization framework has been studied to be extended into 3D while aligning to the international OGC CityGML standard, driven by experiences of the use cases and the test bed.

It should be noted that the research did not aim at innovations regarding the individual techniques. Instead the innovation of the research is that the main building blocks of 3D SDI (needs, data, test bed and standards) are studied in coherence, to ultimately define a generic approach for 3D that covers all these aspects.

The research project is initiated by four national organizations: the Kadaster (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 (co-ordinates and initiates fundamental and strategic research in geodesy and geo-information in the Netherlands) and the Ministry of Housing, Spatial Planning and the Environment (which after the election in 2010 became the Ministry of Infrastructure and Environment).

The methodology of the research is explained and motivated in Stoter et al (2010). The main principle of the methodology is that we divided the study on 3D SDI into four research topics:

1. Identifying 3D needs
2. Generating 3D data and 3D information
3. Designing and implementing 3D test bed
4. Investigating and defining 3D standard-NL

With this approach every organization could contribute with its own expertise and area of interest, while together realising the overall aims of the 3D project.

This paper presents the research that has been done so far on the four topics in Section 2 to Section 5. Section 6 ends with conclusions.

## 2 Identifying 3D needs

To increase the use of 3D information via the anticipated 3D SDI, we were aware that users' needs for 3D information should be specified and evaluated by the (potential) users of 3D themselves. On the other hand we assumed that users might not be aware of their 3D needs in relation to the available data and techniques.

We addressed this problem with the following approach. Several (potential) 3D problem "owners" volunteered to be a use case leader. These use case leaders presented their (potential) 3D problems to all project partners. Based on these discussions the use case leaders further refined the problems. In a next step several of these problems were selected as an appropriate use case. The others were discarded because either the problem was too vague or it was still too much supply driven (i.e. not clear who would benefit in the end). Some use cases with similar problems were eventually combined.

This ultimately resulted in four use cases:

*Geological 3D data for infrastructural planning (leader: Dutch Geological Institute):*

- Integration of continuous (voxel) data and 3D objects
- Integration of 3D data above and 3D data below the surface for infrastructural planning.

*3D data integration within design and building processes (BIM-IFC-CAD) (leader: municipality of Apeldoorn)*

- How to use design data (IFC/BIM/CAD/Collada) for GIS application; and vice versa: how to use 3D geo-information for design and building applications.

*3D in spatial planning (leader: municipality of Apeldoorn)*

- Generating virtual 3D environments for communication with the community, including using design models as input for the environment.
- 3D Change detection.

*3D registrations (leader: Dutch Kadaster)*

- 3D Cadastre: registration of property that is located on top of each other.
- 3D topography base data set for The Netherlands.

Each use case was defined in detail with the following information: specific 3D questions that need to be answered, necessary data, required processing, required tools.

Many of the use cases address the conversion from BIM information to 3D geo-information and vice versa. It should be noted that these questions go beyond the technical conversions as studied in (Berlo and De Laat, 2010; Bormann, 2010; El-Mekawy, 2010). Instead we focus on the semantical issues of the conversions: which property from BIM domain matches which property in GIS domain? How do concepts in different domains relate? Which information is specific for the two domains? How to preserve the relevant characteristics in the conversion? How to deal with differences in concept meanings in both domains? How to deal with the support of different geometries in both domains (i.e. simple geometries in GIS and complex, parameterized geometries in BIM)? These questions extend the work of Isikdag and Zlatanova (2009; 2009b).

After the use cases were specified, all pilot partners were invited to show the added value of their knowledge, tool, data etc for a specific use case with the available test data (see Section 3) within a period of six weeks. This resulted in several intermediate results for the use cases (see Figure 2). For example for the BIM/CAD use case, the municipality of Rotterdam studied the conversion of IFC to CityGML in more detail. For the same use case, Bentley imported an IFC model of a building in an existing LOD1 model and upgraded this model with Bentley Map to a model in CityGML LOD3 and LOD4. Esri NL converted the available underground geological model (voxels of 100x100x0.5m) to vector representation where each voxel corresponds to one polyhedron. In a next step the voxel model was integrated with a tunnel model to calculate the volume per soil type that needs to be removed for the tunnel. NEO BV, experienced in 2D change detection, studied the possibilities of change detection in 3D, i.e. how to model the world in 3D and how to detect changes in this model (Vosselman et al., 2005).

Since the use case on 3D topography is actually a combination of the generation of 3D data (and information) and the 3D standard-NL (with respect to the content), this use case is further studied within those two research activities (Section 3 respectively 5).

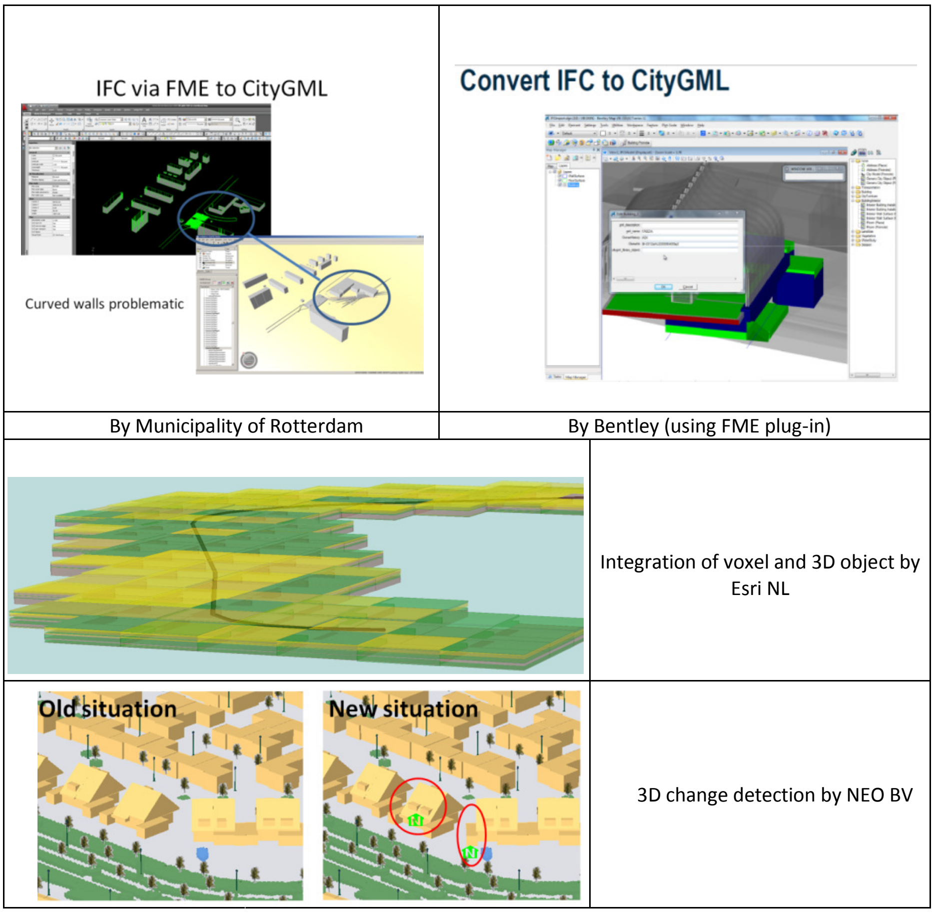
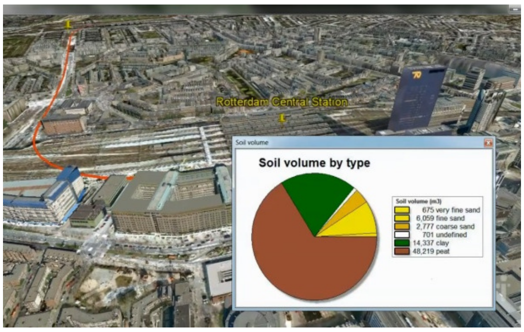



**Figure 2**: First results of 3D Pilot NL use cases

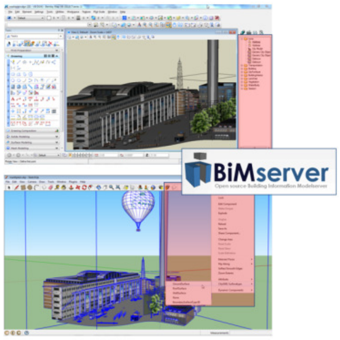
After these first experiences the use case "owners" further experimented with the developed tools and insights, in collaboration with the project partners. Examples are shown in Figure 3.

The main (intermediate) conclusion of the use cases is that in most instances the 3D questions could be answered with the technologies and available data, although in all cases it required time to align the techniques to the specific use case questions. The models created remain software dependent however. Problems were encountered in the exchange of 3D data and information from one software system to another, since the converted data did not automatically contain all original information (geometry and semantics).

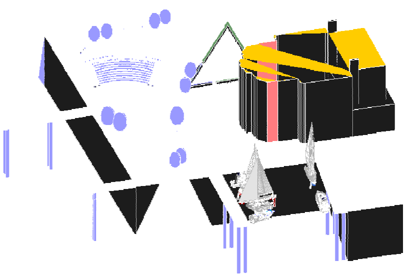
The experiences also confirmed the different characteristics between BIM and GIS data. The integration of both types of data provides benefits since BIM data can feed GIS data and GIS can serve as reference for BIM data. However integration should acknowledge the differences between both types of data. To start with, the object description of BIM and GIS (e.g. CityGML LOD4) differs significantly. In addition GIS is characterized by coverage of large areas (e.g. a complete city) and lower precision, while BIM is characterized by its local and very detailed approach, the 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 the building permit process in the future, it is important that both the original BIM source file and a CityGML representation of the BIM file (in the city model) are available.



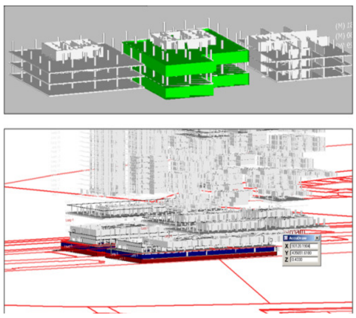

Geological institute (volume of soil types at the location of a planned tunnel calculated with Esri software)




Municipality of Apeldoorn (integrating design files into 3D citymodels)



Crotec (spatial planning objects in CityGML)



Dutch Cadastre (3D cadastral objects generated with Bentley map)

**Figure 3:** Further results of the uses cases, obtained by use case owners

Another conclusion from these experiences is that knowledge about setting up and applying 3D techniques is very scarce and is not easy accessible for new people. In addition since much relevant knowledge is only available at software suppliers and data manufacturers it is difficult to get an independent advice.

Apart from the questions pertaining to the use cases, all use cases had the task to also address the question of how a generic standard for 3D as CityGML could support the use case. The conclusions regarding this question is that CityGML is a good starting point to exchange 3D information. However the format is not yet supported enough by the software to be helpful in practice. It needs further development and support by the software manufacturers to optimally serve as a generic exchange standard. In line with this conclusion we are currently studying extensions of CityGML in the contexts of the use cases and the Dutch domain information models (see Section 5).

# 3 Generating 3D data and information

The research that focuses on generating 3D data and information resulted in many different data sets containing 2D and 3D information for the “Kop van Zuid” test area in the city of Rotterdam. The provided data varies from raw data (imagery, aerial photographs, laser scanning point clouds and data obtained by mobile mapping) to automatically generated 3D models (LOD1) and semi-automatically generated 3D models (3ds Max, Sketchup, IFC), see Table 1:

**Table 1**. Available test data in 3D Pilot NL

| Source | Dataset | Comments |
|---|---|---|
| Altererra | Voxels | with pollution information around a building |
| Cyclomedia | Cyclorama's | Interval 2.5m, acquired october 2010, available via GlobeSpotter webapplication and as central perspective cut-outs |
| Cyclomedia | Stereo10 and Ortho10 | Collected in October 2010, both stereo and ortho images available with 10cm resolution |
| Engineering office “Grandia” | Sketchup files of "De Rotterdam" | Currently being built in test area |
| Fugro | Lidar data | Acquired in november 2008, including classification (surface, nonsurface), intensity and RGB values, 30pnt per square meter |
| Horus Surround Vision | Panoramic video images | Including Horus Movie Player to view them |
| iDelft | CityGML, | 3 building models (LOD2 with ground surface), generated in SketchUp (in Collada) with oblique images |
| Kadaster | TOP10NL | Object oriented topographic data, scale 1:10k |
| Kadaster | Parcels | |
| Municipality Apeldoorn | Several 3D data sets | High detailed model of inner city and newly developed areas in MAX, also DEM (esi format), aerial photographs (10cm resolution) |

| | | |
|---|---|---|
| Municipality Rotterdam | Several 2D and 3D data sets | Buildings, cables and pipelines, large scale topography (scale 1:1k), 3DS-models of Erasmusbrug, IFC model of railway station (generated in AutoCAD Architecture), aerial photographs |
| Municipality Rotterdam | 3D city model, Rotterdam | LOD 1, without textures |
| Rijkswaterstaat | Digital Topographic Data (2.5D) | 2.5D data set available for areas that fall under the responsibility of Rijkswaterstaat |
| TNO Geologial Institute | Geological model of subsurface | Layered grids |
| TopconSokkia | Point data from dynamic laserscanning | with panoramic images, collected autumn 2010 |
| Toposcopie | Lod2 models | Self developed in test area |
| Waterschapshuis | AHN2 | Actual Height Model of The Netherlands, version 2, XYZ-point data and grids (both filtered and unfiltered), aerial photo's , collected in spring 2010, density 10 pnt per sq m |

In addition to these data sets, one of the partners (iDelft) made available a CityGML converter, to convert files in (Esri-) shape format to CityGML. On top of these input data sets several partners have (further) processed this data as part of the research on generating 3D data and information resulting in different types of 3D models of the test area. The achievements of these partners show different possibilities of generating 3D information (semi) automatically with existing and new (i.e. self developed) technologies (examples are shown in Figure 4):

**Toposcopie** generated a photorealistic 3D CityGML model. They collected Sketchup models from Google Earth within the test area, which were generated with Building Maker software based on aerial images and street view images. Toposcopie converted these Sketchup models in CityGML format and further improved the models with self developed software, such as conversion to the national reference system and enrichment with more details.

**Horus Surround Vision** constructed a 3D model from 360 degree video recordings in the test area (nearly real time), a different method to generate 3D information than the other participants used.

**IT-PRO-People** generated 3D buildings from 2D data and pointcloud data and inserted these in the 3D Oracle database of the test bed (see Section 4 on the test bed).

**ITC, University of Twente** applied self developed software to generate a 3D topographic model from laser data (reduced to 1-2 p/m$^2$) and TOP10NL data. Characteristics of both the vector (i.e. topographic class) and the laser data were combined to create 3D objects that either connected smoothly or with a jump in height (Oude Elberink, 2009).

**Object Vision** has generated a LOD1 3D model of not only the test area, but for the entire country using TOP10Vector data, AHN1 data (with a resolution one point per 16 square meter) and a grid database containing land use values for each cell. The 3D model is available via http://www.objectvision.nl/Geodms/products/3dshapes.htm. For the 3D pilot Object Vision furthermore studied the added value of AHN2 (which has a much higher resolution). Conclusion from this experiment is that LOD1 generated with AHN1 is well suited to make a 3D model of the whole country and that models based on input data with higher accuracy are better suited for local applications.

**Kadaster** generated a 3D TOP10NL from the high resolution laser points in the most straightforward way, by firstly adding a z-coordinate to every vertex and by secondly calculating the triangulation of AHN2 and assigning the thematic class of TOP10NL to every triangle.

**iDelft BV** developed software to automatically generate CityGML data of buildings using the footprints of the building with high resolution laserpoint data, textured with aerial photographs (for roofs) and terrestrial images. The surface is modelled with a Digital Terrain Model and visualized in a CityGML viewer. Currently iDelft works on automatically generating highly detailed data without using these footprints, which has the advantage of not having to deal with data sets of different topicality. The focus is on generating 3D models (in shape and CityGML) of large areas as automatically as possible. **Bentley** upgraded the available 2D data (TOP10NL and large scale topographic data at scale 1:1.000) into a 3D model with different Bentley software modules. The generated data is currently being exported to the CityGML database that is implemented in the 3D test bed (see Section 4). **Alterra** and **ITC University of Twente** both generated tree models of the laser point data based on different parameterization principles.

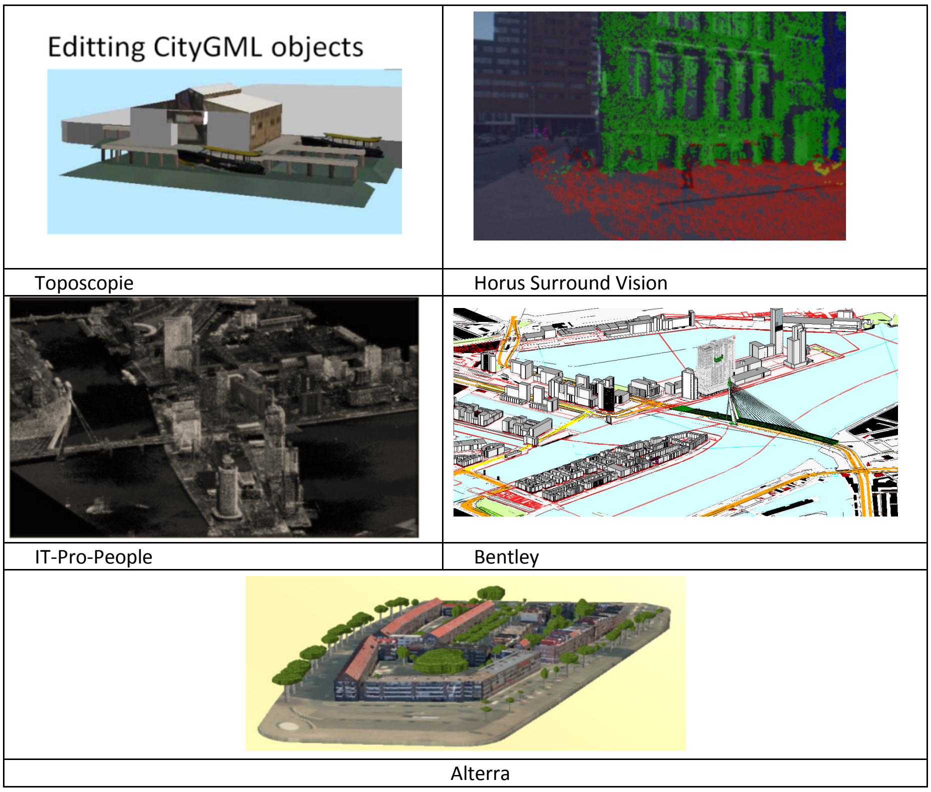



**Figure 4**: Examples of further processed data in 3D Pilot NL

The experiences of modelling the test area in 3D are currently being structured in an overview of available techniques to (semi) automatically generate 3D information as well as to upgrade 2D information to 2.5D and 3D. The aim of this overview is to support organizations with introducing 3D in these organizations, i.e. how to acquire the 3D data; which 3D data is already available; how to generate a 3D model; how much does it cost (both in terms of money and complexity), etc. A template is used for this inventory where the following criteria are being collected:

| | |
|---|---|
| Raw data | **Acquisition**<br>… description of raw data …<br>data type(s)<br>coverage of whole NL?<br>process of acquisition<br>available details<br>quality (positioning, actuality, coverage, …)<br>costs (price, business model) |
| From 1D/2D/3D data to 3D information | **Data sources**<br>…which 1D / 2D / 3D data was used<br>Data sources<br>Update process<br>Relevant precision<br>Quality |
| | **Preprocessing**<br>…description of processes from preparing original sources to integration and modelling 3D information<br>Quality improvements<br>Structuring<br>Ordering<br>Filtering |
| | **Combination**<br>… description of methods and techniques to integrate separate data sources:<br>Description of process<br>Level of automation<br>Improved precision in result |
| | **Modelling**<br>… structuring the result of integration to high quality 3D information<br>Starting data (format)<br>Precision, resolution<br>Quality |
| | **Conversion**<br>… which conversion were done to generate CityGML (and other exchange formats) from the generated 3D information<br>Required conversions<br>Optional conversion<br>Which information disappeared after conversion<br>Which information was added after conversion |

| | |
|---|---|
| | **Application**<br>… description how the information was used in the use cases, description of other potential use cases |

The findings of this inventory will be compared with the work of (Kaartinen and Hyypa, 2006).

Several conclusions can be drawn from the current experiences.

Many techniques to acquire 3D data and generate 3D information are available. In addition it is technically possible to further process 3D data and 2D data into detailed 3D object models. An unresolved issue encountered in the experiences is the generation of 3D information as integration of 3D point data and 2D topographic on the one hand and generation of 3D information based on 3D point data only on the other hand. The first technique has the advantage of knowing the properties for the objects that are to be constructed and has the disadvantage of inconsistencies between two data sets, whereas the second technique does not have to deal with consistency between two datasets but can also not benefit from the knowledge of existing objects. Next to this, the role that photogrammetry can play when it comes to creating 3D objects was also not prominent (we expected more from this).

A gap between the generated information and how it could be used in applications of the use cases was also experienced: Data was not available in the appropriate data format; the data contained too much or too little detail; hardly any objects were modelled as objects (only buildings); it was not straightforward to construct CityGML models (it is mostly a result of converting existing data), detailed semantics is greatly missing in most data. The gap became smaller at the end of the project when use case owners had further processed the initially available data (see Figure 3).

## 4 Design and implementation of the 3D test bed

The aim of the test bed was to establish a "dedicated 3D research environment where services and data can be experimented upon, results can be evaluated and outcomes shared with the rest of the community". Besides this focus on technical aspects, the 3D test bed appeared to be an indispensable instrument to succeed in the general objectives of the 3D Pilot, i.e. realize a proof of concept for a 3D SDI (both at the national level and in specific organizations) to increase the use of 3D applications. In this context the 3D test bed serves as (independent) environment where all test data can be up- and downloaded and as a testing environment for all pilot partners to experience with (new and advanced) 3D technology and reflect upon this in the plenary meetings

Besides a server that hosts all (file based) data of the test area, the '3D test bed' contains the database which implements CityGML in Oracle 11 according to http://opportunity.bv.tu-berlin.de/software/projects/3dcitydb (realized by section GIS technology of the TU Delft). This 3D City Database is a free 3D geo database to store, represent, and manage virtual 3D city models on top of a standard spatial relational database. The database scheme is based on CityGML. Users can upload and download data with a Java based frontend called 3D City Database Importer/Exporter.

Through empirical research several tools have been investigated that complement the 3D test bed implementation: CityGML viewers (such as Aristoteles, CityViewer, LandXplorer, FZK Viewer) and CityGML converters, like FME, RCP by Virtuelcity, SketchUp Plugins, etc. Future research will also study Web Services for access to the database, independent of the software systems used.

The aim of the 3D test bed was to collect all the (enriched) data that is generated in the use cases in one central database in a CityGML data scheme. However, our experiences show that it is not straightforward to convert the data that the pilot partners generated in the use cases into CityGML. Four partners have worked on converting the generated data into CityGML, they are iDelft, Bentley, MOSS, and Toposcopie. Figure 5 shows the work in progress of Bentley.

**Figure 5.** Integrated view of data generated in all uses cases

Bentley collected the generated data of all uses cases in their CAD environment. For each 3D Pilot result data set (3D Shape, Sketchup, point cloud, solids of soil layers, tree models in shape, IFC model) the appropriate Bentley software module was used to insert the data in their CAD environment. The next steps are the conversion of all data into CityGML scheme, which is available in Bentley MAP and the upload to the central CityGML database. This work is currently being performed (no results can be reported yet).

The main conclusion from the research of the test bed is that awareness of CityGML was lacking with the project partners at the beginning of the research (March 2010) and has grown significantly during the course of the pilot. As a direct result, the database was, unfortunately, rarely used in the first eight months of the project. In contrast: the data server that hosts the test data in other file formats was frequently used. The reason for this is mainly that CityGML is not (yet) a common standard in The Netherlands. In fact, at the start of the project, many partners expressed resistance (or reservations) to use it, because it was considered to be too generic (no object definitions) and not supportive of specific information needed for certain applications nor supportive of complex geometries. Other problems identified were the focus on objects above the surface, the use of CityGML as both exchange and information model (i.e. not clear how to use it), poor maintenance of LODs (it is not clear when an object should be LOD2 or LOD3; no relationships between LODs), no support for geometry validation by the commercial software systems and by the CityGML database and lack of software to generate CityGML data (besides the conversion of existing data sets) which results in much work to generate CityGML compliant data.

From both the use cases and the experiences with the test bed, as well as from the work done by the 3D data supply and the standardization groups, the importance of having a standard that aligns with an international standard became clear however. At the end of the project it was therefore no longer a question if we should use CityGML but how we could use CityGML while serving our (national) needs and applications (i.e. making the generic CityGML standard more specific for our national context).

The test bed addressed these questions (of how to use CityGML as exchange standard for national requirements, applications, and information models). The 3D test bed group encouraged the pilot partners to use the CityGML part of the test bed during the second half of the research. A free course '100% CityGML' (with contribution of TU Berlin) as well as a CityGML helpdesk were offered to help partners to learn more about the standard. In addition the test bed implemented a validation tool for the 3D geometries, based on the work of Ledoux et al. (2009).

All these actions were taken to build awareness for CityGML in the Netherlands and to encourage the project partners to test CityGML in their day-to-day 3D applications. It was assumed that the increased use would further develop the CityGML-NL standard and technologies because it would show how CityGML and the supporting technologies should be extended to make it fit to the Dutch context. This is the topic of the next section.

## 5 3D Standard NL

Important for an SDI supporting 3D geo-information is a standard that defines both the geometry and semantics of objects in 3D in a detailed way. As stated before, CityGML is a relevant international "downstream" standard that can be used to further specify a standard for 3D geo-information in Dutch context. In addition, the 3D standard NL should be compatible to 3D standards in other domains in order to allow for an easy exchange of 3D information. The group that had the task to formulate recommendations for a 3D standard NL started by studying existing 3D standards in both CAD/BIM domain and Geo-Information (GI) domain. The results are described in Section 5.1. Later this group studied the extension of the generic model of CityGML to meet the specific Dutch application contexts. The results of this study are summarized in Section 5.2.

### 5.1 Comparison between 3D standards

For the comparison between available 3D standards, we selected the most common 3D standards in both CAD/BIM and GI domain. Table 2 shows the results of the evaluation.

**Table 2:** Comparison of 3D standards

| 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

The explanation of the different criteria that were used in the comparison is as follows:

The criterion '*geometry*' estimates the support of 3D geometries. Standards that support only the simple features (point, line, surface and possibly polyhedron) are classified as giving support to 3D features. Standards that allow use of parametric shapes (cylinders, spheres, etc.), freeform curves and surfaces, sweep representations, etc. are considered to have 'extended' support.

*Topology* evaluates the existence of relationships between the geometries in the model. The basic support means that very simple relationships are stored. For example a 3D object in VRML and X3D is represented by two lists of: 1) all the nodes in the object and 2) polygons which use the sequential number of the nodes (thus no duplication of nodes is required). IFC does not have a topology in terms of neighbourhood relationships but these can be derived from the maintained containment relations. CityGML theoretically supports a topological data structure as specified by OGC but no model thus far has been created using this topology.

*Texture* evaluates the support of texturing with real photos. Standards that support texture mapping (co-registration of images and geometry) are classified as 'supported'. Standards have extended texture possibilities if they allow both texture mapping and texture draping.

*Levels of Detail (LOD)* is an indication for support of several geometries per object. In the case of VRML and X3D this is used for visualization (the browsers use them to speed up the visualization). In the case of CityGML these are used to indicate the resolution (a bit like a scale) an object is represented in. The browsers do not use them in the visualization (in case of several LOD's some browsers show all of them).

*Objects* criterion estimates the possibility to distinguish between different objects in terms of geometry. DXF is layer-based, but has some basic tools to group geometries to indicate that this is one entity within a layer. Using KML and Collada the user should pay a lot of attention to the creation of the file in order to recognize different objects. The best way to keep track of objects is to create separate files. These two standards are therefore indicated as not supporting objects.

*Semantics* indicate the possibility to assign thematic meaning to an object or a group of objects. Using DXF, SHP and 3D PDF this is possible by the names of the layers. Much information regarding the objects can be included as text in a PDF file. IFC and CityGML are considered to have extended possibilities because the classes are well-defined in advance. All other standards allow some basic tricks to get thematic information attached to geometries (by anchors, annotations, etc.)

*Attributes* estimates the possibility to incorporate attributes in the standard. The most elaborated concept is the SHP standard (in combination with the database file). IFC and CityGML both have standard well-defined attributes per object. The attributes of the object in 3D PDF can be listed in the document part next to the 3D geometry.

The criterion *XML* indicates whether the standard is XML-based.

*Web* criterion gives an indication which standards are designed and optimized for Web use. X3D is actually an improved version of VRML. KML (once loaded) has better performance than the current CityGML browsers. Large 3D models create 3D PDF files that are too big and therefore this standard is ranked lower.

*Geo-referencing* estimates the possibility to use geographical coordinates. It should be noticed that there is a version of VRML, i.e. Geo-VRML, which works with geographical coordinates. There are currently discussions on how to incorporate geographical coordinates in IFC.

*Acceptance* indicates the support of the standard by software vendors.

From this comparison it can be concluded that every 3D standard has its own characteristics based on specific purposes. Because of the support of semantics, objects, attributes, georeferencing and Web use, the selection of CityGML as generic standard for 3D SDI envisaged in this study is justified.

Further agreements are necessary to use CityGML as a standard in a specific context, i.e. which additional classes, attributes and attribute values are necessary? Which geometry type should be used for specific object classes? Which codes should be added to the code lists of CityGML to make the code lists appropriate for a specific context? Which Level Of Detail should be used for certain applications? How can concepts from other domains be defined in CityGML (e.g. apartment units)? How can the validity of 3D geometries be enforced? This is studied in the next section.

### 5.2 CityGML and the Dutch Domain Information Models

From the previous findings and conclusions, three prerequisites for the 3D standard NL can be formulated:

a) The 3D standard NL should be compatible with CityGML to be able to use (commercial and open source) applications that are CityGML compliant.
b) Further agreements are necessary to use the generic CityGML standard in a specific Dutch application context, i.e. extend CityGML with new classes, attributes and attribute values. Since the specific contexts are defined in the Dutch domain models, it was decided to study the refinements of CityGML from the perspectives established in these models.
c) The Dutch domain models need to be extended with 3D concepts because in their initial creation these domain models focused on 2D. These extensions should be based on CityGML.

The steps necessary to define the 3D standard NL as further specification of the CityGML model to support a 3D SDI are therefore:

1. Extend CityGML so that it supports the concepts defined in the domain models. This step is done in consultation with OGC, i.e. it is foreseen that the 3D Pilot will submit change requests and proposals for Application Domain Extensions. To prepare this, the intermediate results of the 3D Pilot have been presented at several OGC meetings.
2. Extend the domain models with a notion of 3D compliant with CityGML.
3. Map the 3D concepts from the domain models to CityGML.
4. Use these mappings to translate data compliant with the (3D) domain models to CityGML data so that it can be understood by technologies that support CityGML.

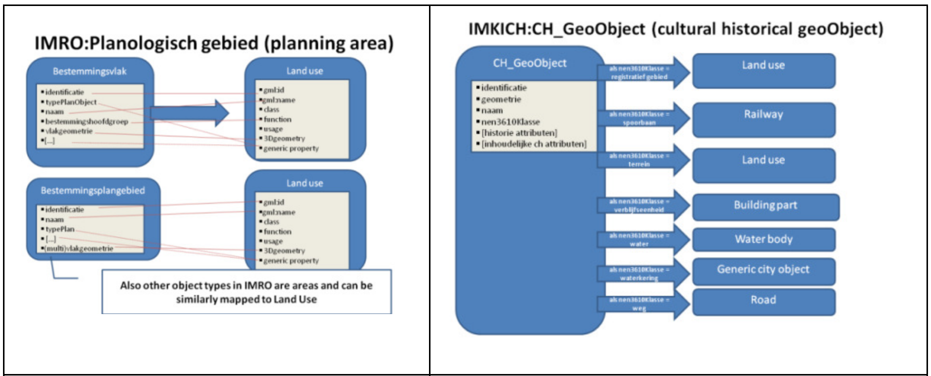
To extend CityGML with the concepts in the domain models (step 1), at first a study was performed on which classes are defined in the current (relevant) domain information models and on how these relate to CityGML classes. In this comparison the focus was on the semantics. First the relevant classes, attributes and attribute values in CityGML were identified. See Table 3 for the relevant CityGML classes.

**Table 3**: Relevant CityGML classes

| | | |
|---|---|---|
| *Building*<br>• Building<br>• Building part<br>• Building installation<br>• Interior building installation<br>• Building furniture | *Infrastructure*<br>• Road<br>• Railway<br>• Square<br>• Track<br>• Traffic area<br>• Auxiliary traffic area | *Water*<br>• Water body<br>• (Water surface)<br>• (Water ground surface) |
| *Vegetation*<br>• Plant cover (forest, gras)<br>• Solitary vegetation object | *Terrain*<br>• Land use<br>• Breakline relief | *Other*<br>• Generic city object<br>• City object group |
| *Street objects*<br>• City furnitute | | |

The concepts modelled in the Application Domain Extensions of CityGML were also checked. These are: Noise, Tunnel, Bridge, GeoBIM, Facility Management, Hydro, and Utility Networks.

Figure 6 shows the comparison study for the planning area in IMRO and cultural historical object in IMKICH.




a b

**Figure 6**: Comparison between planning area (IMRO) and cultural historical object (IMKICH) and CityGML

Table 4 summarizes the comparison for each selected domain model, which shows the potentials of mapping concepts between the specific model and CityGML (step 3). For the Information Model on large scale topography (IMGeo) a more detailed study is being carried out that also performs steps 3 and 4, see further in this section.

**Table 4:** Comparison of Dutch domain information models and CityGML scheme

| | |
|---|---|
| IMOOV<br>*Public Order and Safety* | IMOOV objects: Buildings, Furniture (city and building), Water<br>Thematic mapping is possible from IMOOV to CityGML<br>The other way around information is lost since IMOOV has more attributes and more classes. This can be solved for attributes by mapping them to generic properties. Mapping of some IMOOV objects is uncertain because of the unclear definition of CityGML classes (Building Part). |
| IMKL<br>*Cables and Pipelines* | Utility ADE of CityGML is generic (graph structure)<br>Mapping from IMKL to CityGML is straightforward (for semantics)<br>Differences: IMKL has classes for different network types, categorized according to their physical nature (e.g. pipe, cable),with different attributes and classes for users; geometry is an attribute (not a graph). The classes in the Utility Networks ADE are categorized according to use theme.<br>Classes in IMKL not relevant to map to CityGML:<br>Responsible person, theme map, detailed map, annotation, topography, measurements |
| IMRO<br>*Land Use* | Only mapping to the CityGML class Land Use; no real topographic objects |
| IMKICH<br>*Cultural and Historical elements* | IMKICH has domain specific objects of which it is not clear how to extend these to the 3rd dimension.<br>However links to topographic objects exists:<br>Buildings, areas, constructions, water, road, railway |
| IMKAD<br>*Cadastral parcels* | IMKAD: spatial object scan be mapped to generic CityGML classes (Land use, Building part, Address); no mappings possible for persons and rights<br>IMKAD apartment rights can be mapped semantically to Building part, but there is no geometry for apartment rights available in IMKAD.<br>Other objects in IMKAD are not geo-objects (e.g. aeroplanes, ships, deeds)<br>Cadastral boundaries are not mapped; only the parcels themselves |

| | |
|---|---|
| IMWA<br>*Water* | IMWA objects can be mapped to Land Use, Water Body, City Furniture, Road, Traffic area, and Genetic City Object (for measurements)<br>Mapping IMWA to CityGML is possible; the other way around is not, since IMWA has more attributes. This can be solved for attributes by mapping them to generic properties.<br>IMWA bridge and tunnel objects can be mapped to the Bridge and Tunnel ADEs. IMWA contains more types of man-made objects , as well as classes for river banks and dams/weirs that have no equivalent in CityGML.<br>In IMWA some object types have information on the material which could be mapped using the CityGML Appearance model.<br>The IMWA class for waterbodies has two different classifications of equal weight; in CityGML the Waterbody class attribute is only allowed to occur once.<br>IMWA has properties that have complex values. These cannot be mapped to generic properties, because those must have simple values. |
| IMNAB<br>*Nature management* | IMNAB objects can be mapped to Land Use |
| IMBRO (not final)<br>*Soil and subsurface* | CityGML has no support for geology (yet); Relationships with GeoSciML; GeoBIM; subsurface manmade and natural objects and Observations&Measurements (OGC standard)<br>IMBRO has no solids; only surfaces |
| IMMetingen<br>*Measurements* | Specific thematic classes<br>Specific attributes per class<br>Information about measurements<br>Most objects are 3D |

From this study the conclusion can be drawn that (not surprisingly) the domain models contain more specific information on most concepts than CityGML does. Further study should identify which extra classes, attributes and attribute values (as extensions of the CityGML code lists) are required in CityGML to support the concepts defined in the Dutch domain models.

Extensions of CityGML to serve the Dutch context may either serve all Dutch domain models or may serve a specific domain only. The extensions that serve a generic 3D standard NL ( i.e. at NEN 3610 level in Figure 1) may be modeled in CityGML with the standard extension possibilities of generic properties and Generic City Object. The domain specific extensions may be handled by (new) CityGML Application Domain Extensions. An example of an extension on generic level is a further specification of when to use which LOD. An example of an ADE would be an ADE for cadastral domain with support of a 3D parcel object class or an ADE for geological domain.

The proposed extensions of CityGML to support concepts from specific domains build on previous research. For geology the research of (Tegtmeier et al, 2009) and (Zobl and Marschallinger, 2008) will be used. For 3D cadastre a link will be made with the ISO 19152 Land Administration Domain Model, where 3D cadastral objects are defined, also spatially (see Lemmen et al, 2010). For cables and pipelines, the work of Becker (2010) and Hijazi (2010) is relevant.

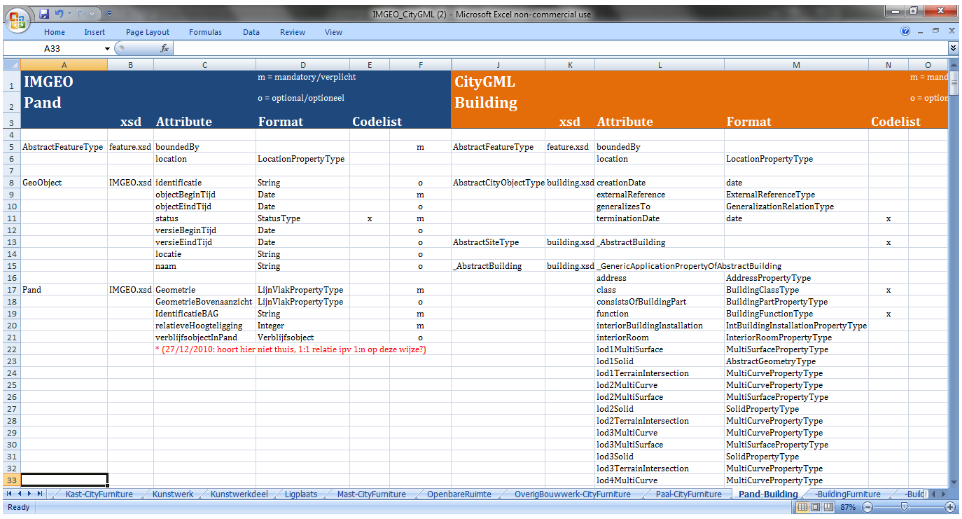
To exploit step 1 and 2, a study is currently being performed in collaboration with the use case owners on how the domain models can include the notion of 3D compliant with CityGML and how CityGML should be extended to serve the various use cases. The next steps will be the mapping between the 3D-aware Dutch Information Models and CityGML (step 3) and the ultimate translation of data compliant with the Dutch domain models to extended CityGML (step 4). These steps are being studied in more detail for the Information Model Large Scale Topography (called IMGeo).

*Information model for 3D topography*

A more detailed comparison was carried between CityGML and IMGeo to actually create an information model that extends the current domain model in the third dimension compliant with CityGML. This study also address the methods to generate the defined 3D information (see Section 3).

At first, a comparison between both models has been performed as was done for the other domain models. See Figure 7 for the concept 'Building' (*pand* in Dutch). From this comparison it can be concluded that IMGeo and CityGML contain mostly the same object classes. But here it can also be seen that CityGML is generic and needs extensions to be able to include all concepts from IMGeo. The study currently identifies which extensions are needed.

Step 2 of the above action plan (extending IMGeo with the notion of 3D compliant with CityGML) is currently under investigation which includes issues such as: What is the required content of a 3D topographical data set? Which objects are required in full 3D, as solids? For which objects is a description in 2.5D sufficient? How can volume objects be integrated in the descriptions of the terrain? Which LOD is required for which application? How can 3D information be generated as an extension of already available 2D topographic data?



| | A | B | C | D | E | F | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | IMGEO | | | m = mandatory/verplicht | | | CityGML | | | | | m = mand |
| 2 | Pand | | | o = optional/optioneel | | | Building | | | | | o = option |
| 3 | | xsd | Attribute | Format | Codelist | | | xsd | Attribute | Format | Codelist | |
| 4 | | | | | | | | | | | | |
| 5 | AbstractFeatureType | feature.xsd | boundedBy | | | m | AbstractFeatureType | feature.xsd | boundedBy | | | |
| 6 | | | location | LocationPropertyType | | | | | location | LocationPropertyType | | |
| 7 | | | | | | | | | | | | |
| 8 | GeoObject | IMGEO.xsd | identificatie | String | | o | AbstractCityObjectType | building.xsd | creationDate | date | | |
| 9 | | | objectBeginTijd | Date | | m | | | externalReference | ExternalReferenceType | | |
| 10 | | | objectEindTijd | Date | | o | | | generalizesTo | GeneralizationRelationType | | |
| 11 | | | status | StatusType | x | m | | | terminationDate | date | x | |
| 12 | | | versieBeginTijd | Date | | o | | | | | | |
| 13 | | | versieEindTijd | Date | | o | AbstractSiteType | building.xsd | _AbstractBuilding | | x | |
| 14 | | | locatie | String | | o | | | | | | |
| 15 | | | naam | String | | o | _AbstractBuilding | building.xsd | _GenericApplicationPropertyOfAbstractBuilding | | | |
| 16 | | | | | | | | | address | AddressPropertyType | | |
| 17 | Pand | IMGEO.xsd | Geometrie | LijnVlakPropertyType | | m | | | class | BuildingClassType | x | |
| 18 | | | GeometrieBovenaanzicht | LijnVlakPropertyType | | o | | | consistsOfBuildingPart | BuildingPartPropertyType | | |
| 19 | | | IdentificatieBAG | String | | m | | | function | BuildingFunctionType | x | |
| 20 | | | relatieveHoogteligging | Integer | | m | | | interiorBuildingInstallation | IntBuildingInstallationPropertyType | | |
| 21 | | | verblijfsobjectInPand | Verblijfsobject | | o | | | interiorRoom | InteriorRoomPropertyType | | |
| 22 | | | * (27/12/2010: hoort hier niet thuis, 1:1 relatie ipv 1:n op deze wijze?) | | | | | | lod1MultiSurface | MultiSurfacePropertyType | | |
| 23 | | | | | | | | | lod1Solid | AbstractGeometryType | | |
| 24 | | | | | | | | | lod1TerrainIntersection | MultiCurvePropertyType | | |
| 25 | | | | | | | | | lod2MultiCurve | MultiCurvePropertyType | | |
| 26 | | | | | | | | | lod2MultiSurface | MultiSurfacePropertyType | | |
| 27 | | | | | | | | | lod2Solid | SolidPropertyType | | |
| 28 | | | | | | | | | lod2TerrainIntersection | MultiCurvePropertyType | | |
| 29 | | | | | | | | | lod3MultiCurve | MultiCurvePropertyType | | |
| 30 | | | | | | | | | lod3MultiSurface | MultiSurfacePropertyType | | |
| 31 | | | | | | | | | lod3Solid | SolidPropertyType | | |
| 32 | | | | | | | | | lod3TerrainIntersection | MultiCurvePropertyType | | |
| 33 | | | | | | | | | lod4MultiCurve | MultiCurvePropertyType | | |

**Figure 7:** Comparison between IMGeo pand (building) and CityGML building in Excel.

In step 3 the comparison (i.e. mapping at the conceptual level) is translated into formal mappings in order to be able to perform step 4, i.e. translate (3D) IMGeo data to CityGML data so that it can be understood by technologies that support CityGML. The formalization of mappings is done with the alignment editor software “HALE” (Reitz et al, 2010). This software can map and transform complex application schemes. It allows the user to define any type of mappings (i.e. 1:1, 1:n, m:n, n:1) between two information models (available as XSD) and to use these mappings to translate the underlying data between two information models in a later stage (step 4). These four steps will implement 3D IMGeo which will be tested with real data.

The experiences on 3D IMGeo (for large scale topography) will be used to also extend the information model for small scale topography in 3D for applications that require more overview and less detailed data (1:10.000 and smaller) and to generate 3D topographic data accordingly.

## 6. Conclusions

This paper presents a large research project in the Netherlands in which many stakeholders are collaborating to push 3D applications in the Netherlands. Use cases have been defined and executed, a 3D test bed has been designed and implemented, many test data sets have been made available and have been further processed by the project partners. Several studies are carried out to extend the established Dutch domain information models into the third dimension and align these to the CityGML OGC standard. In addition CityGML extensions are studied to include the concepts of the Dutch domain models to realize a 3D standardization framework-NL serving a Dutch 3D SDI. These CityGML extensions may be either generic for the Dutch context or limited for a specific domain. These last extensions may contribute to Application Domain Extensions (ADE) of CityGML in development, such as underground constructions, cables and pipelines and integration with Building Information Models.

The innovation of the research is that several aspects of 3D SDI (needs, data, test bed and standards) are studied in coherence to ultimately define a generic approach for 3D covering all these aspects. In the research 3D applications, 3D data, 3D test bed and 3D standard NL are developed, further refined and aligned, based on the integrated study on these basic components of a 3D SDI.

The research will finish in March 2011 and will result in recommendations for a generic approach for 3D geo-information in the Netherlands addressing several aspects for a 3D SDI, both at the national level and in specific organizations (for example a municipality).

To inform others about the results (i.e. the 3D standards, the generated data, the experiences from the use cases and the test bed) and to increase awareness for 3D at governmental organizations (one of the motivations of the research), a public final session is organized in June 2011.

Defining the generic approach for 3D in the Netherlands is one step to establish the 3D SDI and to push forward 3D applications. However the results needs further attention when these are applied in practice. A continuation of the project is therefore currently considered proceeding from the orientation phase as detailed in this paper to the implementation and institutional phases of the 3D SDI. Many research challenges are still open in implementing and institutionalising the 3D SDI. These will be dealt with in the follow-up project.

## References

Becker, T., C. Nagel and T.H. Kolbe, 2010, Integrated 3D modeling of multi-utility networks and their interdependencies for critical infrastructure analysis, 5th International 3D GeoInfo Conference, November 2010, Berlin

Berlo,L. and R. de Laat, 2010, Integration of BIM and GIS: The development of the CityGML GeoBIM extension, 5th International 3D GeoInfo Conference, November 2010, Berlin

Borrmann, A., 2010, From GIS to BIM and back again – A Spatial Query Language for 3D building models and 3D city models, 5th International 3D GeoInfo Conference, November 2010, Berlin

El-Mekawy, M.S., A. Östman, K. Shahzad, 2010, Towards Interoperating CityGML and IFC Building Models: A Unified Model Based Approach, 5th International 3D GeoInfo Conference, November 2010, Berlin

Geonovum, 2011, http://www.geonovum.nl/geostandaarden/informatiemodellen

Hijazi,I., M. Ehlers, S. Zlatanova, T. Becker, L. van Berlo, 2010, Initial investigations for modeling interior Utilities within 3D Geo Context: Transforming IFC-interior utility to CityGML/UtilityNetworkADE, 5th International 3D GeoInfo Conference, November 2010, Berlin

Isikdag, U. and S. Zlatanova (2009) A SWOT Analysis on the Implementation of Building Information Models within the Geospatial Environment, In: Krek, Rumor, Zlatanova, Fendel (Eds.); Urban and Regional data Management, UDMS Annuals 2009, Taylor & Francis/CRC Press, pp. 15-30

Isikdag, U. and S. Zlatanova (2009b) Towards defining a framework for automatic generation of buildings in CityGML using Building Information Models
In: J. Lee and S. Zlatanova (Eds.); 3D Geo-Information Sciences, Springer, 2009, pp. 79-96

Kaartinen, H. and Hyypa, J., 2006. Evaluation of Building Extraction - Report. In EuroSDR Official Publication No.50. 284 pages. ISBN 9789051794748. [Accessible from: http://www.eurosdr.net/2002/publications/publications.asp]

Ledoux,H., E. Verbree and Hang Si, 2009, Geomatric Validation of GML Solids with the Constrained Delaunay Tetrahedralization, In: De Mayeer, Neutens, De Rijck (Eds.); Proceedings of the 4th International Workshop on 3D Geo-Information, November 2009, Ghent, pp. 143-148

Lemmen, C., P. van Oosterom, R. Thompson, J.P. Hespanha and H. Uitermark, 2010, The Modelling of Spatial Units (Parcels) in the Land Administration Domain Model (LADM)
In: Proceedings of the XXIV FIG International Congress 2010, April 2010, Sydney, 28 p.

Oude Elberink, S.J., 2010. Acquisition of 3D topgraphy : automated 3D road and building reconstruction using airborne laser scanner data and topographic maps. Enschede, University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC), 2010. ITC Dissertation 167, 171 p. ISBN: 978-90-6164-288-6

Reitz, Thorsten Daniel Fitzner, Eva Klien and Ulrich Schäffler and Ulrich Schäffler, 2010, Efficient Conceptual Schema Translation for Geographic Vector Data Sets, AGILE 2010 Conference.

Stoter, J.E., M. Reuvers, G. Vosselman, J. Goos, L. van Berlo, S. Zlatanova, E. Verbree, R. Klooster, 2010, Towards a 3D geo-information standard in The Netherlands, 5th International 3D GeoInfo Conference, November 2010, Berlin

Tegtmeier,W., Peter van Oosterom, Sisi Zlatanova and Robert Hack, 2009, Information management in civil engineering infrastructural development: with focus on geological and geotechnical information, In: Kolbe, Zhang, Zlatanova (Eds.); Proceedings of the ISPRS workshop, Volume XXXVIII-3-4/C3 Commission III/4, IV/8 and IV/5: Academic track of GeoWeb 2009 conference, July 2009, Vancouver, pp. 68-73

Vosselman, G., Kessels, P., Gorte, B.G.H., 2005. The Utilisation of Airborne Laser Scanning for Three-Dimensional Mapping. International Journal of Applied Earth Observation and Geoinformation 6 (3-4): 177-186.

Zobl, F., and R. Marschallinger (2008), Subsurface GeoBuilding Information Modelling GeoBIM, GEOinformatics, 8, volume 11, December 2008, p40-43.