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Report

Establishing and implementing a national 3D Standard in The Netherlands

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Summary: This paper describes the 3D developments achieved within the 3D Pilot NL. The first phase of this pilot (January 2010 – June 2011) resulted in a national 3D standard, modeled as CityGML application domain extension (ADE). This standard is briefly explained in this paper. To implement this standard as a nationwide 3D dataset, further research was needed. The second phase of the 3D Pilot finished in December 2012 developed tools, techniques and guidelines to support the implementation of the 3D standard. These are: 1) implementation specifications for the national CityGML ADE to be used in tendering documents, 2) example data compliant to the 3D standard, 3) 3D validator, 4) guidelines to update 3D datasets, and 5) 3D application showcases. These instruments are further explained and presented in this paper.

Zusammenfassung: *Entwicklung und Implementierung eines nationalen 3D Standards in den Niederlanden*. Der Beitrag beschreibt den aktuellen Stand des niederländischen Projektes 3D Pilot NL und zugehörige Entwicklungen zur 3D-Datenmodellierung. Die erste Phase des Projektes führte von Januar 2010 bis Juni 2011 zu einem nationalen 3D Standard, der als Application Domain Extension (ADE) von CityGML modelliert wurde. Für seine Implementierung und Anwendung auf einen landesweiten 3D-Datensatz waren weitere Untersuchungen erforderlich. In der im Dezember 2012 beendeten zweiten Phase des 3D Pilot NL wurden Hilfsmittel für die Implementierung entwickelt: 1.) eine Implementierungsrichtlinie der nationalen Application Domain Extension (ADE) für CityGML zur Verwendung in Ausschreibungen, 2.) Beispieldatensätze, 3.) ein 3D Validator für die Konsistenzprüfung von Datensätzen, 4.) eine Richtlinie für die Fortführung der 3D Daten und 5.) Anwendungsbeispiele. Diese Werkzeuge werden hier vorgestellt.

1 Introduction

This paper describes the definition, establishment and implementation of a national 3D standard in The Netherlands, which was accomplished within the 3D Pilot NL. The Kadaster, Geonovum, the Dutch Geodetic Commission and the Ministry of Infrastructure and Environment initiated the pilot in 2010. The aim of 3D Pilot NL is to push 3D developments in the Netherlands by collaborating with a wide variety of stakeholders on a test bed, a test area and use cases. The 3D Pilot community consists of almost 600 people coming from over 100 organisations.

The activities of the 3D Pilot cover two phases: an explorative phase, carried out between January 2010 and June 2011 and an implementation-oriented phase, finished at the end of 2012.

The major achievement of the first phase was the establishment of a national 3D standard. This standard is embedded in a formal information model, called “Information Model Geography” (IMGeo). IMGeo contains definitions of 2D large-scale representations of

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objects as roads, water, land use/land cover, bridges and tunnels. As IMGeo is modelled as an application domain extension (ADE) of the OGC 3D standard CityGML (OGC 2012). The information model facilitates extensions to 2.5D, i.e. surfaces, equivalent to CityGML LOD0, and 3D, i.e. volumetric representations, CityGML LOD1, LOD2 and LOD3 of the objects according to the geometric and semantic principles of CityGML. See Van den Brink et al. (2012a, 2013) for details.

The advantage of this approach is that firstly the 3D standard builds on 2D efforts, which makes 3D feasible for governmental organisations. Secondly, 2.5D and 3D geometries can be combined in one dataset and depending on the application the most appropriate geometry type per feature class can be chosen. For example, hydrological modelling in urban areas may require accurate 2.5D geometry descriptions of the terrain while block models suffice for the buildings (Fig. 1).

Although the 3D standard is an important prerequisite for 3D applications, wide use of 3D is still not common practice in the Netherlands. The implementation of the 3D standard requires further agreements. This also covers agreements on how to implement CityGML. CityGML allows freedom in its implementation, while a national standard needs clear implementation rules. Therefore, the second phase of the 3D Pilot developed a set of instruments to support the implementation of the national CityGML ADE.

This paper focuses on the second phase of the 3D Pilot and describes the implementation tools and documents that have been developed (section 2). More details on the 3D Pilot can be found in Stoter et al. (2013) and Stoter et al. (2011). The paper ends with conclusions and future research in section 3.

Many others have done significant work in this area. For example North-Rhine Westphalia in Germany has been the first state that provides a statewide 3D model consisting of 3D roads, railways, DTM, and 3D buildings employed for noise dispersion mapping (Czerwinski et al. 2006, 2007). The extension of the German national cadastre model ALKIS towards 3D building models is another important CityGML implementation. In this project a CityGML profile has been defined and most states in Germany provide 3D building models according to this profile. In addition, the INSPIRE data specifications for buildings contain a 3D building profile in line with the CityGML specifications for buildings. Finally, different application domain extensions have been developed. Examples are noise as used in the German state North-Rhine Westphalia and as documented within the CityGML specification, utility networks (Becker et al. 2013), real estate management, robotics, building information models (BIM), and hydrography (CityGML 2013).

This paper extends these previous works, because the unified modeling language (UML) concept for ADEs is not well described in the OGC specifications and experiments on implementing such CityGML extensions are new. Nevertheless, ADEs are and have been specified without UML. Therefore, an important contribution of this project is gaining insights in the procedure of specifying CityGML-profiles with the help of UML to make the standard suitable for a specific context. In addition, the paper may be considered to address a solution, which is limited to one specific country. However, the presented implementation has many global solutions, which are of great interest both for other countries and domains. The wide focus of the CityGML implemen-

Fig. 1: 3D IMGeo for hydrological modelling.

tation is also new. Current CityGML models focus mainly on buildings, while the 3D standard in this paper covers all topographic classes. Therefore, the study of feature classes other than buildings is another contribution. Finally, many vendors from abroad are among the stakeholders involved in this research projects. The list of participants is published at Geonovum (2013a). Therefore, the experiences of this pilot are not only of interest for a specific country. Instead, the 3D Pilot activities have contributed to developments and growing insights worldwide. This is why the delivered instruments and documents have been offered as best practice and discussion material to the OGC working group on CityGML. See for example Van den Brink et al. (2012b).

2 Implementation of the 3D Standard

After it was decided that the national 3D standard should align to both the national 2D information model on large-scale topography (IMGeo 1.0) and the international standard CityGML, the integration of IMGeo and CityGML into IMGeo version 2.0 was the next step, currently evolved into version 2.1 because of minor changes. This was realized by modelling all IMGeo classes as an extension of CityGML classes. In this process the semantics of CityGML was followed as much as possible. Not for all classes in the national model, an equivalent CityGML class could be found. If possible, this was solved by remodelling the classes in the national standard. Examples of remodelling national concepts are the CityGML class AuxiliaryTrafficArea applied for those parts of roads that are not used for traffic but formerly modelled as roads, and the class Vegetation, formerly modelled as CityFurniture for isolated trees and Land Use for plant cover areas. Often the remodelling resulted in an improved modelling of the national concepts. More details on how IMGeo 2.1 was modelled as an Application Domain Extension of CityGML with a UML-based approach can be found in Van den Brink et al. (2013).

After establishing the 3D standard, the next step was its implementation. This refers to a generation of data according to the standard as an extension of the existing 2D data. For this implementation more research was required to understand how the national 3D standard works in practice including the consequences of this new modelling method for IMGeo when applied to both 2D and 3D datasets: How can 2D LOD be upgraded to LOD0 and higher? How can the standard-compliant 3D data be validated and maintained? Also, more insight was needed to the ability of using 3D IMGeo data in CityGML-aware software packages: Are the software systems compatible with the national extensions and which changes are necessary to support the extensions?

These questions have been studied in the second phase of 3D Pilot NL with the main goal to achieve wide consensus on the implementation of the national 3D standard and to explain these agreements to the wider public. The results of this part of the Pilot are ready-to-use instruments available as a toolkit at Geonovum (2012a) that data producers can apply to extend existing 2D IMGeo data into 3D, to maintain it and to use the 3D data in applications.

The ready-to-use instruments, which are detailed in the following subsections, are:

- Implementation specifications for creating 3D data compliant with the national 3D standard;
- Example 3D IMGeo data for several levels of detail and classes;
- 3D validator;
- Guidelines for maintenance, update and dissemination of 3D IMGeo data;
- A web site that collects 3D showcases and portrays these to the wider public to inspire newcomers.

2.1 *Implementation Specifications for Standard-compliant 3D Data*

The national 3D standard IMGeo needs agreements on the precise implementation of the generic standard CityGML. These additional agreements both clarify and unify the demand for the national 3D data and assure a country-wide uniform 3D dataset.

The 3D Pilot participants assumed that these agreements would also be important in tendering processes, since they assure that expectations of governmental organisations (who will mostly outsource their data acquisition) and companies (who will acquire the data accordingly) are aligned. In addition, most governmental organisations lack experience with 3D data and therefore it will be difficult for them to specify the expected 3D deliverables. For those municipalities, the implementation specifications may serve as an important source for their tendering documents. Also, the precise specifications can be used as acceptance criteria once the data is delivered.

With these objectives in mind, the 3D Pilot defined implementation specifications for 3D IMGeo, i.e. CityGML data. These specifications contain data requirements for all IMGeo-CityGML feature types at different levels of details Geonovum (2012b, 2012c). For the buildings, the "Modellierungshandbuch Gebäude" of SIG 3D in Germany has been used as a basis, see SIG 3D (2012b, 2012c).

The implementation specifications have been established after public consultation and also include a description of how each requirement can be checked. The different requirements defined are:

- Generic requirements, e.g. which version of CityGML to use, which reference system.
- Requirements for LOD0 representations of 2D IMGeo polygons.
- Requirements for volumetric representations:
  - LOD0-LOD1-LOD2 Buildings,
  - LOD1-LOD3 Bridges, Tunnels,
  - LOD1-LOD2 Vegetation,
  - LOD2-LOD3 Trees (CityGML-SolitaryVegetationObject) and Cityfurniture.
- Requirements for texture.

The specifications provide precisely defined choices regarding the 3D product and explain the implications of each. A few examples are:

- Representation of vertical surfaces in TIN-type digital terrain models. Most GIS systems do not accept vertical faces.
- Necessity of all (planar) objects above the ground to have a LOD0 representation, including those above surface level, e.g. multilevel crossings.
- Usage of the LOD2 representation of buildings as the base 2D geometry? The laser point data do not always match the 2D footprints, resulting in 'strange' geometries (Figs 2a and b).

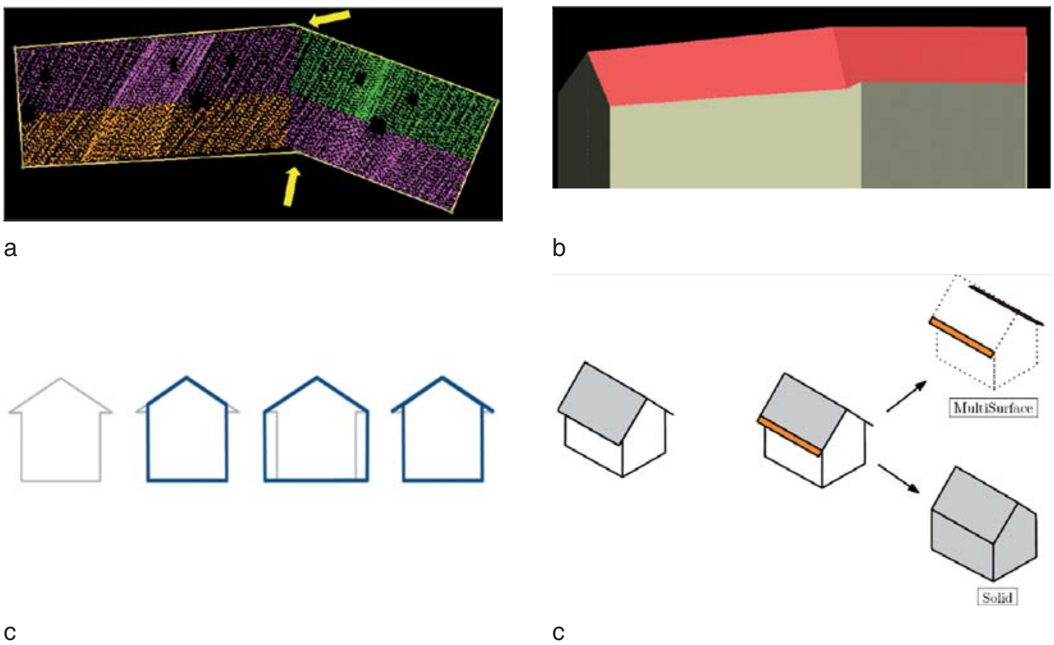


Fig. 2: CityGML implementation choices and consequences. a, b: height point data used to obtain roof-shapes do not match footprints; c, d: modelling roof-edges, footprints and roof-overhangs.

- Representation of building roof-edges, footprints and roof surfaces in LOD2 (Figs 2c and d).
- Inclination of building footprints: Shall the footprints always be horizontal as in the CityGML specifications or are they allowed to be inclined?
- Reasoning for the preference of representing a LOD2 building with a GML:Solid over a GML:Multisurface.
- Representation of curved surfaces. Arcs are allowed in 2D, but are not supported in TINs.
- Significance of the influence of tree-data upon the overall volume of the data.
- Requirements of aerial photographs necessary to automatically obtain height points from image matching.

As can be understood from these choices, several variants of implementations are possible based on the available source data, i.e. point clouds or high resolution photographs, and the ambition level of the data, i.e. the class-dependent LOD. These variants are described in the resulting document and the preferred is given. Since the variants are dependent on the intended use, a specific chapter is dedicated to the requirements in relation to the 3D applications in which the 3D data will be used.

Apart from the experiences in the pilot, the implementation specifications are based on experiences of cities that have invested in 3D city models in the CityGML format, i.e. The Hague and Rotterdam. Both cities faced difficulties in comparing offers from different companies because the specifications in the tendering documents appeared to be interpretable in several ways. This also caused problems in setting up acceptance criteria for the delivered product. Consequently, the CityGML datasets differ between the two cities but it is not always clear whether this was intended. The jointly defined implementation specifications will help to avoid similar situations in the future.

The resulting documentation is of interest for an international public as it serves as a further explanation and refinement of the CityGML specifications. In addition, putting it in an international discussion gives us the opportunity to evaluate our implementation specifications. Therefore, the document has been translated into English (Geonovum 2012c). Also, this document resulted in a few change requests for CityGML, which are currently discussed in the OGC, for example, the restriction that building footprints and roofedges should be horizontal.

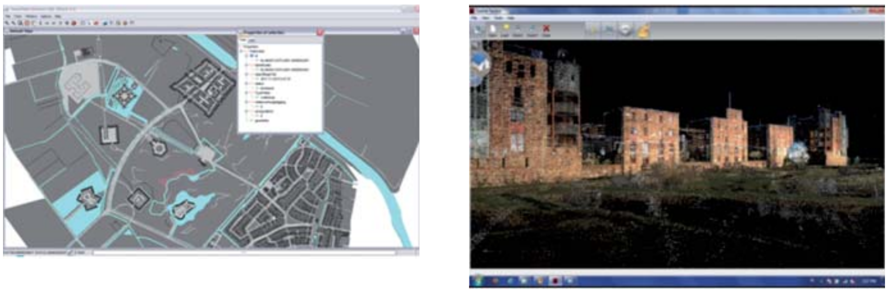
2.2 *Example 3D IMGeo Data*

To understand how IMGeo works for the integrated 2D and 3D approach, example 3D IMGeo data has been built and made available to the public. The objective of the example data is to help newcomers to understand the national 3D standard including the details of the different levels of detail. The example data also serves as source for (new) parties to experiment with 3D IMGeo data and it served as test data in the development of the 3D validator (see section 2.3). Finally, the example CityGML-IMGeo data was used to check whether CityGML compliant software is capable of understanding the 3D IMGeo data (see section 2.4).

The test area for which the example data was built, is situated in the municipality of Den Bosch (southern part of The Netherlands) containing a rural area, a residential area with common houses, a river and a bridge.

The 3D IMGeo data have been generated from 2D IMGeo, i.e. CityGML data (Fig. 3a) and 3D source data. The 3D source datasets that were made available on the 3D Pilot data server, hosted by the Delft University of Technology are:

- stereo photos, provided by the municipality of Den Bosch,
- high-resolution laser data, i.e. *Actueel Hoogtebestand Nederland* (AHN) by Het Waterschapshuis, with an average density of 10 points per m^2, available for the whole country,
- orthophotos by Cyclomedia,
- a high resolution point cloud obtained from terrestrial laserscanning by Cobra, see Fig. 3b,
- point clouds generated from aerial photographs by Imagem,
- oblique photos by Slagboom & Peeters.



a: 2D IMGeo data

b: High resolution laser data, obtained by terrrestrial laserscanning

Fig. 3: Example source data available for the 3D Pilot test area.

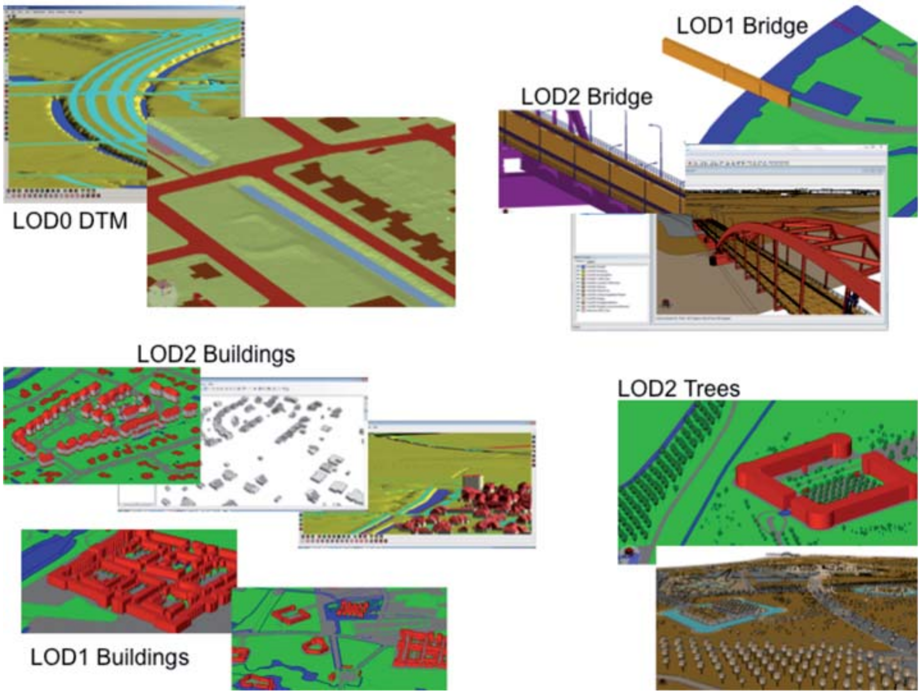


Fig. 4: Example 3D data compliant with the national CityGML ADE, generated in the research.

The following example 3D IMGeo-CityGML data (available at Geonovum 2012a) were constructed from this data, most of them automatically, see Fig. 4:

1. LOD0 Digital Terrain Model, i.e. triangulated surfaces for all polygonal objects that form together a topologically correct data structure, by the Universty of Twente.
2. LOD1 and LOD2 Buildings, by the University of Twente.
3. LOD1 and LOD3 Bridge by the company Coenradie.
4. LOD2 trees by the University of Wageningen.

The geometries for the different feature types and levels of detail were derived by various methods.

The LOD2 buildings with roof-shapes were automatically reconstructed with the method of Oude Elberink & Vosselman (2011). LOD1 buildings are automatically generated by extruding the 2D footprints with the mean height calculated from the height points within the polygon. A filtering-technique is applied to exclude the outliers.

The LOD3 Bridge was captured by terrestrial measurements and manual modelling while the LOD1 representation is a simplification of the LOD3 bridge model.

The LOD2 trees were automatically generated from AHN2 by the method of Clement (2011).

LOD0 (surface) representations for all classes were automatically generated from a combination of the 2D IMGeo data and AHN2. The LOD0 representation of the data is more than a drape of the 2D data over the digital terrain model. It consists of a triangulated surface per polygonal object, generated by means of a constrained triangulation with the polygonal boundaries as constraints. All these triangulated surfaces together form a topological surface of the terrain as in 2D with height variances modelled within a polygon. If necessary, extra points are added on the boundaries to better model the height variance.

The reconstruction of a topologically correct LOD0-IMGeo surface is not trivial. The triangulated surfaces are reconstructed for each polygon separately based on the height points that fall within that polygon. Consequently, gaps may occur at polygon boundaries that are neighbours in 2D but not necessarily in 3D. The approach of Oude Elberink (2010) was followed to fill these gaps. In this approach, heights on polygon boundaries are adjusted depending on the types of neighbours. The result is a closed 2.5D surface.

After the geometries were created following the several approaches, the Karlsruhe Institute of Technology in Germany organized the geometries according to CityGML and assigned CityGML semantics to the features. Finally, the data was validated with the developed 3D validation software (see section 2.3).

The main conclusion from this activity is that many 3D source data is available in the Netherlands as well as significant knowledge on these data. However, there is hardly any company which is capable of restructuring the once captured 3D data according to the CityGML structure. To further help in this process, an automated workflow for 3D IMGeo data reconstruction is currently being developed. This workflow available as a FME workbench and as an Open Source tool starts from 2D IMGeo, i.e. CityGML data and high-resolution point data, i.e. AHN2, and generates the LOD0, LOD1 and LOD2 geometries according to the above-mentioned methods and writes CityGML-IMGeo at the end of this process. The workbench implements the algorithms for 3D reconstruction of Oude Elberink (2010), Oude Elberink & Vosselman (2011) and Oude Elberink et al. (2013). Also this workflow will soon be available for the wider public.

2.3 *3D Validator*

A validator is necessary as an independent tool to verify whether a dataset is compliant with IMGeo 2.1 or not. When validating objects, it is necessary to validate both their semantics and the geometry, the former according to the classes of CityGML and/or of the IMGeo extensions, and the latter according to the international specifications. A validator for 2D IMGeo (and thus 2D IMGeo-CityGML) already exists and is available as open source software (Geonovum 2012d). However, it only checks for two-dimensional primitives.

Therefore, the 3D Pilot studied the required functionalities to validate the geometry of 3D solids and developed a 3D validator accordingly. During this study, we observed that several real-world datasets have objects that appear to be visually valid, but in fact are wrongly built. Fig. 5 shows two examples. These wrong issues are often small and hard to be detected

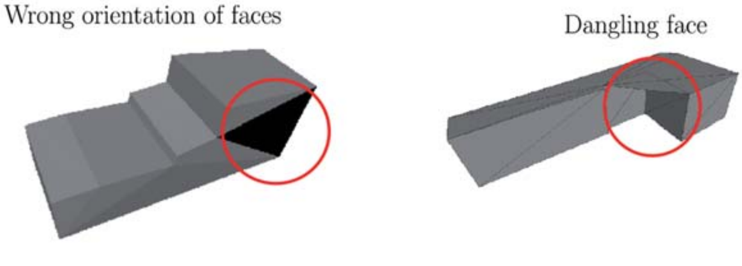


Fig. 5: Two real-world invalid buildings.

at the usual visualization scale of city models. However, they cause problems in practice when for instance converting objects to other formats including BIM and CAD, or when analysing them. The volume of an invalid solid could impossibly be calculated. It may even cause a program crash.

While different definitions of a valid 3D object are used in different disciplines, the developed 3D validator focuses on the definition given in the ISO 19107 standards (ISO 2003) and implemented with GML (OGC 2007). A GML Solid is defined as follows: "The extent of a solid is defined by the boundary surfaces as specified in ISO 19107:2003. gml:exterior specifies the outer boundary, gml:interior the inner boundary of the solid" (OGC 2007). Without going into details, we can state that a solid is represented by its boundaries (surfaces), and that, like its counterpart in 2D (the polygon), a solid can have "holes", i.e. inner shells or cavities, that are allowed to touch another hole or the outer boundary, under certain conditions. To be considered a valid solid, a solid must fulfil several properties. The most important are: 1) it must be simple (no self-intersection of its boundary). 2) It must be closed, or "watertight". 3) Its interior must be connected. 4) Its boundary surfaces must be properly oriented. 5) Its surfaces are not allowed to overlap each other.

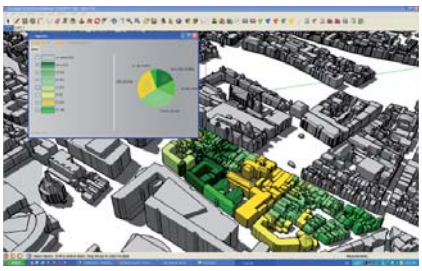
It should be pointed out that the development of a new 3D validator was necessary since none of the surveyed GIS packages was fully compliant with the definition of the ISO: Often a more restrictive definition of a solid is used. For instance, Bogdahn & Coors (2010) and Wagner et al. (2013) discuss the validation of solids for city modelling, but do not consider holes in surfaces and totally omit that interior shells are possible. Gröger & Plümer (2011) give axioms to validate 3D city models, but also do not consider holes in primitives of dimensions 2 and 3. In fact, they define solids as shells without holes in their surfaces. We have also noticed that commercial GIS software products ignore interior shells. ESRI (with ArcGIS) and Bentley are two examples. Oracle Spatial considers interior shells in its validation function, but does not allow holes in surfaces.

Our 3D validator does not contradict the previous results and implementations, but simply extends them so that solids are validated against the international standards. It uses advanced data structures and operations to analyse the topological relationships between 3D objects. It does not only validate solid geometries for LOD2 buildings, but also 3D MultiSurfaces that together form a 3D volume as these are often used in practice. However, it gives a warning to the user that the stricter solid-geometry is preferred. The validator is available as an open source tool (Geonovum 2012e) and is also implemented as standard functionality in FME by Safe software.

2.4 *Maintaining and Updating 3D IMGeo Data*

After the investment in a good 3D model, the maintenance and update of the model become the key questions. Can commercially available database management systems (DBMSs) be used? How shall the update process be organized? Shall it be integrated in the existing processes, shall the 3D data be recreated after a change of the 2D data changes or shall both methods be mixed?

The 3D Pilot identified one open source, i.e. 3D CityDB (3DCityDB 2013), and two com-



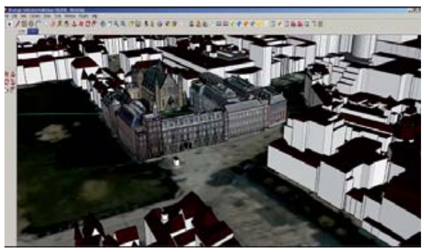


Fig. 6: Screenshots of StrateGis solution for the CityGML-competition.

mercial solutions, CPA Systems and M.O.S.S., for maintaining 3D IMGeo-CityGML data in DBMSs (Oracle and PostGIS).

In addition to test tools for maintaining the CityGML data, two competitions were organized. In the first competition, six companies, i.e. Bentley, CPA systems, M.O.S.S., Safe Software, StrateGis and Toposcopie, proved that they are able to edit and store the updated version of existing CityGML data of The Hague (Fig. 6).

In the second competition, four vendors, i.e. Bentley, M.O.S.S., Safe Software and CPA Systems, executed several tests (published at Geonovum 2012f) on the 3D IMGeo example data that has recently become available. The four companies submitted a video in which they showed the tests followed by a validation process at the end of the process. These experiments proved that software that supports CityGML is also able to recognize and deal with IMGeo-data as IMGeo is an extension of CityGML. This is important for the acceptance of 3D IMGeo in the Netherlands. The compiled video that summarises these four company results is available at Geonovum (2012g).

From the experiences of this activity it can be concluded that for many municipalities a hybrid approach for updating an existing 3D model will work best, i.e. periodically automated updates for larger areas combined with manual updates in specific project areas. The automated updates can be done by a combination of existing 2D topographic data and high-resolution height points. The height-points acquired from laser scanning are a perfect 3D source, but in The Netherlands this dataset, i.e. AHN2, is only collected once every 5 years. In between, aerial photographs with sufficient overlap, i.e. 60 %, can be used to automatically generate high-resolution height points. This may require a change in the requirements of these images.

2.5 *Collecting and Portraying 3D Showcases*

Although 3D applications are common practice for many professionals, 3D is new and considered as "complex" and "expensive" to others. To show the need and potentials for 3D and to offer a source of inspiration to policy makers and newcomers in the field, the 3D Pilot built a website that collects and portrays examples of 3D applications that are already practised. The growing interest for 3D is proven by about 1000 visitors from all parts of the world in a few months.

3 Conclusions and Future Work

This paper presents the 3D Pilot that defined, established and implemented a national 3D standard in The Netherlands. The national 3D standard, IMGeo, is defined as an application domain extension of CityGML. Among the end results are: implementation specifications of the national 3D standard which assures a topologically, geometrically and semantically correct model, example 3D IMGeo data, a 3D validator, best practice documents of how to acquire, maintain, update and disseminate 3D IMGeo data, and a website that collects and portrays 3D showcases.

The main conclusion of running the 3D Pilot between January 2010 and December 2012 is the change of vision concerning 3D in The Netherlands. At the start of the 3D Pilot, many saw that 3D had potentials, but did not know how to apply them. In the course of the pilot the ambitions for 3D have become much more focused, also supported by the national 3D standard. Now, these ambitions are further developed since the second phase of the pilot has finished.

Several aspects appeared to be crucial for the adoption and implementation of the 3D standard. Firstly, the engagement of many stakeholders was important to gain the necessary support. Secondly, the alignment to the international standard CityGML, which made it possible that CityGML compliant software, is able to deal with IMGeo data as well as to the ongoinging 2D efforts let 3D applications become feasible and attractive for governmental organizations. In addition, collaboration appeared to be important to share knowledge on the wide variety of topics in the complex 3D domain. Finally, it was found important that a number of national organizations took the responsibility to facilitate the process. Although the pilot is a joint effort of the 3D community, national organizations have to initiate and facilitate such a network organization and they are important for anchoring the results.

The work of 3D implementation is not finished and several issues remain. These are currently taken up by the national 3D Special Interest Group that has been specially established for this purpose. The objectives of this 3D SIG are to address the still open 3D issues in collaboration with all stakeholders. Among these are open issues concerning implementation of the 3D standard, the integration of 3D IMGeo with the subsoil, i.e. geology and cables & pipelines (see also the work of Becker et al. (2010), Hijazi et al. (2010), Zobl & Marschallinger (2008)), further alignment between BIM and GIS, and 3D extensions in other domains such as spatial planning and noise modelling Stoter et al. (2008).

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