Establishing a national 3D standard compliant to CityGML: good practice of a national 3D SDI

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Abstract: This article describes a research project that realised a national standard for 3D geo-information. The standard was developed as part of a pilot in which more than 65 private, public and scientific organisations collaborated to analyse and push 3D developments in the Netherlands (run between March 2010 and June 2011). The 3D standard was established through several steps. Firstly a comparison between the existing 3D CAD and GIS standards was carried out that selected the OGC standard CityGML as the optimal 3D standard to align to. Secondly, the equivalent concepts in CityGML and the existing national standard for large scale topography (IMGeo) were identified. Thirdly IMGeo was extended to 3D following the principles of CityGML Application Domain Extensions (ADE). The model was tested by applying it to real data. Based on the experiences of this pilot, this paper proposes a framework of guidelines and principles for extending CityGML for national purposes, deduced from the modelling experiences. This is a unique contribution since experiences on extending CityGML are new and not well-described in the OGC CityGML specifications. Finally this paper presents the change requests which have been submitted to OGC to make the CityGML standard more suited for integration with existing 2D topographic information models. The change requests were formulated based on experiences from developing this nationwide 3D standard.

Keywords: 3D standard, 3D geo-information, 2D/3D integration, CityGML

1. Introduction

Over the past ten years technologies for generating, maintaining and using 3D geo-information have matured. Nowadays, many local governments have 3D models of the city, a large number of companies are providing services for constructing 3D models, and universities and research organisations are investigating 3D technologies (3D re-construction, data management, validation and visualisation). Yet many (governmental) organisations face numerous challenges in introducing 3D applications and technologies in their day-to-day processes. Despite the practical difficulties, it is clear that 3D information is becoming increasingly important in many applications. These developments motivated a pilot in the Netherlands to advance the use of 3D in this country. The pilot was initiated by the Dutch Kadaster, Geonovum, the Netherlands Geodetic Commission (NCG) and the Dutch Ministry of Infrastructure and Environment.

From January 2010 until June 2011 more than 65 private, public and research organisations got together to study the state-of-the-art of 3D developments and applications in the

Netherlands and to instigate innovations. The pilot realised a proof of concept for a 3D Spatial Data Infrastructure (SDI) that addresses issues ranging from 3D data acquisition, maintenance of 3D data and use of the 3D information in specific applications. An important goal was establishing a 3D standard NL with wide support of many stakeholders. 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. Finally the established Dutch 2D standardisation framework was studied for extension into 3D while aligning to the international standardisation developments driven by experiences of the use cases and the test bed.

The overall pilot goals and results are described in Stoter et al 2011. This paper describes the development of the national 3D standard and proposes a framework for this that can be used by other countries.

Although other efforts are known for defining agreements on 3D geo-information in formal information models for different domains (Tegtmeier et al 2009, Emgard and Zlatanova 2008, Penninga 2008, Stoter and Salzmann 2003, Stoter and Van Oosterom 2005), no attempts have been made to create a 3D national standard that is aligned to both the OGC (Open Geospatial Consortium) standard CityGML (OGC 2008) and the national 2D standardisation framework. The Netherlands has well-established national standards, but as in most countries, they are all 2D. The new 3D standard preserves valuable 2D concepts from the existing national standard for large scale topography (Information Model Geography: IMGeo), and extends them with 3D concepts from CityGML. The 3D standard is therefore not just another standard on geo-information, instead the realised CityGML implementation profile bridges the 2D and 3D standardisation developments.

The pilot experiments showed four technical reasons to preserve information from existing 2D models, while extending to 3D and aligning with international 3D standards . These are as follows:

- Connection to existing datasets means connecting to existing application areas 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 often provides possibilities to automatically generate a 3D model;
- The update process (which is well-established in 2D) of existing datasets can still be used for updating the 3D datasets, before full update of 3D data sets is developed.

The result of a nationwide 3D standard extending CityGML and integrating it with 2D topographic information may be seen as a solution limited to one specific country as well as to topographical context. However, the defined 3D standard contains many generalities which are of interest to both different countries and domains. In particular, extension of CityGML to a specific context is not well described in the OGC specifications and experiments on CityGML extensions are new. Therefore the major contribution of this paper is the proposed generic framework for extending CityGML for national purposes that structures the findings of this research. Another contribution are the Change Requests (CR's) for CityGML which were formulated (and submitted to OGC) based on insights obtained during the development of the 3D standard and sequential testing.

The article is organised as follows. First, Section 2 motivates why CityGML was elected as the most promising 3D standard for the Dutch case. Section 3 describes how IMGeo was integrated with CityGML, based on principles of CityGML Application Domain Extensions (ADEs). Section 4 discusses the resulting information model. Section 5 presents the framework for extending CityGML for national purposes. The change requests for CityGML are formulated in Section 6 and Section 7 presents conclusions and elaborates on future developments.

2. Motivation to use CityGML as base for 3D standard NL

3D standards have been developed throughout the years for many different purposes: visualisation (fast and realistic), data management (efficient storage), modelling (validity and topology) or data exchange (platform independent). The parties working on 3D standardisation vary from companies to international standardisation organisations, originating from CAD/BIM (i.e. Computer Aided Design and Building Information Models), GIS or Web domains. Many of the company developed formats have become de facto industry standards (e.g. SHP, DXF) or have been approved as open international standards (e.g. KML). Other international standards have been developed without major company involvement (e.g. CityGML). Being developed with different goals, the information (such as type of geometry, textures, semantics, relationships) varies significantly between standards and makes the integration of data in one 3D environment almost an impossible task. The experiences in the 3D pilot have clearly revealed many problems with converting data from one de facto or international standard to another: information was lost or was improperly converted, validity of objects was not ensured, relationships were diminished, etc. Therefore it was important to study and analyse the most used international and de facto 3D standards and their characteristics.

The de facto and international standards that were compared are DXF, SHP, VRML, X3D, KML, Collada, IFC, CityGML and 3D PDF. For more details on the comparison see Stoter et al (2011).

The comparison showed that every 3D standard is designed for specific purposes. DXF, VRML, X3D, Collada, and IFC support the largest variety of geometries. VRML, X3D and Collada are the most advanced in supporting realistic textures. All these standards, except IFC, contain poor support for semantics and attributes. Clearly these standards originate from the CAD domain. In contrast, standards such as SHP, IFC, and CityGML have a very good support of semantics, objects, attributes and relationships between the objects. This means that these standards provide the means to keep information that is important for analysis and not only for visualisation. Because of the support for semantics, geo referencing and Web use, the selection of CityGML as generic standard for a 3D SDI envisaged in this study was justified. IFC shows similar support but is characterised 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. For the 3D SDI a standard for geo-information is needed characterised by coverage of large areas (e.g. a complete city) and lower precision. Since BIM (IFC) files may serve geo-information applications and vice versa, it is important to study the alignment of both standards. Further details on the comparison can be found in Stoter (2011).

The OGC standard CityGML (OGC 2008) originated in academia in Germany (Bonn, TU Berlin) and was originally defined as an exchange format. But it is also - and especially - an information model for representing 3D spatial objects. CityGML distinguishes both at the geometric and semantic level between thematic concepts (buildings, vegetation, water, land use, etc.) (Albert et al, 2003; Groger et al, 2004; Groger et al, 2007). It supports multi-resolution features by means of different levels of detail. A building object can vary from a simple block model (LOD1; accuracy 5m), with roof shapes (LOD2; accuracy 2m), with windows, doors and other exterior features (LOD3; accuracy 0.5m) to a fully detailed interior model (LOD4; accuracy 0.2m) with or without texture information (called 'appearance').

The standard CityGML is based on GML3. Generally volumetric objects are possible as in GML 3, but the validity of closed volumes cannot be enforced in CityGML. In addition 3D topological structures, although available in GML 3, are not utilized; instead a simple xlink approach is followed to connect the surfaces of a 3D geometry. The time and scale dimensions are handled in CityGML, but not in an integrated manner. The time dimension is separately handled by adding attributes to geometrical objects, i.e. creationDate and terminationDate. Scale is intended to be linked to the LOD concept, although our experiences have shown that this is not the case, i.e. many 3D models in LOD1 are created from high-accuracy data.

CityGML is intended as generic standard with limited thematic content compared to the national information models and therefore the standard needs further agreements to make the standard suitable for national purposes. This was studied in a next step, i.e. How to use the generic standard CityGML as a standard in a specific (i.e. Dutch) context, i.e. which additional classes, attributes and attribute values are necessary? Which codes should be added to the code lists of CityGML to make the code lists appropriate for a specific context and how can this be done? Which LOD should be used? These questions are studied in the next sections (for the specific Dutch context in Sections 3 and 4, and in general in Section 5). Note that also the European data specifications for buildings (INSPIRE, 2011) have an optional CityGML profile.

3. Extending CityGML for Dutch context

After the election of CityGML as standard to align with, a CityGML implementation profile has been developed. Because the Dutch information model on large scale topography (IMGeo) resembles CityGML the most, the first focus has been on integrating IMGeo and CityGML into one standard. For this integration we used the available version of CityGML (version 1.0.0). Version 1.1 is currently in consultation (OGC 2011). This section presents the process that established the national 3D standard CityGML-IMGeo (Section 3.2). First Section 3.1 introduces technical aspects of IMGeo.

3.1 IMGeo (BGT)

The Dutch Information model Geography (IMGeo) describes how object-based, large scale (1:1000 and 1:2000) topographic features must be defined to make the national exchange of this information possible. This large-scale topographic map is created and maintained by the municipalities and financially supported by local governments and private companies. Version 1.0 of IMGeo was published in 2007 (IMGeo, 2007). Version 2.0 is due to be completed end 2011. IMGeo 2.0 has a mandatory core, see Figure 1 (and Table 2, Section 3.2.1 for English translation of the main classes).

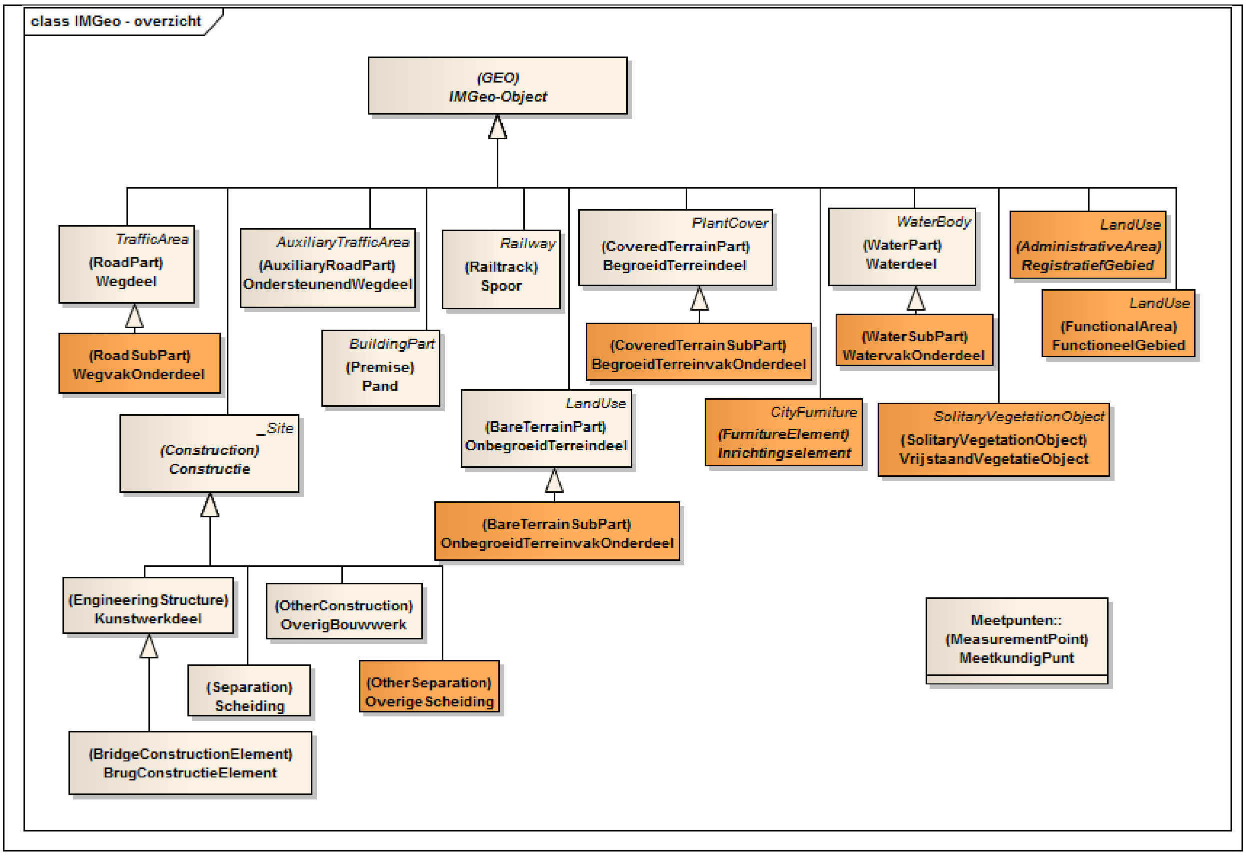

Figure 1: Overview of the classes in the Dutch Information Model Geography (IMGeo); classes in light color are part of the mandatory core, the classes in orange are optional. The names in italics are CityGML super classes of the IMGeo classes; English translation of class names is shown in parentheses.

Data providers such as municipalities, organisations responsible for the road, water and railway infrastructure etc. will be required by law to provide their objects that fall under the definitions of the IMGeo 2.0 core to a national 'basic registry' (*Basisregistratie Grootschalige Topografie, BGT*) where they are available for reuse. The mandatory core contains object definitions for large scale representations of roads, water, land use/land cover, bridges, tunnels etc. The optional part of IMGeo allows further division of these objects into parts suitable for maintenance, and contains definitions for all kinds of city furniture and other non-mandatory classes. It should be noted that utilities and geology objects are not part of IMGeo. They are covered in two other domain models, i.e. respectively IMKL and IMBRO (Geonovum, 2011). The terrain as a regular or irregular grid is also covered in the latter (e.g. *AHN*, Height Model of The Netherlands, http://www.ahn.nl/)

The mandatory core of IMGeo prescribes 2D point, curve or surface geometry for all objects, but since version 2.0 of the model is completely integrated with CityGML (see next section), the optional part of IMGeo 2.0 also allows 2.5D and 3D geometries.

IMGeo (also the 2D part) contains man-made objects above (e.g. viaduct) and below the surface (e.g. tunnels or underground waterways), modelled in 2D with the attribute *relatieveHoogteligging* (relative height). This attribute indicates whether an object is located at surface level (and is thus part of the planar partition, value=0), above (> 0) or below (< 0) the surface. The attribute is mainly used to infer that objects do not exist on the same level and which object is above which.

IMGeo classes have a small number of attributes, besides their geometry. Most have one or two attributes to further classify the object or to indicate their function. Code lists are used to provide allowed values for these attributes. In addition, all classes share attributes for identification and versioning, for a reference to the data provider, for the object's status (planned, existing, or historic) and an indication whether a possible error in the data is under investigation. In addition, all measure points of the object's geometry are stored with metadata such as information on the accuracy.

All objects have 2D geometry for which GML 3 geometry types are used. Topological rules are part of the standard, but are not modelled by GML topological types. The most notable rule is that the complete set of polygon-objects at surface level (height level 0) in the mandatory core must together form a complete coverage of the Netherlands without gaps or overlap.

The IMGeo standard also includes rules for visualisation, e.g. the colour of lines and areas, type and thickness of lines, etc. . These are based on a Dutch standard for web cartography. Two visualisation themes are provided: one where large scale topography is the main focus, and one where it is used as a background for other themes.

3.2 3D IMGeo as extension of CityGML

For the design of 3D IMGeo extending CityGML, the rules for creating Application Domain Extensions (ADE) were applied (OGC 2008; CityGML 2011). That is, 3D IMGeo was modelled as an ADE, even though the intention is not to position 3D IMGeo as a formal (i.e. to be approved by OGC) extension module. It is nevertheless useful to follow the rules for creating an ADE because these rules assure a standard extension method, enabling software systems to not only understand the CityGML part of the model, but also the extensions. Since the rules for modelling an ADE in UML(Unified Modelling Language) are not described in the CityGML standard we followed the rules for implementing an ADE in a GML Application Schema, applying those to UML as much as possible. In addition the publication by (Portele 2009) was used.

The remainder of this section clarifies the main considerations that led to the CityGML implementation profile for Dutch context realised in IMGeo 2.0.

3.2.1 Reuse and extension of CityGML concepts

The main principle of CityGML-IMGeo is the reuse of CityGML concepts, i.e. IMGeo classes are remodelled in accordance with CityGML. This principle made it necessary to map the concepts from IMGeo to CityGML concepts. For this mapping-study both the CityGML core standard and existing (draft) ADEs (bridges, tunnels, noise, and utility networks) were considered. The Bridge and Tunnel models were used (these have become part of CityGML

1.1). However, the other ADEs were not used because the (semantic) details they add to the CityGML standard are not available in IMGeo.

As mentioned above, IMGeo only contains 2D objects, which makes the mapping between IMGeo classes and CityGML LOD0 classes (representing the terrain) the most obvious choice, even though the accuracy of IMGeo (varying between 0.30m and 0.60m) is a far better match for LOD3 . However, only looking at LOD0 classes has limitations because not all CityGML classes have representations at LOD0 (see Table 1). Therefore the mapping also took other LODs into account and LOD0 representations of those classes have been added at a later stage (see Section 3.2.2). It should be noted that LOD0 for Building is added in CityGML 1.1.

Table 1**:** Available LOD representation for each CityGML thematic module

CityGML module	LOD0	LOD1	LOD2	LOD3	LOD4
Building		●	●	●	●
CityFurniture		●	●	●	●
LandUse	●	●	●	●	●
Relief	●	●	●	●	●
Transportation	●	●	●	●	●
Vegetation		●	●	●	●
WaterBody	●	●	●	●	●
Generics	●	●	●	●	●
Bridge		●	●	●	●
Tunnel		●	●	●	●

Table presents the result of the mapping between IMGeo and CityGML classes. In addition to these mappings between classes, also attributes and code lists have been compared (not shown here).

Table 2**:** Mapping between IMGeo and CityGML classes for CityGML-IMGeo implementation profile

IMGeo Class	**CityGML Class (not only LOD0)**	**In CityGML LOD0?**
Kunstwerkdeel (Construction part)	Bridge, Tunnel and other constructions (OtherConstruction class with sub classes added as specialization of _Site)	No
Inrichtingselement (furniture element; generic term for city furniture and other small objects that populate the public space)	Most are CityFurniture Some are Constructions	No
Pand	BuildingPart	No

(building part, premise)		
Spoor (railway tracks)	Railway	Yes, as network; surface from LOD1 (TrafficArea)
Terreindeel (terrain part). To match CityGML this class was split in two classes: bare terrain part and covered terrain part.	LandUse (bare terrain parts, with no vegetation) and PlantCover (covered terrain parts, with vegetation)	LandUse: Yes Vegetation: No
Waterdeel (water part)	WaterBody	Yes
Wegdeel (road part)	Traffic Area	Yes, as network; surface from LOD1 (TrafficArea)
Ondersteunend wegdeel (auxiliary road part). Was introduced to better match CityGML.	AuxiliaryTrafficArea	No
Registratief Gebied (administrative area)	LandUse	Yes

The mapping was the source of the CityGML-IMGeo implementation modelled in UML. Since CityGML 1.0 is only available as xml schema, a UML model was recreated in the modelling tool Enterprise Architect, based on (OGC, 2008). IMGeo classes (with Dutch names) were defined as a specialisation of the relevant CityGML generic class (with English names). The English names of CityGML were reused to make the link to the original classes well-visible (which English class refers to which Dutch class) which is reflected in the UML models via the specialisation-relationships.

New classes have been added if they are present in IMGeo but missing in CityGML. Added classes include constructions related to water management, separating objects like walls and fences, and other constructions which are not quite buildings, like storage tanks or wind turbines. These classes have been added with one superclass called “Construction”, specialisation of CityGML _Site.

Attributes are added to all classes for defining the following aspects: 2D geometry (not modelled in CityGML), the LOD0 geometry if not present in CityGML(see Section 3.2.2) and the Dutch classification code lists.

Retaining Dutch code lists instead of reusing the CityGML code lists breaks the CityGML rules for extending code lists. However several aspects gave reasons to do this (and this is in line with the findings of Portele 2009). Firstly the national character of the standard favors

Dutch language code lists. Secondly the CityGML standard does not provide definitions for the code list values, which makes it hard for users to decide which value to use. Because IMGeo also contains a obligatory part which prescribes data providers to provide a complete set of the core objects with a certain accuracy and semantic correctness, it is even more important that every concept is defined precisely. The Dutch code list values do have definitions and therefore these values are retained (and if possible mapped to CityGML code list values, see Table in Section 4). It should be noted that CityGML 1.1, which was not yet available at the time of writing, allows extension and replacement of code lists.

A final adjustment of the model was the use of CityGML classes which were not present in IMGeo 1.0, but which appeared to be more appropriate for handling specific concepts. These are *Vegetation* for modelling any vegetation-related concept (in IMGeo 1.0 divided over several classes) and *AuxiliaryTrafficArea* for road segments which are not used for traffic (such as verges).

The resulting standard supports both the 2D representations of the mandatory and optional objects, as well as 2.5D and possibly 3D representations of those objects. In addition the consequence of remodeling IMGeo 1.0 concepts into IMGeo 2.0 concepts according to the principles described above is that all matches between IMGeo 2.0 and CityGML are 1 to 1.

3.2.2 Define further agreements on geometry

CityGML-IMGeo contains further agreements on the use of LOD representations, which solves CityGML's ambiguity about the LOD definitions (geometry- or semantic-based):

- ***Accuracy:*** All LODs have the same accuracy according to the positional accuracy required by IMGeo. Consequently the accuracy requirements of CityGML are not adopted, and the LOD only represents the detail of the object in the third dimension, i.e. LOD0 for 2.5D surfaces, LOD1 for block models, LOD2 for semantics for roofs, walls etc and LOD3 for textures and even more details.
- ***LOD0 representation for all classes:*** All CityGML-IMGeo classes get a LOD0 representation (either inheriting from CityGML or added conform the IMGeo geometry type) and a 2D geometry in the 2D-LOD. This makes it possible to have one integrated model that supports the full range of spatial representations of real world objects, i.e. from 2D, 2.5D to full 3D, depending on the application.
- ***Solid and indoor geometry:*** Some classes in CityGML-IMGeo have representations at higher LODs, up to and including LOD3 conforming to CityGML. However LOD4 is excluded from CityGML-IMGeo as indoor information is considered to be information from another domain (i.e. BIM/IFC) than topography.

Other deviations from CityGML geometries are the surface-geometry for Water, Road and the curve-geometry for Railway (instead of LOD0 GeometricComplex for networks), which is according to IMGeo 1.0 geometry types.

3.2.3 Define agreements on topological structure

As mentioned above IMGeo defines a topological structure containing all objects at surface level. This topological principle is extended to LOD0. Consequently the LOD0 representations of all objects at surface level constitute a 2.5D topological structure (without

gaps and overlaps). Because this structure contains also the footprints, no specific Terrain Intersection Curves are necessary to locate the LOD1-LOD3 representations in the terrain.
This principle extends the CityGML topological structure for LandUse (page 94 of CityGML specifications (OGC 2008)) to other classes at surface level which may be additional LOD0 classes compared to CityGML (since LOD0 representations have been added for all classes). At the same time the class LandUse is limited to those objects which do not represent the other classes, such as water, road, railway, vegetation.

Figure 2 shows the result of a 2.5D triangulated surface of IMGeo objects. The 2.5D surfaces are a result of a "constrained triangulation" of high density laser points and 2D IMGeo objects.

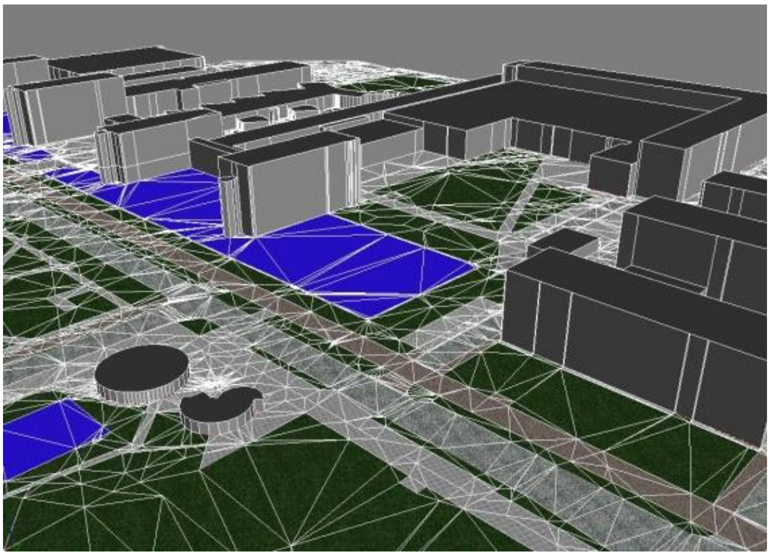

Figure 2:Triangulated terrain integrated with IMGeo objects (Emgard and Zlatanova 2008)

3.2.4 Model objects above or below the surface

The concept of levels (relative height) in IMGeo is reflected in the integrated model. LOD0 representations of objects above and below the surface are located in space while connected to the topological structure at surface level (based on the assumption that those objects do connect to the surface somewhere). This may require adding new 2D boundaries for adding more variance in 3D. It may also be necessary to add extra 2.5D surfaces to the structure at the surface to avoid gaps (see Figure 3). This is explained in (Oude Elberink and Vosselman 2009; Oude Elberink 2010)).

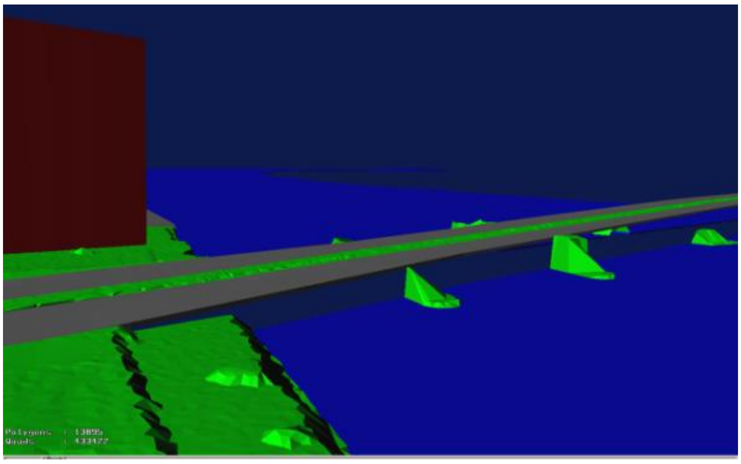

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Figure 3: Example of the employed 2.5D topological principle: 3D model of 3D Pilot test area; generated by Oude Elberink, ITC U Twente based on AHN2 and TOP10NL

Another Dutch dataset, i.e. the 2.5D topographical dataset of Rijkswaterstaat (DTB) already supports a similar 2.5D topological structure of topography. Examples are shown in Figure 4 (Rijkswaterstaat 2011). Although this dataset shows that such 2.5D data structures are already in existence and therefore feasible, it does not yet contain height information within the polygon-surfaces, in contrast to the LOD0 representations of CityGML-IMGeo.


Figure 4: Examples of 2.5D topographic data provided to the 3D Pilot by Rijkswaterstaat and Province of Noord Brabant

3.2.5 Define the reference system

CityGML-IMGeo uses the Spatial Reference System EPSG:7415. This is a combined SRS of x, y coordinates in the national reference system (called *Rijksdriehoeksmeting*) (EPSG:28992) and z coordinates in the national height system (called *Nieuw Amsterdams Peil*) (EPSG:5709). The experiences in the pilot showed that this reference system should be explicitly stated in the CityGML files.

4. Experiments with the model

This section illustrates how the model works in practice by showing how the IMGeo class '*Wegdeel*' (i.e. Road Part; road segments that constitute a road) is modelled in CityGML-IMGeo and by applying the model to real data at the end of this section.

IMGeo *Wegdeel* class is modelled as a specialisation of the CityGML class TrafficArea, thereby inheriting its properties. The UML diagram for class *Wegdeel* is shown in Figure 5.
IMGeo-Object is the collection of the generic properties that all IMGeo classes share. In IMGeo 1.0 all IMGeo classes were specialisations of this abstract feature type. To avoid multiple inheritance in the new model the IMGeo-Object class is no longer a <<featureType>> but an <<interface>>. When a GML Application Schema is created from

this UML model, the specialisation relation between IMGeo-Object and *Wegdeel* is not seen as inheritance but as a realisation of the interface properties. These properties are realised in the GML application schema by copying all properties from IMGeo-Object to the feature types that are linked to it in this way.

The stereotype <<BGT>> indicates the parts that are in the mandatory core of IMGeo. As can be seen, the only part which is not mandatory is Wegdeel.lod0Surface.

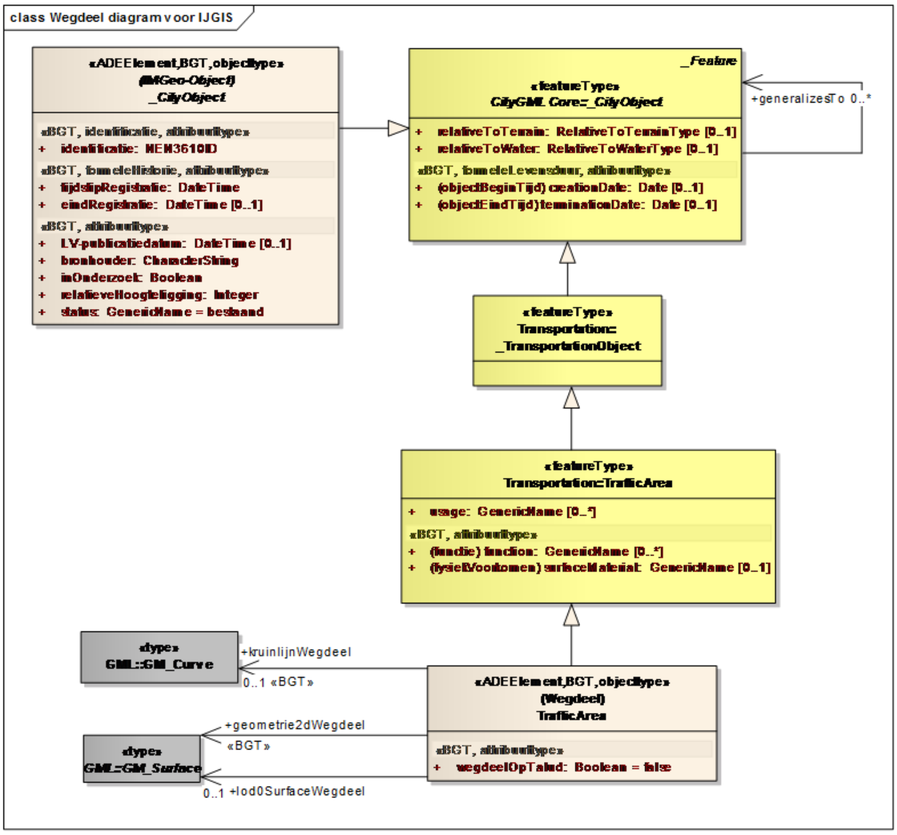


Figure 5:Example – IMGeo modelling of Wegdeel as subclass of CityGML-TrafficArea

The attribute Wegdeel.functieWeg is equivalent to TrafficArea.function; the attribute Wegdeel.fysiekVoorkomen is equivalent to TrafficArea.surfaceMaterial. In a 3D IMGeo dataset both English and Dutch attribute names must be provided. This is also true for the code list values, because the Dutch code lists are retained (see Section 3.2.1). However, the mapping between attributes, code lists and code list values is not modelled explicitly in the UML model. Although it would have been possible to use constraints for this, those mappings are described in a document added to the standard. This is less formal but more accessible by users. The format that was used for the mapping is shown in Table 3.

Table 3: Example - Mapping of code values for Wegdeel-TrafficArea

IMGeo	**CityGML**	**CityGML**
Attribute	Attribute	Attribute
FunctieWeg	TrafficAreaFunctionType	TrafficAreaUsageType
Code list value	Code list value	Code list value
OV-baan (public transport lane)	Rail or (missing: bus lane)	Bus, taxi Train

		Tram, streetcar
Overweg (railway crossing)	(missing: level crossing / railway crossing)	Car Truck Bus, taxi Train etc.
Baan voor vliegverkeer (lane for aeroplanes)	airport_runway, airport_taxiway, or airport_apron	Aeroplane
Rijbaan: autosnelweg (driving lane: motorway)	Motorway	Car Truck Motorcycle
Rijbaan: autoweg (driving lane: main through road)	driving_lane	Car Truck Motorcycle
Rijbaan: regionale weg (driving lane: district road)	driving_lane	Car Truck bicycle etc
Rijbaan: lokale weg (driving lane: road)	driving_lane	Car Truck bicycle etc
Fietspad (cycle path)	Cyclepath	Bicycle
Voetpad (footpath)	Footpath	Pedestrian
Ruiterpad (bridle path)	unknown (missing: path)	Horse
Parkeervlak (parking area)	parking_lay_by or car_park	Car
Voetgangersgebied (pedestrian area)	unknown (missing: pedestrian area)	Pedestrian
Inrit (road to private property)	private_area	Car Truck bicycle etc
Woonerf (pedestrian priority area)	unknown (missing: pedestrian priority area)	Car Truck bicycle etc
Attribute	Attribute	
FysiekVoorkomenWeg	TrafficSurfaceMaterialType	
Gesloten verharding (closed hardening)	asphalt or concrete	
Open verharding (open hardening)	pavement or cobblestone	
Half verhard (semi hardened surface)	Gravel	

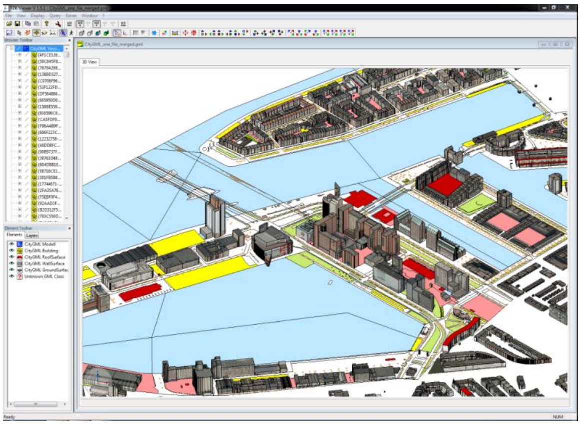
Onverhard (unhardened)	soil or sand	

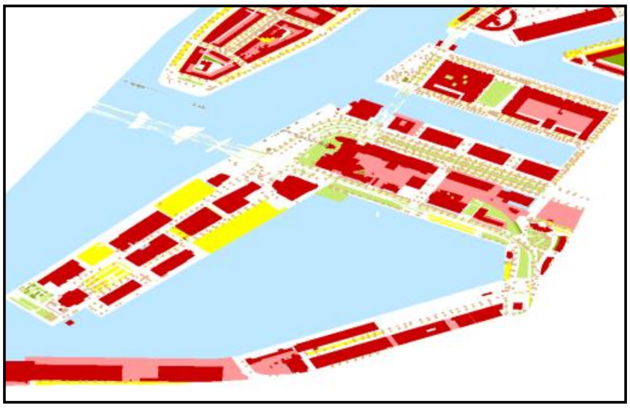
As can be concluded from 3, the mapping between IMGeo and CityGML naming conventions is not perfect, because of several reasons:

1. In IMGeo there is no equivalent class for TransportationComplex or Road. Only road parts (Wegdeel) are modelled. However, the code list for Wegdeel function in some cases gives the function of the road part as well as the function of the whole road it is part of. This is the case with the values starting with ‘rijbaan’ (English: driving lane).
2. Some values are difficult to map because there is no good equivalent in the CityGML code list. For example, there are values available in TrafficAreaFunctionType for cycle path and footpath, but not for paths designated for use by equestrians. A generic term ‘path’ in CityGML would have better suited, in combination with the TrafficAreaUsageType code list to indicate the modes of transportation allowed on the path.
3. The corresponding code list for traffic surface material in IMGeo starts at a more abstract level than TrafficSurfaceMaterialType in CityGML.

These issues of mapping code list value should be addressed in a future version of the model, since currently insufficient experiences are available to show which modelling approach (i.e. CityGML or IMGeo) is best.

To test the CityGML–IMGeo implementation profile, the UML model was converted into an xsd file. In addition, data modelled according to IMGeo 2.0 and laser point data were combined to generate CityGML–IMGeo-encoded data. Figure 6 shows the result. Since the model supports 2D as well as 2.5D and 3D representations; both 2D IMGeo data (Figure 6b) and 3D IMGeo data (Figure 6a) can be generated according to the same model..





a b

Figure 6: Visualisation of CityGML-IMGeo encoded data: CityGML LOD2 (a) and 2D-LOD of our implementation (b)

5. Framework for extending CityGML for national purposes

Based on the experiences of developing the CityGML-IMGeo standard, this section defines a framework for extending CityGML for national purposes. The framework defines how a 2D information model can be integrated with CityGML to support the full range of dimensional geometry types for geographical features in an integrated manner: i.e. 2D, 2.5D and 3D. The current research focused on the integration of CityGML and 2D large scale topographical information. Future research should identify how such an integration works for mid- and small scale topography as well as for geographical information captured in information models from other domains. The framework covers the following aspects:

- Integration of 2D information model and CityGML
- Geometry types and LOD
- Topology
- Use of code lists
- Use of CityGML properties
- Reference system
-

5.1 Integration of 2D information model and CityGML

The main principle of the framework is that the integration of the national information model on 2D topography and CityGML should adhere to the CityGML standard as much as possible while keeping the CityGML standard unchanged. This requires the following steps:

1. Conceptual mapping is needed between CityGML and the 2D information model to identify equivalent concepts, i.e. classes, attributes, code lists and code list values. In these mappings one should compare at semantic level, i.e. considering the concepts in any CityGML-LOD.
2. All classes of the national information model (in most cases with class names in national language) must be modelled as subclasses of CityGML classes (with English class names).
3. For classes for which no equivalent CityGML class can be found, two solutions are possible of which the first one is preferred:
    a. Remodel the 2D concept so that an equivalent CityGML class can be found (as was done for Vegetation and AuxiliaryTrafficAra in IMGeo)
    b. If a. is not possible, CityGML needs to be extended with a new class (as was done for Construction in CityGML-IMGeo).

NB1: For extending CityGML with our own classes and additional class specific attributes we did not make use of the extension possibilities of GenericCityObject and _genericAttribute. The reason was that the extension would not be formally defined in a schema with (Dutch language) names and definitions, and it would therefore not be possible to validate data that uses such extensions.

NB2: Also for extending the generic _CityObject with own attributes (that apply to all classes) we did not make use of _genericAttribute. Instead the stereotype <<interface>> was used to enable that a subclass inherits attributes both from the _CityObject (via a generalisation-specialisation relationship) and the root class of the 2D information model (via the <<interface>> stereotype). The reason for this is that some of the 2D IMGeo attributes have datatypes (complex, Boolean, code list) that cannot be described with _genericAttribute.

5.2 Geometry types and LOD

For the use of geometry types and the LOD concept, the following guidelines apply:

1. Which LOD is used should depend on the required level of detail in the third dimension rather than the positional accuracy as mentioned in CityGML specifications. Therefore the integrated model defines the same positional x, y accuracy for all LODs as prescribed by the 2D information model.
2. Extra attributes defining geometry types are needed to support the full range of geometries for every class: 2D geometry (not modelled in CityGML) and the LOD0 geometry if not present in CityGML (as footprints). With those LOD0 representations the exact 3D location of objects is known and 3D representations of those objects (LOD1 and higher) can easily be placed on the terrain assuring that they do not float in the air or disappear in the ground. In addition this approach supports 2D, 2.5D and 3D representations of objects in an integrated manner. Other deviations of CityGML geometries may be necessary if the 2D information model supports different geometry types than CityGML. For example surface for Water and Road at LOD0 instead of network geometry as in the CityGML-IMGeo case.
3. Special attention should be given to the link between buildings and terrain. Two approaches can be followed:
   a. The buildings have always horizontal foundation in the terrain and can sink, but the above surface and below surface geometries are modelled separately. The 2D representations of the buildings represent the building geometries at surface level, which can straightforwardly be extended into 2.5D. This modelling makes the Terrain Intersection Curves redundant (TIC) redundant. This approach was used in CityGML-IMGeo.
   b. The buildings have always horizontal foundation and may have underground parts (Zlatanova et al 1996). This means that the building can sink under the surface and the TIC for buildings has to be maintained to ensure the consistency with the terrain surface.
4. Terrain object as given in CityGML should be carefully considered. Three different approaches can be followed:
   a. Terrain is represented a surface by regular or irregular grid. The topographic objects are not integrated in the terrain (the current concept of CityGML)
   b. Terrain is represented by constrained TIN, which ensures the consistency between objects and terrain surface. The terrain is still present in the model.
   c. Terrain is not represented as a separate object, i.e. all the object on the ground (such as roads, land use, etc.) incorporate the terrain curvature in their representation (see Figure 2). This approach is used in CityGML-IMGeo.
   d.

5.3 Topology

The following guidelines apply for the topological structure:

1. If the 2D model contains a topological structure, the 2.5D surface (LOD0) should support this as well: all objects at surface level have a representation at LOD0 (= 2.5D surface) which together form a 2.5D topological structure for those objects located at surface level.
2. Objects that are located above and below the surface can also be placed in the third dimensional space with their LOD0 2.5D representation. An important requirement here is the connection to the 2.5D DTM that represents the surface. This may require

adding new 2D boundaries for adding more variance in 3D or extra 2.5D surfaces to the structure at the surface to avoid gaps.

5.4 Use of code lists

To make use of national classification code lists (which will be so specific in most cases that those national lists are preferred over the CityGML code lists) mapping tables between the code lists/ code list values should be provided (see Table as example).

Code list validation can be done using standard XML techniques such as Schematron constraints (ISO/IEC 19757-3:2006(E)). CityGML 1.1, which was not yet available at the time of writing, allows extension and replacement of codelists. Further work is needed to assess how code lists can be used, maintained and validated in the new approach.

5.5 Use of CityGML properties

Mapping tables should prescribe which CityGML properties must, may or must not be filled when exchanging data according to the national 3D standard. For example, in the case of IMGeo, 2D geometry must always be provided, LOD0 – LOD3 may be provided, and LOD4 must not be provided. Another example is that the ‘function’ and ‘surfaceMaterial’ properties of TrafficArea must be present and filled exactly once for each TrafficArea object. For the IMGeo standard more work is needed to describe these rules and mappings.

5.5 Reference system

For a national 3D standard it is required to identify the reference system (x, y, z) to be used in all CityGML files.

6. Change requests for OGC CityGML

The development of the model and sequential testing revealed some deficiencies both for IMGeo and CityGML. The deficiencies for IMGeo have been solved in the modelling process (for example adding classes for Vegetation and AuxiliaryTrafficArea). For CityGML a number of change requests (CRs) have been formulated and submitted to OGC if not yet covered by already submitted CRs (which are being considered for the next version of CityGML, see OGC 2011). The CRs that were formulated as part of this research are summarized and justified in this section.

Firstly, using CityGML as implementation for a national standard requires clearer definitions. The advantage of not having definitions for classes, properties and code list values is that the model can be applied in different contexts with greater flexibility. However lack of definitions makes it difficult to understand what is meant by a concept in CityGML. This issue confirms the CityGML change request (CR09-039, 2010) resulting from the OWS 6 test bed (Portele, 2009). This change request has been accepted with the decision to collect such definitions in a registry which has just been set up.

Another change request relates to the use and extension of code lists. The CityGML codelists are difficult to use because the values may not be ignored. However they are not easy to reuse since definitions are missing, concepts are overlapping or missing, etc. Therefore a guideline is needed for how to extend code lists or replace them. This issue is already addressed by the CityGML change request mentioned above (CR09-039) and is solved in CityGML 1.1.

For an implementation of CityGML further clarification is needed for the CityGML accuracy requirements: are these rules or guidelines? Page 10 of the CityGML standard states that "accuracy requirements in this standard are debatable and should be considered as discussion proposals". Further on, the requirements are formulated as formal requirements ("The positional and height accuracy of LOD2 must be 2m or better"…). This issue is also addressed in the mentioned change request (CR09-039) and is solved in CityGML 1.1.

Clearer guidelines for extending CityGML are needed for CityGML implementation profiles that support a specific context. Currently it is not clear whether the extension mechanisms of CityGML (generic objects and attributes and the ADE mechanism) are guidelines or rules, nor is it clear when to use which method for extension. Also, the ADE mechanism is only described in the context of GML application schemas. How to use the method in UML modelling is not described. The guidelines (or rules) for extending CityGML should be described more fully and clearly so that a working extension of CityGML (i.e. working in CityGML software) can be created by relying on these rules and/or guidelines. This issue is partly addressed by the CityGML CR09-039. A separate change request has therefore been submitted to the OGC to cover this issue. At the time of writing a decision on this CR has not yet been made, but it is likely it will be postponed to a later version of CityGML to allow more discussion on the topic.

LOD0 footprints for all CityGML classes are required in order to integrate the full range of possible geometries of semantic objects in one model, i.e. 2D, 2.5D and volumetric geometries. This enables to use 2D topographic data with a DTM and to upgrade 2D data to 2.5D and 3D. All geometries at LOD0 including these footprints must ideally have a topological structure. This issue is partly addressed by an earlier change requests, which asks for planimetric building footprints in LOD0 (CR10-007, 2010). A separate change request has been submitted to the OGC to cover this issue. At the time of writing a decision on this CR has not yet been made.As a result of having footprints of all classes available at LOD0, the LandUse functions that are not related to terrain but represent other classes that are at the moment missing at LOD0, should be removed from the LandUse class. A change request has been submitted to cover this issue, combined in one change request with the previous, related issue.

Enriching LandUse class with land cover information would improve the semantics for this class significantly. Information on the usage of land is sufficiently addressed in CityGML, but land cover is not. The code list values for the usage often refer to land cover, i.e. the physical appearance. This is often different from the way the land is used, analogue to traffic areas which do have function, usage, as well as physical appearance properties in CityGML. In the INSPIRE domain models Land Cover and Land Use are modelled as separate entities, which might be even better. A change request has been submitted to cover this issue. It has been addressed in CityGML 1.1 by adding a paragraph stating that the LandUse class can also be used for land cover information.

The semantics in CityGML could be enriched with an additional class for constructions other than buildings. In the 3D IMGeo model such a class was added, i.e. Construction as a specialisation of _Site. These other constructions are human-built objects, that are not 'buildings' in the normal meaning: e.g. they have no roof, doors, windows etc, may not be able to be closed off, etc. The INPIRE Building domain model also has a class OtherConstruction. This issue is partly addressed by earlier change requests:

- Harmonisation with Inspire Themes (CR10-062, 2010)
- Thematic module for bridges (CR10-051, 2010)
- Thematic model for man-made subsurface structures (CR10-048, 2010)
- Thematic model for walls in cities (CR10-053, 2010)

Since those thematic models do not cover all types of Constructions represented in IMGeo, a change request has been submitted to cover this issue in line with these earlier requests. At the time of writing a decision on this CR has not yet been made.

7. Conclusions and further research

This paper presents the development of a national standard for 3D geo-information as one of the main results of an extensive collaboration pilot in the Netherlands. The standard aligns both to the existing 2D standardisation framework and the OGC standard CityGML. Aligning to existing 2D information models is considered as important to reuse the valuable concepts as defined in those domain models. In May 2011 the proposed model has officially been approved as information model for large scale topography in the Netherlands. The involvement of stakeholders in the development of the standard appeared to be essential to obtain the necessary support for the national 3D standard. Some work unrelated to the 3D aspects of the model is still being done. However the IMGeo 2.0 information model will be finalised this year. From that moment it will be the standard for both 2D and 3D 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 3D use and a unique achievement for standardisation in 3D.

The main contributions of this paper can be characterised as a nationwide 3D standard on geo-information, covering all topographic classes, extending OGC CityGML standard, while integrating the different CityGML LODs with a 2D LOD and preserving the concepts of the 2D information model. Other main contributions are the generic findings deduced from our experiences: the proposed framework for extending CityGML for national purposes (Section 5) and change requests submitted to OGC to make the CityGML standard a better fit for integration with 2D topographic information models (Section 6).

In the development of CityGML-IMGeo a number of aspects were identified for further research.

Firstly, follow-up research is needed to test the 3D IMGeo model on its usability in practice including the consequences of this new modelling method for IMGeo when used for both 2D and 3D datasets (e.g. how to preserve the links between the different LODs and how to upgrade 2D LOD to higher LODs). Secondly, technical issues must be tested such as the ability to use 3D IMGeo data in CityGML-aware software. The new insights will lead to further refinements of the model.

Also the other domain information models need to be studied for extension into 3D when appropriate. Besides specific IMGeo aspects, CityGML-IMGeo contains generic aspects that can be reused for extending other domain information models such as for 3D cadastre (Stoter and Salzmann 2003) and 3D noise mapping (Stoter et al 2008). To get a feeling of the possibilities a study was carried out in the context of the 3D pilot on how to match the concepts of the other Dutch domain models to CityGML. For this matching also several ADEs were considered, such as the extensions for Tunnel and Bridge. In the future the planned ADE for cables and pipelines may be relevant (Becker, 2010; Hijazi, 2010). A proposal for support of voxels in CityGML is already in preparation. This proposal builds on (Tegtmeier et al, 2009) and (Zobl&Marschallinger, 2008).

Other aspects that warrant further research are:

- use of the CityGML Relief module to represent specific aspects of elevation (not used in current approach);
- use of the Tunnel and Bridge ADEs for more detailed modelling of these types of constructions;
- classify certain types of LandUse using the Vegetation class;
- define constraints to exclude CityGML concepts that are not used by IMGeo (or other external model), such as LOD4 geometry;
- define constraints to make optional properties of CityGML classes mandatory and to relate them to class properties of IMGeo (or of another external model);
- describe use, maintenance and validation of code lists;
- define constraints to link attributes that inherit from a CityGML class to added attributes with specific codelists of IMGeo (or of another external model).

Finally, more research is needed concerning the creation and management of CityGML-IMGeo data. Which methods can be used to generate CityGML-IMGeo data? How should this data be maintained? How can 2.5D topology be created, validated and maintained? Best practice documents could be a useful result of such studies. Therefore a new project has been started (more than 120 participants have subscribed) in which the results as presented in this paper are being made ready for use in practice.

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