# Standards for Exchange and Storage of 3D Information: Challenges and Opportunities for Emergency Response


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***Abstract***

*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 independence). The developers also vary from companies to international standardisation organisations that originated from CAD/BIM, GIS or Web domains. Being developed with different goals, the information in them (such as type of geometry, textures, semantics, relationships) varies significantly and this makes the integration of data in a single 3D environment almost an impossible task. Many problems can be experienced when converting data from one standard to another: information may be lost or models may be improperly converted, validity of objects may not be ensured, relationships might be diminished, etc.*

*This paper presents a comparative study of 3D standards with respect to a number of characteristics such as type of geometry, relationships, semantics, possibilities for realism, etc. The paper compares several well-known international and de facto standards. The characteristics of them are then discussed in the context of 3D models (and needed functionality) for (facilitating) emergency response.*


## 1. INTRODUCTION

Many applications require integration of data representing above and below the surface, indoor and outdoor, which implies 3D modelling and management of information. One of the most appealing examples is in management of infrastructure projects, such as construction of tunnels and development of new or renovation of existing neighbourhood in cities, harbours, and industrial areas. (Tegtmeier et al 2010, Zlatanova et al 2010). In the last years, risk management and emergency response applications has been also increasingly focusing on 3D models (Kemec et al 2010, Zlatanova 2008). 3D representations are used not only for 3D visualization but also for analysis (route navigation, damage detection, flood simulations, etc.) and query of thematic/attribute information.

However, the exchange and integration of 3D data sets is still quite problematic. Challenges can be seen in many aspects: varying definitions (semantics), representations, data models, accuracy, interpretation approaches (of modelling sub-surface geological formations), etc. 3D models have been developed throughout the years within various domains and for different purposes.

- Some of the first 3D models have been developed for geometric modelling (Bayer et al 1979). The aim of these first models was to maintain topologically correct geometric models to ensure consistent editing and visualisation. They are based on well-formed surfaces, which means they have the following properties: closed, orientable, non-self-intersecting, bounding and connected.
- Another group of models, which has been developed for data management, emphasizes on efficient storage and query of large data sets, and maintenance of various attributes (Breuning and Zlatanova 2011). Topologically correct data sets are not first priority although validity of object can be checked.
- Third group of models has been created specifically for fast and realistic visualisation. Such models provide extended tools to create a graph scene (maintaining textures, lights, events and animations) and do not consider valid object or structure issues.

The designers or developers of 3D standards and models also vary. Many models are devised by international standardisation organisations originated from CAD/BIM, GIS or Web domains, but a large number of models are vendor-based. Since the models are developed with a different goal, the information (such as type of geometry, textures, semantics, relationships) varies significantly. In many cases, the integration of data in one 3D environment is almost an impossible task. Typical problems that can be experienced when converting data from one standard to another are: information loss (attributes, textures, identifications, etc.), improper conversion (orientation of faces, data types), violation of topologic validity (intersections, or gaps), relationships lost, etc.

This paper presents a study on modelling approaches and compares several well-known 3D standards/formats. Large parts of the study are completed with in the 3D pilot project of the Netherlands. The first (explorative) phase was carried out between January 2010 and June 2011. Currently the second phase of the 3D Pilot is running, which will end in autumn 2012. The paper is organised as follows. Next section elaborates on possible 3D representations and 3D standards. 3D standards are compared with respect to 11 criteria. Section 3 presents the developments within the 3D pilot and explains how a 3D international standard is adapted for a national use. Finally, the findings of this project are now estimated with respect to risk and emergency response.

## 2. OVERVIEW OF 3D MODELS AND FORMATS

This section gives a short overview on approaches for 3D modelling, and 3D standards (models), which are largely used by software vendors.

### 3.1 Approaches for 3D representations

In the literature, two major 3D abstractions are distinguished for modelling 3D objects and phenomena (Mäntylä, 1988, Lattuada, 2006): Surface-based and Volume-based (see Figure 1, left). Constructive Solid Geometry (CSG) and Boundary representation are typical examples of Surface-based representations, while voxel (regular space subdivision) is an example of volume-based representations. A voxel is a regular 3D volume element, i.e. 3D 'pixel'. A 3D object is then represented as an array of voxels. Each voxel holds one (or more) data values. Voxel representation is appropriate for modelling of continuous phenomena such as geology, ocean, climatology, soil, etc. (Figure 1, right). The benefit of voxels is in that they are regular in modelling and thus their management and analysis on them is simple (i.e. the volume is very easy to compute). A disadvantage of voxels is that high resolution data results in large volumes of data. Furthermore, the surface is always somehow "rough", which might result in unrealistic visualisations. In contrast to the regular voxel, Constructive Solid Geometry (CSG) uses spheres, cubes, and cylinders as basic primitives. Set operations (union, intersect, difference) are applied to the basic primitives to construct 3D bodies. The advantages of CSG models is in that they are good in Computer-Aided Manufacturing: a brick with a hole drilled through it -is represented as just that-. The disadvantages for the use of CSG in real world modelling are that the objects and their relationships might become very complex.

Boundary representation is the approach that is widely accepted for modelling discrete real-world objects and design (computer graphics) models (Foley et al 1995). The 3D object is represented by bounding low-dimensional primitives (vertex (0D), line (1D), polygon (2D), polyhedron (3D)), which are organised in data structures. The primitives can be either simple such as planar faces and straight edges or complex such as curved surfaces and edges. The main advantage of boundary representations is that they represent real-world objects as they are perceived by humans. The boundary of the objects can be obtained by measuring properties that are visible (i.e. "boundaries"). Main disadvantages of boundary representation include that the complexity is high and no unique data structure exists. The primitives may vary and i.e.can be a face (topologically described), a triangle or a polygon (geometrically described). Depending on the used primitive (triangle or polygon) different constraints can be enforced such as: 'polygons must be planar', 'orientation of polygons must be clockwise', etc. Although more complex, boundary representation is in the basis of most the file formats (models) used in GIS and CAD used for exchange of information. Therefore the following section will continue further with standards mostly based on Boundary representations.

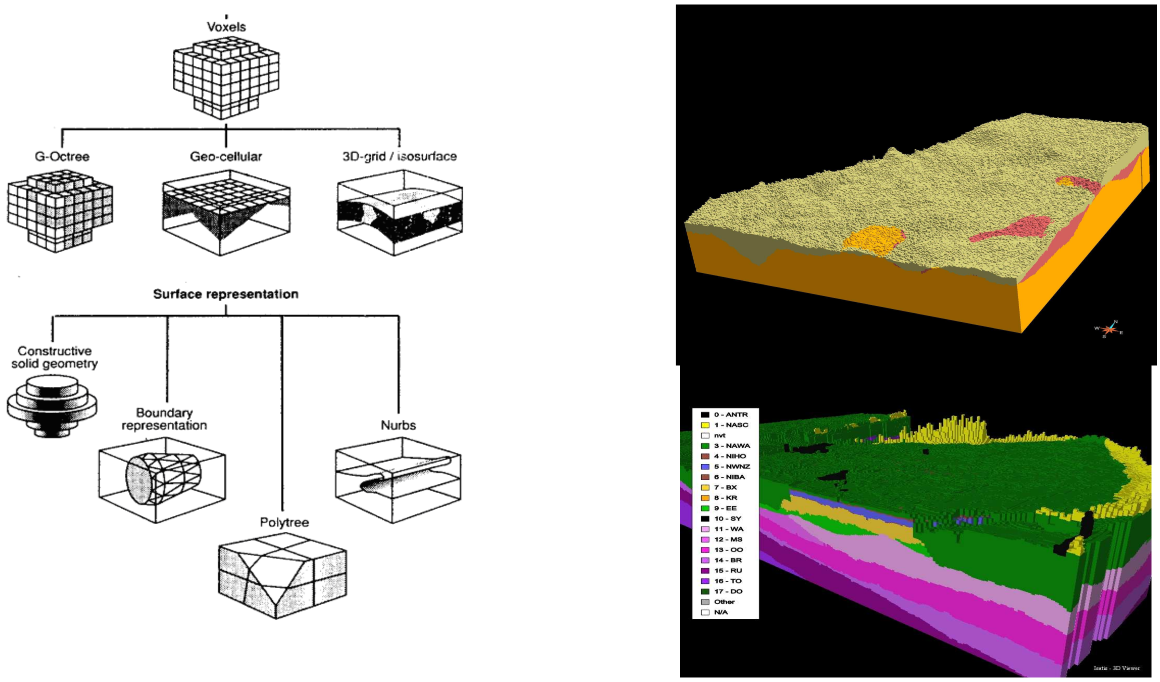


*Figure 1: 3D spatial representations (courtesy Lattuada 2006) and voxel models with interpretation of voxel values (courtesy TNO, Netherlands)*

## 3.2 3D file formats

A diverse range of file formats exist for exchange of 3D data. Some of them have been developed as standards by international organizations (VRML, X3D, IFC, CityGML), others have been developed by vendors, but due to their wide use they are accepted as standards (KML), and a third group of standards have become *de-facto* standards due to their wide acceptance by users and software vendors (SHP, DXF, COLLADA, 3D PDF). The file formats are created to serve a specific goal (i.e. SHP to have geometry and attributes), VRML (to allow realistic visualization and interaction), COLLADA (to support modelling and visualization), IFC (to keep semantics along with geometries), etc., and therefore all have different characteristics. Some of the most well-known file formats are shortly reviewed below.

The Virtual Reality Markup Language (VRML) was released in 1995 and accepted as a standard by the Web 3D consortium. It was designed as a web standard for exchange of graphics while providing possibilities for interaction with 3D world. Practically it is a language for modelling 3D realistic scenes and interaction. The format offers several texturing mechanisms and a variety of different geometries. Good visualisation performance can be obtained when using compressed binary representations (i.e. gzip), but still simple visualisations look 'too schematic'. This was one of the major reasons for rather limited use of VRML for real world projects. Taking into account some of the disadvantages of VRML (being not XML-based, large models result in large files, etc), the Web 3D consortium has stopped the development of the standard after 1998 and concentrated on the XML based X3D file format. This file format is an enhancement of VRML, in fact, this file format is even less used than VRML. Only few viewers are available for visualisation of data on Internet and almost no vendor supports export and import of X3D. Some experts suggest that the format became too complex for interpretation.

Keyhole Markup Language (KML) is an XML format for geographic annotation and visualization of objects inside Google Maps and Google Earth. KML was developed by the company Keyhole, Inc. which was then taken over by Google. At that time KML was adopted as standard by the OGC. The support of geometry in KML is aligned with GML. KML is suitable for Web applications and widely accepted, but geometries are represented without semantics. COLLADA is another open standard for describing 3D data. Originally, this standard is from Sony (used for Playstation). Google uses this standard frequently (it is the core of all 3D objects in Google Earth and a key part of Google SketchUp) which has greatly increased the use of COLLADA. COLLADA (stands for COLLAborative Design Activity for establishing an interchange format of 3D interactions) focuses solely on 3D data, independent of the architectural context. COLLADA provides possibilities for describing geometry, topology and texture, but has no semantics. KML and COLLADA are often mentioned together because both are jointly used in

Google SketchUp and Google Earth. KML files are often bundled in a compressed KMZ file, which may also contain COLLADA 3D models, texture overlays and other graphics and icons.

GML (Geography Markup Language), also known as ISO 19136, was created by the Open Geospatial Consortium (OGC) and is an XML structure for the representation of geographic (spatial and location) information. It is a typical example of a standard created for the exchange of data. GML 3 has a modular structure, which allows to select the schemas or schema components that are needed for a specific application. The geometry model of GML follows the ISO 19107 standard and therefore GML provides classes for 0D to 3D geometric primitives, 1D-3D composite geometries (e.g. CompositeSurface), and 0D-3D geometry aggregates (e.g. MultiSurface or MultiSolid) consisting of geometries which are not connected by common boundaries. GML 3 includes support for spatial and temporal reference systems, topology, dynamic features, units of measure, metadata, gridded data, and is designed to be semantically extendable.

CityGML is the newest standard (OGC, 2008) for representing of 3D real-world information. CityGML is an object-oriented model that allows semantic, geometry, topology and appearance characteristics to be stored per each object. The second version has been released in April, 2012 (OGC, 2012). The semantics is expressed by classes, which aim to cover a large group of commonly used real-world objects. There are currently 11 classes (CityGML 2.0.0). In addition to these core classes there are classes for appearance, and generic information. Generics class is used to extend the model with new objects (not defined by the core) and attributes. Another mechanism to describe new objects is by creating an Application Domain Extension (ADE). This mechanism is more powerful since it allows new objects to be defined with their semantic, geometry, appearance and topology properties. Several extensions are already provided such as: Noise (for noise analysis), GeoBIM (populated wıth detailed information from /BIM/IFC), Facility management (CAFM), Hydro (for flood analysis) and Utility Networks. Discussions are going on extension for geology and geo-technology. An ADE for indoor navigation, i.e. objects and their attributes that are specifically important for indoor routing, is also under development.  The model is based on GML3 and all the geometry of GML are inherited by the semantic extension. GML supports 0D to 3D primitives (point, curve, surface and solid) and supports composition objects. A very useful geometry in this respect is Composite Surface, which is a set of connected surfaces. Almost all 3D objects (buildings, city furniture, waterbody) are represented by *CompositeSurface* geometry. *CompositeSurface* can be mapped with textures (artificial or photorealistic). Optionally the 3D objects can be represented as *Solid*. *Solids* must be watertight and the software that creates the CityGML model has to ensure this property.

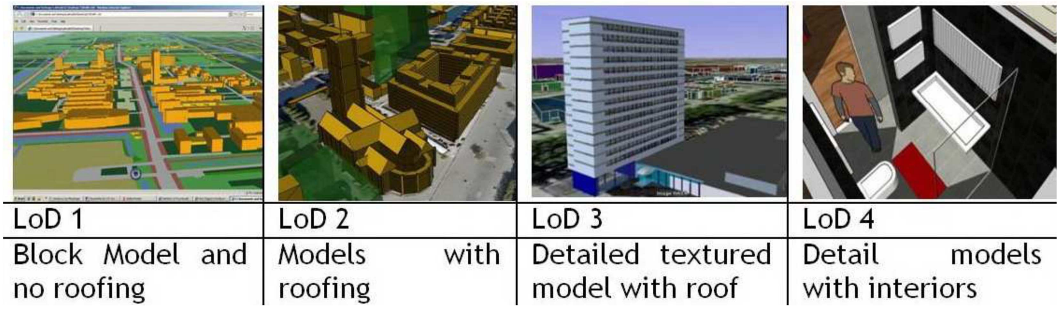


*Figure 2 CityGML LOD for buildings (Kibria et al 2009 )*

CityGML supports 5 different levels of details. The most prominent are the LOD of buildings (see Figure 2). Buildings have 5 LOD starting from LOD0 to LOD4 (indoor). The CityGML idea of LOD differs significantly from the well-known LODs of computer graphics. CityGML LODs represent a specific resolution of real-world objects that might be of interest for a specific application. For example, an application to determine the coverage of telecommunication antennas, will only need simple extrusion boxes (e.g. LOD1), while an urban planning application will require models with well-represented facades, roofs, etc. The LOD are not intended for fast visualisation (as this is the case in computer graphics), although recent attempts has been  made to use them speeding up the visualisation of large city models. LODs are intended to represent the accuracy of the objects, i.e. LOD0 has the lowest resolution (few meters) and LOD4 the highest (few millimetres). LOD0 is a 2,5D model and represent only surface objects. LOD4 for buildings is the first well-structured GIS representation of indoor environments. In contrast to Building Information Models (BIM), it offers indoor representation that reflects the human vision on buildings, i.e. the buildings consists of rooms and the rooms have doors, windows and furniture.

CityGML conceptual model exists currently in two implementations as GML file and spatial schema for DBMS. CityGML file export is supported or going to be supported by several vendors such as Safe software, Autodesk, ESRI, Bentley Systems. Some companies (e.g. Bentley Systems, Autodesk) and Universities (e.g. TUBerlin, TUDelft) have experimented with database implementations of CityGML. TU Berlin has developed 3DCityDB for Oracle Spatial. The spatial schema follows closely the conceptual model and uses the Oracle Spatial geometry data types. An import/export application for this database is also available. The application reads CityGML files and populates the database. Export is possible to CityGML and KML files.

A Building Information Model (BIM) can be defined as 'a digital representation of physical and functional characteristics of a single building. As such, it serves as a shared knowledge resource for information about a building forming a reliable basis for decisions, during its lifecycle from inception onwards' (NBIMS, 2007). Furthermore, BIM is used as common acronym for Building Information Modelling, which is 'a collaborative process which covers business drivers, automated process capabilities, and open information standards use for information sustainability and fidelity'. BIM is also seen as a facility lifecycle management tool to support all the information exchange used throughout the building lifecycle. In this paper we refer in particular to the model and not the process of modelling. One of the most accepted BIM is the standard Industry Foundation Classes (IFC, ISO16739) model. IFC is the effort of IAI/buildingSMART whose goal is to specify a common language for technology to improve the communication, productivity, delivery time, cost, and quality throughout the design, construction and maintenance life cycle of buildings. In IFC, a building is modelled as a collection of objects (with properties and relationships) that represent parts of the building. The 3D geometry is one of the properties, at the same level as the name of the vendor, cost, etc. IFC objects may represent any building element such as  walls, doors and windows but also the glass in the windows, window frames, materials in the walls, etc.  BIM is used mainly in construction and is suitable for 3D modeling in a very precisely manner and much detail. It is often used to model a limited site (e.g. a building). It is not used for large areas, as is typical in GIS applications. The immediate vicinity of the object of interest may be modelled in BIM for informative purposes (often at a much lower level of detail). Today, BIM also provides geo-reference models (i.e. the inclusion of the coordinates on the surface of the modelled object).

DXF (Drawing Interchange Format) has been created by Autodesk, December 1982 as part of AutoCAD 1.0, and has grown through the years as one of the most used formats for exchange of 2D and 3D CAD drawings. The file structure is ASCII-based and well described. Specifications for DXF from AutoCAD Release 13 (November 1994) to AutoCAD 2008 (March 2007) are available on the web site of AutoDesk. The file formats supports many different geometries (simple and complex), layers and drawing attributes. Since it has been designed as drawing Interchange format, it does not support thematic attributes. DXF is not designed for web, but tools have been provided by some vendors for web-based visualisation.. The file format is mostly used to exchange data from one software package to another. Topology, texture, objects, level-of-details are not explicitly supported, although the user can apply some tricks.

The shapefile (SHP) is created by the Environmental System Research Institute (ESRI) in 1998 and is a typical example of a GIS file format. It supports simple geometry (i.e. OGC point, multi-point, polygon, polyline and since ArcGIS 10 polyhedron), including vendor specific data types (i.e. multi-patches). SHP is binary file format and adapted for faster drawing speed and editing capabilities. The major advantage of this file format is that the objects are kept with their thematic attributes. The file format consists of three files: main file: *.shp; index file: *.shx and DBase file: *.dbf. Shapefile is the most commonly used format for GIS data. There are many tools and applications that can read and export SHP file. SHP does not have a topological structure and the representation of textures is very basic.

A very interesting  new development is the 3D PDF. The intention of this file format is to publish and share 3D design information within a normal PDF file format. Several Large CAD vendors (Bentley Systems, Autodesk) allow export to this file format. The 3D geometry is exported in a PDF format and can be integrated in a text document using Adobe sofwatware. The 3D model can be the explored by a special tool box for interaction (developed by Bentley Systems). It is also possible to run animations, add comments, etc. if not digitally viewed, the document can be printed. Then the 3D model appears as picture.

### 3.3 Comparison of 3D standards

The comparison of standards was performed on the basis of eleven criteria, which were important for the goals of the 3D pilot. The level of support with respect to these criteria is classified into: - (not supported), 0 (basic support), + (support) and ++ (extended support). The explanation of the eleven criteria organised in three groups: shape and appearance, object identification and attributes, and syntax and web visualisation:

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 GML, 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 visualisation). As mentioned above, in the case of CityGML these are used to indicate the resolution of an object. The browsers do not use CityGML LODs in the visualisation (in case of several LODs some browsers show all of them).

The *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. KML and COLLADA are indicated as not supporting objects, because the user needs to pay a lot of attention to the creation of the file in order to recognise different objects. The best way to keep track of objects is to create separate files. *Semantics* indicates the possibility to assign thematic meaning to an object or a group of objects. Using DXF, SHP and 3D PDF this is possible by using 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 object 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. The *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 for the Web and therefore this standard is ranked lower. *Geo-referencing* estimates the possibility to use geographical coordinates. It should be noted 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.

*Table 1: Comparison of 3D standards*

| | Standard/Criterion | VRML | X3D | KML | COLLADA | IFC | GML3 | CityGML | DXF | SHP | 3D PDF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Geometry | ++ | ++ | + | ++ | ++ | + | + | ++ | + | ++ |
| 2 | Topology | 0 | 0 | - | + | + | + | + | - | - | - |
| 3 | Texture | ++ | ++ | 0 | ++ | - | + | + | - | 0 | + |
| 4 | LOD | + | + | - | - | - | - | + | - | - | - |
| 5 | Objects | + | + | - | - | + | + | + | 0 | + | + |
| 6 | Semantic | 0 | 0 | 0 | 0 | ++ | 0 | ++ | + | + | + |
| 7 | Attributes | 0 | 0 | 0 | - | + | + | + | - | + | + |
| 8 | XML based | - | + | - | - | + | ++ | + | - | - | - |
| 9 | Web | + | ++ | ++ | + | - | - | + | - | - | 0 |
| 10 | Georeferencing | - | + | + | - | - | + | + | + | + | + |
| 11 | Acceptance | ++ | 0 | ++ | + | 0 | 0 | + | ++ | ++ | ++ |

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

The comparison in Table 1 clearly shows 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 (with exception of IFC) however contain poor support for semantics and attributes. Clearly these standards originate from the CAD domain.

In contrast standards such as SHP, IFC, CityGML have a very good support of semantics, objects and attributes. It is clear that CityGML scores relatively good on all criteria. Because of the support of semantics, objects, attributes, georeferencing and Web use, the selection of CityGML as generic standard for a 3D SDI envisaged in this study is justified. Compared to SHP files (one of the most used GIS format), CityGML has almost the same power to describe real-world objects and at the same time allows better visualisation and use over the web.

Our study paid a lot of attention to the IFC standard and CityGML. IFC contains detailed information about buildings, constructions and utilities (Hijazi et al 2011), which can be compared to the CityGML LOD4. The integration of both types of data via a common exchange format is beneficial since BIM data can feed detailed GIS representations and GIS can provide reference and environment data for BIM. Isikdag and Zlatanova (2009) propose that transforming information from IFC to CityGML requires a two-step approach: transforming semantic information and transforming geometries. Since the objects (classes) in these two models are very diverse, the two steps cannot be performed separately. An object in one of the models might be mapped to a group of objects (and vice versa), which requires a careful consideration on the order or converting geometries and semantics. In order to perform a successful transformation operation; 1) A set of rules (a rule base) needs to be clearly defined in the first stage, in order to define the semantic mappings between the classes of two models for each LOD of CityGML; 2) The second stage will be building up the rules/algorithms for geometric model simplification. A BIM model view can facilitate model simplification in this stage; 3) The final stage will be defining the information that will be transformed to form the attributes of the CityGML objects for each LOD. A lot of research has been completed on approaches for achieving this integration, e.g. via web services (Lappiere and Cote 2008), ontology (Peachavanish et al 2006; Akinci et al 2008, database (BIM server 2009), formal mapping (Benner et al 2005). Also, software packages are provided for IFC to CityGML conversion e.g. SAFE Software FME (Safe Software 2012).

The two models have many similarities but also have many differences. Both IFC and CityGML are semantic models and maintain some relations between the items. The relations are not topological (although CityGML can incorporate a topological structure). Both models can be queried and a subset of the model can be visualised. The models have many differences as well. Being created for two different application domains, the class definitions may differ significantly. For example, both models have a notation for a 'wall'. However, while the wall in the IFC represents the entire physical (solid) wall between two rooms, the wall in CityGML is only one of the wall surfaces visible from one room. Many classes that are defined in IFC do not exist in CityGML and vice versa. The spatial relationships may differ as well. For example, in IFC, a window is given with its relative coordinates with respect to the wall it belongs to. CityGML would maintain a relation 'belong to' between window and a wall but the coordinates of the window will be absolute. Currently, two different approaches for integration of IFC and CityGML can be observed: 1) Querying of both models and integrating the results in a Web application (applying web services) and 2) Conversion of IFC model into a CityGML model

In the first approach, no real conversion is made but a set of features from the two models is visualised in a single environment. One of the most significant initiatives regarding this approach is the OGC Web Services – Phase 4 (OWS-4) test-bed, in which 72 organisations collaborated to demonstrate interoperability of internet based OGC services. The main activities of the test-bed took place in 2006. A number of software and data components were developed to demonstrate a concept of integrating AEC and GIS information via web services. Especially important was the emergency response scenario which demonstrated the variety of OGC conformant components (Lapierre and Cote 2008). The scenario required numerous components and services along with IFC and City GML models to coordinate the response to the hypothetical forest fire incident. The activity was divided into a number of threads each of which addressed a particular set of technical issues affecting the scenario such as security, workflow and sensor web enablement. The test bed has clearly shown that information queried from IFC and CityGML models can be transferred to a client and visualised together. While appropriate for observation, this approach has drawbacks when performing spatial analysis. For example, it might be difficult to indicate which indoor corridor should be used for evacuation.

The second approach assumes that an appropriate conversion of classes/attributes/relations at the semantic and geometric level can be performed. This conversion requires transformation at several levels: semantic (description of classes), geometric (representation of shapes and coordinates) and corresponding attributes and relationships (Isikdag and Zlatanova 2009). Commercial applications such as Karlsruhe IFC Explorer (IFC Explorer 2009), SAFE Software FME (Safe Software 2012), Autodesk Land Explorer (Autodesk 2009) can directly transfer 3D geometries of the building elements in IFC into CityGML models. The tests that have been conducted so far with two of these tools indicated that although there are unsolved issues related to the conversion of geometries, i.e. from Sweeping/CSG representations of IFC to BRep of CityGML, the mismatches on the semantic side is much more apparent and important. These mismatches occur as a result of i.) transfer methods and ii.) the different object models of IFC and CityGML standards.

## 3. 3D PILOT IN NETHERLANDS

The study of 3D standards was largely performed during the 3D pilot in the Netherlands (Stoter et al 2012). The pilot was initiated by the Dutch Kadaster, Geonovum (the National Spatial Data Infrastructure executive committee in the Netherlands which develops and manages the geo-standards), the Netherlands Geodetic Commission (NCG) and the Dutch Ministry of Infrastructure and Environment. From January 2010 until June 2011 a uniform approach for acquiring, maintaining and disseminating 3D geo-information has been explored in a collaboration between over 65 stakeholders in The Netherlands (Stoter et al. 2011). A major result of the pilot was the proof of concept for a 3D Spatial Data Infrastructure (SDI), covering issues on the acquisition, standardisation, storage and use of 3D data. The findings of the pilot were formally established in a national 3D standard realised as a CityGML Application Domain Extension. The ADE completely integrates the OGC CityGML Encoding Standard (OGC, 2012) with a new version of the existing national Information Model for Geo-information (called IMGeo). IMGeo contains object definitions for large scale representations of roads, water, land use/land cover, bridges, tunnels etc. and prescribes 2D point, curve or surface geometry for all objects. As the new version of IMGeo is completely integrated with CityGML, IMGeo version 2.0 also facilitates extensions to 2.5D representations (i.e. as height surfaces; equivalent to CityGML LOD0) and 3D (i.e. volumetric; i.e. CityGML LOD1, LOD2 and LOD3) representations of the objects according to geometric and semantic principles of CityGML. Further technical details about the ADE are reported in Van den Brink et al (2012a; 2012b).

In the development process of CityGML ADE IMGeo 2.0 a number of topics that requires further attention were identified before the standard can be widely implemented. Firstly, more research is needed to understand how the national 3D standard works in practice including  the consequences of the new modelling method for IMGeo when used for both 2D and 3D datasets, e.g. how to preserve the links between the different Levels of Detail (LODs) and how to upgrade 2D LOD to higher LODs. Also, knowledge is required on the ability to use 3D IMGeo data in CityGML-aware software, i.e. whether software systems are compatible with our extensions and which changes are necessary. 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 validated and maintained? These open issues are currently being studied in a follow-up project of the 3D Pilot. The goal of the follow-up pilot is more result-oriented than the first pilot and aims at writing best practice documents by joint effort of the 3D Pilot community. The best practice documents are based on tools and techniques that are being developed for supporting the implementation of the 3D standard. Specific attention is being paid how to align CityGML to IFC. About 100 organisations Geonovum (2012), participate in the second phase of the 3D pilot and are currently executing the six activities of the second 3D Pilot NL (see www.3dpilot.nl)

3D test data have been prepared for the test area and several participants are currently working on generating different LODs and different themes for 3D IMGeo data. The 3D Pilot will finish in summer 2012. End results include: examples of 3D IMGeo data, a 3D validator, best practice documents on how to acquire, maintain, update and disseminate 3D IMGeo data, demonstrators that show the potentials of 3D, and recommendations for further developing CityGML compatible with 3D standards in other domains and with the established 2D information models. Setting a standard for 3D topography was the first step. In the near future different application domains will align their domain models to be able to reuse 2D and 3D IMGeo data in their applications. Examples of relevant domain information models that have been established in the Netherlands and that are currently seeking alignment are: Public order and safety: *Informatiemodel Openbare Orde en Veiligheid* (IMOOV), Cable and Pipelines: *Informatiemodel Kabels en Leidingen* (IMKL), Spatial Planning: *Informatiemodel Ruimtelijke Ordening* (IMRO), Cadastre: *Informatiemodel Kadaster* (IMKAD), Water: *Informatiemodel Water* (IMWA), Subsurface: *Informatiemodel Bodem en Ondergrond* (IMBRO).

## 4. IMPLICATIONS FOR EMERGENCY MANAGEMENT

All these developments have influence on the risk and emergency management in Netherlands. An increasing number of companies developing software for risk and emergency response provide tools for 3D visualisation but still all tools are mostly experimental. Furthermore if 3D dimensional models are created, they are not extensively exchanged and maintained.

In Netherlands, 3D models are predominantly used in virtual training (for preparing emergency responders). The 3D models created are usually artificial (non-existent) cities, which only simulate some important for the training characteristics. For many training goals (e.g. communication, orientation, situational awareness, etc.) such models are very appropriate.  However, for some learning objectives it is very useful to train with real-world environments, like a specific high-risk city environment or an industrial settlement. When such real-world cities are needed, they are presently tailored by a serious gaming company. Such re-construction projects are relatively expensive and time consuming. The 3D models are usually very realistic, highly interactive (usually based on game engines) but lack semantic or topological properties or a formally defined data structure. An integration of such models with other data is almost impossible. In contrast, many municipalities have CityGML models of their whole city or parts of it in one or more LOD. Usually most of the models contain the entire core CityGML features. Examples are Rotterdam, Den Haag, Apeldoorn, Enschede and Amsterdam. Furthermore, with the development of 3D IMGeo more and semantically richer models will be soon available. These models will be maintained by the local authorities, which brings a number of advantages for training software: 1) they have the potential to include much more semantics about the different parts of the buildings such as roofs and walls in LOD2, or doors, windows and balconies in LOD3, 2) they are created and maintained by professionals, which ensures reliability and higher quality, 3) the set of attributes can be extended if the applications requires it, 4) if an object has more LOD, they can be used with respect to the needs of the training. Governmental organizations, like public safety and security services, which wish to use such models for serious gaming is increasing, beacuse: 1) Lots of efforts will be saved for tailor-made 3D reconstructions. The existing 3D model can be just loaded in the game engines; 2) 3D city models represent the real world just as well or even better since they are created by measuring the real-world objects (buildings, roads, trees, etc.), 3) The accuracy is often higher and in some cases the models are very realistic, as they are (also) made to support construction and city management and planning activities, 4) Different parts of the model can be used in the training. The virtual environment has therefore the potential to become as large as the real world.

The software in support of emergency response operations is presently based on 2D models. In contrast to training, during emergencies, accurate and reliable information about the real world is required. For the purpose of decision-making, large amount of spatial analysis have to be performed, which a result of questions as 'which is the affected area?', ' how many people have to be evacuated?', 'which are the closest shelters, hospitals', etc. Therefore many emergency response applications are developed on top of GIS packages (e.g. ArcGIS) to be able to complete the spatial analysis or are kind of a Web-based application (Ushahidi, Suhana Software foundation, Google, Open Street Map) to support situational awareness and allow volunteered collection of information. Therefore the step to 3D is depended on the availability of 3D models (data exchange standards) and 3D software which will allow the integration of data. In this respect the design of 3D IMGeo in Netherlands is a very promising step. If the large topographic map of a country is extended to 3D, all other maps and models can be relatively easily upgraded to 3D. As mentioned in the previous section, the Dutch model for Public order and Safety (IMOOV) will be linked to 3D IMGeo and effectively extended to 3D. As result IMOOV will be able to record information more accurately, i.e., considering the vertical directions, including the facades of the buildings. IMOOV is a rich semantic model representing mostly the dynamic information (Dilo and Zlatanova, 2011) during incident and originally designed to cope with any kind of disaster as discussed in the Dutch procedures for emergency response (Diehl en v/d Heide, 2005). The combination of 3D IMGeo and IMOOV will provide powerful basis for exchange and re-use of information for any kind of incident.

## 5. OUTLOOK AND FUTURE INVESTIGATIONS

In this paper we have presented a study focused on 3D standards for exchange of geometric and semantic information. The study has clearly revealed that CityGML is a very promising standard as it has the ability of representing geometry, topology, appearance and semantic properties. The 3D pilot in Netherlands has shown that such international standard is still too generic for a national purpose, and as a result the national standard 3D IMGeo was developed.

These developments open new directions for emergency management as well. 3D IMGeo can be used in the preparedness phase for training with real-world models and in the response phase for increasing the situational awareness and performing 3D spatial analysis. Still many developments have to take place, prior the third dimension is adopted by the stakeholders of the emergency response processes. Availability of appropriate 3D city models is one of the most important issues. For example, first discussions with emergency experts have already revealed that the CityGML method of applying textures for building facades (i.e. one texture for the whole façade) might not be sufficient. Experience has shown that textures on the street level should be with much higher resolution, compared to texture on 1$^{st}$ and 2dn floor.

Furthermore the issue of "what kind of additional thematic classes will be of interest for emergency response" should be further investigated. Additional questions to be explored include, "Which codes should be added to the code lists of CityGML (3D IMGeo) to make them appropriate for a specific context and task?", "Which Level Of Detail should be used for certain tasks?", "How different textures can be used for street level visualisation?", "How can the validity of 3D geometries be enforced, to increase the realism?"

A very important question is "which emergency response tasks will benefit from 3D models?" Clearly not all the actors in the process would need them. For example, disaster managers located in the response centre, who are responsible for the overall management of disaster operation might only need overview 2D maps. 3D models are expected to help emergency responders on the field. Many handheld devices may also provide better overview using 2D representations than 3D representations. To be able to answer to all these questions, we have initiated an investigation on the benefit of 3D data versus 2D, which will be performed until the end of 2012.

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