Design of an integrated 3D information model

L.Emgård & S.Zlatanova
GISt, OTB, Delft University of Technology, Delft, the Netherlands

ABSTRACT: 3D city models and traditional 3D GIS have so far neglected underground structures and features both in theory and practice. Many applications are looking for such integrated approaches, however. In this paper we define a thematic semantic framework for integrated modeling of geographic 3D data, combining man made and natural features above and below the earth surface. Our approach extends the semantic concept and the information model created for the exchange format CityGML by dividing features close to the earth surface into: *above*, *in* and *below* the earth surface. Further, the concept of implicit storage and terrain intersection objects is extended to connect features to a TIN based earth surface model. All features, intersecting or touching the earth surface TIN, create a projected geometry that is integrated in the DTM geometries. A suggestion for a possible database implementation of the extended information model is also addressed.

1 INTRODUCTION

Computerized 3D city models, 3D virtual environments and 3D visualizations have existed for several decades. Realistic 3D models describing parts of the earth surface in urban environments or natural phenomena like mountains or forests can regularly be observed at every major GIS software exhibition. So far, 3D city models and 3D GIS have neglected underground structures and features both in theory and practice. The integration of subsurface spatial objects, the digital terrain model and spatial objects on the terrain remains a problem to be solved (Kolbe & Gröger 2003). Although, geological data models and software provide tools to represent sophisticated geological situations in three dimensions (Apel 2006), one critical question is: 'how these models can efficiently be integrated with subsurface man made features, features on the surface, as well as, 3D city model data above ground'. In addition to this, existing 3D city models still frequently miss thematic semantic information, i.e. information about what real feature a geometric object describes (Kolbe & Gröger 2003). Currently, data integration is limited to export and import of data between software in well known file formats i.e. DXF or VRML97, which almost always results in loss of thematic data and/or metadata.

A number of international standards and industry specific formats have been developed for geometric and semantic description of natural features as well as design features both above and below the earth surface. Though, the formats are often specific for one domain. For example, NADM 43a, GeoSciML and XMML are representing geological observations and features under the surface, IFC standard (ISO/PAS 16739) is dealing with semantic description of design objects (mostly buildings) and CityGML built on Simple feature specification (ISO 19107:2003) is representing city features above ground.

Additionally, file formats describing 3D geometry and occasionally semantics exist such as Multipatch, OpenFlight, X3D, GeoVRML, U3D, KML, LandXML, QUADRI etc. Even though it is not a realistic task to integrate domain specific variables such as pollution, wind flow calculation, radio wave coverage or ground water simulations in one representation we argue that there is need for an integrated representation model describing the geometric representation of 3D physical objects in 3D space and thematic semantics describing what geometry is representing what feature in the real world. We present a framework to integrate subsurface features in an existing concept and thematic semantics for the top-level objects in our information model.

2 THEMATIC SEMANTIC REPRESENTATIONS

For 3D city models few thematic semantic models exist. A common understanding is that buildings and terrain objects are the most important features to describe in a 3D city model (Billen & Zlatanova 2003) and Köninger & Bartel (1998) founded the following top-level object classes: buildings, streets, green areas, public areas and terrain surface while Dahany (1997) suggests only three groups: terrain, vegetation and built form. Within the geo information field several subdivisions of space into objects on a national level can be found, and also some international initiatives. The Dutch harmonized base model called NEN3610 based on the ISO/TC 211 is one example of a recent specification of top-level objects in urban space (Quak & de Vries 2006).

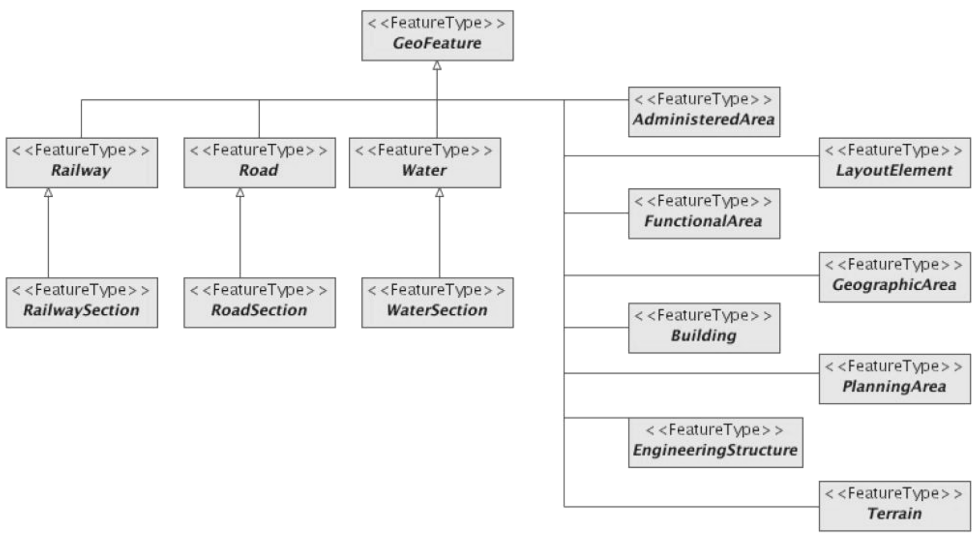

Figure 1. First level of the hierarchy in NEN3610 without details (Quak & deVries 2006)

The NEN3610 model constitutes a basis for exchange formats within the Netherlands defining 11 base elements (NEN 2005). Within the EU project INSPIRE a set of 21 spatial data themes has been defined. The themes cover infrastructural units i.e. buildings, terrain models and transport networks as well as administrative and environmental themes i.e. cadastral parcels, addresses and human health and safety (INSPIRE 2007). Since the INSPIRE framework is still under development no detailed descriptions or UML notations of the themes are available.

Within the field of ontology a number of thematic semantic models are to be found. For example, the Towntology project aims to produce taxonomy of ontologies in the Urban Civil Engineering (UCE) field. To achieve this goal an ontology tool suite call Towntology Tool Suite and a set of ontologies has been developed (Towntology 2007).

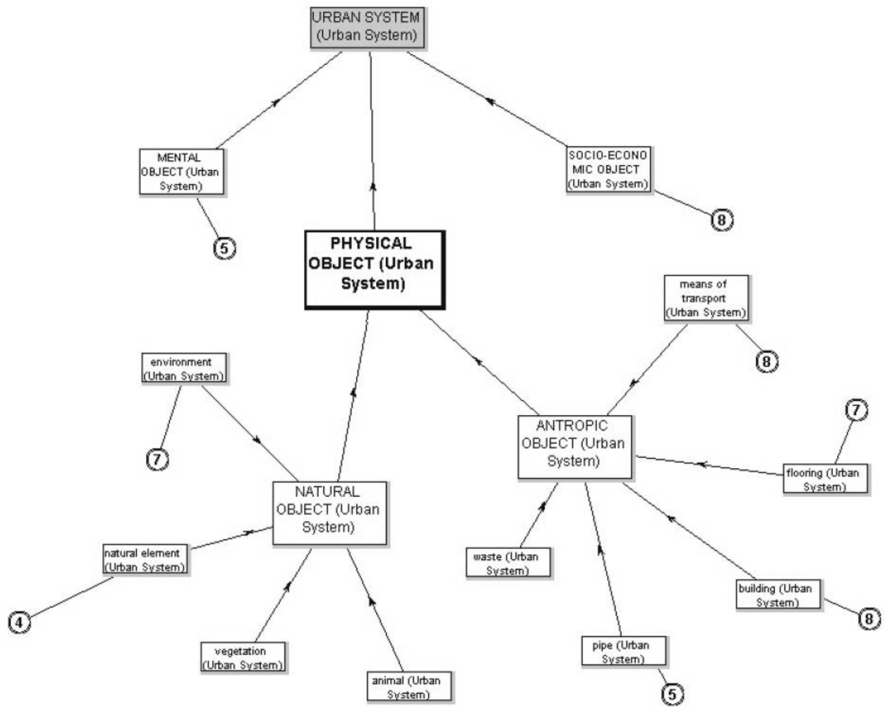

Figure 2. Example of taxonomy for the Urban System built using Towntology software. Physical, Socio-economical, and mental objects are linked to the Urban System with part-of relationships. It is possible to observe the first two levels of Physical objects taxonomy (Caglioni 2006).

The thematic semantic representations described are examples of subdivision of urban space into features, but they anyhow do not contain mapping to the geometric representations of 3D city models. In our opinion the semantic model require a strong relation to the methods used to describe features within 3D city modeling.

3 CITYGML

Due to the described lack of an information model covering both geometry and semantics for 3D city models a standardization initiative was started in Germany 2002. The exchange format CityGML has been developed since 2002 by the members of the Special Interest Group 3D (SIG 3D) of the initiative Geodata Infrastructure North Rhine-Westphalia (GDI NRW). The SIG 3D is today an open group consisting of more than 70 companies, municipalities, and research institutions from Germany, Great Britain, Switzerland, and Austria working on the development and commercial exploitation of interoperable 3D models and geovisualization.

CityGML does not only represent the graphical appearance of city models but especially takes care of the representation of the semantic resp. thematic properties, taxonomies and aggregations of Digital Terrain Models, sites (including buildings, bridges, tunnels), vegetation, water bodies, transportation facilities, and city furniture. The underlying model differentiates five consecutive levels of detail (LOD), where objects become more detailed with increasing LOD regarding both geometry and thematic differentiation.

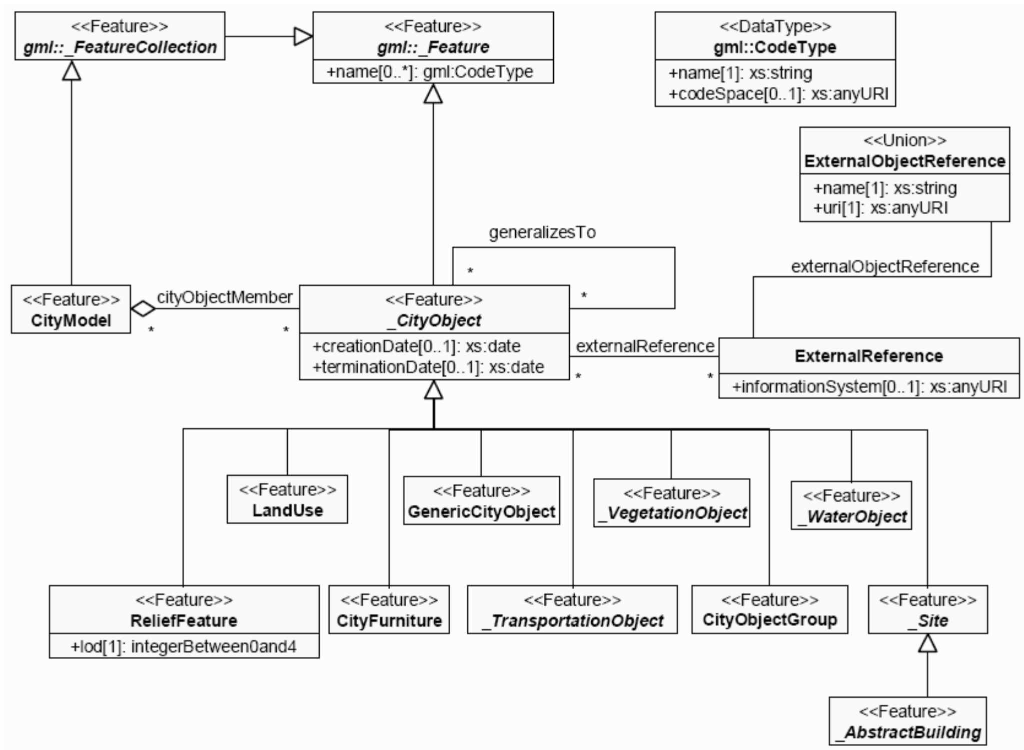

Fig 3. UML diagram of the top level class hierarchy of CityGML (Gröger et. al. 2006)

In CityGML, objects which are not geometrically modeled by closed solids must be virtually sealed in order to compute their volume (e.g. pedestrian underpasses, tunnels, or airplane hangars). They can be sealed using *ClosureSurfaces*. The concept of the *TerrainIntersectionCurve* is used to integrate 3D objects with the Digital Terrain Model at their correct positions in order to prevent e.g. buildings from floating over or sinking into the terrain. Furthermore, objects can have external references to corresponding objects in external datasets, assigned textures and material properties.

CityGML uses a subset of GML3's geometry model, based on the standard ISO 19107 'Spatial Schema' (Herring 2001) representing 3D geometry according to the well-known Boundary Representation (B-Rep, cf. Foley et al. 1995) with the base geometry types: point, curve, surface and solid. In CityGML, the term *implicit geometry* refers to the principle that "a geometry object with a complex shape can be simply represented by a base point and a transformation, implicitly unfolding the object's shape at a specific location in the world coordinate system". *Explicit modeling*, on the other hand, is to represent the object using absolute world coordinates (Gröger et. al. 2006)

We believe that the information model provided in CityGML is the most extensive and well described thematic semantic approach for 3D city modeling. Therefore, in our integrated information model, many of the concepts and objects are directly adopted from CityGML while some of the concepts are extended or new.

4 DESIGN

We introduce an integrated information model including thematic semantics and mapping to geometry types for man made and natural features based on the subdivision of features into:

- Earth surface features
- Above earth surface features
- Below earth surface features

The modeling of the earth surface as a digital terrain model (DTM) represented by a triangular irregular network or a GRID is commonly used and accepted and the earth surface feature is the most central object in our approach. Due to the fundamental difference between features above and below the surface we believe that a distinction is defendable, even though some objects exist both above and below (i.e. utilities). For instance, the underground requires a full partition of space (e.g. for neighborhood calculations) while above ground, the air does not necessarily has to be expressed by geometries (Zlatanova et. al. 2004). The possibility to examine objects and their assembly is also significantly more complex below the surface (Lattuada 2006).

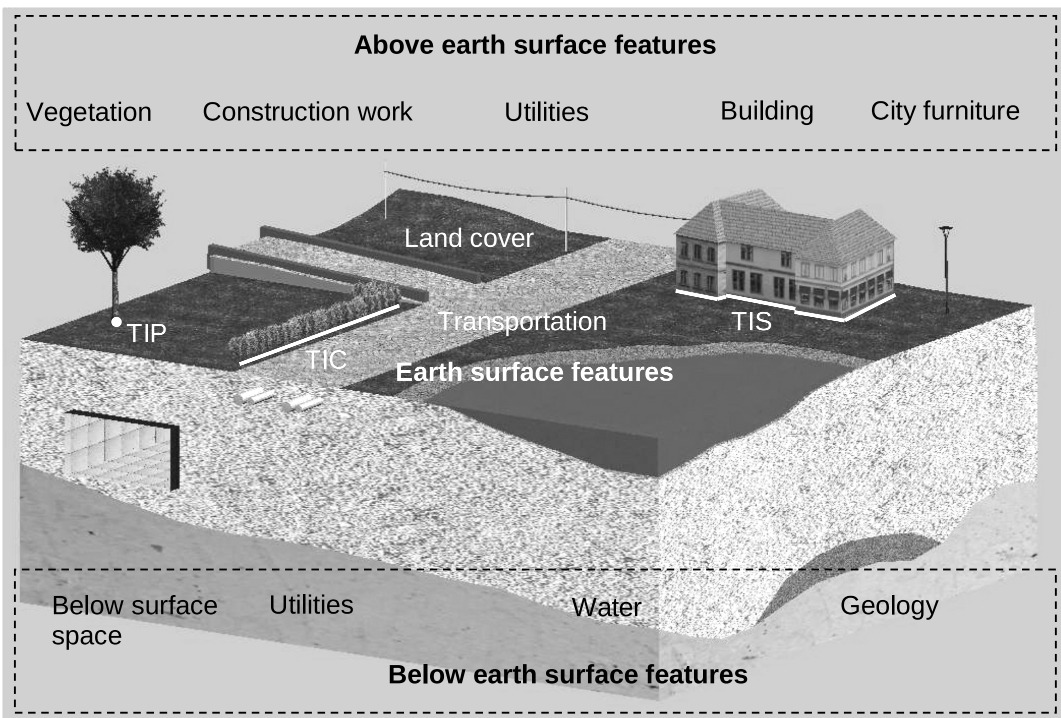

Figure 4. Thematic semantic subdivision of features close to the earth surface.

Objects above surface are separated into the top-level classes (*building, vegetation, construction work, city furniture and above surface utility*) and objects below surface into (*geology, water, below surface space and below surface utility*). Objects that compose the earth surface are divided into *land cover, transportation, TIS, TIC and TIP*.

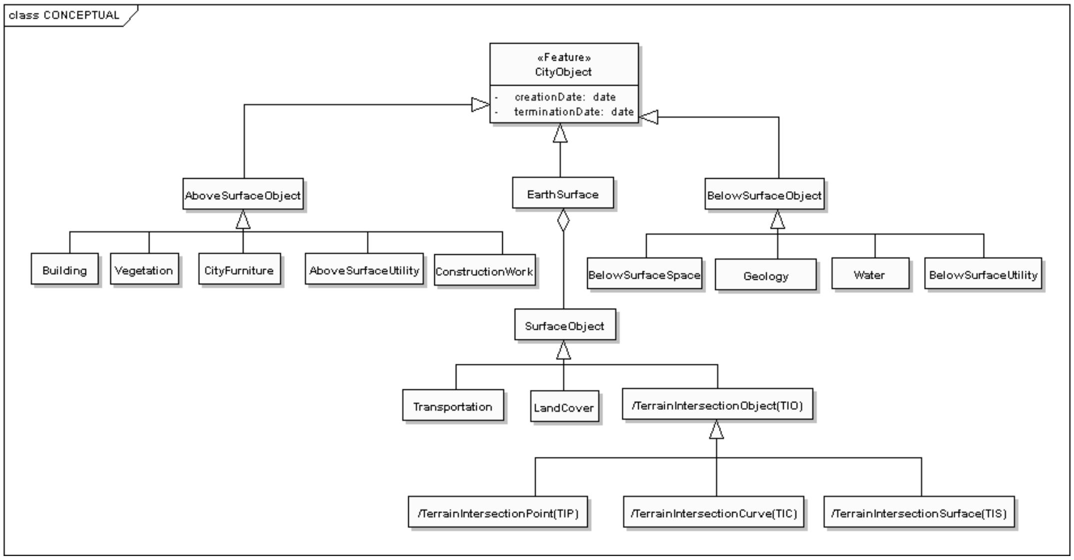

Figure 5. UML diagram of top level object hierarchy.

Historically, computer graphic cards, rendering 3D graphics, require triangulated surfaces arranged in a scene graph that is rendered to visualize three dimensional objects. This fact has affected the methods to represent geometric 3D data to the degree that the term 3D data is for many technicians synonymous with triangular mesh objects in 3D space. 3D data stored in other geometric representations e.g. geologic data (2D points with depth attributes), GIS data (2D point, line and polygons with z-values) or point clouds (scattered 3D laser scanning observation points) in 3D space is commonly transformed to meshed objects by extrusion, sweeping, segmentation or interpolation for visualization by graphic cards. Another reason for the widespread usage of triangulated meshes is the compliance for import and export between different software packages. Nowadays, planar surfaces with more than three nodes can automatically be triangulated and rendered by graphic cards. With this extension, GRIDs are more effectively stored and large planar surfaces i.e. water surfaces require less storage space when not triangulated.

In this initial version of the information model we restrict the geometry representation to include points, curves, planar surfaces, and solids (created from planar surfaces) in accordance with ISO 19107 ‘Spatial Schema’ (Herring 2001). This excludes parametric surfaces as well as CSG solids but include usage of the polyhedron or tetrahedron solid features. In the design phase the choice of internal topologic structure within geometries is not yet necessary to be specified.

In our approach, features above ground are allowed to be modeled as open surfaces or surfaces closed into solids, where defined solids may not overlap. The air above the surface may not be modeled and below ground only volumetric (solid) objects are allowed in a full partition of the underground (except utilities that are modeled by points and curves).

4.1 *Earth surface model*

The earth surface model we propose is represented by a fully partitioned 2.5D surface object of geometry type TIN or GRID where the entire surface is divided into non-overlapping parcels in one of the following top-level classes: transportation, land cover or *terrain intersection surface* (*TIS*). In addition to this subdivision, each part of the terrain can also belong to a class according to a specified thematic land use. The thematic land use class can be for example residential or industrial area etc. The full partition of the 2.5D surface and solid objects above and under it can be compared with the hybrid cadastre approach by Stoter & Oosterom (2005).

Transportation surfaces are parts of the earth surfaces used for transportation. The transportation surfaces can be classed into detailed classes e.g. pavement, street or square or according to transportation classes e.g. pedestrian, bike, car, bus, train etc.

Land cover surfaces are surfaces that are a part of the earth surface not used for transportation. They can be classed into detailed classes e.g. grass, soil or mud. Continuous vegetation higher than 20 cm is not classed as a land cover surface since this earth surface is then occupied by a vegetation object (see vegetation).

Transportation surfaces and *land cover surfaces* may only be used to cover parts of the ground that are not occupied by an object on top of it. An object classed as “above surface” is always somehow connected to the surface and the projection of the object on the surface is introduced as a terrain intersection object.

Terrain intersection objects (*TIOs*) are points, curves and surfaces that are integrated in the earth surface geometry. Thus, a TIO does not represent a typical semantic feature. *Terrain intersection points* (*TIPs*) are identified as nodes in the surface, *terrain intersection curves* (*TICs*) are identified as groups of edges in the surface and *terrain intersection surfaces* (*TISs*) are represented by a number of adjacent planar polygons in the surface.

- A *TIP* is a point where for example a pole or a tree intersects the surface. The node holds certain attributes about the object that projects it.
- A *TIC* is a curve in the surface model projected by vertical plane or surface features for example a fence.
- A *TIS* is a part of the surface where a body, for example a building or construction work intersects or touches the ground.

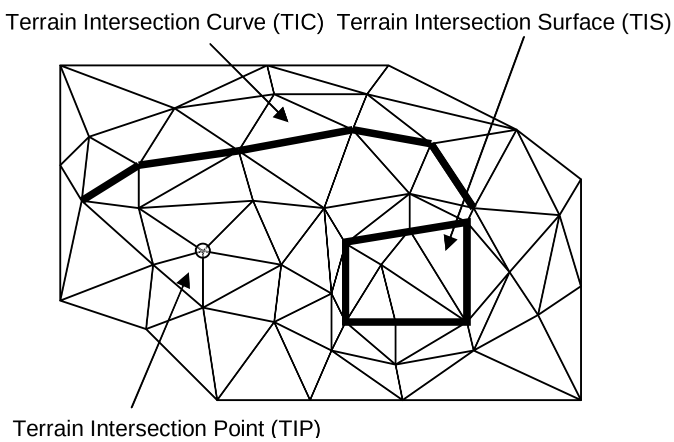

Figure 6. Terrain intersection object types

The relationship between the object and the corresponding *TIO* is not always 1:1. One object can project several *TIOs* (even different types of *TIOs*). For instance a building with external pillars can be projected into one or more *TIS* and one or many *TIP*. A *TIS* can also have wholes in it. Potential openings in the surface may be modeled by *closure surfaces* since every underground object must be bounded upwards by the earth surface (Kolbe & Gröger 2003). Closure surfaces are surfaces that are not visible (rendered). They are used to constitute boundaries of bodies that are invisible, for example the opening of a tunnel. As a result of this, the *TISs* for below surface spaces are always represented by closure surfaces (see underground spaces, section 4.3). The TIOs are integrating features with the earth surface and hence preventing a well known problem; objects not connected to the surface are often displaced along the z-axis (Gröger et. al. 2006).

4.1.1 *Defining the earth surface*

The surface model may be triangulated from scattered height values or laser scanning points. In addition, 2D features from GIS systems can be used as constraints within the triangulation to create 2.5D surfaces of individual objects (van Oosterom et. al. 2005) which we refer to as *TIOs*. If height data is created by aerial laser scanning, no data is collected for the terrain where objects intersect the terrain. In a simple situation the height values for the terrain may in these cases be interpolated, but in complex situations where the surface is not well defined it should be chosen manually depending on the situation (see figure 7). An object intersecting the surface is divided into two objects; the part above the surface and the part below the surface. The relation between the two objects is preserved.

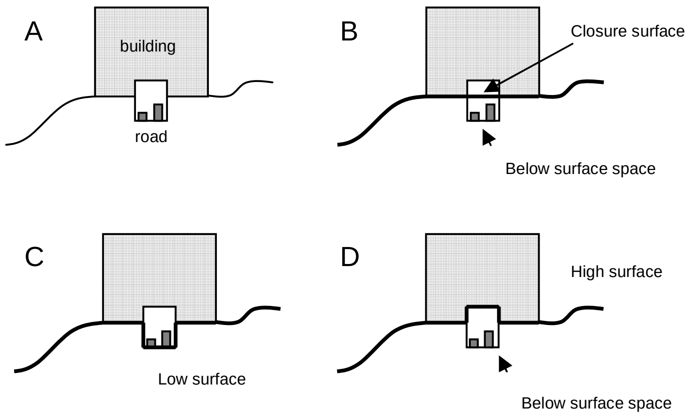

Figure 7. Examples of a complex situation where the earth surface level has to be chosen.

In figure 7, a complex situation is described, where a road is passing under a building (A). The surface can be defined in three ways (B, C or D). In B, the surface is placed underneath the building, intersecting the tunnel. The above part of the divided space is defined as air (not modeled) and the below part is modeled as below surface space. In C, the surface is defined in the bottom of the tunnel (the space is not modeled) and in D the entire tunnel is modeled as below surface space.

4.1.2 *Implicit representation*

As explained earlier, an *implicit geometry* is described as “an object with a complex shape that can be simply represented by a base point and a transformation” (Gröger et. al. 2006). We extend this concept by additionally defining curves and surfaces as implicit geometries. Thus, *TICs* and *TISs* can be regarded implicit geometries that may be replaced by a more complex shape. A *TIC* together with attributes can be used for describing a textured vertical plane and a *TIS* can be used for describing a volume vertically extruded from the *TIS* with an equal height. In this manner, *terrain intersection objects* are not only a projection of objects on the surface but also a base for reconstruction of the object in a low level of detail (LOD). With this method, features with low (LOD) can easily be constructed by the well known extrusion modeling technique, not only from 2D to 3D but from 2.5D to 3D. Today, many commercial CAD and GIS systems are representing geometries implicitly (points, lines and polygons) with attributes to define the 3D extent and appearance (ViaNova Systems 2006) and the 3D mesh geometry is automatically placed or extruded when required.

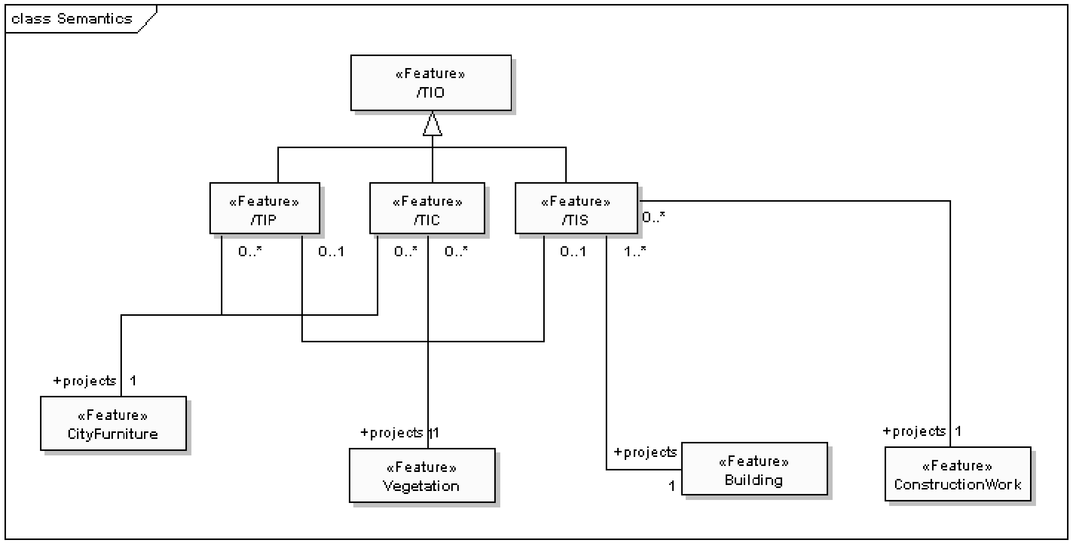

Figure 8. Relation between objects above ground and their projected surface geometries (TIO).

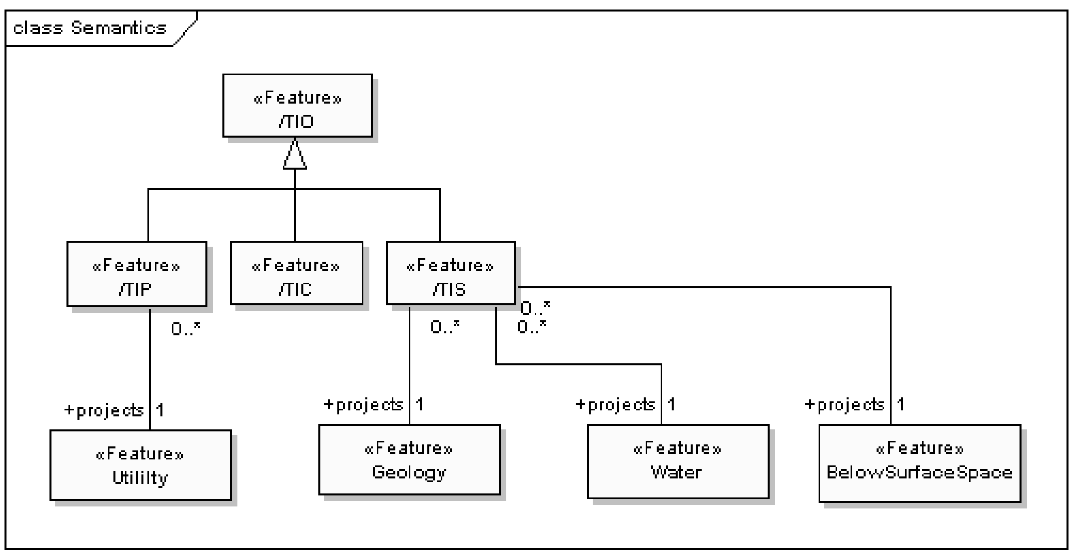

Figure 9. Relation between objects below ground and their projected surface geometries (TIO).

4.2 *Objects above the surface*

Buildings are objects above ground that are occupied by people for living, working, storage or other activities. A building is composed by walls, a roof and ground into an open or closed aggregation of surface geometries that can be created in four increasing levels of detail. In LOD1 the building is represented by an extruded box model and in LOD4 detailed building parts are modelled e.g. openings like doors and windows. Even the inside of the building is modelled by objects classed as interior walls, ceilings and floors.

Where the building is intersecting or touching the surface the *TIS* (ground) is to be defined. If the building is intersecting or partly intersecting the surface the *TIS* is modelled by a *closure surface* object. Basements in private buildings that can be represented by the building footprint and a depth value are not modelled as underground spaces (see underground spaces). Except for the stated *TIS* extension, the information model for buildings is completely adopted from CityGML (see CityGML specification for further explanation about building representation).

Construction works are man made features above the ground for example bridges, traffic constructions, walls or skywalk passages that are built between two buildings and is not a building part to any of the buildings (van Oosterom et. al. 2005). Construction work objects are created of one or an aggregation of surfaces optionally closed to a solid. The construction work feature is adopted from the Dutch NEN3610 specification (NEN 2005) to describe miscellaneous constructed items that do not generally belong under the expression building.

City furniture are man made non removable objects that intersects or touches the ground for example street lights, traffic signs, bus stops, large flower pots, benches, telephone booths, fences or advertisement signs. If the city furniture object (for example a lamp or a traffic sign) intersects with the surface the object is represented as a *TIP* referencing an object created from surfaces. All city furniture objects are implicitly stored as symbols in one of the following ways.

- A *point city furniture* is an object that can be represented by a *TIP* (node) in the surface e.g. lamp or pole.
- An *oriented point city furniture* is an object that can be created from a symbol with a *TIP* and translation matrix e.g. phone booth or bus stop shelter.
- A *curve city furniture* is a city furniture feature that can be created by repeated symbols along a *TIC* e.g. a fence or thin wall.

Vegetation objects are all natural growing objects that raise more than 20 cm above ground. All vegetation objects are implicitly represented objects that are connected to the terrain by a *TIO*.

- A *point plant* is a tree or bush that is not a part of a bunch of trees or bushes. The point where the tree is intersecting the ground is a *TIP* with attributes describing type, height etc. The tree is represented as a symbol created from surface geometries. The terrain intersection points for trees are replaced by the single tree in visualization.
- A *curve plant* is a row of bushes or trees of the same type. It is implicitly described by a *TIC* with an attribute describing the type of plant.
- A *plant cover* (plant cover) is a bunch of trees, bushes or seed of the same type that rises more than 20 cm above ground. The plant cover is implicitly stored as a *TIS* and a height value that is equal or random for the whole 2.5D surface.
- A *plant cover body* is a bunch of trees or bushes with defined variable height. It is created of a solid and may be filled by randomly set trees according to the height bounded by the body. The plant cover body is composed by the *TIS* and a surface geometry describing the body.

Above surface utilities are cables that are hanging in the air and are connected by poles (city furniture) or buildings and constructions. The utilities are implicitly represented by curves or point geometries that may not intersect or touch the terrain. Hanging lamps that are attached to line utilities are represented by points. The utilities above surface are modelled as a subclass of the superclass *utilities* since utilities above and below surface have several shared properties.

- *Point utilities* are described as points with a reference to a surface geometry symbol.
- *Curve utilities* are implicitly described curves together with a diameter attribute to describe the thickness of the cable.

4.3 *Objects below the surface*

Below surface spaces are manmade cavities in the ground used for different purposes e.g. wells, extended basements, tunnels, railway tunnels and stations, shops, parking garages or underground storage rooms. If the cavity touches the terrain the *TIS* of the below surface space is modelled by a closure surface to bound the underground solid. Below surface spaces are divided into two classes.

- Space for transportation of vehicles (tunnels, parking garages)
- Space for storage, living or working and other activities

Water is describing the extent of a lake, sea or river etc. A body is created by a combination of the water surface (*TIS*) and the surface geometry describing the bottom of the water body. The water body can also include dissolved soil or floating objects. However, the bottom surface is defined as the surface where an object with higher density than the water stops sinking. To close a water body which exceeds the bounds of the modelling space *closure surfaces* are used.

Geology is describing different bodies of earth material below or in the terrain. In cases where the bedrock is to be seen in open (e.g. outcrops or beach) the geology is touching the terrain creating a *TIS*. In other cases the geological body does not project *TIS* features on the surface. To close a geologic body exceeding the model space, *closure surfaces* are used. Below a water body the geologic objects are created starting were it touches the water body. The geologic features are divided into following classes.

- *Natural geologic bodies*
  - *Soil layer bodies*
  - *Rock layer bodies*
  - *Cavity bodies (oil, gas, air)*
- *Altered geologic bodies (filling material)*
- *Artificial filling material*

Below surface utilities are underground features used for transportation e.g. pipes, power lines and telecom or smaller electronic devices and water management devices. The utilities are implicitly represented by lines or points and that are not necessarily connected to the terrain.

- *Point utilities* are described as points with a reference to a surface geometry symbol.
- *Curve utilities* are implicitly described curves together with a diameter attribute to describe the thickness of the cable or pipe.

5 SEMANTICS AND GEOMETRY

The relations between features and geometry are described in three UML diagrams divided into features related to point, curve and surface features according to the simple feature specification (as in CityGML we use GML notation for geometries). Point and curve features are merely used for description of *implicit geometries.*

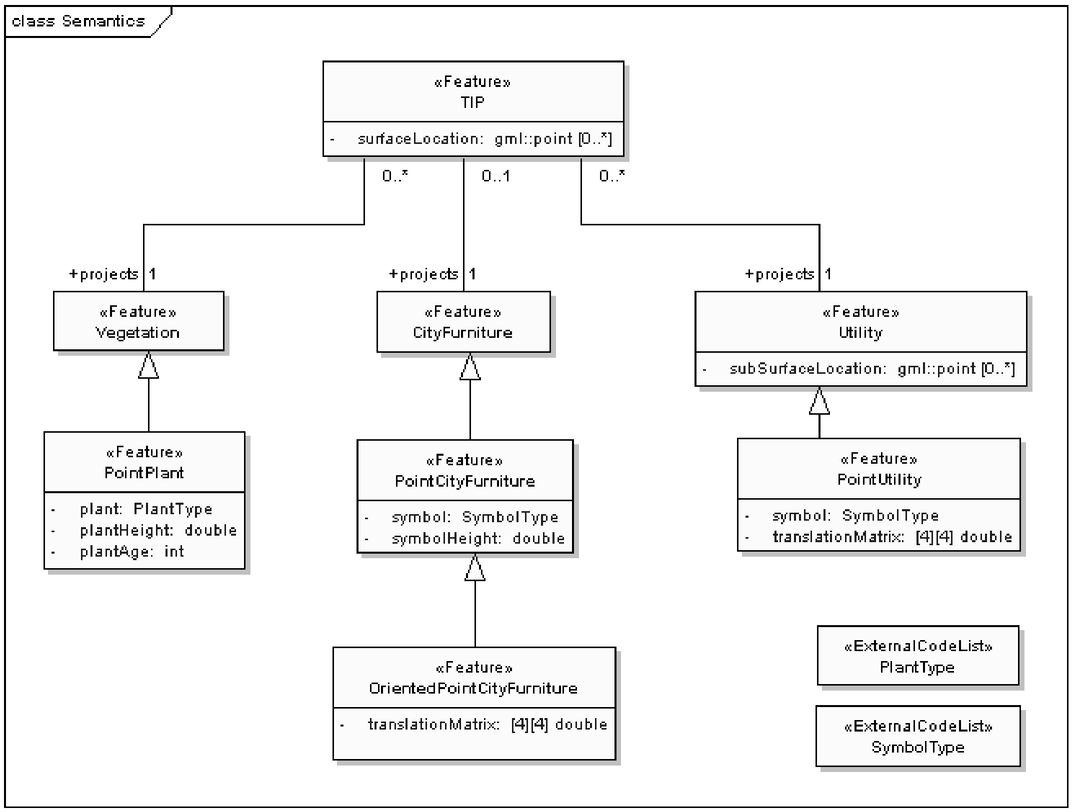

Figure 10. Top level objects related to the gml::point geometry type for implicit storage

In figure 10, both vegetation and city furniture classes are always related by a projection to the TIP feature, which is represented by a point geometry. The utility point feature is either related to one or many TIP or to one or many 3D points in the subsurface. External code lists are noted for attributes using code lists.

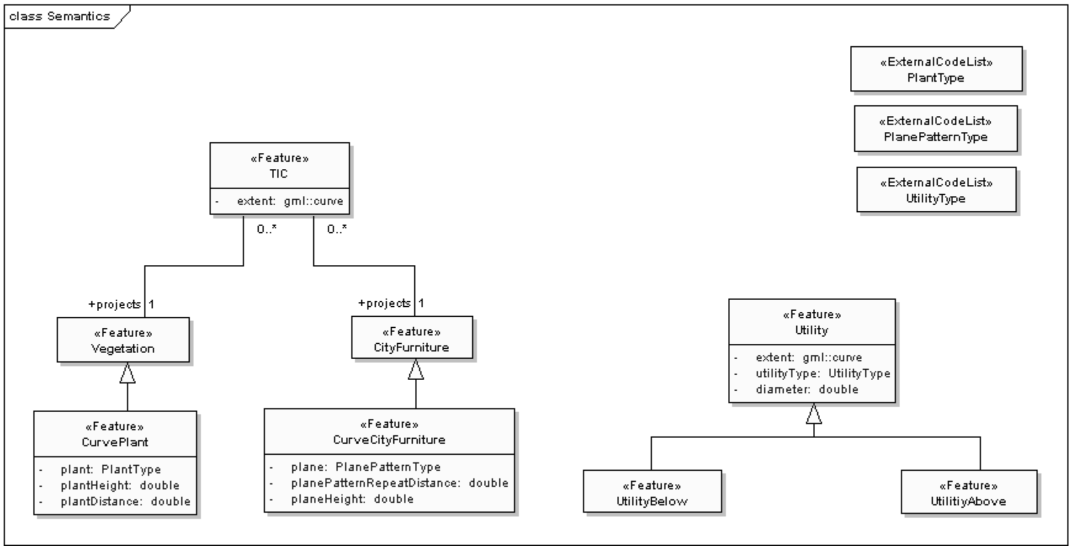

Figure 11. Top level objects that are using the gml::curve geometry for implicit storage (similar to figure 10).

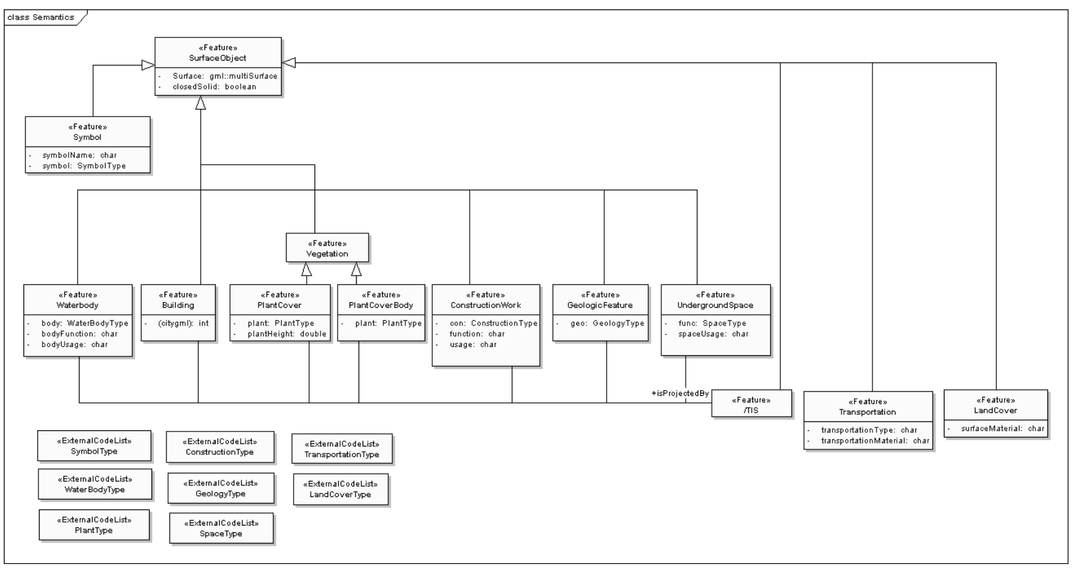

Figure 12. Top level objects that are using open or closed gml::multisurface geometry.

In figure 12, all objects are described that are modeled by *surface objects* (gml::multisurfaces) that can also be defined as closed solids. Also the earth surface features (TIS, transportation and land cover) are subclasses of the surface object. The relation between the features and the TIS is specified. The surface representation of the point plant, point city furniture and the point utility as well as the curve plant, curve city furniture and utility is described in the class *symbol*.

5.1 *3D geometric representations*

For modeling of 3D surface objects, some alternative representations needs to be considered (that can be created with the simple feature geometries). Objects can for example be modeled by the solid geometry types tetrahedron or polyhedron as well as a non solid surface method.

The tetrahedron is the simplest 3D primitive (3-simplex). It consists of 4 triangles that form a closed object in 3D coordinate space (Stoter and Van Oosterom, 2002). In the Full 3D TEN model approach by (Penninga 2006; Pilouk 1998) the entire space is represented by non overlapping volumes described by a TEN (Tetrahedral Network). Also the air is modeled by tetrahedron primitives. When relating the tetrahedron feature to the semantic 3D city model a problem is that no 1:1 relationship exists between the actual object and the object's representation in the geometric representation. On the other hand there are benefits with this model that can be compared with the benefits of a TIN (Triangular Irregular Network). The model is consequently well defined and suitable for computations. A 3D city model represented in the Full 3D TEN approach would contain a large amount of geometry when including modeling of the open space (air). From a practical point of view, this method is currently difficult to implement, even though it provides a consistent structure for example for volume and topology computations.

The polyhedron is the equivalent of a polygon, but then in 3D. It is made up of several flat faces that enclose a volume. An advantage is that one polyhedron equals one feature. Because a polyhedron can have holes in the exterior and interior boundary (shell), it can model many types of objects (Stoter and Van Oosterom, 2002).

There is also an alternative to represent features with a visual representation that is not of the same dimension as the real feature geometry (Coors 2003). A 3D feature can for example be represented by a textured or double textured surface. Instead of creating a polyhedron feature for each leaf and branch in a tree the whole tree can be represented by a texture covering a plane (billboard). In visualization the normal vector of the plane is turned to be oriented against the spectator so that the texture is always visible. Objects may also be represented by non-closed textured meshes that are combined to constitute a visual impression of a solid object. A tree may for instance be modeled by a set of tube formed intersecting meshes (larger branches) and textured planes (smaller braches and leafs).

6 COMPARISION WITH THE CITYGML INFORMATION MODEL

We have proposed a framework for integration of subsurface features into the existing concept of the CityGML information model by:

- Division of top-level objects into above surface, integrated in surface and below surface
- Addition of top-level subsurface object types and one new object type above surface. Top-level objects have been complemented with the new classes: *Utilities*, *ConstructionWork*, *LandCover*, *BelowSurfaceSpace* and *Geology*.
- Connection between the surface and all objects that is intersecting or touching it by extension of the idea of terrain intersection objects. *Terrain intersection surfaces* and *terrain intersection points* where introduced to more broadly incorporate objects with the terrain surface since we believe that the Terrain Intersection Curve used in CityGML is insufficient. In our approach, the closed *TIC* used in CityGML can be derived from the *TIS*.
- Extension of the implicit representation of objects. The concept of vegetation and city furniture was extended for further implicit representation. Here, we take advantage of the *TIS* and *TIP* to get the implicit storage a step further.
- Definition of a full partition of the surface model. The introduction of full partitioning of the surface model changes the role of the land use concept in CityGML. In our model a part of the surface can only be occupied by one top-level class. In addition to this a thematic land use attribute can be attached i.e. residential or industrial area or another administrative attribute.

The base geometries: point, curve, surface and solid are currently preserved in order to maintain the idea of creating a simple base model to be used in several applications. In our opinion, the introduced extension to the CityGML is reverse compatible. Thus, a CityGML representation can be created from a model represented in our framework.

7 FUTURE WORK

The presented model can be implemented in GML3 or as a database model. GML3 is an AscII file format limited to the geometry features in the simple feature specification which makes it suitable for exchange purposes within the GIS domain. However, parametrically (implicitly) stored datatypes from the AEC domain e.g. freeform surfaces and constructive solids (CSG) are not included in the simple feature specification. To later be able to extend our design further with more complex geometries and to validate that manifolds are closed we suggest testing our design approach in a spatial database management system. There are currently methods to store both tetrahedrons (Penninga 2006) and polyhedron (Arens et al 2005) in a spatial DBMS. Furthermore, in 2007 it will also become possible to implement 3D geometry types in a commercial database, since the version 11g of Oracle Spatial supports the new data types polyhedron, point cloud and TIN. A database model also simplifies the ability to evaluate data in different level of detail, planning versions and history over time (Gröger et. al. 2005). A choice that still remains to be made is whether the data should be stored in a topological model, a geometric model or both (Verbree & Zlatanova 2004). In order to enable overhanging parts of the earth surface model the 2.8D approach (Gröger & Plümer 2005) will be evaluated for representation of the surface. The 2-manifold described in their approach can be illustrated as a cloth, which is draped over the earth surface. This cloth can be stretched arbitrarily, but it may not be folded or touch itself, and no hole may be torn in the cloth. Thus, the 2-manifold does allow overhanging parts of the surface but does not support bridges and tunnels (handles).

REFERENCES

Apel, M. 2006. From 3d geomodelling systems towards 3d geoscience information systems: Data model, query functioality, and data management. *Computers & Geosciences, v. 32, iss. 2, p. 222-229.*

Arens, C., Stoter, J. & van Oosterom, P. 2005. Modelling 3D spatial objects in a geo-DBMS using a 3Dprimitive. *Computers & Geosciences 31* (2005) 165–177.

Billen, R. & Zlatanova, S. 2003. 3D spatial relationships model: a useful concept for 3D cadastre? *Computers, Environment and Urban Systems 27* (2003) 411–425

Caglioni, M. 2006. Ontologies of Urban Models, Technical report n°4, *Short Term Scientific Mission Report, Urban Ontologies for an improved communication in urban civil engineering projects Towntology Project. Cost Action 21 http://www.towntology.net/*

Coors, V. 2003. 3D-GIS in networking environments. *Proceedings of International Workshop on "3D Cadastres" Delft 2001*

Danahy, J. 1997. A set of visualisation data needs in urban environmental planning&design for photogrammetric data. *Proceedings of the Ascona Workshop '97: automatic extraction of man-made objects from aerial and space images* (pp. 357–365), Monte Verita, Switzerland.

Foley, J., van Dam, A,. Feiner, S., Hughes, J., 1995: Computer Graphics: Principles and Practice. *Addison Wesley*, 2nd Ed.

Gröger, G., Kolbe, T., Schmittwilken, J., Stroh, V. & Plümer, L. 2005. Integrating versions, history, and levels-of-detail within a 3D geodatabase. *Proc of the 1st Intern. Workshop on Next Generation 3D City Models*, Bonn 2005.

Gröger, G. & Plümer, L. 2005. How to Get 3-D for the Price of 2-D Topology and Consistency of 3-D Urban GIS, *GeoInformatica 9:2*, 139–158, 2005.

Gröger, G., Kolbe, T & Czerwinski, A. 2006. OpenGIS CityGML Implementation Specification.

Herring, J., 2001: The OpenGIS Abstract Specification, Topic 1: Feature Geometry (ISO 19107 Spatial Schema), Version 5. OGC Document Number 01-101.

INSPIRE, The European Parliament. 2007. Directive of the European Parliament and of the Council establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) (PE-CONS 3685/2006, 2004/0175 (COD) C6-0445/2006)

Kolbe, T. & Gröger, G. 2003. Towards unified 3D city models. *Proceedings of the ISPRS Comm. IV Joint Workshop on "Challenges in Geospatial Analysis Integration and Visualization II2 september 8-9, 2003 in Stuttgart.*

Köninger, A. & Bartel, S. 1998. 3D-GIS for Urban Purposes. *GeoInformatica 2:1*, 79-103 (1998)

Lattuada, R. 2006. Three-dimensional representations and data structures in GIS and AEC. *Zlatanova, S. & Prosperi, D. (eds.), Large-scale 3D data integration–Challenges and Opportunities*. 57-86. London: Taylor&Francis.

NEN3610:2005 .2005. Basic scheme for geo-information – Terms, definitions, relations and general rules for the interchange pf information of spatial objects related to the earth's surface. (In Dutch), Nederlands Normalizatie-instituut, Delft, the Netherlands.

Penninga, F., van Osteroom, P. & Kazar, B. 2006. A Tetrahedronized Irregular Network Based DBMS approach for 3D Topographic Data Modeling. *Progress in Spatial Data Handling*

12th International Symposium on Spatial Data Handling. 581-598 Springer Berlin Heidelberg 2006

Pilouk, M. 1996. Integrated modelling for 3D GIS, Ph.D. Dissertation, ITC, The Netherlands.

Quak, W. & de Vries, M. 2006. Building a harmonized base model for geo-information in the Netherlands. *Proceedings of UDMS '06, 25th Urban Data Mangement Composium* Aalborg, Denmark.

Stoter, J., Van Oosterom, P. 2002. Incorporating 3D geo-objects into a 2D geo-DBMS. *Proceedings FIG ACSM/ASPRS*, Washington DC, USA, 12pp, CD-ROM.

Stoter, J. & van Oosterom, P. 2005. Technological aspects of a full 3D cadastral registration. *International Journal of Geographical Information Science, Volume 19, Number 6, July 2005, pp. 669-696(28)*

Towntology, 2007. http://www.towntology.net. 2007-02-13

van Oosterom, P., Ploeger, H. & Stoter, J. 2005. Analysis of 3D Property Situations in the USA. *Proceedings of the FIG Working Week and GSDI 8 : From Pharaohs to Geinformatics, Cairo, 16-21 April 2005. Frederiksberg, FIG, 2005. ISBN 87-90907-43-4. 17 p.*

van Oosterom, P., Stoter, J. & Lemmen, C. 2005. Modelling of 3D Cadastral Systems. *K Kyu-Tae (Ed.), Proceedings of the 28th Cadastral Seminar (pp. 594-606). Busan: Korea Cadastral Survey Corp..*

Verbree, E. & Zlatanova, S. 2004. 3D-modelling with respect to boundary representations within geo-DBMS. *GISt Report No. 29, Delft, 2005, 30 p.*

ViaNova Systems 2007. http://www.vianova.se/ 2007-02-13

Zlatanova, S., Rahman, A. & Shi, W. 2004. Topological models and frameworks for 3D spatial objects. *Computers & Geosciences 30 (2004) 419–428*