Multidimensional aspects of GeoBIM data: new standards needed

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Abstract

The standard design tools for buildings and civil engineering infrastructure are not prepared for working with real world subsurface information that originate from the 3D geological and geotechnical models. Also GIS standards (as the OGC standard CityGML) or BIM standards (as IFC) are not ready for that. That is why it recently attains attention to study how 3D subsurface data can be processed in architectural design software (BIM) and in GIS/CAD by combining single standards. However, to offer required information in the best possible way for the users of both, above ground and subsurface applications, extensions to existing standards are required.

1 Above ground & subsurface data characteristics

1.1 Introduction

On the application side an increase in the use of subsurface data is noticeable for the building and civil engineering world. This is partly because structures and their interaction with the subsurface get more complicated, partly because the use of the subsurface is increasing (heat and cold storage, tunnels, parking, storage, shopping malls, railway stations, etc.) and partly because of a changing risk perception in society.

Geosciences consider phenomena to be essentially 3 dimensional at one moment of time and 4 dimensional when involving dynamics. Untill recently this approach conflicted with the common way of thinking in two dimensions (horizontally or vertically) driven by available technologies. This restriction of modeling the world in two dimensions led to mistakes, for example in foundation planning or groundwater flow interpretation. Because geological properties perpendicular to the plane of consideration could be different but were not taken into account nor were the gaps between profile sections and surface geology.

However, within any underground construction project the most significant factor in controlling the cost and feasibility is the subsurface ground properties. Thus, in most geotechnical projects as well as in underground and building constructions, geologists and civil engineers have to consider both natural bedrock objects and technical objects conscientiously. Since the building information modeling approach focuses on building data and underground construction information systems on subsurface data, a framework for processing and handling all geotechnical project-relevant data is recommendable. This motivates the approach of Geo Building Information Model (Zobl & Marschallinger 2008). GeoBIM encompasses technical-/ BIM elements as well as natural/ "geo" objects on, above and below earth´s surface, including (i) an Above-(earth´s)-Surface Information Model (AIM) and (ii) a Subsurface Information Model (SIM). To support both, above ground and underground applications in all project phases, a GeoBIM should particularly contain the "precise" geotagged geometry and attributes of earth´s surface, subsurface- and above ground objects together.

Until now, the tools available for 3D geological and geotechnical subsurface modeling mainly aimed at the mining and hydrocarbon industry and, therefore, often only dealt with specific scenarios and data types. On the other hand CAD and GIS tools were also customised to deal with geological environments but this often led to a convoluted multi-software solution which became hard to use and implement as single work flow (Kessler et. al. 2008).

1.2 GeoBIM data: 2D, 3D, 4D

1.2.1 Discrete and continuous data

Discussing the ensemble of natural and man-made/planned surface/subsurface objects in the context of available data structures, it is convenient to distinguish 2D/3D objects and, as to the internal structure of these objects, to discern

- discrete, internally homogeneous objects and

- objects with a more or less continuous variation of properties.

In the 2D realm the vector data types points, arcs and polygons are used for defining internally homogeneous objects and raster data types for describing continuous variation. Moving into the third dimension, in the vector domain arbitrary surfaces (e.g., the boundary of a folded stratum with multiple z instances per xy location) and volumes (e.g. the hollow space of a cavern) need to be added for specifying homogeneous objects and voxel models for delineating continuously varying objects.

In contrast to subsurface realm, numerous high-quality data are available for objects on and above ground. These datasets can be acquired either for building purposes (as used in BIM) or for geoinformation applications (including the area of GIS & CAD).

1.2.2 Space & Time

Moving on from static to dynamic scenarios (buildings/constructions on/in unstable ground, groundwater fluctuation, building under construction, etc.), for process characterization the time dimension has to be added to the above objects (Marschallinger et al. 2009). Temporal aspects of geo-data is fundamental for recording or monitoring changes, for describing processes, and for documenting future plans: for example monitoring the status change of a set of related features (Figure 1, left) or monitoring changes of moving objects (Figure 1, right).
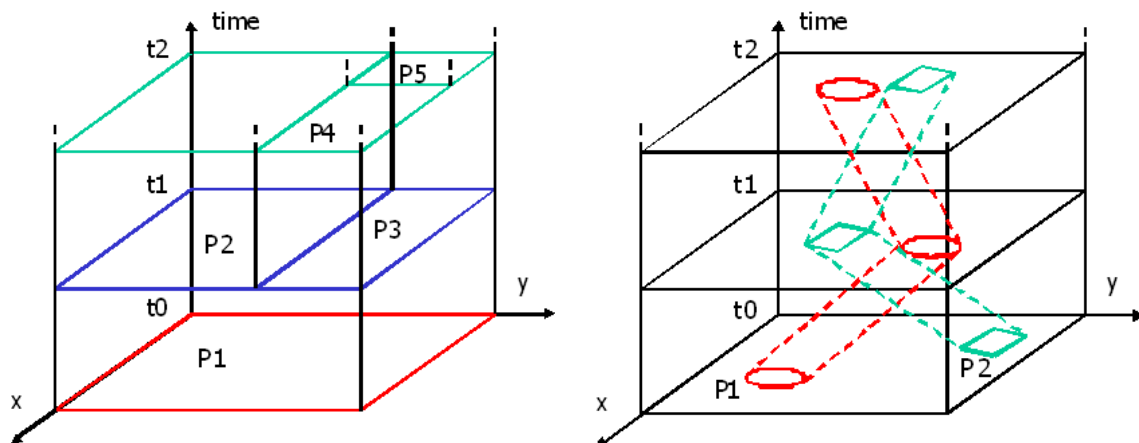
Figure 1: Visualisation of time as third dimension: division of parcels (left) and moving objects (right; Oosterom 2006)

An example of artificial subsurface processes is the geometry change of leaching caverns in salt mines. Starting with an initial drilling and leaching, the caverns develop bottom-up (see Figure 2).
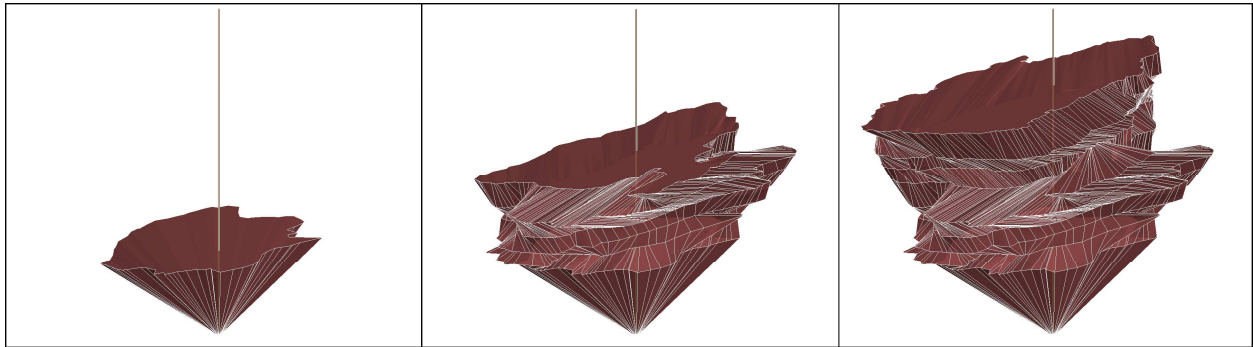
Figure 2: Caverns developing bottom up: B-rep solid model at arbitrary times 1,2,3

Many Spatio-Temporal data models have been designed to model changes of geo-information (Hornsby & Egenhofer 2000, Peuquet 2002, Raper & Livingstone 2001). The semantics of the time dimension included in these models vary from model to model and generally addresses:

- *Temporal granularity* specifies to which units of data one temporal attribute is added, e.g. whole dataset, object class, object instance or attribute

- *Temporal operations* for spatio-temporal analyses

- *Modeling foundation for time* describes which type of changes can occur to the value of a thematic or geographic characteristic, i.e. discrete changes or more continuous/gradual change

- *System (or transaction) time* indicates the time an event is recorded in the database

- *Valid (or real-world) time* describes the time that an event happened in the real world

- *Lifespan* identifies the history track of real world objects. Some events last only one short moment, e.g. an explosion or a traffic accident, which are like point objects. Other situations last for a longer period of time, e.g. the fact that a building has a particular owner, which are like linear objects representing a time interval

- *Representation of time* can differ from maintaining the duration of the status of an object (i.e. period) to recording events (i.e. start- and end-moment) that imply status change

- Spatio-temporal modeling should not only support changes at discrete moments, as currently supported by most of the ST models via timestamps and versioning, but also *continuous temporal changes* as is common in geosciences domain to describe the movement or change of objects independently from their object identification

2   Current standards & data models for the management of GeoBIM data

2.1 Introduction

For the representation of surface data and related attributes various standards have been developed. In addition, a number of international data models and industry specific formats have been developed. Since (physical and chemical) properties of subsurface objects are relevant for many purposes, various national and international standards exist, describing or defining soil, rock and hydro(geo)logical objects. However, currently a number of methods exist for representing natural and technical objects below and above ground.

2.2 Present geo-information & technical object´s standards

One of the most common ways to represent surfaces is the triangular irregular network technique, which can be applied by GIS and CAD systems. Non Uniform Rational B-Splines (NURBS, e.g. Fisher & Wales 1992, Rogers 2001) represent the object boundary surfaces as piecewise polynomial functions which allow for an adapted precision of generated surfaces (i.e. controlled deviation of surfaces from defining points). However, NURBS interpolation which is computing time and memory saving is suitable for geological modeling because smooth and congenial surfaces can be created, which provide realistic, close to nature and analysable representations of geological bodies (contact surfaces).

Solid modeling is the technology of choice when working with geological structures and their mutual geometric relations in 3D space. There are several ways to represent solids, so the same object (e.g. rock bodies or tunnels) can be represented in many different ways, but it is the same object that represents the same volume or space. Currently, one of the most common ways to represent solids is boundary representation (B-REP). Currently mainly offered by CAD systems, solid modeling operates on the volumes of involved objects (the so-called solids) and enables their combination by means of basic Boolean operations: union, subtraction or intersection. Thus, the power of solid modeling derives not only from its internal representation but mostly from the set of Boolean operations (intersection, subtraction, union) that are used to create new solids from existing ones (Marschallinger 2007).

As voxel models excel in representing continuous spatial variation and in their analytical, converting solids to voxels should be feasible. A voxel is a volume element, representing a value on a regular grid in three dimensional space. The value of a voxel may represent various properties. Geologically relevant interpolation algorithms and geostatistical estimation or simulation programs output their results to three dimensional regular grids which can be directly processed by voxel analysis and visualisation systems (e.g. IDL or Voxler). CAD systems can be used to manage voxel models by converting voxels to B-REP solids prisms, enabling the analysis and visualisation together with B-REP solids of geological and geotechnical objects (Marschallinger 2007).

Spatial data are stored in spatial databases (e.g. PostGIS, Oracle Spatial, or DB2 Spatial extender) using spatial data types and relationships where spatial features such as spatial querying and distance calculation are provided. To enable bidirectional analytical functionality, a 3D geological & geotechnical framework can therefore currently be best maintained by a combination of B-REP solid modeling and database systems. To link database records to geometrical objects, 3D CAD systems provide standard interfaces to relational databases, such as ODBC or OLEDB. With database information attached to CAD objects, subsurface objects can then be subject to concurrent spatial and attribute queries in 3D. The resulting 3D GIS framework enables geologists and civil engineers to manipulate, analyse and interpret 3D subsurface models (Apel 2006). The Open Geospatial Consortium (OGC) and ISO establish standards for handling spatial data (geo-information), which has resulted in Simple Features Specifications for Structured Query Language (SQL) in 2003 (OGC 2001, ISO 2003, Herring 2006). These specifications define how to support 0D, 1D and 2D spatial objects (that can be defined in 2D and 3D space) in object-relational DBMS environments. Mainstream DBMSs have implemented these specifications, resulting in a shift from ad hoc use of geo-data to interoperable geo-data as part of generic information flows.

Many initiatives have studied modeling the 3D concepts of geo-data in information models driven by applications such as facility management, urban planning, 3D cadastre, noise modeling, flooding, disaster and crisis management. To unify these initiatives, OGC and ISO TC 211 established a standard for exchanging 3D city information in 2008 (Gröger et al. 2006, Gröger et al.

2008, OGC 2009, Kolbe 2008). This information model, called CityGML and based on the Geography Markup Language (GML), provides a common definition and understanding of basic entities, attributes and relationships of 3D city objects. 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). The geometry in CityGML follows the ISO 19107. Generally volumetric objects are possible, but the validity of closed volumes cannot be enforced in CityGML. In addition 3D topological structures are not standardised in CityGML.

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 handled via the Level-of-Detail (LoD) concept (LoD0 to LoD4, see Table 1). Further, LODs are required to reflect independent data collection processes.

Table 1: Positional accuracy for different LOD's in CityGML

	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city districts, projects	architectural models (outside), landmark	architectural models (interior)
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation (classification of land use)	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented

For the exchange of BIM models often the standard Industry Foundation Classes (IFC, ISO16739) is used. IFC is an international open standard and contains rich semantics. A building is modeled as a collection of objects (with properties and relationships) that represent parts of the building. The 3D geometry is one of the properties, for example, as the name of the vendor, cost, etc. BIM objects may be walls, doors and windows but also the glass in the windows, window frames, bricks in the walls, etc.

BIM is used mainly in construction and is suitable for 3D modeling in a very precise manner and with great detail. It is often used to model a limited location (e.g. a building). It is not used for larger areas, as is typical in GIS applications. Altough BIM may model the immediate vicinity of the object display (often at a much lower level of detail). Today, BIM also provides the georeference models, i.e. the inclusion of the coordinates on the surface of the modeled object.

3 Combining single standards to make natural and technical objects available: Examples from Austria & The Netherlands

3.1 Case study 1: Linking ground objects and associated properties

3.1.1 Introduction

On today´s underground construction sites an increasing amount of data is produced in different ways and formats at different times and places, by different parties and sources and must be processed and managed efficiently adapted to the respective project phase. In tunnelling, complex subsurface conditions have to be managed and analysed. Rapid subsurface model analysis and thus selective identification of critical zones is of particular importance for geotechnical engi-

neers during design and construction. To cope with this challenge, an integrated solution for data acquisition, subsurface modeling, check, storage, evaluation and analysis, visualisation and, finally, distribution is necessary.

Within the scope of the European research project TUNCONSTRUCT (http://www.tunconstruct.org), Geodata, Inc. and the Institute for Rock Mechanics and Tunnelling, Graz University of Technology realized a GeoBIM framework for tunnelling projects with focus on the development of an Underground Construction Information System (UCIS) and a prototype of a 3D geotechnical ground model (Chmelina et al. 2009). To manage all relevant geospatial data of a tunnelling project interactive data input must be feasible (Figure 3).
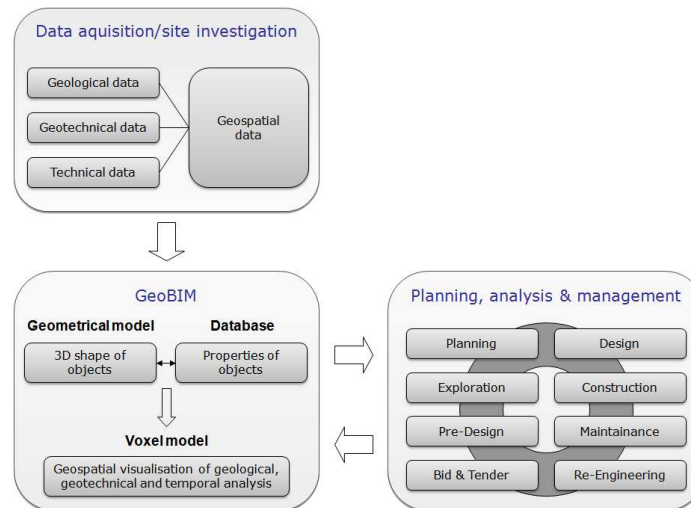

Figure 3: Interactive workflow of GeoBIM data input and data processing to support the underground construction in all project phases

3.1.2 BIM and ground objects in one framework

Technically, the system is based on current relational database technology (MSSQL Server) allowing the management of any kind of digital data produced during a tunnelling project. Data is either stored by help of database tables and relations or, if no such relational data model yet exists, can be managed in a special document management section. The developed relational data model covers following data categories: geometry, geotechnics, geology, structures, machines (TBM), monitoring and alarming reporting. Users can access the database via two front ends, a local Windows client application ("Kronos" Client) and/or a web-interface ("Kronos" Web). A variety of data exchange formats is supported (for details see Chmelina 2009, Prader & Chmelina 2008).

Because currently no subject-based software for the integration, modeling and analysis of all relevant data is available, because of technical specifications and common subject-specific usage, products from Autodesk® have been chosen as central 3D modeling platform. Three dimensional information of both, above ground and subsurface BIM objects (e.g. drillings, tunnels, cables, building components, etc.), natural objects (e.g. strata and discontinuities) as well as land register elements are required throughout several underground construction project phases. Therefore, these data can be used for instance for the calculation of the distance from tunnel alignment to ground surface, building foundations or cables and enables e.g. simulation of three-dimensional spatial location of a tunnel alignment (Figure 4).
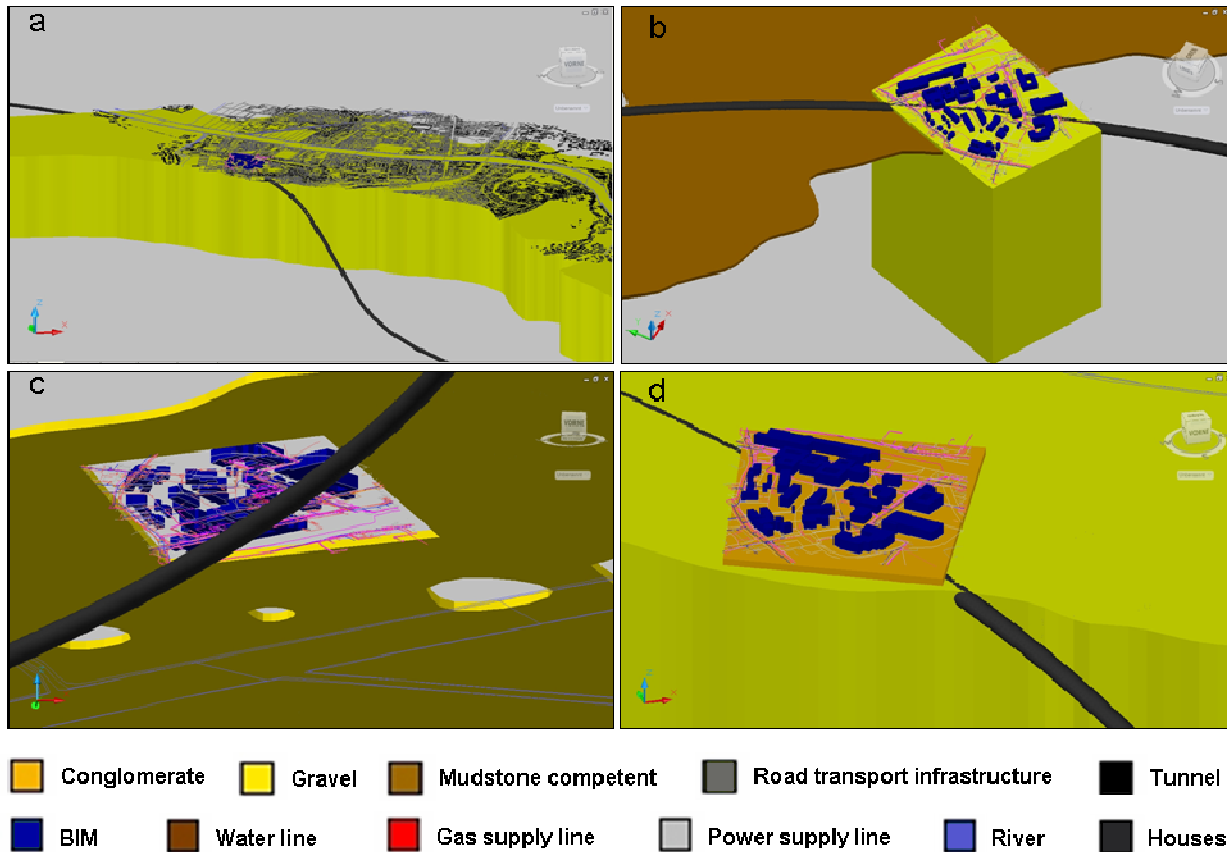
Figure 4: Cadastral objects, building information models and tunnelling information enabling subject- or object-based analysis

3.1.3 3D objects linked to associated properties

Conceptually, each 3D geotechnical ground model object (e.g. an AutoCAD® solid defining a homogeneous lithological unit, an AutoCAD® mesh defining a discontinuity surface) consists of three parts: a specific AutoCAD® entity, a set of UCIS database records and a link between the entity and the records. Technically, this concept is realised by connecting the software application AutoCAD® with the UCIS database by using "DBConnect" via ODBC (i.e. an AutoCAD® feature which is available since AutoCAD® 2004). A connection to the UCIS database is used to assign geological property sets to 3D solids (where, for example, every solid represents a geologically homogeneous region). If the link between 3D solids and database entries is established, the query window allows the selection of solids that match user specified charges. It is also possible to select a property in the data view window and to identify/mark the corresponding 3D solid (Figure 5).
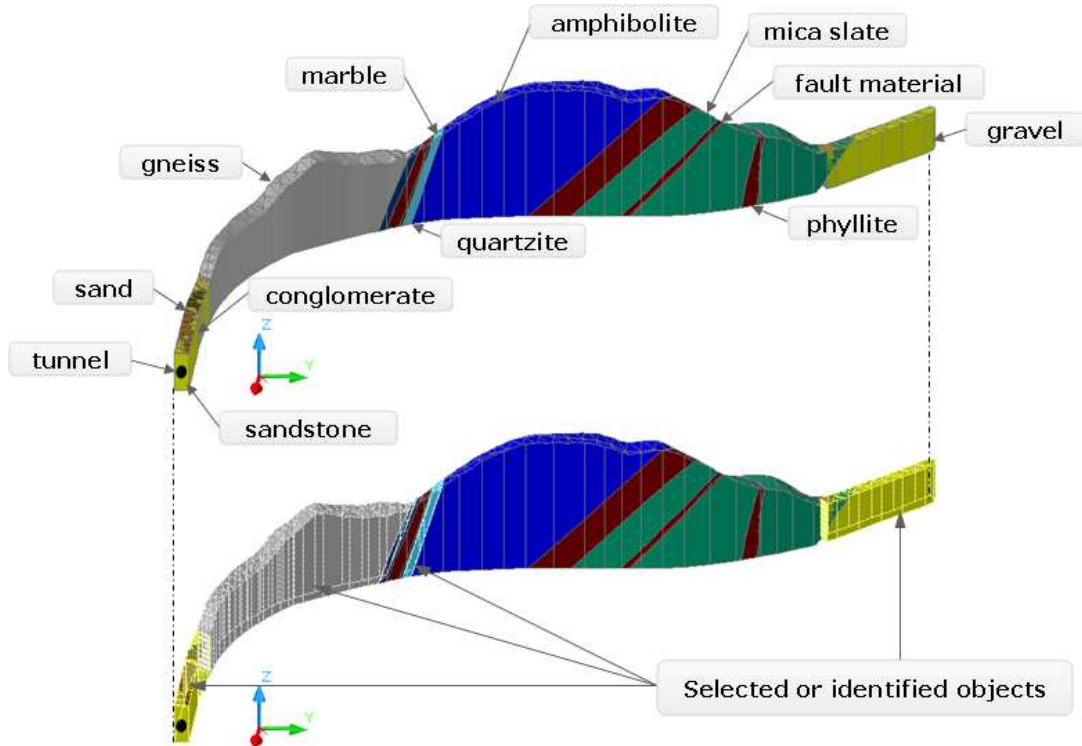
Figure 5: Example for selected or identified objects (select weathering ="fresh"; cross section of TUNCONSTRUCT prototype model

3.2 Case study 2: Developments of voxel models

3.2.1 Development of the GeoTOP voxel model

In the Netherlands there is an abundance of borehole data, cone penetration tests and a large quantity of borehole and surface geophysics, mainly managed by the TNO Geological Survey of the Netherlands. Combined with the increasing need for subsurface data this led to the decision to model the subsurface not as maps but as spatial models:

- The Digital Geological Model "DGM" and the Geohydrological Model "REGIS-II": These are stacked layer models with information of depth, extent, continuity and properties laid down on a regular grid being characterized as 2.5D models, ready for the entire country in various versions for different purposes, covering several hundreds of meters of depth

- The GeoTOP and NL3D Models:
  3D grid or voxel models, ready for the west and in production for the east of the country and covering 30 to 50 meters of depth below surface

The model GeoTOP gives a detailed 3-dimensional picture of the subsurface in the Netherlands till a depth of 30 to 50 meters below the surface. In fact it describes in more detail the upper part of the other models where borehole logs of the national geoscientific database "DINO" serve as basis for the development of the GeoTOP model. In the provinces Zeeland and Zuid-Holland that are ready now, 23.000 resp. 50.000 boreholes were available, where every borehole provides detailed information about the sequence of sedimentary layers at one specific location. With the aid of 3D stochastic interpolation techniques, applied per geologic formation, the borehole information is translated to grid cells of 100m x 100m horizontally and 0.5m vertically (Figure 6).
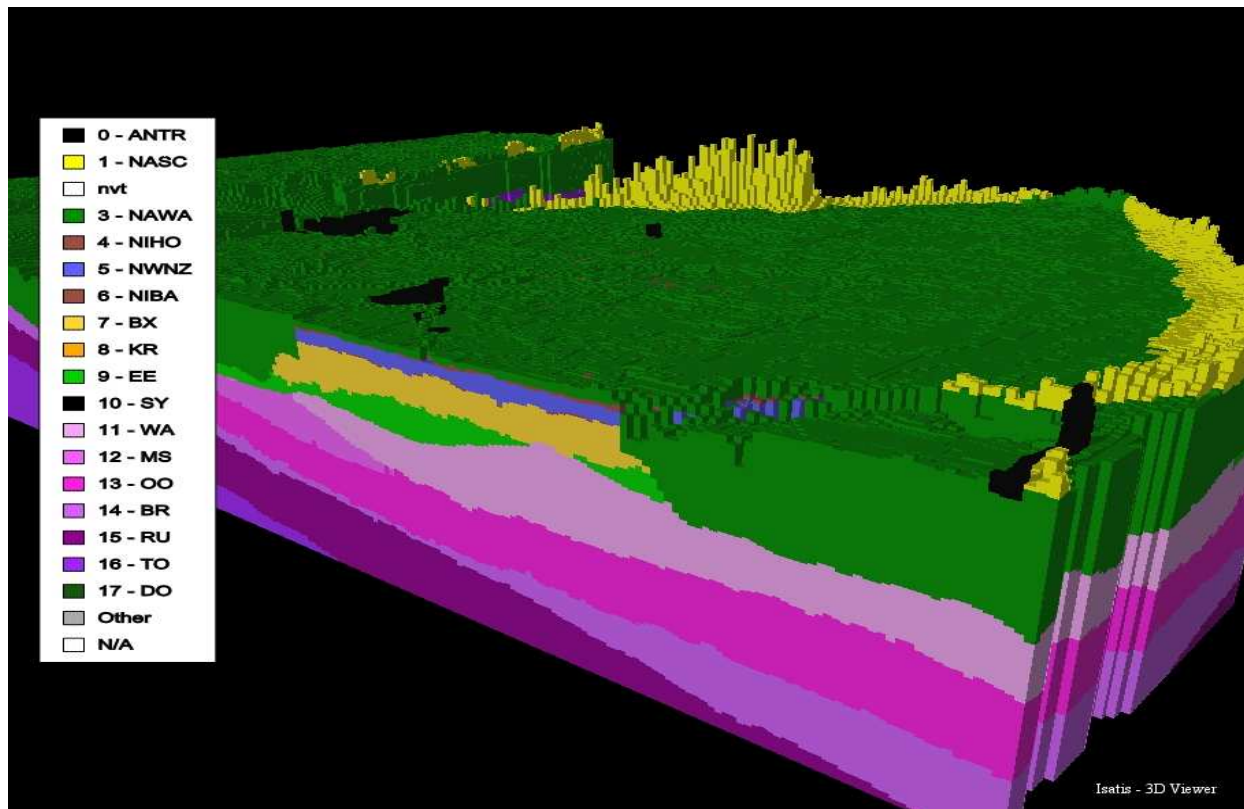
Figure 6: Clip of Netherlands GeoTOP voxel model, 100x100m horizontally, 0.5m vertically

3.2.2 Integration of GeoTOP to the 3D pilot testbed

The Geological Survey's main task is to provide data and information for the sustainable use and management of the subsurface. Therefore the Survey was eager to participate in the project "3D-Pilot", conducted in 2010 and 2011 in the Netherlands (Stoter 2011). In parallel the Building Information Council run a project to integrate BIM with environmental geographical data.

At the start of the pilot TNO assumed that taking up the Tegtmeier extension for sub-surface objects in CityGML (Tegtmeier 2009) would suffice to make subsurface modeling data available in the context of buildings, built-up areas and civil-engineering infrastructure, above and below surface. This assumption covered as well integrated visualization as evaluation of interaction between subsurface and above surface objects. However, in the course of the project, several insights concerning the practical use of the "BelowSurfaceObject" proposed by Tegtmeier (2009) were made during the 3D-pilot:

- To ease work obtaining object instances, volumes (for use on a single building location, already selected) - homogeneous with respect to some property and in its definition depending on the application - could be obtained by interpolation of cone penetration testing data for a specific building project

- To be cost-effective in the planning phase of projects covering larger areas, the data source of choice should be the existing voxel models

- For the purpose of calculations on the interaction between technical objects and the subsurface, voxels would do better than volumes of some arbitrary shape

- For integrated visualization the objects itself would be optimal

In the testbed of the 3D-pilot the voxel model of a part of the city of Rotterdam was made available for the area of a recently constructed railway tunnel, connecting the central station area with

the regional railway. Also the outline of the tunnel was made available in IFC format, Collada, and CityGML by means of the TNO OpenBIM server. ESRI Nederland, Bentley and Pitney Bows succeeded in entering GeoTOP data in ArcGIS, Microstation and MapInfo/Discover3D respectively. This is probably favorable to lowering thresholds for using voxel models, but it did not help integrating voxel data in CityGML. Thus more research is needed to find an efficient way to integrate voxel model data in object models.

4 Necessity to develop new standards covering both, natural and technical objects

Currently, GeoBIM objects can be represented depending on the approach by individual standards partially. BIM is used mainly in construction and is suitable for 3D modeling in a geometrically precise manner and with great detail and is used to model a limited location (e.g. a building). It is not used for larger areas, as is typical in GIS applications. However, the worlds of BIM and GIS are becoming more integrated. This provides benefits for both domains since BIM data can feed GIS data and GIS can serve as reference for BIM data. However integration should acknowledge the differences between both types of data. To start with, the object description of BIM (in which data is captured in formats as IFC, CAD) and GIS (in which data is defined in CityGML) differs significantly. In addition GIS is characterized by coverage of large areas (e.g. a complete city) and lower precision, while BIM is characterized by its local and very detailed approach, the limited number of construction models usually available in a city and high precision necessary for reliable construction calculations. Assuming that original BIM files may serve specific applications (e.g. building permit process), it is important that both the original BIM source file and a GIS representation are available.

Therefore research questions should not only address how to integrate BIM and GIS. Moreover it is as important to discuss how to balance between strict agreements that provide interoperability between the two domains and at the same time keep sufficient flexibility. In addition converting between BIM and GIS standards is not only a matter of technical conversions. Instead the semantic issues are important as well: which property from BIM domain matches which property in GIS domain? How do concepts in different domains relate? Which information is specific for the two domains? How to preserve the relevant characteristics in the conversion? How to deal with differences in concept meanings in both domains? How to deal with the support of different geometries in both domains (i.e. simple geometries in GIS and complex, parameterized geometries in BIM)?

Ideally, much as in the 2D realm where a typical GIS can switch between vector and raster representation of objects, in the 3D realm a toggling between boundary and voxel representation is recommended. Therefore, the combination of boundary representations and voxel modeling ensures the unambiguous representation, spatial, spatio-temporal analysis and modeling tasks of arbitrarily shaped 3D objects and their internal parameter variation (like e.g. physical properties of buildings or strata). However, taking good advantage of vector and voxel representation and to have a smart and applicable tool for the design and administration of GeoBIM projects, shape and associated properties of natural and technical objects need to be available on a platform conforming to open standards. Thus, increasing applications make further research on developments of new standards necessary, which are not targeted to domain-specific issues. In addition, quite some effort is needed to align user tools, generic information models and data supply formats and services to let the data flow smoothly.

4   Acknowledgments

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