

An integrated 3D model including (sub-) surface real world and design information – supporting information management in infrastructural development

W. Tegtmeier, H.R.G.K. Hack, S. Zlatanova & P.J.M. van Oosterom

An integrated 3D model including surface and subsurface real-world and design information for infrastructural development

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Abstract

In infrastructural projects, communication as well as information exchange and (re-) use in and between involved parties is difficult. This is mainly caused by a lack of information harmonization. Various specialists are working together on the development of an infrastructural project and are all using their own specific software and definitions for the various information types. In addition to this variety of information types, also the lack of and/or differences in the use and definition of thematic semantic information regarding the various information types adds to the lack of information harmonization. Realistic 3D models describing and integrating part of the earth already exist, but are generally neglecting the subsurface, and especially the aspects of geology and geotechnology. This paper summarizes the research towards the extension of an existing integrated semantic information model to include surface as well as subsurface objects and in particular, subsurface geological and geotechnical objects. Standards, exchange formats and existing models used as a basis for the development of an integrated 3D information model are described in this paper. Definitions of subsurface geological objects and required attribute information (to be) included in the integrated 3D information model are given.

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1 INTRODUCTION

In today's society, mobility is of major importance. In order to allow the world's citizens unconstrained, secure and safe travelling, sufficient infrastructure capacities (e.g. highways, railways, airports, etc.) have to be built. As a result, around the world numerous people are busy with the planning, design, realization, or maintenance of infrastructural projects. During the various phases of infrastructural projects different tasks must be accomplished, requiring different skills from different professionals, such as civil engineers, engineering geologists, GIS technologists, etc. These professionals are working on a range of problems often requiring the combination of a variety of information and knowledge .

For the execution of the different tasks, large quantities of geo-information (e.g. GIS-, CAD-, and other data sets) are collected and meant to be (re-) used during various stages of a project. It is well known, although not often expressed publicly, that the re-use and exchange of information is only seldom achieved. Mostly, the various experts involved in the project collect their own information and the sharing of information with other professionals is limited. The re-use of information is additionally limited, since in different stages of a project new experts may be involved, who generally do not trust the formerly acquired information. The limited exchange and re-use of information then leads to the fact that the realization of projects becomes more expensive because the same information is acquired more than once, and, more importantly, may lead to a less than optimum design of projects. The latter may cause hazards and risks for the project itself but may also cause risks for other structures, the environment, or for the users. Main reasons for the discussed lack of information exchange and re-use are that 1) the information is not harmonized; i.e. the same information used by different professionals is not in the same format and structure and might have similar naming, but different meanings; and 2) the quality and uncertainty of most of the information is not quantified.

⑩ ⇒ Overview of paper (Sections and their purpose)

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2 SUB-SURFACE INFORMATION

Overview of larger section

2.1 *Subsurface information and computer representation*

The creation of a real world representation of the earth subsurface is completely different from the creation of real world representations of the earth surface. The real world subsurface is neither visible nor accessible. Subsurface representations are inverted from limited numbers of point and line information (e.g. surface exposures, borehole samples, penetration tests, etc.) and two- and three-dimensional geophysical information. Interpretation by an expert, i.e. a geologist, brings this information into one coherent model of the subsurface. The interpretation however, requires a substantial quantity of a-priority expert knowledge on geology, and therefore the interpretation is dependent on the expert. The more complex the geology the more expert knowledge will be incorporated.

Before computers became common, a model of the subsurface was made based on interpretation of the geology along sections on paper. The sections were made in various directions on which the information of boreholes and other sources of information were plotted and the geology then drafted. The various sections were combined into a so-called “three-dimensional” fence diagram. In the oil and gas and mining industries and for large projects in civil engineering, mostly a three-dimensional physical model was made of wood or later of perspex to show the subsurface in three-dimensions.

When computers became normal the methodology of working did not change. In the database in the computer all information is stored and the computer programs give the option to interpret along sections and fence-diagrams (Figure 1). These are then combined into a three-dimensional model of the subsurface by the computer. The large advantage of the use of computers is that the tedious handwork of drawing sections and fence diagrams is facilitated by the computer and that hence, many more sections and fence diagrams can be made in the same amount of time improving quality of the geology interpretation. The three-dimensional model improves in quality as well because the data has to be coherent everywhere in the model and not only at crossing points of sections as for the paper interpretations (Houlding, 1994, Raper, 1989). However, what has not

See section 3

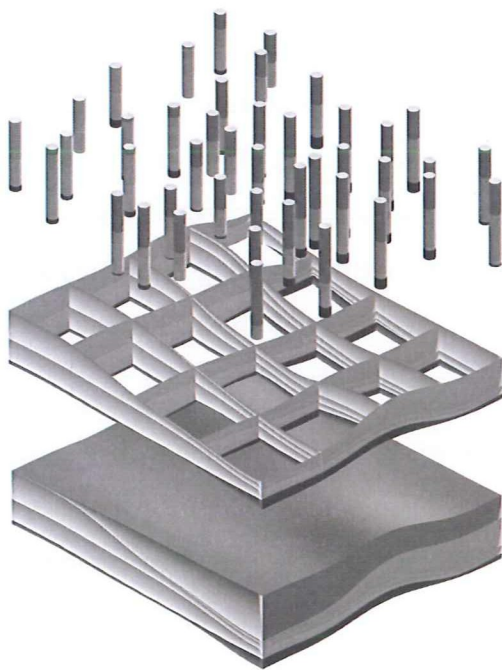
↳ also : better sensors / measurements ?

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changed with the use of computers is the interpretation of the data as well as the incorporation of a-priori knowledge of the expert.

Thus, computerized real world representations of the subsurface have been made for many decades. The development started with property programs specifically developed for the oil and gas and mining industries. The programs were originally based on two-dimensional GIS programs that were extended into 2.5 dimensional programs (i.e. two-dimensional GIS programs that were able to model different layer boundaries at different levels; using the “z”, i.e. elevation, as property at (x y) locations) and later into full 3D programs, in which the database stores properties for every (x, y, z) location. The oil and gas industry developed programs directed towards the interpretation and representation of the subsurface based on information of a limited number of boreholes, but with extensive geophysical information, while the mining industry developed programs based on the availability of large numbers of boreholes.



Ⓢ figure is color
(at least for on-line
version)

Figure 1. Computer generated fence diagram (middle), with above boreholes and below the solid model. The (sub-) horizontal layers with different colours represent various geological layers. (after Rockware, 2010).

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2.2 Subsurface computer programs used in civil engineering

In civil engineering, computer use was directed to represent the real surface world in CAD programs (AutoCad/Autodesk, 2010, Microstation/Bentley, 2010, etc.). For subsurface representations (Apel, 2006), however, either the GIS-type programs from the oil and gas industry (e.g. Schlumberger/Petrel, 2010), mining industry (e.g. Vulcan/Maptek, 2010), or from universities (GoCAD, 2010) are used, or CAD and GIS systems with extended functionality for representing the subsurface (Microstation, AutoCad, ESRI, 2010). In addition, a whole series of three-dimensional special purpose modelling programs have been made that model for example groundwater flow (MODFLOW, 2010) or mechanics (Itasca, 2010). These special purpose programs have built in (numerical) relations that calculate the relations between different voxels ~~(which is the name for a three-dimensional cell analogue to pixels in two dimensions).~~

niet twee Keen 'relations'

2.3 Subsurface information sources

Many geological societies in the world are, nowadays, working on making geological information available digitally. Some provide only geological maps with sections and legends (for example, Catalunya, Spain: ICC, 2010, and USA: USGS, 2010). Within the project OneGeology, eighty national geological surveys are presently making all their geological map information available digitally and interoperable (OneGeology, 2010). Many also try to deliver a three-dimensional model of the subsurface digitally. The DINO database in the Netherlands (DINO, 2010) and British Geological Survey (BGS3D, 2010) provide digital subsurface models. These models are based on the available data in the various organisations. Interpretation is done by the organisation themselves to the best of their possibilities. Most of the models consist of solemnly layer boundaries with descriptions of the properties in between the boundaries. It may take many tens of years before the maps are all converted to geological models (Culshaw, 2005).

Some word

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2.4 Geotechnical information

Public geotechnical digitally available information is very seldom available in the form of three-dimensional models. The information in public repositories is mostly not more than scans of the original boreholes, penetration tests and test data. Data density is often very much dependent on the area (urban much data – rural few data) and on the type of geotechnical investigations that are common in the area and for the type of geological subsurface. Three-dimensional models if any are limited to very small areas and mostly to a specific project.

2.5 Data and work flow in many civil engineering projects

The general data and workflow in civil engineering projects is that a geotechnical sub-contractor investigates the site. The consultants of the project, who may be the same as the geotechnical sub-contractor, interpret available data from public sources and integrate these with the data from the site investigation. A three-dimensional program may be used to integrate the data in one model. Then the data is transferred to the civil engineers in a full report with (digital) model sections and drawings of the subsurface. However, ~~in the experience of the authors~~ thereafter very often somebody with or without much geological knowledge simplifies the information of the subsurface to one or more simplified sections or plans (for example, a plan of the design foundation level). These become then the main base for design and construction, and all other information from the site investigation on the subsurface is more or less forgotten. One of the reasons is that the information from the site investigation cannot or only partially be integrated into the digital design and constructions models in civil engineering CAD programs. Obviously knowing that the subsurface is an interpretation of the real situation, this practice involves a large risk. Any uncertainty information is lost in the simplified information and the simplified information is taken as the truth.

2.6 Subsurface data formats

Data formats used in three-dimensional modelling vary widely. The three-dimensional modelling programs are able to model the geology in three-dimensions and allow prop-

- Sub surface
- (*) types of models :
- voxel
 - layers (2D surfaces)
 - TENS
 - polyhedrons
 - ...

(of the soil or
of the test
documents)

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erty values assigned to voxels (e.g. Orlic, 1997). The various programs use their own formats for storing information in the database and more importantly use their own semantics to describe objects in the underground (e.g. boreholes, layer boundaries, volumes, etc.). The public data sources on geology are limited to maps (which still have to be interpreted into a three-dimensional model) and some three-dimensional models, which basically consist of layer boundaries. Transfer of data from one program or data source to another is sometimes possible for basic data items such as location-property values, boreholes, samples, etc. Surfaces and boundaries are normally also exportable and sometimes volumes. Mostly these latter objects are transferred as separate items, and any structure between the items is often lost. For boreholes and samples this may be a nuisance, but it is a problem for surfaces and volumes. For example, the method to generate the surface or volume from borehole information is lost. More importantly any information on the expert-input in making the surface or volume is also lost.

other type of models ?

Concluding, the subsurface data model represents a “may be” real world representation of the subsurface that is very much depending on the quality of the original input data, the quality of the geologist that did the interpretations, and is in a program or data source own format that is not or very limited transferable. On top the information is often simplified before used for design.

and above surface

3 SURFACE INFORMATION

When compared to subsurface objects, natural phenomena and man-made objects on and above the surface can rather ‘easily’ be measured. The shape and size of surface objects is, in most cases, well visible and, thus, easily derivable as well as visually representable. In addition, in the ‘surface world’ sufficient quantities of good quality and well described information can be collected that facilitate the creation of real world representations of the surface objects and conditions. As a result, in the ‘surface world’ the emphasis is put on the best representation of the complexity of the various objects, including information concerning their thematic properties and relationships, as well as on the management of the collected geo-information.

? (quality / metadata) ?

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Resulting from the on-going, present work of several initiatives (i.e. such as the OGC), various standards have been made available to be used for the representation of surface objects and their attribute data (e.g. ISO, NEN, OGC, etc.). Especially the ISO standards, international standards among others developed for the management of geo-information and the representation of surface objects, are frequently applied and can also be related to this research. Examples are:

- ISO 19107:2003 Geographic Information – Spatial schema
- ISO 19108:2003 Geographic Information – Temporal schema
- ISO 19113:2002 Geographic Information – Quality Principles
- ISO 19114:2003 Geographic Information – Quality Evaluation Procedures
- ISO 19115:2003 Geographic Information – Metadata
- ISO 19123:2005 Geographic Information – Schema for coverage geometry and functions

In the same way as the ISO, the OGC and NEN have developed standards for the measurement and representation of surface objects as well as for the definition of proper geo-information exchange. The most relevant NEN standard for this research is probably the NEN 3610, i.e. the 'Basic scheme for geo-information – Terms, definitions, relations and general rules for the interchange of spatial information of spatial objects related to the earth's surface' (see also Section 5.1). The Open Geospatial Consortium (OGC), for example, has, among other things, developed the document OGC 05-087r4 'Observations and Measurements'. This document is dealing with a framework for measurements and encoding (see also Section 5.3).

Further, a number of international data models and industry specific formats have been developed for geometric and/or semantic descriptions of existing features as well as design features on and above the earth surface. IFC (i.e. for the representation of building objects) (IFC, 2010) or CityGML (i.e. for the representation of design features above ground) (CityGML, 2010) for example are, still, often specific and their design and definition aimed at the application within a certain domain. Formats, such as X3D (i.e. a scalable and open software standard for defining and communicating real-time, interactive 3D content for visual effects and behavioral modeling) (X3D, 2010), VRML (i.e. a standard file format for representing 3-dimensional (3D) interactive vector graphics)

Note
still domain
independent
(16) still in
developing standards
for 3D specific
features, incl.
geology)

first time
full

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(VRML, 2010) or KML (i.e. an XML language focused on geographic visualization, including annotation of maps and images) (KML, 2010) are widely used, but mostly specific to certain fields of use and interest and still hard to be combined.

4 INTEGRATION OF SURFACE AND SUBSURFACE DATA

Integration of subsurface and surface data would apparently be useful in civil engineering (Fookes, 1997, Hack, 1997, Hack et al., 2006, Yanbing et al., 2006). This not only is important when planning or designing surface or subsurface structures, but is necessary to make risk assessment more transparent. Risk assessment for civil engineering structures becomes more and more important and required, accelerated by a series of disasters with underground excavations (Atkins, 2006; Clarke 2004, Fenton and Griffiths, 2008, Royse et al., 2009, Staveren, 2006).

no subsection (if section is short)

4.1 Existing data harmonization and standardization

At present, the integration of the various information types and formats into one representation is still rather difficult. There is an apparent need for an integrated model regarding the geometry as well as the thematic semantics describing what geometry is representing what feature in the real world and, additionally, what its properties and relationships are. Therefore, an integrated 3D information model has been developed. This model focuses on the harmonization and integration of geometry and also thematic semantic information with regard to the different objects and features of concern in infrastructural development (i.e. surface and subsurface features). Within the model, a framework is provided in order to integrate subsurface features into an existing concept and, thus, include geometry and thematic semantics for all features (i.e. natural and man-made, surface and subsurface, survey and design) into one information model. Many groups in the world are working on comparable research topics, which makes the importance of this development clear (e.g. AGS, 2009, Chang and Park, 2004, Choi et al., 2009, Toll, 2007).

by who?
(as in
this
paper)

An important development in this field in a geological sense, that is in form of the implementation of GML as well as XML, was the definition of the GeoScience Markup

⇒ O.K. but what are the limitations of these cited activities?

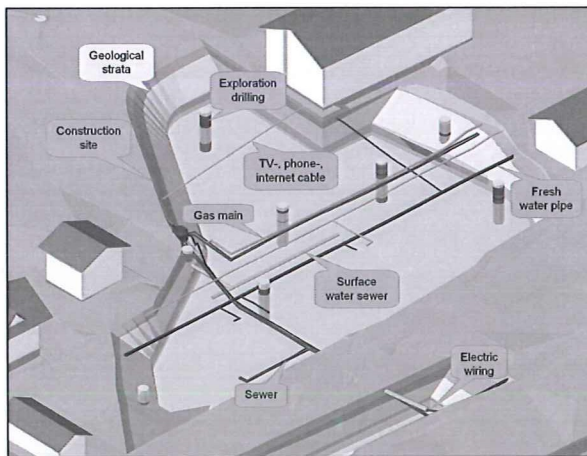
* only doing parts?

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Language (GeoSciML, 2010), and the meta-standard for geotechnical data, the Geotechnical Markup Language (Geotech-XML, 2010). The latter is a version of XML specifically adopted for geotechnical data. Implementations have been made for soil slope case histories (SlopeSML, 2010) and retaining walls based on GML. The Geo Building Information Modelling (GeoBIM) is a subset of CityGML, which among others integrates surface and subsurface data (Figure 2) (Zobl and Marschallinger, 2008). Also the Joint Technical Committee number 2 of the Federation of the International Geo-Engineering Societies (JTC2, 2010) is working on standards for digitally describing and storing geotechnical data.

meta data ?



⊗ Oh, but what are their limitations (that we try to solve)

Figure 2. Building pit excavation in an area previously covered with buildings. Small infrastructure, geology and boreholes are indicated (after: Zobl and Marschallinger, 2008)

5 THE BASIS OF THE INTEGRATED 3D INFORMATION MODEL

For the design of the integrated 3D information model, a number of existing and frequently applied common information models, base models, data models and exchange formats were used as inspiration. First, the common information model as provided by CityGML (Gröger et al., 2007) has been extended by adding surface natural and man-made features as well as a set of subsurface features. Following, this newly developed information model has further been extended by adding subsurface geological and geotechnical features. The Dutch standard geotechnical exchange format GEF (2007) and

by who

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the international information model GeoSciML have, therefore, been used as inspiration for this extension.

give overview and refer to subsection

5.1 Thematic semantic representations: NEN 3610, INSPIRE

Few thematic semantic models exist for 3D city models (Emgård & Zlatanova, 2008). According to Billen & Zlatanova (2003), buildings and terrain features are the most important features to describe in such 3D city surface models. On national and international level, various subdivisions of the thematic semantic models into a number of different features exist. An example for the subdivision of the thematic semantic models into various features, on national level, is the Dutch harmonized base model of geoinformation NEN 3610 (NEN 3610:2005). The NEN 3610 gives specifications of features on and above the surface, but also covers underground utilities (Quak & de Vries, 2006). As a consequence, the NEN 3610 provides a basis for a facilitated data exchange between different specializations. *domains / sectors*

Organization / Classification

On an international level, a first approach towards an integrated information model has been undertaken within the EU initiative INSPIRE. Within Europe the INSPIRE Deliverable 2.5 of the Data Specifications Drafting Team, the ‘Generic Conceptual Model’ (INSPIRE, 2008), has similar goals as the ones behind the Dutch NEN 3610 developments (Quak et al., 2007). Also within the INSPIRE initiative an attempt is made to establish a common semantic framework. With it, 34 different spatial data themes have been defined, covering natural and man-made features, such as buildings, transport networks, terrain, water, geology, atmosphere, ocean, etc. as well as administrative and environmental themes, such as cadastral parcels or safety. Within the themes of INSPIRE surface features are covered in the same way as subsurface features (INSPIRE, 2007).

⊗ (more on the 3D aspect => see one of the previous version of this

5.2 CityGML

The initiative for developing a 3D city model has been started in Germany in 2002 in order to take on the problem of lacking 3D information models covering both geometry and semantics (SIG3D, 2010). Within this initiative the information model CityGML has been developed.

*paper
⇓
file
(list)*

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CityGML is a common information model used for the representation of 3D urban objects. Within CityGML, 1) classes and relations, and 2) geometrical, topological, semantical and appearance properties are defined for the most relevant topographic objects in cities and regional models (e.g. Digital Terrain Models, sites including buildings, bridges, tunnels, vegetation, water bodies, transportation facilities and city furniture) (Figure 3). CityGML includes generalization hierarchies between thematic classes, aggregations and also relations between objects and spatial properties. The underlying model differentiates Levels of Detail (LOD) for some of the considered features. For buildings, for example, five LOD are intended.

Why not total?

not clear to me

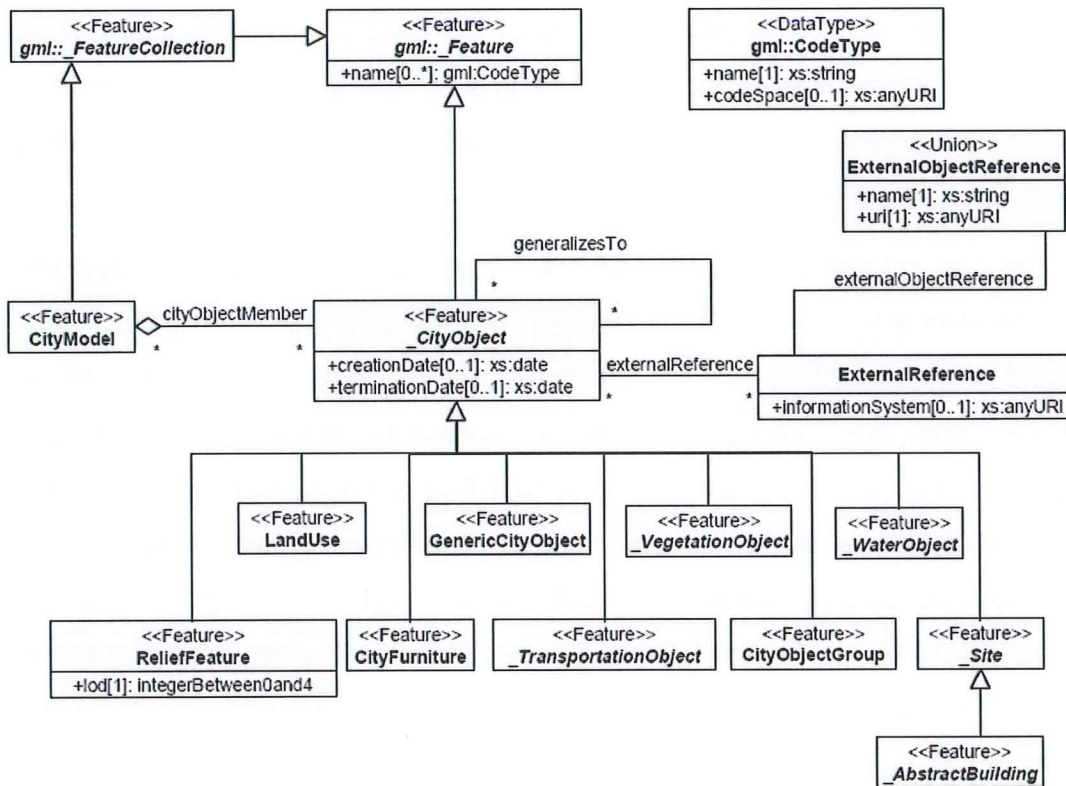


Figure 3. UML diagram of the top level class hierarchy of CityGML (Gröger et. al., 2006).

At present, the information model provided in CityGML is considered one of the most extensive and well-described thematic semantic approaches for 3D modelling of surface and above surface features.

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Also, specific software has been developed, which allows the visualization of data sets that are provided in the CityGML specific format. The LandXplorer CityGML Viewer and the LandXplorer CityGML Viewer Professional provide visualization, navigation and analysis functionalities as well as specific functions, such as the possibility to view stereo images (LandXplorer, 2010).

Would be nice to mention at least one other CityGML viewer

5.3 Standard geotechnical exchange format (GEF)

=> more for source data ?

The standard geotechnical exchange format GEF (2007), developed in the Netherlands, is a general language structure for storing and transferring geotechnical information. The objective of the geotechnical exchange format is to store measurement results in a way that they can easily be analyzed at a later stage. The Dutch GEF standard, which is entirely aimed at geotechnical information, is on ^{at} an international level comparable with the 'Observations and Measurements (O&M)' schema (OGC, 2007). The 'Observations and Measurement schema' has been developed within the Open Geospatial Consortium (OGC) and defined as part of the Sensor Web Enablement (SWE) activity. Within the Observations and Measurement model a framework and encoding for measurements and observations is described as required for the Sensor Observation Service as well as for OGC compliant systems dealing with technical measurements in science and engineering.

According to the GEF standard, three types of information are required when a measurement has been carried out and when the measurement results are available: 1) Observations (i.e. information about the circumstances under which the measurements have been carried out), 2) Observations Metadata (i.e. information about how the measurement results are stored), and 3) the Measurement Results themselves (i.e. including interpretations, derived models, etc.). This implies that, in addition to the measurement results, complete metadata such as additional information about how a measurement has been made, what the measurement conditions were, how the measurement results have been stored, and what the different figures in the files represent must be provided.

Circumstance

1 and 3
the same
for me

As to the collection of this information, a specific methodology has been suggested within the GEF standard. As regards the requirements of the information, which have

⊕ perhaps also show GEF model (or example)

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been set within the GEF standard, and the fact that performing measurements is a process, within which several phases are to be covered, it is suggested to apply a more structural approach during the data collection process. With it, as an example, five phases are distinguished for the data collection methodology, that are namely 1) Setup (i.e. description of the setup of the field or laboratory measurement equipment), 2) Measurement (i.e. description of the field or laboratory measurement process), 3) Analysis (i.e. description of the analysis undertaken on the raw data collected in field or laboratory measurements), 4) Report (i.e. description of the requirements, styles, etc. as defined for the report regarding field or laboratory measurements), and 5) Filing (i.e. description of the storage and management of the data collected in field or laboratory measurements). In each of these phases specific required information is collected and, in most cases, passed on to the next phase. To ensure information consistency and easy understanding of the various types of information collected, certain types of metadata (i.e. additional information) should be included, that are namely purpose, identification, reliability and accuracy.

As to organization of the data, the actual measurement results (i.e. the raw data) will be saved, preceded by a header which describes in a readable form (i.e. ASCII) how the measurement is composed. In addition, information is structured using fixed code words (e.g. 'ANALYSISCODE', 'PROJECTNAME', 'FILEOWNER', etc.). A code word is recognized explicitly and followed by information. The interpretation of the information is depending on the code word provided together with the information.

not (yet)
XML
based!

5.4 *GeoSciML information model* ⇒ more for interpreted data (models) ?

GeoSciML is a geoscience specific data model and encoding, which has, in particular, been designed for the storage and exchange of geoscience information (GeoSciML, 2010). The GeoSciML project was initiated in 2003, under the surveillance of the 'Commission for the Management and Application of Geoscience Information (CGI)' working group on 'Data Model Collaboration' and is now part of the 'CGI Interoperability Working Group'. GeoSciML is a GML 3.1.1 Application Schema and recognized within the Open Geospatial Consortium (OGC).

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The GeoSciML application is a standards-based data format providing a framework for application-neutral encoding of geoscience thematic data and related spatial data. GeoSciML holds the short-term goal of representing geoscience information associated with geologic maps and observations, as well as allowing extension to other geoscience data. Background information is drawn from many geoscience data model efforts, and from these a common suite of feature types based on geological criteria (e.g. units, structures, fossils) or artefacts of geological investigations (e.g. specimens, sections, measurements) is created. Supporting objects are also considered (e.g. timescale, lexicons, etc), so that they can be used as classifiers for the primary objects. Figure 4 shows the GeoSciML top level model describing the features 'Mapped Feature' and 'Geologic Feature'.

(classes)

So both source data and interpreted results?

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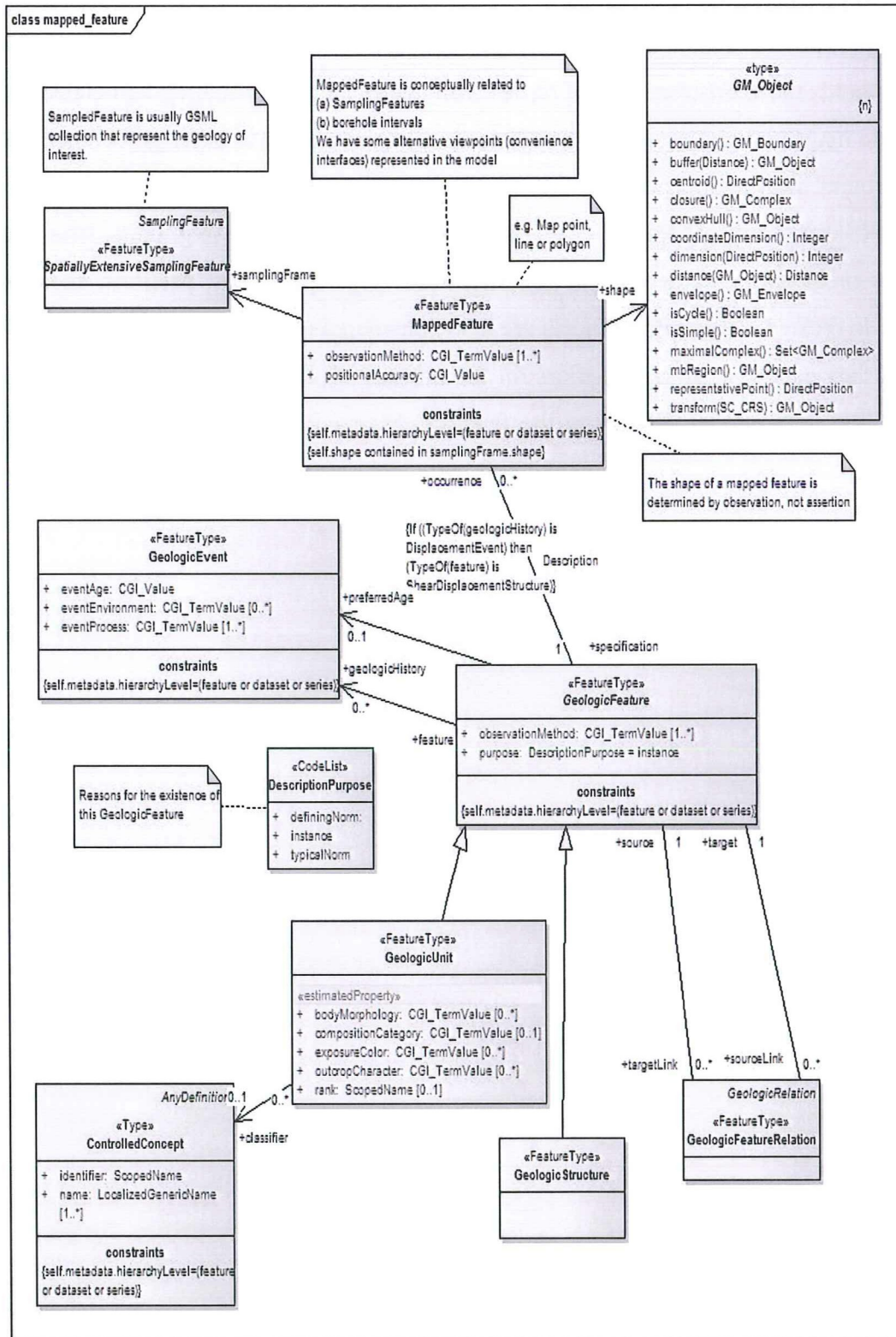


Figure 4. Top level of the GeoSciML ver2.0 model; Top package_Mapped feature (GeoSciML, 2007)

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The choice to use these specific base models, information models, standards, etc. has been made due to a number of reasons. The CityGML information model is used as a basis for the integrated 3D information model, since it allows a near complete representation of 3D urban ^{model} objects and provides geometrical as well as semantical information for these objects. With it, CityGML is almost the only existing model providing a combination of these types of information. The CityGML information model, however, misses information describing the underground, in particular, geological and geotechnical objects. To include geological and geotechnical information in the integrated 3D information model, the GeoSciML information model is used as an inspiration. Just as CityGML, GeoSciML also provides geometrical and semantical information. In the same way as CityGML, the GeoSciML information model does not stay on a generic level, but goes deeper and offers specific schemas for the descriptions of geological features, such as 'MappedFeatures', 'Boreholes', 'Faults', 'Folds', etc. For the development of the integrated 3D information model, also the Dutch standards NEN 3610 and GEF as well as information from the INSPIRE initiative are additionally used to ensure that the developed model also fulfils national and international standards. In contrast to CityGML and GeoSciML information models, NEN 3610, GEF, and INSPIRE do, however, only provide semantical information. No geometrical information is included in these standards.

ARE THERE NO OTHERS ATTEMPTING THIS?

bit vague mapped feature

We know from these initiatives

(Not TRUE FOR INSPIRE, however)

for INSPIRE

Further, it should also be noted that, regarding the fact that both, the GEF standard exchange format as well as the GeoSciML information model, cover a broad and rather general range of information related to geology and geotechnology, only the information relevant for infrastructural development has been acquired from these exchange format and information model.

||
rather avoid this statement

stated (in this paper)

6 DEVELOPING AN INTEGRATED 3D INFORMATION MODEL

As ~~has been~~ mentioned before, the integrated 3D information model, which basis (Section 2) and design (this Section) is being described in this paper, has been developed in several steps. In the first step, the information model provided in CityGML has been extended with man-made and natural features on the surface, but also for features in the subsurface (see also Emgård & Zlatanova, 2008). In the second step, this resulting ver-

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sion of the integrated 3D information model, which is intended to be developed especially for the use in infrastructural development, is further extended by adding subsurface geological and geotechnical features and their thematic semantic description. As opposed to the first extension by Emgård & Zlatanova (2008), this second extension is not kept at a general, conceptual level, but further worked out for the use in ‘Engineering Geology’ (Section 6.2).

6.1 *Extending the CityGML information model towards an integrated 3D information model*

Emgård & Zlatanova (2008), for the development of their integrated 3D information model, adopted many of the concepts and features from CityGML. Using the Dutch harmonized base model NEN 3610, they extended some of the existing concepts in the information model of CityGML and, to some extent, developed and added new concepts to the CityGML information model (e.g. ‘AboveSurfaceUtility’, ‘BelowSurfaceObject’, etc.). Included are thematic semantics as well as geometry for man-made and natural features based on the subdivision of features into 1) earth surface features, 2) above earth surface features, and 3) below earth surface features (Figure 5). Within this subdivision into features, the earth surface feature is the most central feature. Considering the fundamental differences between features above and below the surface as well as the differences between the conditions met above as compared to below the surface, a distinction clearly needs to be made between those features.

and on
and on

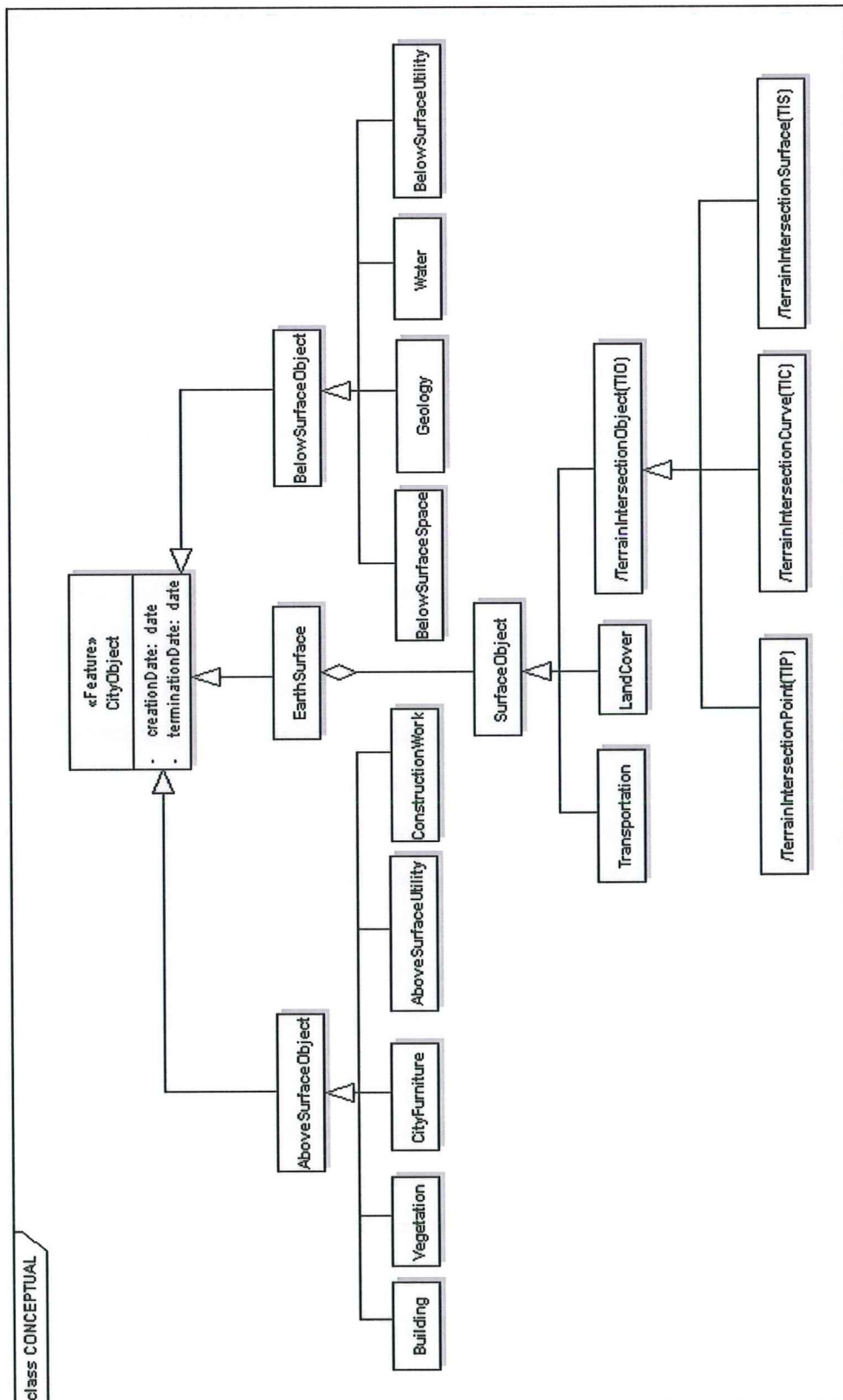


Figure 5. UML diagram of top level feature hierarchy (Emgård & Zlatanova, 2008).

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As described by Emgård & Zlatanova (2008), features above surface are separated into five classes: *Building*, *Vegetation*, *ConstructionWork*, *CityFurniture* and *AboveSurfaceUtility* and features below surface into *Geology*, *Water*, *BelowSurfaceSpace* and *BelowSurfaceUtility*. Features that are part of the Earth surface are divided into *LandCover*, *Transportation* and *TerrainIntersectionObject*. This first version of the integrated 3D information model, however, kept at this general conceptual level.

"on"

6.2 Extending the integrated 3D information model towards subsurface geological information

As has been explained before, a class *Geology* should be included in a 3D city model in order to combine surface and subsurface features and to further extend the integrated 3D information model. For the extension of Emgård & Zlatanova's (2008) first conceptual version of the integrated 3D information model as regards subsurface geological and geotechnical information, the Dutch standard geotechnical exchange format GEF and the international geoscientific specific data model and encoding GeoSciML are applied. Using these two models as inspiration, subsurface geological and geotechnical features, which are considered to be of importance in infrastructural development, are added to the extended 3D city model provided by Emgård & Zlatanova (2008). Additional information is included concerning the geological and geotechnical features; in particular information as regards results from measurements, field and laboratory tests undertaken in order to characterize the various geological features and their properties. With it, also the possibility to include information about the quality and (possible) uncertainties as to measured and processed data is given.

(see 5.3 and 5.4)

The different steps undertaken for the extension of the first version of the integrated 3D information model with subsurface geological and geotechnical features are now further described. Also, information about the meaning of several geological and geotechnical features as well as the required additional information concerning, for example, site measurements as well as field and laboratory tests is given.

Figure 6 shows the UML diagram of the top level feature hierarchy as regards the subdivision of the class *Geology*. In the integrated 3D information model, the class *Geology*

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is part of the class *BelowSurfaceObject*, which again makes up part of the feature
CityObject.

super

super class

(all abstract clones)

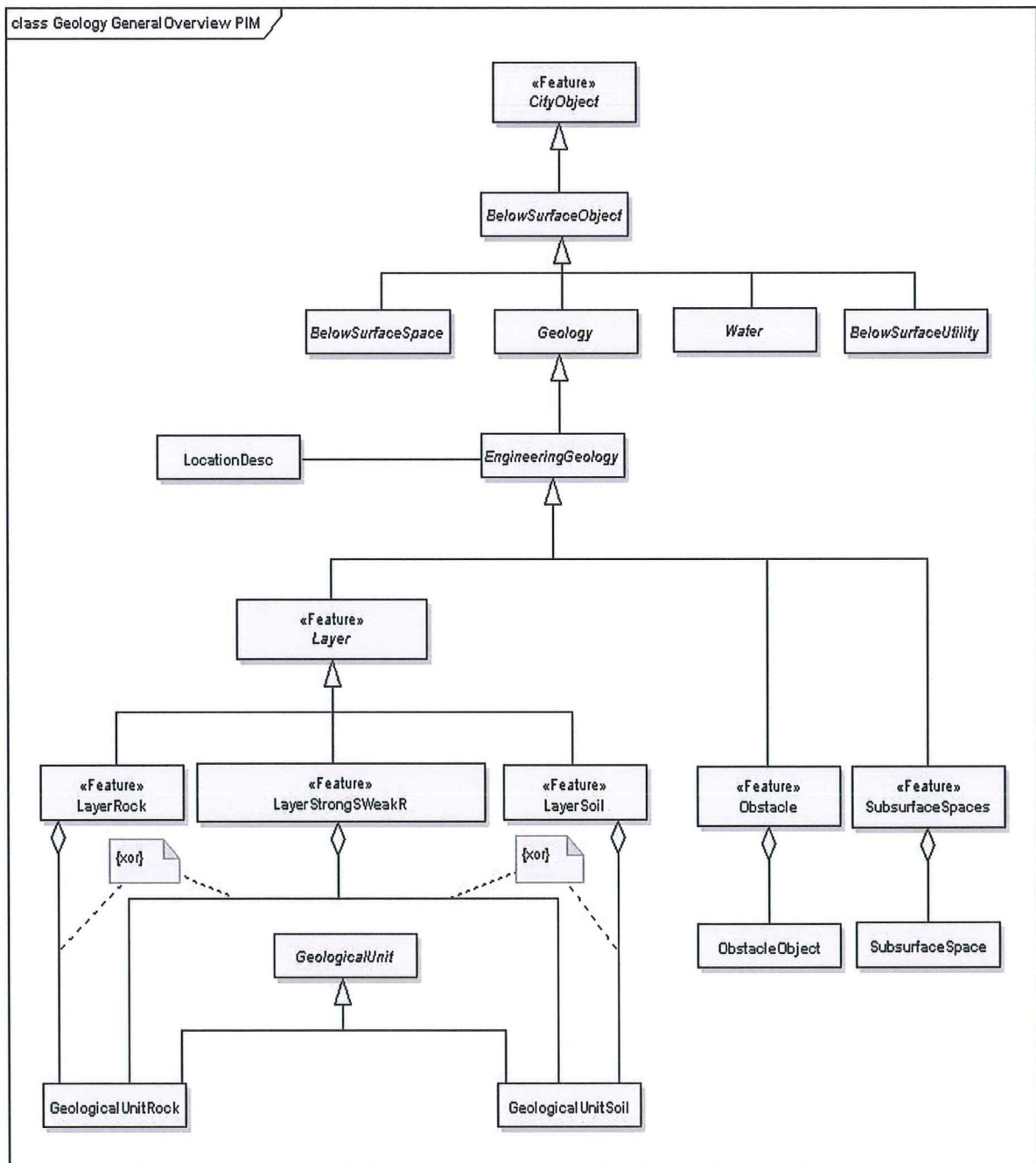


Figure 6. UML diagram of top level feature hierarchy – The subdivision of the ‘Geology object’.

The rather general class *Geology* can be split up in different Geology-specific sub-classes, such as Engineering Geology, Hydrogeology, Mineralogy, etc. Since this model extension is aimed at the improvement of communication and information exchange in infrastructural projects, the focus is put on Engineering Geology. A sub-class *EngineeringGeology* is, thus, created.

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Regarding the fact that this integrated 3D information model is, thus, mainly designed for use in infrastructural development, only geological objects considered to be of importance for infrastructural projects are included in this model. Consequently, this model should not be considered a complete model of the general geology, but rather a model containing the most important subsurface geological and geotechnical information for a specific infrastructural project.

The sub-class *EngineeringGeology* can be further split up in different features, namely various geological and geotechnical objects. In this specific case, it is chosen to subdivide the sub-class *EngineeringGeology* into five specific geological features, that will following be described. ^{Further} It should be noted that most definitions used are based on the 'Dictionary of Geological Terms' prepared under the direction of the American Geological Institute (AGI, 1976), the 'Geological Nomenclature' by the Royal Geological and Mining Society of The Netherlands (Visser, 1980), the British Standard BS 5930-1999 (BS, 1999) as well as several ISO standards. The subdivision of the class *EngineeringGeology* is as follows:

The general feature 'Layer', ^{is used to describe} which includes the subsurface geological features that occur as continuous layers in the subsurface. In geology, a 'Layer' can generally be defined as 'a tabular unit of igneous, sedimentary or metamorphic origin, of comparatively homogeneous composition and separated from the material above and below by well defined boundary planes'. The feature 'Layer' can, depending on the material it consists of, further be described by the three specific features, that are namely: ^(in UTM models, reference to exact source of definition of term is given.) (real, non-abstract,

1 LayerRock: Subsurface geological layers mainly built up of rock material; that is 'strictly, any naturally formed aggregate or mass of mineral matter, whether or not coherent, constituting of an essential and appreciable part of the earth's crust' and 'ordinarily, any consolidated or coherent and relatively hard, naturally formed mass of mineral matter'. Different layers of rock material can be defined by the occurrence of different rock materials and/or significant variations in material properties.

2 ~~LayerStrongSoilWeakRock~~: Geological layers built up of material, which cannot be clearly classified as a rock or a soil type. The material might fulfil the classification and description of a soil, however, it may be cemented and according to its material properties should be classified as a rock. In the same way, the material might fulfil the classi-

abstract class
good!
but refer to source of definition (everywhere when such a quote is used)

(in UTM models, reference to exact source of definition of term is given.)
(class with instances)

same as in diagrams



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fication and description of a rock, however, it may be weakened and according to its material properties should be classified as a soil. Different layers of strong soil/ weak rock material can be defined by the occurrence of different materials and/or significant variations in material properties.

3 LayerSoil: Subsurface geological layers mainly built up of soil material; that is namely ‘the unconsolidated material on the earth’s surface that serves as a medium for the growth of plants’ or ‘the earth material which has been so modified and acted upon by physical, chemical, and biological agents that it will support rooted plants’. Different layers of soil material can be defined by the occurrence of different soil materials and/or significant variations in material properties.

4 Obstacle: Obstacles are objects, which do not fit the classification and description of the geological layer, in which they are found, but are too big to be neglected throughout the construction process. Obstacles are, for example, boulders, that are ‘large rounded blocks of stone lying on the surface of the ground, or sometimes embedded in loose soil, different in composition from the rocks in the vicinity and which have been therefore transported from a distance’.

5 BelowSurfaceSpaces: (Empty) Subsurface spaces, whose size and extension is too big to be neglected during the construction process. With it, natural as well as man-made subsurface spaces need to be included in the description. Natural subsurface spaces can, for example, be karst holes, that are naturally developed underground cavities to be found in karst areas. Karst areas are generally defined as areas with a water-soluble rock type (such as calcium-carbonate and gypsum), in which solution has produced fissures, sinkholes, and caverns. Man-made subsurface spaces, on the other hand, can, for example, be abandoned shallow mines.

Further, for the extension of the first version of the integrated 3D information model with regard to geological subsurface features, specific thematic semantic information (sub) models have been designed. These thematic semantic information (sub) models have been developed separately for each of the five geological features as defined in the subdivision of the sub-class *EngineeringGeology*. In Figure 7 and Table 1 & 2 an example is given in the form of the UML diagram and two class tables indicating the required thematic semantic information for the geological feature ‘LayerRock’. This should give a

time ?

including properties and delimited code links with possible values

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suggestion about the type of information (e.g. location, depth, descriptions, characteristics, properties, etc.) that needs to be collected in order to provide a useful description of the different geological features of interest in infrastructural development.

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For the description of the geological feature 'LayerRock' a number of various types of information are needed. In addition to information concerning the method of observation ('ObservationMethod') that is applied for the description of the geological feature as well as the purpose ('DescriptionPurpose') for the description of the geological feature (e.g. facilitates the planning of a site investigation, if the type of project and purpose of investigation is known), a number of different types of information need to be collected (e.g. location information, layer depth, thickness and extension, weathering and composition properties, physical and mechanical properties, etc.). Regarding the fact, that, within the project area, different types of rock layers might occur and/ or the properties within one type of rock layer might vary, the geological feature 'LayerRock' will, thus, be described as an aggregation of a number of homogeneous geological units. A 'GeologicalUnit' can be defined as a homogeneous unit of the same material with none or only slight variations in material characteristics and properties. For each 'GeologicalUnit' the information in Tab. 1 needs to be collected.

attributen

← via associations to other classes

attributen

Table 1. Geological unit

identification

objectcode Integer Public	ObjectCode: Unique code linking to the specific object 'GeologicalUnit' within the geological feature 'LayerRock'.
objectlocation BoundingBox Public	ObjectLocation: Location and extension of the geological unit described by a Bounding Box.
objectname RockSoilName Public	ObjectName: Name of the rock of this geological unit. Naming according to BS5930 (1999); examples given in the 'CodeList' 'RockSoilName'.
geologicformation GeologicalFormation Public	GeologicFormation: Description of the geological formation, to which the geological unit is ascribed to; examples are given the the 'CodeList' 'Geological-Formation'.
objectdepth Decimal	ObjectDepth: Rough indication regarding the vertical depth (m), at which the

«...»

nieuw regels voor attribute name
data type
(public may be skipped as all attributes are public)

Public	geological unit (i.e. specific layer rock) is assumed to start.
objectdepthrange Decimal Public	ObjectDepthRange: Range of measurement results for the vertical depth (m) of the geological unit (i.e. specific layer rock).
objectthickness Decimal Public	ObjectThickness: Rough indication regarding the vertical thickness (m) of the geological unit (i.e. thickness of the rock layer).
objectthicknessrange Decimal Public	ObjectThicknessRange: Range of measurement results for the vertical thickness (m) of the geological unit (i.e. thickness of the rock layer).
objectextension Decimal Public	ObjectExtension: Rough indication regarding the horizontal extension (m) of the geological unit (i.e. extension of the rock layer).
objectextensionrange Decimal Public	ObjectExtensionRange: Range of measurement results for the horizontal extension (m) of the geological unit (i.e. extension of the rock layer).
objectgeometry GM_MultiSurface Public	ObjectGeometry: Geometrical description of the geological feature; according to 'The OpenGIS Abstract specification "Feature Geometry" ' (OGC 2001).

In addition to this rather 'general' information, specific information needs to be collected for the description of each 'GeologicalUnit', that is, for example, information concerning the physical properties of each specific 'GeologicalUnit'. The required information for the class 'PhysicalDescRock' is shown in Table 2.

Table 2. PhysicalDescRock

rockunitweight RangedValue	RockUnitWeight: Description of the unit weight of the rock in the geological unit, that is the weight per unit volume of a material, given in kg/m ³ .
--------------------------------------	---

attributes

is it a range? (I can not detect this, but the letters are also very small)

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Public	
rockbulkdensity RangedValue Public	RockBulkDensity: Description of the unique density of the rock in the geological unit, that is the apparent density or the mass or quantity of a substance per unit volume, given in g/cm3.
rockeffectiveporosity Porosity Public	RockEffectivePorosity: Description of the porosity of the rock in the geological unit, that is the percentage of void space to be detected in the rock or ‘the ratio of the aggregate volume of interstices in a rock to its total volume’, given as a percentage and in the <u>‘DataType’</u> ‘Porosity’.
rockpermeability Permeability Public	RockPermeability: Description of the permeability of the rock in the geological unit, that is ‘the capacity of a rock for transmitting a fluid. The degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the latter. It is measured by the rate at which a fluid of standard viscosity can move a given distance through a given interval of time’, given in Darcy or m2 and as <u>‘DataType’</u> ‘Permeability’.
rockunitweight RangedValue Public	RockUnitWeight: Description of the unit weight of the rock in the geological unit, that is the weight per unit volume of a material, given in kg/m3.
rockbulkdensity RangedValue Public	RockBulkDensity: Description of the unique density of the rock in the geological unit, that is the apparent density or the mass or quantity of a substance per unit volume, given in g/cm3.

Each ‘GeologicalUnit’ can be described using various means, that are namely visual descriptions as well as field measurements and field and laboratory testing. Information concerning these various types of description means is also included in this thematic semantic model. The raw measurement and laboratory test results can be stored in a specifically developed ‘GeologyMeasurementDetail’ model, which is shown in Figure 8 and which can be linked back to each ‘GeologicalUnit’ of concern. The model ‘GeologyMeasurementDetail’ (Figure 8) is just inter-linked with each model describing specific geological features, such as the model ‘LayerRock’ (Figure 7). The link between all these parts of the thematic semantic model is achieved via a certain location and the location class ‘LocationDesc’. The class ‘LocationDesc’ has been chosen to be the central class in the integrated 3D information model, since the model is aimed for the use in

Via the Location Description

(relevant for all 5 subclasses of Engineering Geology)

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infrastructural projects, where the various specialists, in general, require and exchange information of the surface and subsurface for a certain location, namely the project location.

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Thus, next to the descriptive models (including derived and processed information) for each geological feature of importance in infrastructural construction processes, such as the model 'LayerRock' (Figure 7), more detailed information collected from site investigation as well as field and laboratory measurements will be needed throughout the whole lifecycle of the infrastructural project. A clear picture of the geological and geotechnical situation at the construction site as well as sufficient information about the properties and possible behaviour of the geology with respect to the construction activities is needed to ensure a safe and economic planning of the infrastructural project. For that reason, another level of the thematic semantic information model has been developed in the process of extending the integrated 3D information model towards geology. This thematic semantic information model can be considered a rather general model, which can be applied for all five geological features (as shown in Figure 6) equally. It includes information, which should be collected during site investigation, field measurements and laboratory tests (see Figure 8).

bit vague
consider
a more
descriptive
term than
'another'

For the 'VisualFieldDesc', for example, undertaken directly in the field, the information in Tab. 3 is required.

Table 3. VisualFieldDesc

<p>geobjectdesc Integer Public</p> <p><i>name repl</i></p>	<p>GeoObjectDescCode: Unique code linking this visual description and/or field measurement to the specific geological object (i.e. 'LayerRock') that is described.</p>
<p>locationcode Integer Public</p>	<p>LocationCode: Unique code defining the location, at which a certain visual description and/or field measurement for the description of the geological object, has taken place.</p>
<p>projectcode Integer Public</p>	<p>ProjectCode: Unique code identifying the project, for which the visual description and/or field measurements have been undertaken.</p>
<p>projectname CharacterString Public</p>	<p>ProjectName: Name of the specific project, for which this visual description and/or field measure-</p>

← 1

← 1

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	ment is undertaken.
projectlocation CharacterString Public	ProjectLocation: Name of the general project location.
client CharacterString Public	Client: Name of the company that is responsible for the project and giving out the contract to undertake a certain field measurement, laboratory test, visual description, etc.
clientcontact ContactDetails Public	ClientContact: Information with regard to the client; including information such as company, contact person, address, telephone number; given as <u>'DataType'ContactDetails'</u> .
consultant CharacterString Public	Consultant: Name of the company that is hired in, in order to undertake a certain field measurement, laboratory test, visual description, etc.
consultantcontact ContactDetails Public	ConsultantContact: Information with regard to the consultant; including information such as company, contact person, address, telephone number; given as <u>'DataType'ContactDetails'</u> .
descdatetime DateTime Public	DescDateTime: Information about the date and time at which the visual description and/or field measurement has been undertaken; given as 'DateTime' according to 'The ISO/TC 211 Draft Technical Specifications 19103, Geographic Information - Conceptual schema language (ISO, 2001)'.
locationcond LocationConditions Public	LocationConditions: Description of the conditions at the location where the visual description and/or field measurement is undertaken; given as <u>'DataType'LocationConditions'</u> .
notes CharacterString Public	Notes: Space for notes and comments, taken during the visual description and/or field measurement for the description of the geological object.

← >>

←

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In the thematic semantic model shown in Figure 8, most information that is included should, thus, be collected throughout site investigation, field measurements and laboratory tests in order to achieve a complete description of the geological features to be dealt with throughout infrastructural development. This information can generally be organized in 4 general categories, that are namely: VisualDescription, FieldMeasurement, Sample and LabTest. These categories are then further subdivided into the specific measurements and tests applied.

In these categories, next to information concerning the sampling and measurement ID, name and location (i.e. defined using ID, name and coordinates) also information as regards sampling description, date, origin and possible alterations, the description of field measurement types, phases and measurement archive names as well as the description of laboratory tests, procedures and analysis is included. Further, the data sets and results (i.e. in the form of raw data as well as interpretations) derived through fieldwork, site investigation, field and laboratory measurements are included and linked to in the thematic semantic model, which makes up part of the extended version of the integrated 3D information model.

Unfortunately, it is not possible to list all levels of the developed model in this paper, but it is therefore referred to Tegtmeier (2010) (in preparation).

⇒ or refer to UPL model www.gdmc.nl/tegtmeier

7 CONCLUSIONS AND RECOMMENDATIONS

As has been emphasized throughout this paper, communication as well as information exchange and (re-) use is difficult in relation to infrastructural development. In order to facilitate the information exchange and communication between different parties involved and also to achieve an economic and safe planning of infrastructural projects, a harmonization of the various types of geo-information handled in infrastructural development must be approached. Such type of data harmonization is additionally of importance in order to avoid information simplifications and to allow transparent risk assessment. Ideally, a conceptual model for the thematic semantics of information frequently used in infrastructural development should be built up. Consistent application of terms is thereby a prerequisite for successful implementation and unambiguous adoption of legislation, regulations, guidelines and interpretations and should also decrease possible

9 rev-

definition and

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misunderstanding

semantic uncertainties caused by inconsequent applications of terms and definitions. As described throughout this paper, realistic 3D models describing and integrating part of the earth already exist, but are generally neglecting the subsurface, and especially the aspects of geology and geotechnology. In addition to missing information concerning the subsurface, many existing models still simply miss thematic semantic information completely.

A solution to the harmonization of the various types of geo-information as well as the lack of thematic semantics has been investigated within this research. With it, a thematic semantic information model has been developed including information concerning all subsurface geological and geotechnical features considered to be of importance during the process of infrastructural development. This thematic semantic model has been developed in accordance with the user requirements as determined in questionnaires and interviews with companies and institutes involved in infrastructural projects.

The thematic semantic information model of subsurface geological and geotechnical features is ~~generally~~ an extension of the CityGML model. In order to include subsurface geological and geotechnical features in the CityGML model, the CityGML information model has, in an earlier research, been extended toward the subsurface by including so-called 'BelowSurfaceObjects', of which the 'Geology' is one. Further in this research, within this thematic semantic information model, the 'Geology' has been specified as 'EngineeringGeology' and further been subdivided into several features, the so-called geological objects. For each of these geological objects, a thematic semantic model has been developed to support a clear definition and description of each object. In addition, a general thematic semantic model has been developed that can be applied for all geological objects universally and that includes information regarding sampling, in situ and field measurements as well as laboratory testing (compare to the 'OGC Observations and Measurements (O&M)' schema).

=> list them

*=> name top-clan
Location Desc*

This is one of the advantages of the developed thematic semantic model, that it allows not only the handling and storage of information concerning the physical description of the various geological objects, but also of information and results as derived through field and laboratory measurements aiming at a thorough description of the geology in the project area. Further advantages of this thematic semantic information model become clear when comparing it to the information models, base models and standards

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used as a basis for the development of this model. More advantages of this thematic semantic information model are the following:

- Just as the CityGML information model, the thematic semantic information model provides a combination of geometrical as well as thematic semantic information for all objects included in the model.
- As an extension of CityGML, the thematic semantic information model now makes the integrated handling and exchange of surface and subsurface information possible.
- The thematic semantic information model is designed to provide detailed information to be used for a specific purpose, namely the construction of infrastructures, as opposed to the GeoSciML information model, for example, which provides general geological information.

To prove the usefulness of the newly developed thematic semantic information model, future research will concentrate on the database implementation of this extended version of the integrated 3D information model as well as the testing of the set of thematic semantic information models using real world data as derived from infrastructural project case studies within The Netherlands. *and outside*

ACKNOWLEDGEMENTS

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CC: Robert Hack <hack@itc.nl>

Hallo allemaal!

Kunnen jullie er heel goed naar kijken...we hebben het toch wel aardig veranderd!

En...wanneer zullen we eens afspreken?! Ik zou het erg leuk vinden, om het in Enschede te doen! Robert is deze week op vakantie, maar vanaf volgende week (29-03) kan het weer!

Groeten,
Wiebke

Faculty of Geo-Information Science and Earth Observation (ITC)
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