3D-GEM: Geo-technical extension towards an integrated 3D information model 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. Mainly this is caused by a lack of information harmonization. Various specialists are working together on the development of an infrastructural project and all use their own specific software and definitions for various information types. In addition, the lack of and/or differences in the use and definition of thematic semantic information regarding the various information types adds to the problem. Realistic 3D models describing and integrating parts of the earth already exist, but are generally neglecting the subsurface, and especially the aspects of geology and geo-technology. 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. The major contributions of this research is the definition of geotechnical objects and the mechanism to link them with CityGML, GeoSciML and O&M standard models. The model is called 3D-GEM, short for 3D Geotechnical Extension Model.

Keywords: CityGML, database, harmonization, geotechnique, geology

1. Introduction

During the various stages of infrastructural projects, different tasks must be accomplished, requiring different skills from different professionals, such as civil engineers, engineering geologists, and GIS technologists. They are working on a range of problems often requiring the combination of information and knowledge. For 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.

The data and workflow in civil engineering projects related to geotechnical information is often as follows: a geotechnical sub-contractor investigates the project site. The consultant of the project, who may be the same as the geotechnical sub-contractor, interprets available data from public sources and integrates 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, (cross-) sections, and drawings of the subsurface. Thereafter often somebody with or without 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 source for design and construction, and all other information on the subsurface is more or less forgotten. The difficulties with integrating the information from the site investigation into the digital design and constructions models in civil engineering CAD programs is one of the reasons for the simplification. Any uncertainty information is mostly also lost in the simplified information and the simplified information is taken as the truth.

Another problem in large projects is the re-use and exchange of information. Although not often expressed publicly, re-use and exchange of information is only seldom achieved. The main reasons are: 1) the information is not harmonized; i.e. the same information used by different professionals is not in the same format and structure, and does not have similar naming, but even if the naming is the same the concept or substance assigned is often different; and 2) the quality and uncertainty of most of the information is not quantified (Tegtmeier et al., 2009).

Integration of subsurface and surface data is very advantageous for planning or designing surface or subsurface structures, and is necessary to make risk assessment more transparent (Culshaw, 2005, Fookes, 1997, Hack, 1997, Hack et al., 2006, Yanbing et al., 2006). Modelling uncertainty in Earth Sciences and risk assessment for civil engineering structures becomes more and more required (Clarke, 2004, Atkins, 2006, Staveren, 2006, Fenton and Griffiths, 2008, Royse et al., 2009, Caers, 2011). Several research groups are working on comparable topics (e.g. Chang and Park, 2004, Toll, 2007, AGS, 2009, Choi et al., 2009, Krämer, 2010). However, most of the developed models and data structures are either application-specific (e.g. for the management of slope or borehole data) or kept on a more general and ‘geology-wide’ level.

Therefore, a 3D Geotechnical Extension model (3D-GEM) is developed as application domain extension of CityGML. This model focuses on the harmonization and integration of geometry and thematic semantic information with regard to different geotechnical objects and features needed in infrastructural development. A new view on geological objects is proposed that may differ from the traditional geological view but is expected to help in integration of interdisciplinary knowledge and information. A framework is provided to integrate those subsurface features into existing concepts (GeoSciML and O&M) 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.

The paper is organised as follows. Section 2 gives an extended overview on how the subsurface is modelled and digitally represented and summarizes the most common data formats in geotechnical engineering. The differences between handling and processing of subsurface and surface data are addressed in Section 3. Section 4 elaborates on the standards that have been used for the design of the model, which is based on the integration of CityGML (Gröger et al, 2012), GeoSciML (CGI, 2012), and O&M (ISO 19156:2011, OGC 2013). Section 5 presents the geo-technical modelling, i.e. 3D-GEM. Section 6 concludes with recommendations and directions for future research.

2. Subsurface information and its representation

Nowadays many geological survey organisations are making geological information available digitally at national (for example, Catalunya, Spain: ICC, 2012, and USA: USGS, 2012) or international level (OneGeology, www.onegeology.org). Many also try to deliver a 3D model of the subsurface digitally (DINO, 2012, BGS3D, 2012). Most of the models consist of only layer boundaries with descriptions of the properties in between the boundaries (Figure 1).

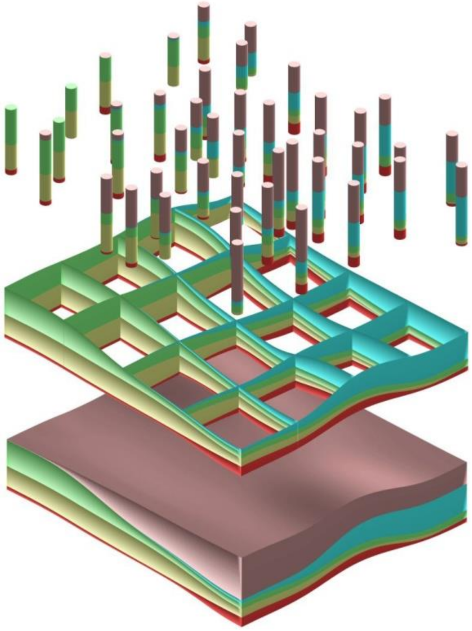


Fig. 1. Computer generated fence diagram (middle), with above boreholes and below solid model; (sub-) horizontal layers with different colours or grey scales represent various geological layers (reprinted from Rockware, 2012).

Data models used in subsurface 3D modelling vary widely. In addition to layer boundary modelling (boundary surfaces), programs exist that allow property values assigned to voxels, Triangulated Networks (TIN), TEtrahedral Networks (TENs), polyhedrons, lines, points, etc. (e.g. Orlic, 1997). Public data sources on geology are mostly limited to measurements (boreholes, test sample data), maps (which have to be interpreted into a 3D-model), and sometimes 3D models consisting of layer boundaries only. Transfer of data from one program or data source to another is mostly possible for basic data items such as location-property values, boreholes, samples, surfaces, boundaries and sometimes for volumes. Objects are often transferred as separate items, and any structure in-between may be lost.

Internet triggered developments such as the definition of the GeoScience Markup Language (GeoSciML, 2012) which is directed to modelling geology with quite limited options for geotechnical features, and the Geotechnical Markup Language (GeotechML, 2012) directed to modelling specific geotechnical problems. Both languages cannot be used universally in civil engineering projects and do not include all surface and subsurface items. The DIGGS (2012), GSI3D (2012) and AGS (2012) initiatives are for a part developments similar to 3D-GEM, but are less generic and have less integration of sub- and surface data. A detailed discussion of the differences is outside the scope of this paper.

Geotechnical information is partially a subset of geological information. The geology together with the environment (stresses, presence of water, etc.) is input for the geotechnical model, however, the geology and environmental models are not part of the geotechnical model. The terminology and expressions may be different; sometimes the expressions for the same object in geotechnical and geology modelling differ or the perception differs. For example, a "bedding plane" in geology marks an interruption or change in the sedimentation while in geotechnical modelling it is mostly regarded as a plane with strength along or perpendicular to the plane less than the surrounding material. Public geotechnical digital information is seldom available in the form of three-dimensional models. Mostly it consists of scans of paper documents and logs of boreholes and test data. Data density depends on the area (urban many data – rural few data) and on the type of geotechnical investigations that are common in the area and for the type of geology. 3D models if any are limited to very small areas and mostly to a specific project.

Until recently most countries had their own standards for geotechnics and engineering geology such as in the USA ASTM (2013), in Britain the British Standard (BS) (BSI, 2013), in Germany DIN (2012), and in The Netherlands NEN (2005). Other countries adopted BS or ASTM standards, sometimes modified. Therefore, a geo-information system based on BS and ASTM could be used without major modifications throughout large parts of the world. Internationalisation (ISO, 2012) and the forming of the European Union triggered development of new international standards to be used compulsory in, for example, all countries of the European Union (Eurocode, 2010). Some resent standards are subject to (severe) criticism on methodologies and the coherence (Hencher, 2008, Bond and Harris, 2010). Revisions and amendments are therefore frequently published and likely, the final revisions have not been made yet. The INSPIRE data specifications (see section 3) are also important in the context of the development of an integrated model. However, the most relevant themes (Geology and Energy Resources) are only in draft. The present situation is, thus, rather confusing - with regularly changing standards sometimes applicable worldwide, or only to specific countries or regions. This leads to a problem as it is not feasible to change the digital models continuously while maintaining backward compatibility on every change made. The authors have therefore chosen to follow the Dutch 'Geotechnical Exchange Format' (GEF, 2013) and British (BSI, 1999) standards for engineering geology and geotechnical work supplemented by

ISO (ISO 14688-1:2002, 2002, ISO 14689-1:2003, 2004), as these are very commonly applied.

3. Surface and above surface information

Natural phenomena and man-made objects on and above the surface can rather ‘easily’ be observed and measured. The shape and size of surface objects is, mostly, well visible and, thus, easily derivable. Moreover, in the ‘surface world’ sufficient quantities of good quality and well-described information can be collected that facilitate the creation of real world representations. As a result, the emphasis is put on the best representation of the complexity of the various objects, in the ‘surface world’, including information concerning their thematic properties and relationships, as well as on the management of the collected geo-information.

Resulting from on-going initiatives (i.e. OGC, 2013), 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 for the management of geo-information and the representation of surface objects are frequently applied (Spatial schema (ISO 19107:2003, 2003), Temporal schema (ISO 19108:2002, 2002), Quality Principles (ISO 19113:2002, 2002), Quality Evaluation Procedures (ISO 19114:2003, 2003), Metadata (ISO 19115:2003, 2003), Schema for coverage geometry and functions (ISO 19123:2005, 2005) and the XML geometry encoding GML (ISO19136).

The above-mentioned ISO standards are domain-independent and can be applied in various domains (e.g. GIS technology, geotechnics, and surveying). ISO, the OGC and NEN have also developed standards for the measurement and representation of surface objects as well as for the proper geo-information exchange. The most relevant NEN standard for this research is NEN 3610. NEN 3610 also covers underground utilities, e.g. small infrastructure as pipes and cables, but it does not cover geotechnical information (Quak and de Vries, 2006).

The INSPIRE Deliverable 2.5 of the Data Specifications Drafting Team, the ‘Generic Conceptual Model’ (INSPIRE, 2008), has similar goals as NEN 3610 (Quak et al., 2007). 34 different spatial data themes have been identified, covering natural and man-made features as well as administrative and environmental features. For the first 9 themes (‘Annex I’), the data specifications have been finished by the end of 2009. INSPIRE Annex I themes do hardly ever mention 3D explicitly and in the UML class diagrams the GM primitives of ISO 19107 Spatial Schema are used without stating if this refers to a primitive in 2D or 3D space. One exception is the theme Cadastral Parcels, which mentions 3D cadastral objects. After the completed Annex I data specifications, the draft data specifications for Annex II (e.g. Elevation and Geology) and Annex III (e.g. Soil, Buildings, Atmospheric conditions, Oceanographic geographical features, and Energy resources) themes are currently being specified and contain more often explicit reference to 3D aspects. The draft Data Specification on Geology (Theme Working Group Geology, TWG GE) has 3D aspects in many places, e.g.: a. classes for representing 3D seismics and 3D resistivity survey in the GeophysicsCore model, b. the GeophysicsExtension model (Annex D3) uses an explicit 3D solid grid, and c. 3D models are mentioned several times in the use cases in Annex B in relation to waste disposal (UC02) and tunneling operations (UC10). Further, the draft Data Specification on Energy Resources (INSPIRE TWG ER) mentions data using 2-D or 2.5-D geometries, or 3D may be used following the geometry types defined in ISO 19107:2003. This standard provides the type GM_Solid for volumetric data.' The draft Data Specification on Buildings (INSPIRE TWG BU) defines 4 profiles: Core2D and Core3D and Extended2D and Extended3D, clearly indicating the importance of 3D in this draft data specification. It should be noted that INSPIRE does not cover geotechnical data.

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. CityGML (i.e. for the representation of topographic features, mainly above ground) or IFC (i.e. for the representation of building objects) (BuildingSmart, 2012) are often specific and their design and definition aimed at the application within a certain domain. The Geo Building Information Modelling (GeoBIM) is a straightforward extension of the BIM concept, which among others integrates surface and subsurface data (Zobl and Marschallinger, 2008). GeoBIM allows surface and subsurface features, that is buildings and geology, to be modelled in one framework. At present, the GeoBIM framework does not allow to model the original site investigation data following the published literature, but only an interpreted model of the geology. In addition, the Joint Technical Committee number 2 of the Federation of the International Geo-Engineering Societies www.issmge.org/en/fedigs) is working on standards for digitally describing and storing geotechnical data, which may be partially based on the work described in this paper.

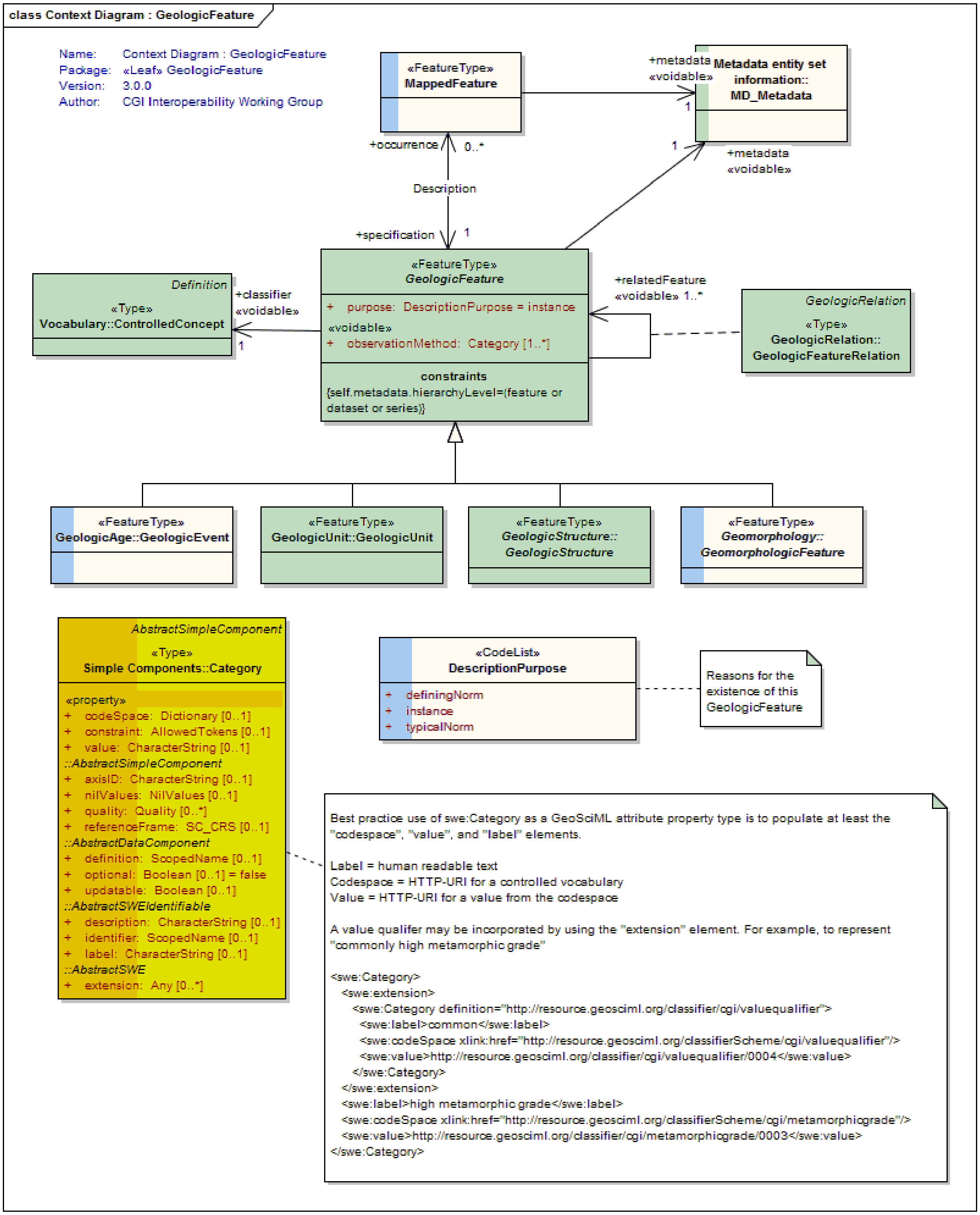
4. Components of the integrated 3D information model

To design an integrated 3D information model for infrastructural design, CityGML is selected as a starting model, which is augmented with 3D-GEM to represent subsurface geotechnical information. The integrated 3D information model reuses all surface and subsurface features as defined in CityGML (Gröger et al., 2012). To design the 3D-GEF model, the GEF (2013) and OGC standard Observations and Measurements have been used as basis to model geotechnical measurements. Finally, the international information model GeoSciML has been used for inspiration for defining subsurface geotechnical bodies.

CityGML is a common information model used for the representation of 3D urban objects (CityGML, 2012a). Within CityGML, 1) classes and relations, and 2) geometric, topological, semantic, 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). 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. Some man-made subsurface features (e.g. tunnels) have been included in CityGML 2.0.0 (Gröger et al, 2012). CityGML also provides two different ways of extension. The first is by generic city objects and generic attributes, both defined within the module ‘generics’. The second is by the so-called Application Domain Extensions (ADE) (Kolbe, 2009). The ADE mechanism has been used in our approach.

```
#GEFID = 1, 0, 0
#FILEOWNER= Lws
#FILEDATE= 2001,07,21
#PROJECTID= CO, 377500, 300
#TESTID = BORING 'V.1'
#COLUMN = 2
#COLUMNINFO = 1, m, diepte bovenkant laag, 1
#COLUMNINFO = 2, m, diepte onderkant laag, 2
#COLUMNTEXT = 1, verplicht
#RECORDSEPARATOR = !
#COLUMNSEPARATOR = ;
#COMPANYID = GeoDelft, 8000.97.476.B.01, 31
#LASTSCAN = 13
#MEASUREMENTCODE = NEN5104, 1, 0, 0, Normblad
#REPORTCODE = GEF-BORE-Report, 1, 0, 0, GEF-BORE-Report2.doc.doc
#MEASUREMENTTEXT = 2, 2001-07-14, datum boring
#MEASUREMENTTEXT = 3, Oostvoorne, plaats boring
#MEASUREMENTTEXT = 5, 2001-07-15, datum boorbeschrijving
#MEASUREMENTTEXT = 6, B. E. Schrijvers, beschrijver boring
#MEASUREMENTTEXT = 9, maaiveld, horizontaal referentievlak
#MEASUREMENTTEXT = 13, GeoDelft, boorbedrijf
#MEASUREMENTTEXT = 31, AVH, boormethode
#MEASUREMENTVAR = 31, 300, boorbuisdiameter
#XYID = 31000, 65345.23, 436789.481, 0, 0
#ZID = 31000, -0.55, 0.0
#EOH=
0.0;1.05;'Ks2h1’;!
1.05;2.48;'Ks3’;!
2.48;3.35;'Ks2’;!
3.35;4.47;'Ks2’;!
4.47;5.05;'Vm’;!
5.05;6.2;'Ks1h3’;!
6.2;6.42;'Ks3’;!
6.42;6.62;'Ks3’;!
6.62;7.55;'Zs2’;!
```

Fig. 2. Observation Data, Observation Metadata and Measurement Results structured according to GEF.



Best practice use of swe:Category as a GeoSciML attribute property type is to populate at least the "codespace", "value", and "label" elements.

Label = human readable text
Codespace = HTTP-URI for a controlled vocabulary
Value = HTTP-URI for a value from the codespace

A value qualifer may be incorporated by using the "extension" element. For example, to represent "commonly high metamorphic grade"

```
<swe:Category>
   <swe:extension>
      <swe:Category definition="http://resource.geosciml.org/classifier/cgi/valuequalifier">
        <swe:label>common</swe:label>
        <swe:codeSpace xlink:href="http://resource.geosciml.org/classifierScheme/cgi/valuequalifier"/>
        <swe:value>http://resource.geosciml.org/classifier/cgi/valuequalifier/0004</swe:value>
      </swe:Category>
   </swe:extension>
   <swe:label>high metamorphic grade</swe:label>
   <swe:codeSpace xlink:href="http://resource.geosciml.org/classifierScheme/cgi/metamorphicgrade"/>
   <swe:value>http://resource.geosciml.org/classifier/cgi/metamorphicgrade/0003</swe:value>
</swe:Category>
```

Fig. 3. Top level of GeoSciML ver3.0 model; GeoSciML_GeologicFeature (reprinted from GeoSciML, 2012).

GEF (2013) is a general language structure for storing and transferring geotechnical information, with an emphasis on source data, i.e. raw measurement results. The GEF standard complies at an international level to the conceptual model as defined by the

‘Observations and Measurements (O&M)’ schema (OGC, 2013, ISO 19156). GEF requires three types of information: 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.) (Figure 2). 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.

GeoSciML is a geoscience specific data model and encoding for the storage and exchange of geoscience information (GeoSciML, 2012), with an emphasis on the "interpreted geology" that is conventionally portrayed on geologic maps. 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 classes are also considered (e.g. timescale, lexicons, etc), so that they can be used as classifiers for the primary objects. Figure 3 illustrates the GeoSciML MappedFeature as a specialisation of GeologicFeature.

5. Developing an integrated 3D Geotechnical Extension Model (3D-GEM)

Prior to the design of the 3D Geotechnical Extension model (3D-GEM) an user requirements study was performed to define the required types of information and data sets for large civil engineering projects (Tegtmeier et al., 2009). Users of 8-10 large Dutch companies involved in civil engineering projects were questioned and interviewed to clarify optimum geo-information environment. The group of approached specialists consisted of engineers (geo-technology, engineering geology, and civil engineering), (project) managers, architects, planners and policy makers. The major finding of the study was that the geo-technical features should be defined in such a way to present the progress of the project to multiple users (professionals and interested citizens). An integrated 3D model was seen as one of the first steps in achieving better communication and interoperability. Therefore the goal was to define features (definitions) and attributes that are sufficiently simplistic yet descriptive and can be perceived by (explained to) all participants in a project. A more specific study in a form of discussions with geological and geotechnical specialists clarified which classes and attributes of most used standards are of interest for a large group of participants. This user requirement study resulted in rather broad and general formulated requirements and wishes. That is inherent to the group of users. Typical civil- and geotechnical engineers have a general idea of what they want to have, but normally have no idea about the details in IT terminology, let alone an idea about structures of databases, IT infrastructure, etc. Moreover, they do not want to think about it or to be bothered by the details at all. Hence, the outcome of the user study was a set of general-formulated requirements that would probably be called vague by IT standards. These 'vague' requirements have been converted and incorporated in the model as described in this article.

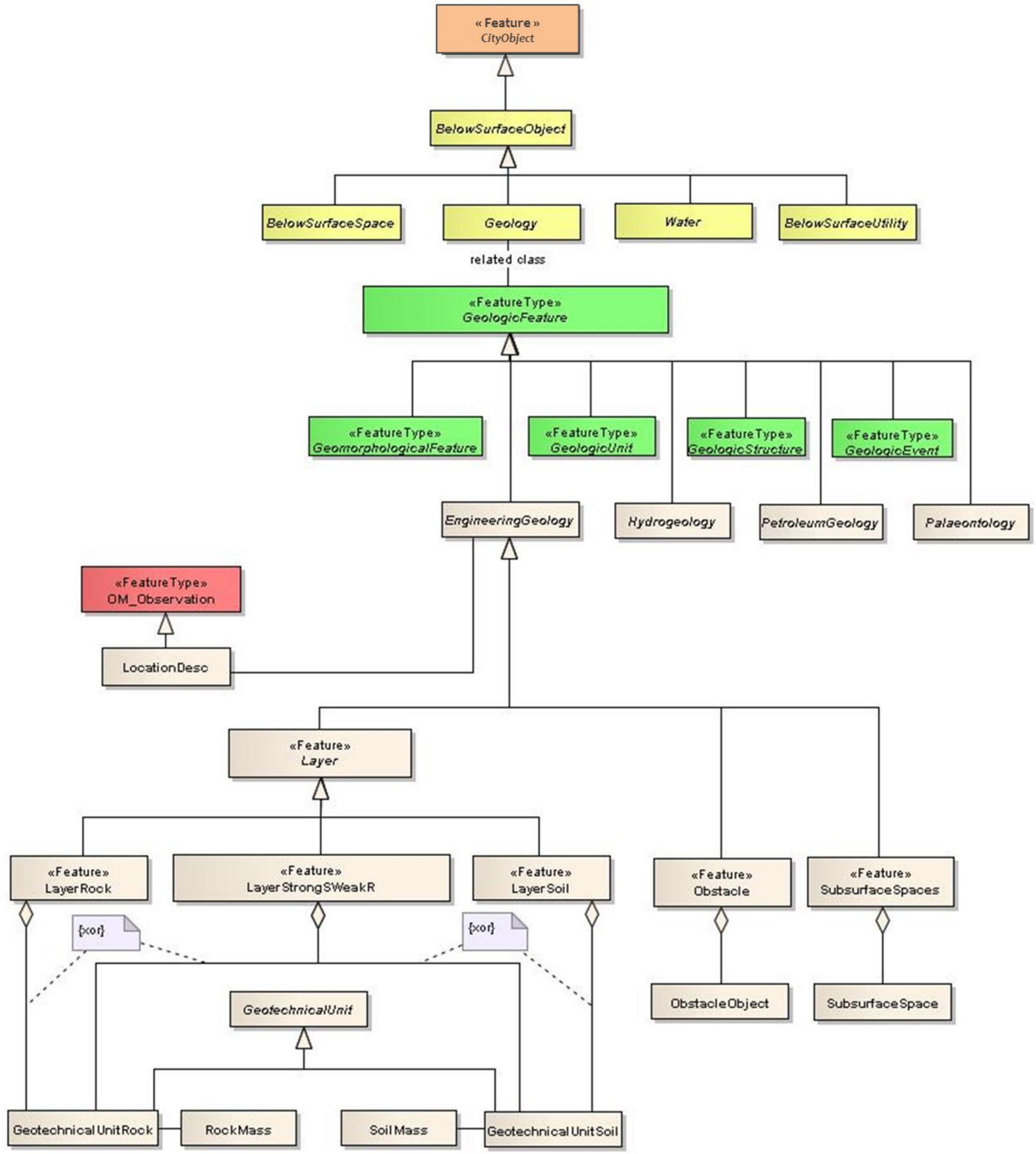


Fig. 4 UML diagram of top level feature hierarchy – Subdivision ‘Geology object’

The definition of the classes, properties, and relationships was developed in steps. Firstly, the information model provided in CityGML has been extended with man-made and natural features on the surface and subsurface required for infrastructure projects. Secondly, the model is further extended by adding subsurface geological and geotechnical features and their thematic semantic descriptions. As opposed to the first extension, the second extension is not kept at a general conceptual level, but further worked out for the use in ‘Engineering Geology’. Finally the module for measurements and lab tests is developed.

Following previous developments (e.g. Emgård and Zlatanova, 2008), additionally classes are introduced to represent the geotechnical and engineering geology objects. Figure 4 shows the UML diagram of abstract top-level classes and illustrates how CityGML class CityObject (orange colour) has been integrated with GeoSciML classes (green colour) and O&M classes (red colour). The classes in yellow are kept as proposed in (Emgård and Zlatanova, 2008). This UML provide the basis for the 3D-GEM extension with geotechnical classes (light grey). In the integrated 3D information model, the class Geology is sub-class of BelowSurfaceObject.

The rather general CityGML class *Geology* is associated to the GeoSciML class *GeologicFeature*, which consists of different Geology specific subclasses, such as *GeologicUnit*, *GeologicStructure*, *GeologicEvent* and *GeomorphologicalFeature* (as defined in GeoSciML). This has been further extended in 3D-GEM with *Engineering Geology*, *Hydrogeology*, *PetroleumgeoMineralogy*, and *Paleontology* (new extension in 3D-GEM).

The sub-class *EngineeringGeology* is divided in various geological and geotechnical objects. In this paper, it is impossible to present all classes. Therefore only five specific geological features are described. The 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), GEF, BS 5930-1999 (BS, 1999) as well as several ISO standards (see also section 3). The class *EngineeringGeology* is associated to the class *LocationDesc*, a sub-class of the standard O&M class *OM_Observation*.

The first class to be presented is abstract class ‘*Layer’*. It is used to describe the subsurface geological features that occur as continuous layers in the subsurface (Table 1). The feature *‘Layer’* can, depending on the material it consists of, further be described by the three specific features (i.e. real, non-abstract classes with instances) (Figure 4 and Table 1):

In addition to the layer sub-classes, the *EngineeringGeology* super-class has two more subclasses: Obstacle and SubsurfaceSpaces (Table 1)

1. These thematic classes are further developed in separate UML models . In Figure 5a and 5b as well as Table 2a and 2b 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 *‘LayerStrongSoilWeakRock’*, including its properties.

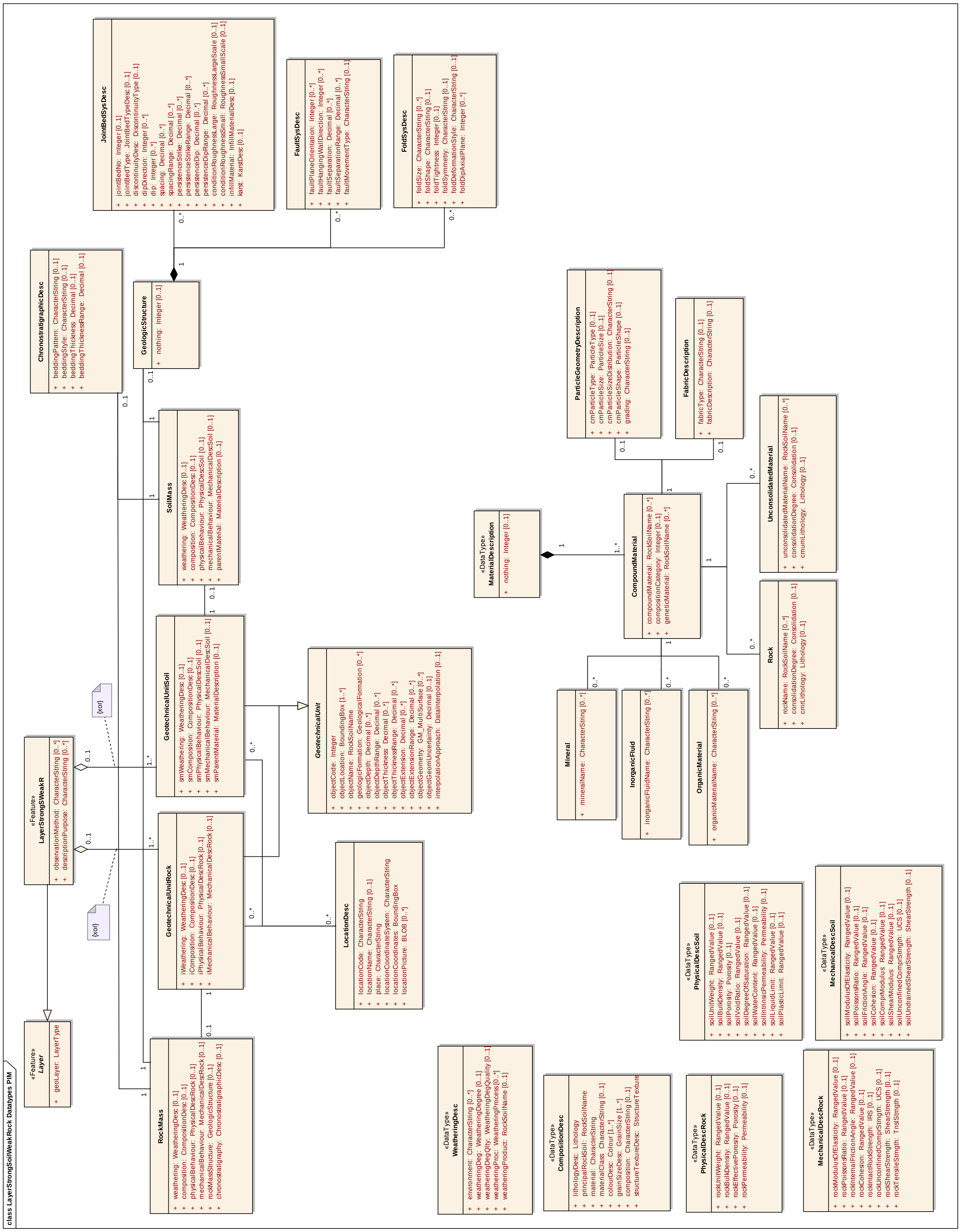


Fig. 5a UML diagram of feature ‘GeologicalObject’ – Example of geological feature ‘LayerStrongSoilWeakRock’, Part 1, Classes and DataTypes.

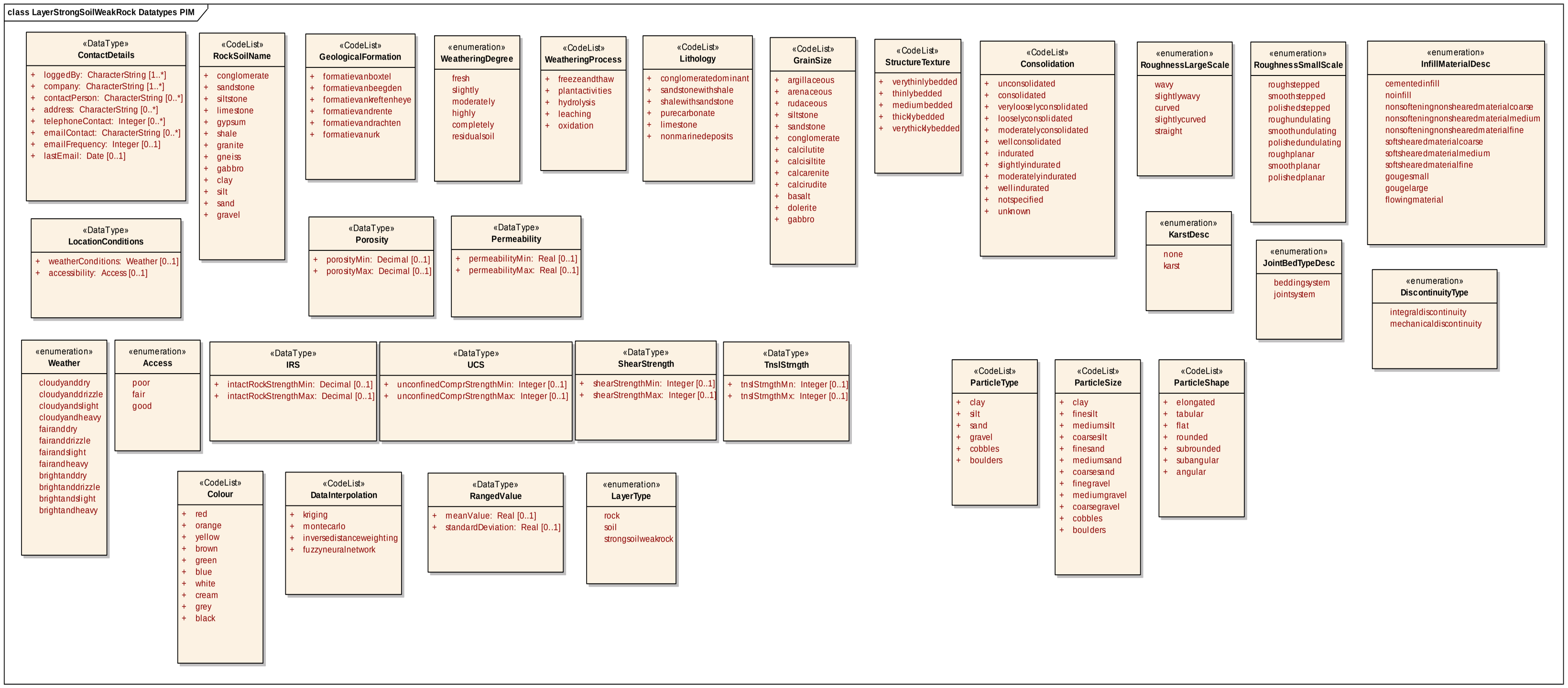


Fig. 5b UML diagram of feature ‘GeologicalObject’ – Example of geological feature ‘LayerStrongSoilWeakRock’, Part 2, CodeLists, Enumerations and DataTypes.

TABLE 1. Class Layer.

class ‘Layer’	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.
features	
LayerRock	Subsurface geological layers mainly consisting 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.
LayerStrongSWeakR	Geological layers built up of material, which cannot be clearly classified as a rock or a soil type. The material might fulfill 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 fulfill the classification 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.
LayerSoil	Subsurface geological layers mainly consisting 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.
EngineeringGeology	
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 embedded in loose soil, different in composition from the rocks in the vicinity and which have been therefore transported from a distance’.
SubsurfaceSpaces	(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 or gypsum), in which solution has produced fissures, sinkholes, and caverns. Man-made subsurface spaces, on the other hand, can, for example, be abandoned mines.

TABLE 2a. Geological unit.

objectcode Integer	ObjectCode: Unique identifier linking to the specific object 'GeologicalUnit' within the geological feature 'LayerRock'.
objectlocation	ObjectLocation: Location and extension of the geological unit described by a

BoundingBox	Bounding Box.
objectname RockSoilName	ObjectName: Name of the rock of this geological unit. Naming according to BS (1999); examples given in the <<CodeList>> 'RockSoilName'.
geologicformation GeologicalFormation	GeologicFormation: Description of the geological formation, to which the geological unit is ascribed to; examples are given the <<CodeList>> 'GeologicalFormation'.
objectdepth Decimal	ObjectDepth: Rough indication regarding the vertical depth (m), at which the geological unit (i.e. specific layer rock) is assumed to start.
objectdepthrange Decimal	ObjectDepthRange: Range of measurement results for the vertical depth (m) of the geological unit (i.e. specific layer rock).
objectthickness Decimal	ObjectThickness: Rough indication regarding the vertical thickness (m) of the geological unit (i.e. thickness of the rock layer).
objectthicknessrange Decimal	ObjectThicknessRange: Range of measurement results for the vertical thickness (m) of the geological unit (i.e. thickness of the rock layer).
objectextension Decimal	ObjectExtension: Rough indication regarding the horizontal extension (m) of the geological unit (i.e. extension of the rock layer).
objectextensionrange Decimal	ObjectExtensionRange: Range of measurement results for the horizontal extension (m) of the geological unit (i.e. extension of the rock layer).
objectgeometry GM_MultiSurface	ObjectGeometry: Geometrical description of the geological feature; according to ‘The OpenGIS Abstract specification "Feature Geometry" ' (OGC 2001).

TABLE 2b. 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/m3.
rockbulkdensity RangedValue	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	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 <<DataType>> 'Porosity'.
rockpermeability Permeability	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 <<DataType>> 'Permeability'.

The models contain all the required information as concluded by the user requirements. In the class *‘VisualFieldDesc’*, for example, information collected during a visual inspection undertaken directly in the field, is stored. The required attribute information for the class *‘VisualFieldDesc’* is shown in Table 3.

TABLE 3 VisualFieldDesc.

geoobjectdesccode Integer	GeoObjectDescCode: Unique code linking this visual description and/or field measurement to the specific geological object (i.e. 'LayerRock') that is described.
locationcode Integer	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.
projectcode Integer	ProjectCode: Unique code identifying the project, for which the visual description and/or field measurements have been undertaken.
projectname CharacterString	ProjectName: Name of the specific project, for which this visual description and/or field measurement is undertaken.
projectlocation CharacterString	ProjectLocation: Name of the general project location.
client CharacterString	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	ClientContact: Information with regard to the client; including information such as company, contact person, address, telephone number; given as <<DataType>> 'ContactDetails'.
consultant CharacterString	Consultant: Name of the company that is hired in, in order to undertake a certain field measurement, laboratory test, visual description, etc.
consultantcontact ContactDetails	ConsultantContact: Information with regard to the consultant; including information such as company, contact person, address, telephone number;

	given as <<DataType>> 'ContactDetails'.
descdatetime DateTime	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	LocationConditions: Description of the conditions at the location where the visual description and/or field measurement is undertaken; given as <<DataType>> 'LocationConditions'.
notes CharacterString	Notes: Space for notes and comments, taken during the visual description and/or field measurement for the description of the geological object.

6. Conclusions and recommendations

As emphasized throughout this paper, communication, information exchange and (re-) use is difficult in relation to infrastructural development. To facilitate the information exchange and communication between different parties involved and to achieve a better economic and safe planning of infrastructural projects, a conceptual model for the thematic semantics of information frequently used in infrastructural development should be used to represent all information. Consistent definition and application of terms is thereby a prerequisite for successful implementation and unambiguous adoption of legislation, regulations, guidelines and interpretations and should also decrease possible semantic uncertainties and misunderstandings caused by inconsequent applications of terms and definitions.

This research has addressed three key challenges: 1) 3D city models generally neglect the subsurface, and especially the aspects of engineering geology and geotechnics and 2) many existing 2D models miss thematic semantic information completely and 3) existing 3D models for the subsurface describe the geology and geotechnics of the subsurface without or with only a very rudimentary surface representation.

Here we have presented a thematic semantic information model, the 3D Geotechnical Extension Model (3D-GEM) including information concerning all subsurface geological and geotechnical features of importance during the process of infrastructural development. 3D-GEM 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 (Tegtmeirer et al 2009). The model is based on existing standards for digital data handling, i.e. the integration of CityGML, O&M , and GeoSciML, and has been extended with geotechnical features (as GEF(2013) and BS5930 (1999)).

Although the tests are only partially realised (Ghawana and Zlatanova, 2013), it is clear that 3D-GEM 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 the 3D-GEM model become clear when comparing it to the information models, base models and standards 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 3D-GEM model provides a combination of geometric as well as thematic semantic information for all objects included in the model.
- As an extension of CityGML, the 3D-GEM model now makes possible the integrated handling and exchange of surface and subsurface information.
- The 3D-GEM 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 3D-GEM 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 abroad. The developed top-level model is on-line available at http://www.gdmc.nl/oosterom/GeologyGeneralOverview_v2.EAP.

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References

AGI, 1976. Dictionary of Geological Terms. Prepared under the direction of the American Geological Institute (AGI), Dolphin Books, Anchor/ Doubleday, Garden City, New York, 472 pp.

AGS, 2012. Association of Geotechnical and Geoenvironmental Specialists (AGS) - AGS 4 FILE FORMAT. http://www.ags.org.uk/datatransferv4/intro.php#AGS4 [Accessed November, 3rd 2013]

Atkins, W. S., 2006. The risk to third parties from bored tunnelling in soft ground. Research report 453 Health and Safety Executive, Sudbury, UK, 78 pp.

BGS3D, 2012 British Geological Survey – 3D Geology (BGS3D). http://www.bgs.ac.uk/services/3Dgeology/home.html?src=ep [Accessed November 3rd 2013]

BSI, 2013, British Standard Institution; British Standard BS 5930:1999 Code of practice for site investigations http://shop.bsigroup.com/ProductDetail/?pid=000000000030190275, [Accessed November, 3rd 2013]

Bond, A., Harris A., 2008. Decoding Eurocode 7, Taylor & Francis, London, 616 pp.

Breunig, M., Borrmann, A., Hinz, S., Rank E., and Schilcher M., 2012. Towards 3D Geoinformatics and Computational Engineering Support for Cooperative Tracks Planning. In proceedings FIG Working Week 2012 (Roma, Italy).

BuildingSmart, 2012 International home of openBIM; Industrial Foundation Classes (IFC), http://www.buildingsmart.org/standards/ifc [Accessed November, 3rd 2013]

Caers, J., 2011. Modeling Uncertainty in the Earth Sciences, Wiley-Blackwell, Chichester, West Sussex, UK, 246 pp.

Chang, Y.S., Park, H.D., 2004. Development of a web-based Geographic Information System for the management of borehole and geological data. Computers & Geosciences 30(8), 887-897.

Choi, Y., Yoon, S.Y., Park, H.D., 2009. Tunnelling Analyst: A 3D GIS extension for rock mass classification and fault zone analysis in tunnelling. Computers & Geosciences 35(6), 1322-1333.

Clarke, S.M., 2004. Confidence in geological interpretation. A methodology for evaluating uncertainty in common two and three-dimensional representations of subsurface geology. British Geological Survey Internal Report IR/04/164, UK, 29pp.

Culshaw, M. G., 2005. From concept towards reality: developing the attributed 3D geological model of the shallow subsurface. Quarterly Journal of Engineering Geology and Hydrogeology 38, 231–284.

DIGGS, 2012. Data Interchange for Geotechnical and GeoEnvironmental Specialists (DIGGS). http://www.diggsml.com/ [Accessed November, 3rd 2013]

DIN, 2013. Deutsches Institut für Normung. Berlin, Germany. http://www.din.de/ [Accessed: 8 November 2013]

Emgård, L., Zlatanova, S., 2008. Design of an integrated 3D information model, In: Coors, V., Rumor, M., Fendel, E., Zlatanova, S. (Eds.) Urban and regional data management: UDMS annual 2007, Taylor&Francis, pp. 143-156.

Eurocode, 2010. Eurocode 7: Geotechnical design - Part 1 & 2, BS EN 1997-1:2004 & BS EN 1997-2:1997, ICS 91.010.30; 93.020 & ICS 91.060.01; 91.120.20, British Standards Institution (BSI), London, UK, 174pp. & 202pp.

Fenton, G. A., Griffiths, D. V., 2008. Risk Assessment in Geotechnical Engineering, John Wiley & Sons, 480 pp.

Fookes, P.G., 1997. Geology for Engineers: the Geological Model, Prediction and Performance. The First Glossop Lecture. Quarterly Journal of Engineering Geology and Hydrogeology 30(4), pp. 293-424. doi: 10.1144/GSL.QJEG.1997.030.P4.02.

GEF, 2013. Geotechnical Exchange Format. http://www.geffiles.org/index.html [Accessed November, 3rd 2013].

CGI, 2012, GeoSciML, Commission of the International Union of Geological Sciences, http://www.geosciml.org/ [Accessed November 3rd 2013]

Ghawana, T. and S. Zlatanova, 2013, 3D topological modeling of urban structures, Geospatial World Weekly, 4 February 2013.

Gröger, G., Kolbe, T.H., Nagel C., Karl-Heinz Häfele., 2012. OGC City Geography Markup Language (CityGML) En-coding Standard, Open Geospatial Consortium Inc. OGC 12-019. Version 2.0.0. http://www.opengis.net/spec/citygml/2.0 [Accessed November, 3rd 2013]

GSI3D, 2012. Geological surveying and investigation in three dimensions (GSI3D). http://www.gsi3d.org.uk/ [Accessed November, 3rd 2013]

Hack, H. R. G. K., 1997. Digital data for engineering geology: disaster or benefit? In: European Science Foundation Conference: Virtual environments for the Geosciences: Space–time modelling of bounded natural domains. Rolduc, The Netherlands,

Hack, R., Orlic, B., Ozmutlu, S., Zhu, S., Rengers, N., 2006. Three and more dimensional modelling in geo-engineering. Bulletin of Engineering Geology and the Environment 65(2), 143-153.

Hencher, S., 2008. Eurocodes-The 'new' British and European standard guidance on rock description. New Civil Engineer. http://www.nce.co.uk/eurocodes/1709994.article [Accessed November, 3rd 2013].

INSPIRE, 2008, European Commission Directives, http://inspire.jrc.ec.europa.eu/ [Accessed November, 3rd 2013]

Kolbe, T.H., 2009. Representing and Exchanging 3D City Models with CityGML. In: Lee, J., Zlatanova, S. (Eds.), Proceedings of the 3rd International Workshop on 3D Geo-Information. Lecture Notes in Geoinformation & Cartography, Springer Verlag.

Krämer, M., 2010. Dreidimensionale Visualisierung von ober- und unterirdischen Konstruktionen in DeepCity3D. Presented DeepCity3D, Workshop „3D-1 Stadtmodelle, http://www.3d-stadtmodelle.org/3d-stadtmodelle_2010/08_Kraemer_DeepCity3D.pdf, [Accessed November, 3rd 2013]

NEN 3610:2005, 2005. Basic scheme for geo-information – Terms, definitions, relations and general rules for the interchange of information of spatial objects related to the earth's surface. Nederlands Normalisatie-Instituut, Delft, The Netherlands [in Dutch].

OGC, 2013, Observations and measurements, XML Implementation http://www.opengeospatial.org/standards/om [Accessed November, 3rd 2013]

Orlic, B., 1997. Predicting subsurface conditions for geotechnical modelling. Ph.D. Dissertation, ITC, Enschede, The Netherlands, 192pp.

Quak, W., de Vries, M., 2006. Building a harmonized base model for geo-information in the Netherlands. In: Proceedings of UDMS '06, 25th Urban Data Management Composium Aalborg, Denmark, (on CDROM), 12pp.

Quak, W., de Vries, M., Vermeij, M., Oosterom, P.J.M., van Raamsdonk, K., Reuver, M., 2007. An analysis of the harmonized base model for Spatial Data in the Netherlands for applicability in a European context. In: 13th EC-GI & GIS Workshop, INSPIRE Time: ESDI for the Environment, July 2007, Porto, Portugal, 9pp.

Royse, K.R., Rutter, H.K., Entwisle, D.C., 2009. Property attribution of 3D geological models in the Thames Gateway, London: new ways of visualising geoscientific information. Bulletin of Engineering Geology and the Environment 68 (1), 1-16.

Staveren, M. V., 2006. Uncertainty and ground conditions: a risk management approach. Elsevier, Boston, MA. 332pp.

Tegtmeier, W., van Oosterom, P.J.M., Zlatanova, S., Hack, H.R.G.K., 2009. Information management in civil engineering infrastructural development : with focus on geological and geotechnical information. In: Proceedings of the ISPRS workshop Vol. XXXVIII-3-4/C3 Comm. III/4, IV/8 and IV/5 : academic track of GeoWeb 2009 conference: Cityscapes, Vancouver Canada, 27-31 July 2009.

Toll, D.G., 2007. Geo-Engineering Data: Representation and Standardisation. Electronic Journal of Geotechnical Engineering, http://www.ejge.com/2007/Ppr0699/Ppr0699.htm, [Accessed November, 3rd 2013].

USA ASTM, 2013, ASTM International; ASTM Geotechnical collection, http://www.astm.org/DEMO/Geotechnical.htm [Accessed November, 3rd 2013].

Visser, W.A., 1980. Geological Nomenclature. Royal Geological and Mining Society of The Netherlands. Martinus Nijhoff, The Hague, The Netherlands, 1980, 540pp.

Yanbing, W., Lixin, W., Wenzhong, S., Xiaojuan, L., 2006. 3D Integral Modeling for City Surface & Subsurface. In: Rahman, A.A., Zlatanova, S., Coors, V. (Eds.) Innovations in 3D Geo Information Systems, Springer Verlag, Berlin and Heidelberg, 95-105.

Zobl, F., Marschallinger, R., 2008. Subsurface GeoBuilding Information Modelling GeoBIM. GEOinformatics, 8, volume 11, December 2008, 40-43.

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Fig. 1. Computer generated fence diagram (middle), with above boreholes and below solid model; (sub-) horizontal layers with different colours or gray scales represent various geological layers (reprinted from Rockware, 2012).

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