INFORMATION MANAGEMENT IN CIVIL ENGINEERING INFRASTRUCTURAL DEVELOPMENT: WITH FOCUS OF MODELLING OF GEOLOGICAL AND GEOTECHNICAL INFORMATION

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ABSTRACT:

In civil engineering infrastructural projects, 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. The variety of information types adds to the differences regarding the use and definition of thematic semantic information. Also the source of the information may vary from surveyed and interpreted to designed objects. This makes harmonization of geo-information extremely difficult. Realistic 3D models describing and integrating part of the earth already exist, but are generally neglecting the subsurface, and especially the aspects of geological and geotechnical information. This paper summarizes the first steps undertaken towards the extension of an existing integrated semantic information model to include (above and on) 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 a core geological model as part of an integrated 3D information model are described in this paper. Examples of definitions of subsurface geological objects and required attribute information (to be) included in the integrated 3D information model are given. Web-based visualisation tools are, too, investigated to be able to access and visualise the model also in an application-independent environment.

1. INTRODUCTION

Around the world people are busy with the planning, design, realization, or maintenance of infrastructural projects. During these various phases of infrastructural projects tasks must be accomplished, which require different skills from professionals. The execution of these tasks involves large quantities of geo-information (e.g. GIS-, CAD-, and other data sets). On the example of infrastructural development, it becomes clear that the lack of information harmonization is still a problem. It is, for example, well known, although not often expressed publicly, that the re-use and exchange of information is only seldom achieved. The limited exchange and re-use of information increases the project costs and more importantly, may lead to less optimisation in project management.

One of the main problems of professionals working in infrastructure projects is the lack of common models in which data created in the different applications can be represented together. Furthermore, due to differences in semantic or geometric properties, no guarantees are given that the set of data from one GIS or CAD system can be seamlessly converted in another (Apel 2006, Oosterom et al 2006). By defining a reference model, application-specific models can be integrated and exchanged between system platforms using service-oriented architectures (Bodum et al 2005, Döllner and Hagedorn, 2008, Lapierre and Cote 2008, Haist and Coors 2005).

3D models have been extensively used in many areas but all the developments have been restricted to particular tasks (design, visualisation, etc.) and application areas. Integrated generic models discussing real-world features on the surface, above and beneath the surface are still in their infancy (Emgård & Zlatanova 2008). The integration of subsurface features, the digital terrain model and features on the terrain remains a problem to be solved (Kolbe & Gröger 2003). Although, geological data models and software provide tools to represent sophisticated geological situations in three dimensions (Apel 2006, Hack et al 2006 Lattuada, 2006, Raper and Maguire 1992, Raper 1989, Breuning and Zlatanova 2006), these models are not integrated with the surface (and above surface) models. A number of international standards and industry specific formats have been developed for geometric and semantic descriptions of existing features as well as design features both above and below the earth surface (e.g. GeoSciML, IFC, or CityGML) but they are still quite specific for a certain domain and not integrated. Challenges are in both, geometry and semantic (thematic) heterogeneities.

Looking at all information types available, especially geological and geotechnical (sub-)surface conditions play an important role in most construction processes. The geological situation at and around the construction site can have significant impact on how the construction process and design will be planned and undertaken as well as on the security of the construction itself. Various examples all over the world show that the geological conditions should not be neglected throughout any construction process.

This paper concentrates on the options for integrating geological and geotechnical data in an existing integrated 3D information model to be used in civil engineering projects. First current problems and user requirements for an integrated management of information are briefly presented. Then several information models, data models, exchange formats, and standards are discussed. Section 3 gives a short overview of some of the designed geological classes to be included in the integrated 3D information model. Section 4 discusses general system architecture for access and exchange of data. Finally, Section 5 concludes on the presented research and provides recommendations for further developments.

2. MANAGEMENT OF INFORMATION IN INFRASTRUCTURE PROJECTS

In the last years several studies have been performed on the need for integrated management of information during large civil engineering infrastructure projects. For example Young et al. 2007 report that 3.1% of project costs are related to software non-interoperability. Between the factors impacting data sharing, software incompatibility issues are leading (62%). A study performed in the Netherlands within the project 'Geoinformation management for civil infrastructure works' (GIMCIW, www.gimciw.nl) in the period 2006-2007 has revealed similar low efficiency in data management. Within the study several large companies were interviewed; the number of involved companies differs but in any case more than 8-10. The major conclusions of the study are:

- Large amounts of the data have a geo-component.
- The work within a project is file-based as each partner maintains a copy of all necessary data sets and is responsible for their management.
- Much of the design information is based on 2D CAD drawings (and not 3D models).
- GIS is used insufficiently, while the benefit of possibilities to perform spatial operations is well-understood.
- Geological data (boreholes, soundings, etc.) are given mostly as measurements and tests, and hardly any 3D models of geology or geotechnical data of the underground are used.
- The name of the file provides information about the content of the file, the version and the phase in the project (e.g. concept, final/approved).
- The exchange of information is via e-mail after a request by the project leader.
- The project leader is responsible for the management of data, which usually done in Excel sheets or specific software for document management (e.g. Meridian, www.meridiansystems.com).
- Often it is difficult to create a global overview on the status of the project. A company is responsible for a part of the work.
- Exchange of data and information is complicated by the use of different data formats (software).
- Data might be lost in consequent stages of the project especially when a partner has completed his/her obligations to the project.

The companies have agreed that improvements in management, access and sharing of information are urgently needed and can be achieved by: centralized storage of the most important data, web-access to all the needed data from all parties (and from the server), facilitation of data (model) conversions, standardized metadata information, extended use of 3D models, and better management of administrative data. There is strong understanding that tools should be available to present the progress within the project to both the professionals and interested citizens. In this respect an integrated 3D model is seen as one of the first steps in achieving better communication and interoperability (assuming that much of 2D interoperable challenges can be solved with recently developed national and international standards). The work on such model is ongoing. Within this work, Emgård & Zlatanova 2008 took the first step towards the development of an integrated 3D information model (3DIM) by conceptually enriching the CityGML information model with top-level abstract classes for above, on and below surface features. As discussed elsewhere (Tegtmeier et al, 2008), the concept of an integrated 3DIM is considered very appropriate for infrastructure projects Following, we have investigated available standards for the handling of geological and geotechnical subsurface objects to develop the geology abstract class as proposed in 3DIM.

This paper will now concentrate further on the developments related to organization and management of geological and geotechnical data.

3. STANDARDS FOR GEOLOGICAL OBJECTS

Currently the exchange of geological and geotechnical information in The Netherlands is largely based on the Dutch Geotechnical Exchange Format (GEF) standard (CUR 1999, GEF 2009), but for the purpose of our study we have investigated several existing and frequently applied common information models such as the Dutch NEN 3610, INSPIRE, CityGML (Gröger et al. 2007), 3DIM (Emgård & Zlatanova 2008), and the international geoscience information model GeoSciML.

The Dutch harmonized base model of geo-information NEN 3610 (NEN 3610:2005) gives specifications of features on the surface and above the surface including the time. The model defines a base class and a hierarchy of sub-classes that can be extended by sectors (domains). Such a sector extension is the the Duth topographic model for scale 1:10000 (TOP10NL) as described in (Quak & de Vries 2006).

At an international level, a first attempt 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). In the directive 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 are currently being created and expected to be finished before the end of 2009. In the current draft version of the theme Coordinate Reference Systems (INSPIRE TWG CRS, 2008) it is stated that 'When using both ETRS89 and EVRS the CRS used is a compound one (ISO 19111) and shall be designated as ETRS89/EVRS. It allows unambiguous 3D geo-referencing, as requested by INSPIRE.' The other 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 (INSPIRE TWG CP, 2008), which mentions the need for 3D cadastral objects. After the Annex I data specifications have be created, it can be expected that in the Annex II (e.g. Elevation and Geology) and Annex III (e.g. Soil, Atmospheric conditions, Oceanographic geographical features, and Energy resources) themes more often explicit reference to the 3D aspects of the objects will be made.

Very promising developments are observed within the new OGC standard CityGML. CityGML is a common information model used for the representation of 3D urban objects. CityGML allows for a description of classes and relations, and geometrical, topological, semantic and appearance properties for the most relevant topographic objects in cities. CityGML includes hierarchies between thematic classes, levels of details and also relations between objects and spatial properties. Presently, CityGML does not provide support of geological features. Moreover CityGML considers below surface features (utilities, tunnels, geology, etc.) a subject of the so called application domain extensions (ADE), which are subclasses directly to the *CityObject* or *Site* class. For example, a subsurface ADE (focusing on tunnels) is already available (www.citygmlwiki.org).

The Dutch GEF standard is a typical example of a format for the exchange of geotechnical information. It can be compared with the 'Observations and Measurements (O&M)' schema by the OGC (OGC 2007). The GEF standard consists of three types of information about: 1) the manner and circumstances in which the measurements have been carried out, 2) how the measurement results are stored (metadata), and 3) measurements including interpretations, derived models, etc. To be able to collect all this information, a specific methodology has been suggested as well. As to the organization of the data, the actual measurement results (i.e. the raw data) are saved in the file, 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 keywords (e.g. 'ANALYSISCODE', 'PROJECTNAME', 'FILEOWNER', etc.).

Table 1: Comparison of the characteristics of the various standards and models

	NEN3610	INSPIRE	CityGML	GEF	GeoSciML
Covered features	On & above surface features & utilities	(Sub)sur-face natural & man-made features	Relevant topographic features in cities	Geo-technical features	Geo-scientific features
Way of modelling	Semantics	Semantics& Geometry	Geometry & Semantics	Semantics	Geometry & Semantics
Complexity	Only surface information & utilities; no geology	Surface & Subsurface information; but basic geology	Only city objects; no subsurface information, no geology	Only geotechni-cal measure-ment results	Good geology information; geology-specific
Relation above and below surface	Partly	Partly	Partly	None	None
Dimension	-	2D	3D	-	-

The last model considered is GeoSciML. GeoSciML is a geoscience data model, which has been designed for the storage and exchange of geoscience information (GeoSciML 2007). GeoSciML represents geoscience information associated with geologic maps and observations and allows an extension to other geoscience data. A common set of feature types is defined based on geological criteria (e.g. units, structures, fossils) or artefacts of geological investigations (e.g. specimens, sections, measurements). Supporting objects such as time scale and lexicons are also considered so that they can be used as classifiers for the primary objects.

These different standards and models have been investigated because of their appropriate characteristics for geological and geotechnical features. These characteristics have also been summarized in Table 1.

3DIM might become the bases for an integrated 3D information model for , since it allows a near complete representation of 3D urban objects. To include geological and geotechnical information in 3DIM, the information covered by GeoSciML, which provides geometrical and semantic information, is evaluated with respect to the needs of the larger audience of professionals working in civil engineering projects. In contrast to CityGML and GeoSciML, NEN 3610, GEF, and INSPIRE provide only semantic information or focus on 2D representations. However, they are considered to ensure that the developed model is compliant with national and international standards.

4. GENERIC 3D INFORMATION MODEL EXTENSION FOR GEOLOGY

The thematic semantic information model (thematic semantics = the meaning of data with regard to a specific subject) of subsurface geological and geotechnical features as developed by Tegtmeier et al. 2008 is considered an extension of the 3DIM. In order to include subsurface geological and geotechnical features in 3DIM model has first been extended by including *Geology* in the subsurface class *BelowSurfaceObjects* (Emgård & Zlatanova 2008). The 3DIM has adopted many of the concepts of the base model NEN 3610 and achieved subdivisions of features into: 1) earth surface features, 2) above earth surface features, and 3) below earth surface features (Figure 1). One of the below surface classes is *Geology*. This class is the super class of all the object classes described in this section. The super class *Geology* includes, next to general geological information, mainly the geotechnical aspects of geology of importance for infrastructural construction processes.

The class Geology is further split up into different features (geological objects) to support infrastructural development. After an extensive study on the use of geological objects in infrastructure works, the following five subclasses are defined:

- *Layers* include the subsurface geological features that occur as continuous layers in the subsurface. Usually these are units of igneous, sedimentary or metamorphic origin, of comparatively homogeneous compositions with well-developed boundaries. The *Layer* can, depending on the material it consists of, further be subdivided into three sub-features, that are namely: *LayerRock, LayerStrongSoilWeakRock* and *LayerSoil.*
- *Obstacles* are objects, which do not fit the description of the geological layer, in which they are found, but which are too big to be neglected for the construction process. Obstacles are, for example, boulders, that are 'large rounded blocks of stone lying on the surface of the ground, or are sometimes embedded in the ground, different in composition from the material in the vicinity and which have been therefore transported from a distance.
- *Cavity* represents natural underground empty spaces, whose size and extension is large enough and cannot be neglected during construction processes. Natural underground spaces can be karst holes.

- *Reservoir* (water, oil and gas). Reservoirs can be described as a body of rock or soil carrying water or containing an accumulation of hydrocarbons; or as natural underground containers of liquids, such as water, oil, and gases. In general, such reservoirs are formed by local deformation of strata, by changes of porosity, and by intrusions.

The definitions used are based on the *Dictionary of Geological Terms* prepared under the direction of the American Geological Institute (AGI 1976) and the *Geological Nomenclature* by the Royal Geological and Mining Society of The Netherlands (Visser 1980).

The above mentioned classes are further specialised. Figure 2 is an example of the required subdivision for the geological feature *LayerRock* with its attributes and associations. As within a project area, different types of rock layers might occur and/ or the properties within one type of rock layer might vary, *LayerRock* will 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. Each *GeologicalUnit* can be described by visual descriptions, field measurements, and field/laboratory testing. Therefore all three possibilities are included in the model (not shown here). For the management of field measurements, sampling and laboratory testing, a separate model has been developed and linked to the relevant information in another thematic semantic model with the help of IDs (e.g *sampleID*, *measurementID*, *labtestID*) (not shown here). The attributes are largely derived from the Dutch GEF.

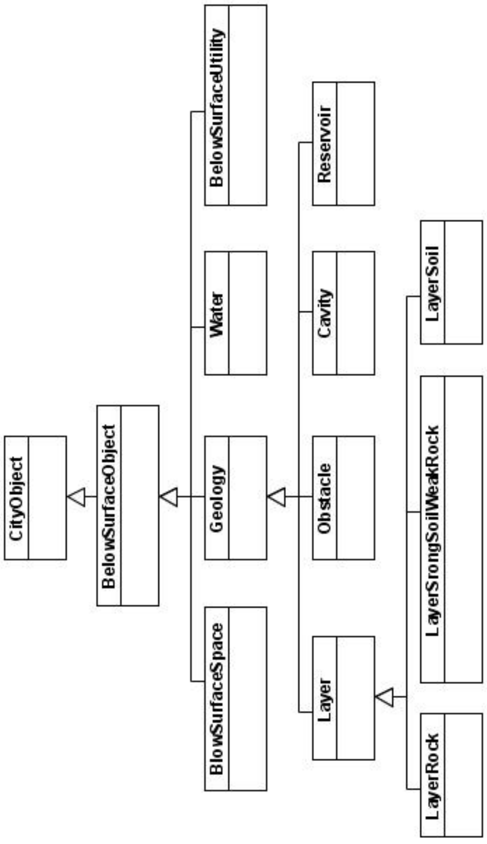

Figure 1. 3DIM top level clases of the *BelowSurfaceObject* hierarchy

The class *GeologicalUnit* can be further classified as *IntactRock* (i.e. rock that does not contain discontinuities of sedimentological, structural or other origin) and *RockMass* (i.e.rock as it occurs in situ, including discontinuities). All attributes are based on the standards discussed above and agreed with the users. For example *WeatheringDesc* refers to the possibility of the destruction of the rock material by physical, chemical and/or biological processes (Figure 2). Several attributes give further information on the weathering (not shown here).

Next to these descriptive models (including derived and processed information) for each geological feature, more detailed information collected from site investigation as well as field and laboratory measurements are 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 and included in the complete model (not shown here).

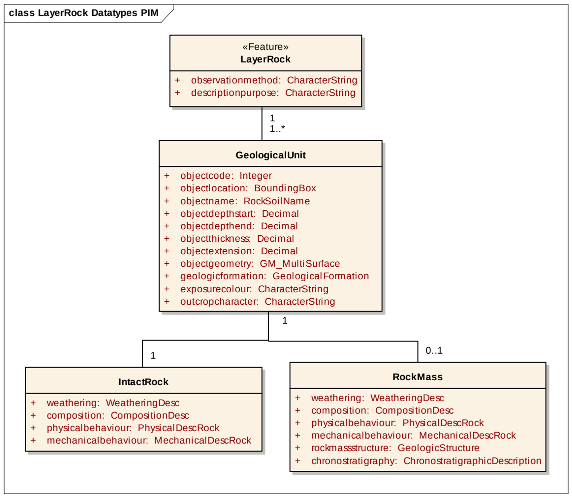

Figure 2: Subdivision of *LayerRock* into *IntactRock* and *RockMass*

At this stage the model contains all the data that might be collected and have to be available during the entire project life cycle. Practically most information included in the model should be collected throughout site investigation, field measurements and laboratory tests. The information model allows for differentiation and management of measurement data and derived results (i.e. interpretations). This is to say that the geological objects can be represented with their approximated geometries (using surfaces or/ and solids). These geometries can be used for integrated 3D visualisation with construction objects (e.g. tunnels) and above surface objects (buildings and terrain objects).

The model can be used as both exchange model and data model for centralised management of all underground measurements during infrastructure projects.

5. IMPLEMENTATION AND TESTS

As mentioned above, large infrastructural projects involve many parties, which are responsible for portions of the project and possess a variety of data sets. Although some data sets still remain for a single user only, there are large amounts of information, which has to be shared. The information could be vector (2D and 3D), raster, documents and videos (animations). Most of the information should at least be visualised (in integrated 2D/3D visual environment). Based on this analysis, we have proposed access to data via geo-portal based on web-services (Figure 3). The project web site will allow authorised access to information either to the data sets maintained by the project partners (or other data sets) or to the centralised data management system. The geo-counter provides metadata information as well.

The graphics user interface on the project site should allow for visualisation of 2D and 3D data via freeware as well as commercial viewers available within the project. Figure 3 portrays the system architecture. At the moment, only the 2D visualisation components are fully operational. Via the geo-locket the user can access files and databases needed during a specific infrastructure project and visualise the information either in 2D or in 3D viewer. The information remains accessible trough the entire period of the project.

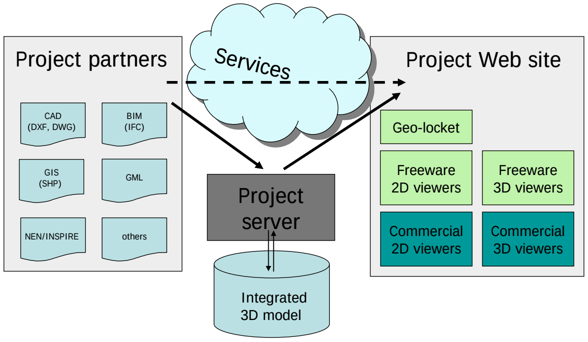

Figure 3: System architecture (GIMCIW)

The developed conceptual model (in UML) was transformed to Oracle Spatial relational model using the Enterprise Architect MDA prototype (Bennekom-Mennema, 2008). Enterprise Architect (SparxSystems, 2007) offers standard support for (relatively) straightforward MDA transformation rules from object-oriented models to relational database models. However more sophisticated transformations such as enumerations or attributes as base table check constraints required considerable custom development. The developed scripts were adapted for the geological classes and successfully executed to define a database schema. Several test sites are defined and the availbe data are in process of converting to the developed data model.Trial 3D visualisation was completed for only one (i.e TUDelft campus) had features above, on and below surface (Figure 4).

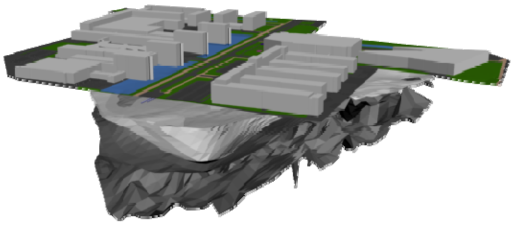

Figure 4: Visualisation of test site TUDelft campus in 3DIM (Emgard and Zlatanova 2008)

6. CONCLUSIONS AND RECOMMENDATIONS

Communication and information exchange and (re-) use is difficult in relation to civil engineering 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, harmonization of the various types of geo-information handled in infrastructural development must be realized. Ideally, a conceptual model for the thematic semantics of information frequently used in infrastructural development should be built up. As described throughout this paper, semantic models 3D models describing and integrating part of the earth already exist, but are generally neglegting geological and geotechnical information.

A solution to the integration of geological and geo-technical information 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.

The development of this model has been guided by the discussions and interviews with companies and institutes involved in infrastructural projects. Therefore it can be seen as a more general model aiming at a broader group of users who work with geology and geo-technology information (in contracts to GeoSciML, which is intended for geologists). The features and the terminology in the model are also adapted with respect to this broader audience.

Another advantage of the model is 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 and geo-technology in the project area (i.e. information that is currently available in GEF).

Just as the CityGML information model, the thematic semantic information model provides a combination of 3D geometrical as well as thematic semantic information for all objects included in the model. As an extension of 3DIM, the thematic semantic information model now makes the integrated handling and exchange of above, on and below surface information possible.

The model can be also seen as an ADE of the CityGML information model, which will allow the same browsers as developed for CityGML to be used for the visualization of the features in this model.

To prove the usefulness of the newly developed geological model, future research will concentrate on the database implementation of this extended version of the integrated 3D information model as well as testing of the set of thematic semantic information models using real world data as derived from infrastructural project case studies within The Netherlands. Emphasis will be given on 3D geometric representation and storage of the geological features, since such representations are still not a common feature. Currently the model is designed as a data model, but GML coding will be investigated as well.

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