Technische Wetenschappen

Title: 3DIM: a formalised and integrated three-dimensional information model

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This proposal aims at providing solutions to the challenges in integrating 3D spatial features (situated above, under and on the surface) for the purpose of different applications. Three large national projects are investigating these problems: RGI-029 'Geo-information management in large civil engineering works' (Netherlands), RGI-011A 'Top-up Comparing different 3D models' (Netherlands) and 'VR interaction with interpolated geological data in combination with 3D city modelling' (Sweden). Some initial investigations and developments related to the research topics in this proposal have already been funded by RGI-011A (http://www.rgi-otb.nl/index.htm) and the VR interaction project (http://www.sweco.se/templates/Page____18819.asp).

Keywords:
3D-GIS, 3D Data integration, Semantics, Information Modelling, 3D Harmonization, 3D Virtual Environments, Spatial Database Management Systems

1 Summary

1.1 English Summary

At the moment we are facing an important paradigm change of spatial information; from 2D to 3D organisation, management, integration and exchange of spatial data describing the real world, like buildings, bridges, roads, dikes, tunnels, pipelines, cables, vegetation, waterways etc. Companies, municipalities and state organizations are looking for tools to organise, integrate and exchange spatial data in three dimensions (3D). Currently, mapping institutions are far from consensus on this issue since information models are diverse and application specific.

This proposal will offer fundamental tools for management and sharing of 3D information.

By defining a reference model, application-specific models can be integrated and exchanged between system platforms using service-oriented architectures. Our research aims at creating a 3D information model that can be used as a reference model for harmonizing different 3D models within various institutions world wide.

Most of the developed spatial standards consider 2D geometric representations. Some 3D standards such as VRML or X3D concentrate on geometry and other visualisation properties and lack semantics. The proposed research aims at an application independent model for three-dimensional geometric representations in connections with the meaning (semantics) of the real world phenomena. Such standardization will be a breakthrough in sharing of 3D spatial information. Many municipals are waiting for standardization before they want to invest in data collection for their infrastructure.

The results of this research will be a 3D information model and a formalized methodology for creating it. The information model is intended for physical features above, below and on the earth surface representing both man-made and natural phenomena. The 3D information model and the corresponding methodology include both semantics (meaning) and geometry (representation) in 3D and it is domain independent (i.e. reference model).

Therefore the developed outcome will be unique. The formal methodology will provide strict rules for extensions of the information model, which will keep the model consistent.

1.2 Dutch summary

Op dit moment staan wij tegenover een belangrijke wijziging in manier waarop ruimtelijke informatie weergegeven kan worden, namelijk van 2D naar 3D. Dit betreft zowel de organisatie, het beheer als de integratie van ruimtelijke gegevens, die de werkelijke wereld, zoals gebouwen, bruggen, wegen, dijken, tunnels, leidingen, kabels, vegetatie, waterwegen etc., beschrijven. Bedrijven, gemeenten en overheidsinstellingen zijn op zoek naar gereedschappen om de ruimtelijke gegevens in drie dimensies (3D) te organiseren, te integreren en uit te wisselen. Omdat informatiemodellen divers en toepassingsgericht zijn, hebben karteringsinstellingen nog lang geen consensus op dit punt bereikt.

Dit onderzoeksvoorstel biedt fundamentele gereedschappen voor het beheren en delen van 3D informatie.

Door middel van het definiëren van een referentiemodel, kunnen toepassingsspecifieke modellen worden geïntegreerd en uitgewisseld tussen besturingssystemen, waarbij gebruik gemaakt wordt van service-georiënteerde architecturen. Ons onderzoek richt zich op het creëren van een 3D informatiemodel dat gebruikt kan worden als een referentiemodel voor het harmoniseren van verschillende 3D modellen binnen uiteenlopende instellingen wereldwijd. De meeste van de ontwikkelde ruimtelijke standaarden hebben betrekking op 2D representaties. Sommige 3D standaarden, zoals VRML en X3D richten zich op geometrie en andere visualisatie-eigenschappen en daarbij ontbreekt het aan de semantiek. Het onderzoeksvoorstel richt op een toepassingsonafhankelijk model voor driedimensionale geometrische representaties in relatie tot de betekenis (semantiek) van de fenomenen van de werkelijke wereld. Een dergelijke standaardisatie zal een doorbraak zijn bij het delen van 3D ruimtelijke informatie. Veel gemeenten wachten op standaardisatie voordat zij willen investeren in het verzamelen van gegevens ten behoeve van hun infrastructuur.

De uitkomsten van dit onderzoek zullen een 3D informatiemodel en een geformaliseerde methodologie om dit te realiseren zijn. Het informatiemodel is bedoeld om de bovengenoemde fysische kenmerken, die zich boven, onder en op het aardoppervlak bevinden, te representeren. Daarbij gaat het zowel om kunstmatige als om

natuurlijke fenomenen. Het 3D informatiemodel en de bijbehorende methodologie omvatten zowel semantiek (betekenis) als geometrie (representatie) in 3D en zijn domeinonafhankelijk (d.w.z. het referentiemodel).

Om die reden is het ontwikkelde resultaat uniek. De formele methodologie zal strikte regels voor de uitbreiding van het informatiemodel bevatten, waardoor het model consistent zal blijven.

1.3 Utilisation

Huge economic scale advantages can be obtained when geo information from different sources can be combined easily. A recent development in the field is the establishment of the KLIC services by the Kadaster, but still it is only 2D. If we would have a uniform 3D model that comprises both subsurface and above surface objects, the exchange of information would be much easier and reliable. This would contribute to significant economic and social benefits, because better information supply can decrease time spent on adapting data and help reducing failure in infrastructure, utilities and asset management.

Municipalities particularly involved in this research are Rotterdam, Netherlands and Gothenburg, Sweden. These municipalities are already busy with developing virtual reality models that can be used for different users within the municipality and outside it. They expect that such an integrated 3D model will bring them large economical advantages by: providing flexible possibilities to extract only needed data for a given client, managing larger variety of data and reducing effects from failures in infrastructures.

All the companies, consortium partners in a project 'Geo-information management for large civil infrastructure works', RGI-029 (2005-2009) (http://gimciw.nitg.tno.nl/) are prepared to support this research by providing data, and sharing their experience as well as helping in developing the prototype and the graphic user interface. The companies expect that such a model will reduce drastically time and efforts for exchange of data, increase awareness in quality of data, increase the re-use of data (easy exchange will reduce the need to re-measure certain phenomena), allow for better decision-making by extended 3D visuals and analysis.

The resulting information model and methodology is intended to be used as:

- A 3D reference model for database storage at various data providers, e.g. municipalities, topographic offices, etc.
- An information model for integration of data from different domains (via services) for large civil engineering works.
- Knowledge to be applied in further development of a GML-based file format for exchange of 3D data between different commercial software, e.g. CityGML.

This research will be actively supported by DHV BV, Bentley Systems Inc., ULI Sweden, City of Goteborg, SWECO, Grontmij Nederland BV, Fugro Inpark B.V, Gemeente Rotterdam, Arcadis, RWS and TNO.

2 Research Team

2.1 Current research group

The GIS technology section at the Delft University of Technology is dealing with infrastructure concepts for handling spatial information. The realisation of the Spatial Information Infrastructure (SII) will enable the effective sharing of resources (spatial information and spatial services), which in return will bring benefits to large number of (non-) professional users. The GIS technology section concentrates on specific aspects of SII such as the use of spatial data types, operators, functions, clustering and indexing in Database Management Systems (DBMS). GIS Technology research topics relevant for this proposal are 3D spatio-temporal modelling, knowledge engineering and distributed GI processing.

- 3D spatio-temporal modelling (4 researchers involved). This research topic focuses on the challenges related to static and dynamic data as well as investigating new concepts for representation and modelling. Research on 3D spatial modelling and 2D spatio-temporal modelling is going on, whereas 3D spatio-temporal modelling is at very early stage. Various aspects of data integration and data harmonisation are extensively investigated in context of national/international standardisation initiatives, e.g. NEN, INSPIRE & ISO TC211 (http://www.opengeospatial.org/ogc/partners/isotc211)
- Knowledge engineering (ontology/semantics) (2 researchers involved). This research topic deals with the semantic aspect of information (what it means) and aims at achieving understanding between different application (thematic) models. Besides for human, semantics is also essential if machines have to perform useful things with this information. Therefore, the semantics will have to be formalised using semantic web, ontologies, etc.
- Distributed GI processing (network protocols/interoperability/web services) (3 researchers involved). This theme emphasises research in the field of distributed GIS, data transfer between various systems, web services (protocols), interoperability, geo-information standards, spatial models and query languages. Aspects like components and storage of quality, metadata and error propagation are also taken into account.

The GIS technology section consists of staff members (one section leader, one associate professor, several assistant professors and other tenured staff), post docs and PhD researchers. The section leader prof. dr. Peter van Oosterom is well-know in the area of spatial data handling and spatial databases. He is an active member of various international organisations, leading several national project and author of many scientific publications and books. He is also a leader of a theme group ‘Spatial Information Infrastructures’ and formal promoter of 8 PhD students within Netherlands and abroad. Dr. Sisi Zlatanova is leading a theme group ‘Geo-information for crisis management’ within the section and an international working group (WG IV/8) ‘Spatial data integration for emergency services’ (http://www.commission4.isprs.org/wg8/) within the International Society of Photogrammetry and Remote Sensing. She serves as expert and advisor for the EC (Information Society and Media Directorate-General). Her research interests focus on three-dimensional aspects of geo-information with application in disaster management. She is supervising 5 PhD students from Netherlands and abroad working on 3D subjects. She is author of numerous scientific papers, conference proceedings and books.

The section GIS technology is leading 6 RGI projects (http://www.rgi-otb.nl/) with total amount of 3 720 000 (part of GIS technology is approximately 1 680 000) euro and participating in 10 others (one of which international) with an approximate contribution of 1 600 000 euro. All projects are with duration between 3 and 4 years.

2.2 New members

Ludvig Emgård is an employee at the SWECO company group, Sweden, the Nordic region's largest provider of consulting services in all fields of infrastructure with a staff of 3,800 employees. Within the projects of the company, he has access to valuable knowledge on challenges in harmonization of data for improving the interoperability between information exchange for various users in large engineering works such as tunnel constructors, geologists, water recourse experts and architects. His recent experience in 3D data storage for municipalities is particularly valuable for this research.

Ludvig Emgård has visited the GIS technology section in the period of February-September, 2007. The research period was funded by two projects: Harmonization of geologic data and designed objects (Roy C. Davies and Joakim Eriksson at Lund Institute of Technology and Ludvig Emgård, funded by the Swedish Richter Foundation) and RGI-011A ‘Comparing different 3D models’ (the Netherlands). During this visit he has investigated spatial database storage and visualization of subsurface features. The project has resulted in a first version of the integrated 3D information model (3DIM). The acquired knowledge and performed developments have motivated the submission of this proposal. Ludvig's practical experience within the company SWECO as well as his research on conceptual data modelling, implementation and testing would be an essential part of the developments within 3DIM in the GIS technology section.

At the second period of the research (year 4 and 5), it is expected that professional programming help will be needed for the development and testing of the prototype. A second research (post doc) will join the group for 6 months (2 months in year 4 and 4 months in year5). This can be a part time working programmer.

3 Scientific description

3.1 Research Scope

Spatial information is becoming widely used in daily life. Large companies, small business as well as private persons have access to spatial information infrastructures in various scales. At the moment we are facing an important paradigm change of spatial information; from 2D to 3D (Coors 2003, Eriksson 2005, Penninga et al 2006, Penninga en Oosterom 2007, Raper 1989, Shiode 2001, Smith and Friedman 2004, Stoter and Zlatanova 2003, Zlatanova 2006, Zlatanova and Stoter 2006). This can be directly seen in the societies growing interest for 3D geographic tools such as Google Earth (http://earth.google.nl), Virtual Earth (http://www.microsoft.com/virtualearth/), Second Life (http://www.secondlife.nl/), etc. and also in the trend of development of all the large GIS manufactures. In 2007, the majority of the large companies dealing with spatial information have announced 3D functionality within database technology (Oracle Spatial 2007, http://www.oracle.com/database/spatial.html, Architecture Engineering and Construction (AEC) software (Bentley Systems Inc. http://www.bentley.com/en-US/Markets/Geospatial, Autodesk, www.autodesk.com), GIS Software (ESRI www.esri.com) and spatial data processing (SAFE http://www.safe.com/). This new technology brings new challenges, however.

Companies, municipalities and state organizations are challenged with the organisation, integration and exchange of 3D spatial data describing the real world (Billen and Zlatanova 2003, Breuning and Zlatanova, 2006, Quak and de Vries 2006, Oosterom et al 2005, Teller 2007, Tegtmeier et al 2007a, Tse and Gold 2007, Xu and Zlatanova 2007, Zlatanova et al 2007, Zlatanova and Prosperi 2006). Currently, national mapping institutions are far from consensus in this issue since information models are diverse and application specific (Lemmen et al, 2006, Merritt and Whitbread 2008, Oosterom et al 2005, Resnik 1999, Scarponcini 2002, Young et al 2007). 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, Brenner 2004, Isikdag, 2006, Kampshoff 2005). 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). This suggested research aims at creating a 3DIM that can be used as a reference model for harmonizing different 3D models within various institutions world wide.

The above mentioned problems are not new. Governments and international organizations have for a long time been working on standards and formats to enable integration and exchange of spatial data. A number of international standards and industry specific formats have been developed for geometric and semantic description of natural and man-made features as well as design features above, below and on the earth surface (IFC 2007, ISO/FDIS 10109, ISO 19775, Herring 2001, Pittarello and De Faveti, 2006). However, at least one of the three major problems can be observed in every representation:

- Formats and information models are often application specific
- Geometry representation is mostly two-dimensional
- 3D models or formats often miss semantics

For example, the North American Data Model, NADM (NADM2004), Geology Science Markup Language, GeoSciML (GeoSciML 2007) and eXploration and Mining Markup Language, XMML (XMML 2007) are elaborated information models representing geological observations and features only under the earth surface. TransXML provides a schema for exchange of data in transportation world (Ziering et al 2007). The IFC standard (ISO/PAS 16739) is dealing with semantic and geometric description of design objects (mostly buildings). The INSPIRE initiative (INSPIRE 2007) deals with harmonization of information from different applications (themes) but is only defined in 2D. The CONGOO (Pantazis 1997) and Towntology (Caglioni 2006, Teller 2007) project concentrate on city environments. These semantic representations are examples of subdivision of urban space into features, but they do not contain mapping to the geometric representations of 3D spatial models. Most of the developed spatial standards consider only 2D geometric representations (Koch 2005, Laurini 1998). Some 3D standards such as VRML or X3D concentrate only on geometry and other visualisation properties and lack semantics completely.

Within the Open Geospatial Consortium (OGC 1999), the Working Group on 3D Information Modelling is currently discussing an information model for data exchange of 3D city models. One of the reasons for creating such a model was to enrich 3D city models with semantic information. The information model of CityGML (Kolbe and Gröger, 2003, Gröger et al 2006, Stadeler and Kolbe 2007), which is implemented using Geography Markup Language, GML3 (Lake et. al. 2004), is today the most well defined framework for semantic-geometric relations of 3D objects. Nevertheless, CityGML still lacks integration of subsurface features (Gröger et. al. 2006) such as geology (Lattuada 2006, Orlic 1997), underground constructions (e.g. tunnels, ITA 2007) and utility networks (Pu and Zlatanova 2006).

Motivated by the increasing need for an integrated 3D representation of different application models containing geometric and thematic semantics of 3D features as well as the lack of a suitable scientific conceptual modelling framework, the GIS technology section has initiated this research.

3.1.1 Current developments of 3DIM

In the last several months, the GIS technology section has began the investigations on 3DIM, by developing conceptual models in the Unified Modelling Language (UML, Booch et al 1997), which verified by mapping into two database spatial schemas (using Oracle Spatial). The starting point was the current developments within CityGML. The concepts of CityGML were extended to include underground features and enhanced with constraint rules. The underground features were introduced after extensive studies of existing underground models (GeoSciML, NADM, etc). Additional features were introduced on the earth surface, which define the intersection between the above and below surface features with the earth surface. These can be points, curves and surfaces and therefore the names: terrain intersection point (TIP), terrain intersection curve (TIC) and terrain intersection surface (TIS) (see Figure 1). The set of rules currently consider the features on the earth surface: all the features on the earth surface must form a non-overlapping full partition. Figure 2 shows the test area of the TU Delft campus organised according to the 3DIM. The detailed spatial schemas of the current developments (represented in Unified Modelling Language) are given in Appendix 2.

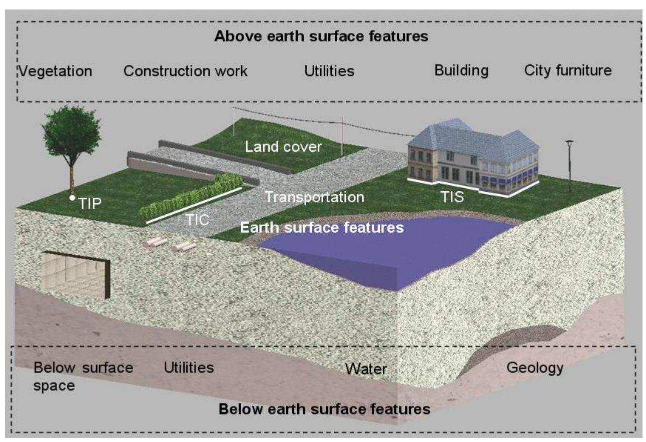


Figure 1. Features in the 3DIM

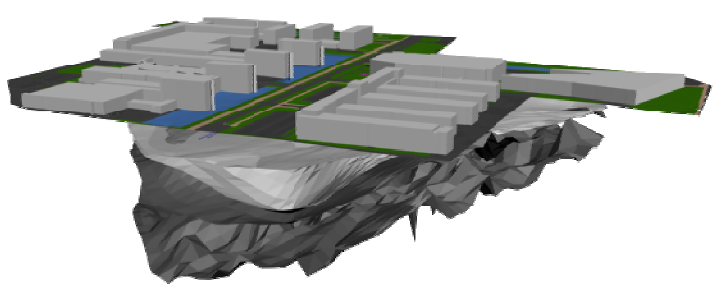


Figure 2. Test dataset organised according 3DIM in Oracle Spatial (Emgård & Zlatanova 2008b).

The definition of the current model has followed the top-down approach i.e. current information models have been studied and decision for the 3DIM have been made. Existing semantic models in 2D can be further used to refine the features above ground. The intention is to develop a methodology that will allow defining new features and place them in the semantic hierarchy of the model. Formal geometric rules defining intersections, levels of detail, etc. will be developed for the features above and below the surface. The set of semantic and geometric rules will ensure consistent representation of 3D features.

3.1.2 Motivation

As mentioned above, the conceptual model of our developed 3DIM has borrowed several concepts from CityGML. However, the information model of CityGML can be questioned. For example, the information model only describes one method for the topologic relations between features classes (i.e. terrain intersection curve) that can assure data integrity of the model. The concept of levels of detail (LOD) is well defined for building exteriors, but only one level can be found for building interior. In addition, LOD of texture and geometry may benefit from being separated. CityGML assumes multiple representations of geometry for different LOD. This concept may also be questioned when considering CAD representations where lower LOD are derived from higher LOD using the model view concept (Isikdag, 2006). Therefore, some concepts may be inherited from the CityGML information model, but in addition completely new concepts need to be created and added to 3DIM.

When performing the conceptual modelling of features one issue is of great importance; how, and to what extent is the relation between the semantic feature and a geometric primitive defined? A well defined relation between a certain feature and its geometry can be called *strong typing* while a non-defined relation can be referred to as *loose typing.* An advantage of *strong typing* is that the geometric representations of one semantic feature class are created in a similar manner and follow certain rules. Therefore, a collection of objects of one features class may be processed geometrically by automatic routines. Standards such as the "Swedish standard for road and railway geospatial information", SS 6370 04-1: 2006 rely on a strong typing between semantics and geometry while information models such as the information model for GeoSciML for geology prefers loose typing where any geometry is allowed for any semantic features as long as it follows GML3. The *strong typing* approach is preferred to be used in this research. A detailed investigation is needed to clarify what features in our model 3DIM are in need of a strong typing and why.

In traditional 2D maps scale has been the factor defining the features on the map and for 3D environments the concept of LOD somehow replaces the concept of scale. The information model of CityGML has well-defined levels for the buildings, five levels of detail (0-4). Even if certain rules are specified for the allowed geometry for each feature in each LOD, the concept has to be further elaborated. For example one issue is whether the features are allowed to have multiple representations for each LOD or a feature in higher LOD consists of parts from a lower LOD.

3.1.3 Research question

- *Can we define a formal methodology that allows integration of geographic 3D features into an application independent reference information model?*

3.1.4 Research objectives

To answer this theoretical research question, the following three major objectives are defined:

1. **Definition and classification of features and their properties.** The 3D spatial data model 3DIM will be further developed using rules for defining integration of new features classes for the ability to extend the model. This will be tested by the integration of features and properties from different applications e.g. tunnelling, geology, bathymetry, architecture and utilities.
2. **Definition of a semantic hierarchy of features based on semantic relations.** The features in the model will be conceptually organized in a semantic hierarchy. Generalizations and specialization rules will be created to support harmonisation between different application models as well as enable extensions of 3DIM with new features.
3. **Definition of a rule based methodology for the semantic-geometric relation for every feature class**. The link between semantic features and their 3D geometric representations will be defined, considering finite number of abstraction levels in an application independent 3D data representation of urban space. General rules for integration of semantics and its geometry will be developed.

3.1.5 Methodology

To achieve the objectives as specified above, an elaborated investigation of existing models and concepts (1) will be carried out, followed by conceptual modelling (using UML) (2), implementation in DBMS data model, testing output using GML (3) and validation by discussions with end-users and software developers (4). The development will furthermore be completed by revision (5) based on experience from the validation. These first five steps will be iteratively repeated as shown in Section 3.2. Three iterations are planned to be performed during the 6 years project time. Iteration A performed year 1-2 will focus on existing models and rules where a concept will be derived from existing concepts (top-down approach). Iteration B performed year 3 will focus on a bottom-up approach for features below ground where available data and expertise in the field will be gathered to complete the model (also partly investigated in RGI-029). Iteration C performed year 4-5 will once again use the top-down approach to generate the final model and methodology based on the knowledge from implementation and testing in iteration A and B. The data model will finally be continuously disseminated (6) and finalised by preparing a PhD dissertation (7).

1. **Analysis**. 2D and 3D data representations within various applications will be studied. Special focus will be given to the data models using well defined relations between semantics and geometry (strong typing) with clear rules for allowed geometric modelling such as the Swedish standard for road and railway geospatial information, SS 6370 04-1: 2006 and the Dutch information models NEN 3610, PAIS, IMRO, IMWA, IMKL, IMKICH, etc.. Also models that do not define relations will be studied as well as the motivation for such a decision. National standards of geographic features and industry specific implementations of frameworks will be considered as well. The methodology of existing conceptual frameworks such as TransXML, the CONGOO framework and the Towntology project will be investigated in detail.

2. **Conceptual modelling.** More detail from the incorporated applications will further be brought into the conceptual model of 3DIM. Different options will be investigated, i.e. application-based (following existing models and standards in an application) or application-independent (defining a general theoretical framework for 3D modelling). Different alternatives for semantic-geometric modelling will be evaluated and rules will be defined for each semantic class and each chosen abstraction level. As data from different applications e.g. tunnelling and geology meet in 3D space the relations between the classes must also be defined. Rules for the connection between geometries from the included classes will be investigated and defined.

3. **Implementation**. Using the Oracle Spatial DBMS semantic feature classes will be implemented using tables and geometric features will be stored using available geometric data types. Topology representations will be investigated as well. By evaluating developed alternatives for semantic-geometric modelling using different table structure implementations preferable alternatives will be distinguished. Two less detailed implementation alternatives are compared in a previous work (Emgård & Zlatanova 2008b). Validation and evaluation of insertion, querying, update and delete of features for selected alternatives shows advantages and disadvantages with the respect to potential for commercial usage. To insure consistency, rules will be implemented in three levels; the database level, application level and user level. Users will be given access to detailed instructions of how to create data.

4. **Validation**. By applying use cases from real world scenarios within urban planning and infrastructure relevant 3D data is going to be used for testing of implementations. With a convenient developed database implementation datasets will be prepared and imported using spatial processing tools (e.g. FME). Testing with datasets from infrastructure situations will help to evaluate the developed implementation alternatives. Tools such as Bentley Map, AutoCad Map, LandXplorer, Google Earth (when applicable) or virtual environments will be used for visualization of selected features classes. This will be helpful for iterative elaboration of the methodology framework. The GO Publisher tool (http://www.snowflakesoftware.co.uk/) will be used for generation of GML files from the database to test the exchange ability of the framework. The ideas from the framework will also be of much use in the further development within OGC and for CityGML.

5. **Revision of the conceptual design.** After each testing period, the conceptual model will be revised based on test results with the users of the developed technology. In the last iteration the conceptual model will be formalised.

6. **Dissemination.** The results will be reported first within the related projects, interested companies and involved municipalities for discussion and direct evaluation. Relevant investigations and results will be regularly reported at OGC meetings, workshops and international journals. The methodology for usage of the model

(creating, populating with data, consistency control, export in various formats) will be provided in manuals and other supporting documentation.

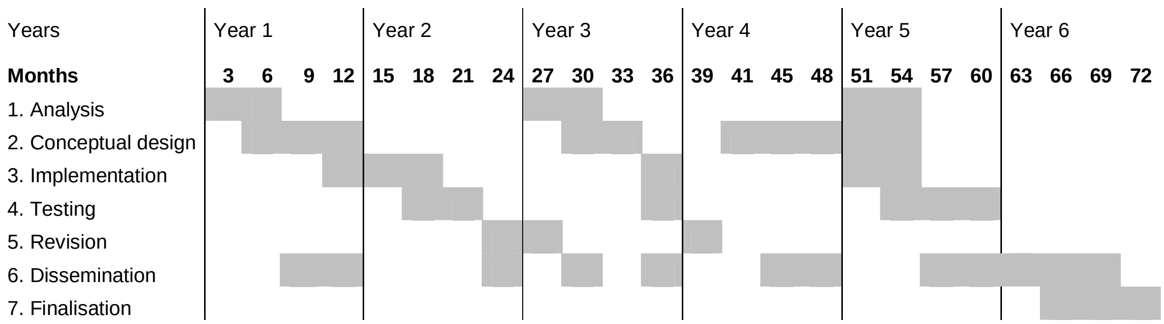
7. **Finalisation.** The most significant research outcome will be reported in a PhD dissertation thesis.

3.1.6 Original Methods and Techniques

This research will follow a strictly formal approach, but it will take into account exiting 2D solutions of domain specific applications. The framework will be applicable for representing any real world phenomena (above, beneath and in the surface) with their geometry and semantics. Such methodology is not applied until now and therefore it will be breakthrough in current modelling of the real world. The techniques will be developed with emphasis on 3D spatial information but the developed framework will be dimension independent and compliant with the 2D case, which will allow for preserving existing 2D solutions.

3.2 Scheduling

The research as described will be completed in the period of 6 years by Ludvig Emgård working 67% on the project. The applicant (Sisi Zlatanova) for this proposal will be involved in the project on the overall supervision of the research. A supporting staff will join the project at year 4 and 5 to extend the development concerning the implementation and testing parts.



3.3 Available infrastructure

The described research is in line with current developments of the section. Several of the GISt members are currently in progress with 3D spatial projects. Friso Penninga is developing the tetrahedron 3D data type approach (Penninga et al 2006, Penninga and Oosterom 2007), Wiebke Tegtmeier is investigating semantics of geological features (Tegtmeier et al 2007a, Tegtmeier et al 2007b), Wei Xu is defining ontologies for emergency response domain (Xu and Zlatanova, 2007). Marian deVries is developing distributed storage of data and web 3D visualisation (Hess and de Vries, 2006) and Hugo Ledoux is studying continuous features in 3D data representations (Ledoux and Gold 2007). Research studies on constrains (Louwsma et al 2006), complex geometric data types (Arens et al 2005, Khuan et al 2007, Khuan et al 2008, Pu and Zlatanova 2006, Meijers et al 2005, Verbree and Zlatanova 2005, Zlatanova et al 2006), topological representations (Zlatanova et al 2003, Zlatanova et al 2004a), extended 3D visualisations (Du and Zlatanova 2006, Zlatanova et al 2003) as well as test with existing representations (Zlatanova et al 2004b, Stoter and Zlatanova 2003) has been already completed and can be used as a background knowledge.

The GISt section is responsible for the Geo-Database Management Centre (GDMC, http://www.gdmc.nl), which enables cooperation with large vendors such as Bentley Systems Inc., Oracle, ESRI, Safe Software, etc. Furthermore, by the cooperation with Lund Institute of Technology the suggested project has access to the Reflex Reality Lab in Lund. The lab contains VR CAVE equipment and a driving simulator as well as hardware for data processing of huge amounts of data. Using this environment the information model may be tested using commercial VR software and hardware.

The GIS technology section has contracts for cooperation with most of the Dutch organisations and institutions responsible for management of spatial information: In 2006 a four-year cooperation contract with AGI/RWS (Advisory Service Geo-information and ICT of the Directorate General for Public Works and Water Management) has been signed. Several projects have been completed in cooperation with the Dutch Cadastre, i.e. PhD research on 3D cadastre, networks of cables and pipes in the cadastral registration, a standardised core cadastral domain model covering land registration and cadastre in a broad sense (multipurpose cadastre).

3.4 Relations to other research projects

The research proposed here is closely related to ongoing Dutch national projects, funded within the program 'Space for Geo-information' (RGI). Besides the previously mentioned RGI-029 'Geo-information management in large civil engineering works' and RGI-011A 'Top-up Comparing different 3D models', several other ongoing projects are also related to this research: RGI-011 '3D Topography', RGI-011B 'Tetrahedron computation', RGI-008 'Dealing with uncertainty in spatial plans'; RGI-116 'Survey of innovations of geo-standards for NGII'; RGI-013 'Virtual reality and urban safety'; RGI-239 'Geospatial data infrastructure for disaster management' and RGI-128 'Geo-information for risk prevention'. The GIS technology section has also participated in the following RGI projects: RGI-001 'Definition study geographical dimensions of risk management' and RGI-002 'Generating and use of base maps for integrated querying of digital spatial plans'.

At an international level, GIS technology participates in two large projects: INSPIRE and HUMBOLD. Since the beginning of INSPIRE in 2005, the head of the section Prof. P.J.M. van Oosterom is participating in the core drafting team 'Data Specifications and Harmonisation' of INSPIRE ('Infrastructure for Spatial Information in Europe'), which aims to harmonise spatial information across Europe. The results of this proposed research are closely related to the ideas of INSPIRE. This research will also complement the developments on data harmonisation carried out within the EC funded international project HUMBOLDT (http://www.esdi-humboldt.eu/). The HUMBOLDT project has started in October 2006. 27 partners from 14 European countries are working in the four-year project with a total volume of 13.5 million Euros. The GISt section is responsible for the data harmonisation work package.

The proposed research is strongly supported by the working group 3DIM within the OGC and Thomas Kolbe at TU Berlin, Lund University, Sweden and the Öresund GIS research cluster in the Copenhagen/Malmö (Öresund) area involving Lund University and Copenhagen University. The results of this research are going to contribute to ongoing cooperation on 3D issues with Jonathan Raper (Department of Information Science, City University of London), Christopher Gold (Geographical Information Systems Research Unit, University of Glamorgan), Andrew Frank (Institute for Geoinformation and Carthography, Technical University of Vienna), Lars Bodum (Geomatics division, Aalborg University) Roy C. Davies (Flexible Reality Studio, Auckland, New Zealand), Rolland Billen (Geomatics Division, University of Liège), Jantien Stoter, (International Institute for Geo-Information Science and Earth Observation, ITC, The Netherlands), Alias Abdul Rahman (Department of Geoinformatics Faculty of Geoinformation Science and Engineering Universiti Teknologi Malaysia).

The research is closely followed by the industrial partners of the GIS technology section at Bentley Systems Inc. and Oracle. Partial funding on specific theme investigations is expected to be provided by Bentley Systems Inc.

4 Utilization

4.1 Usage of research results

Three main areas of use can readily be specified as follows:

1. 3D reference model for database storage at various data providers, e.g. municipalities, topographic offices, etc. Municipalities particularly involved in this research are Rotterdam, Netherlands and Gothenburg, Sweden. These municipalities are already busy with developing virtual reality models that can be used for different users within the municipality and outside it. They expect that such a integrated 3D model will bring them large economical advantages by: providing flexible possibilities to extract only needed data for a given client, managing larger variety of data (which will increase the clients of the municipally); reducing effects from failures in infrastructures (more and better organised data would allow for better analysis and decision making). The municipalities expect that such model would also contribute to better planning and monitoring of urban structures. Exchange of ideas and framing the cooperation are going on. The municipality of Rotterdam is specifically interesting for this research, since Rotterdam is the only municipality in the Netherlands holding data for utilities. At first instance data sets and definitions/requirements will be obtained from the municipalities. Lately the 3DIM (and provided functionality) will be tested and evaluated.
2. Interoperability model within large infrastructure projects for integration of data from different applications (topography, architecture, construction, utilities, transport, etc.). Developments within this research will be evaluated and validated by the partners of the RGI-029 (2005-2009) (http://gimciw.nitg.tno.nl/). The cooperation with the companies in this project is very strong. A case study (data, user requirements for functionality, systems architecture and graphic user interface) will be

provided. The first available version of the model (with focus on geological underground objects) is planned for testing at the end of 2008. The companies expect that such a model will drastically reduce time and efforts for exchange of data (currently extremely limited due to the different formats and software), increase awareness of data (accuracy, owner, updateness), increase the re-use of data (easy exchange will reduce the need to re-measure certain phenomena), allow for better decision-making by extended 3D visuals and analysis

3. 3D exchange GML-based file format. The usage of GML is particularly interesting for further development of CityGML as discussed within 3DIM WG, OGC (Thomas Kolbe). The first results of this research as specified in section 3.1.1 have already been reported at the OGC Technical Committee in June, 2007, Paris. The applicant (Sisi Zlatanova) and the researcher (Ludvig Emgård) are members of the 3DIM WG of OGC.

4.2 The users

By a close cooperation with end users during the research period, concepts can be tested and improved continuously. Following partners are intended for this project: the municipality of Rotterdam, the Netherlands (Walter van der Vos, www.rotterdam.nl), Gothenburg, Sweden (Eric Jeansson, http://www.goteborg.se), SWECO Infrastructure consultancy group (Anna Brunzell, http://www.sweco.se), TNO (Jan Kooiman, http://www.tno.nl/), Arcadis (Bram Mommers, http://www.arcadis.nl/), Grontmij Nederland BV (Bart van de Lely, http://www.grontmij.com), DHV BV (Bujar Nushi, http://www.dhv.nl), Fugro Inpark BV (Martin Kodde, http://www.fugro.com/) and RWS (Hans Nobbe, http://www.rws.nl/rws/bwd/home/www/cgi-bin/index.cgi)

Software developers have also expressed interest in the current research: Bentley Systems Inc. (Alain Lapierre, http://www.bentely.com), Oracle (Siva Ravada) and Snowflake Software (United Kingdom).

Contact data are listed in Appendix 1.

4.3 Implementation

The developed model will be translated into database schemas and imported into the databases of the end users for further testing. The first testers will be the municipalities of Rotterdam and Gothenburg, Grontmij Nederland BV, SWECO and Fugro Inpark B.V. Lately Arcadis and DHV BV will be involved. A detailed description of the methodology framework and the possibility for own additions to the methodology will be given each user together with manuals for data import and visualisation. Methods for linkage of existing software to the database structure will also be described. Courses will be given to the users for more detailed information on how to create own implementations following the developed methodology. Training will be organised at two stages. The researchers in this project will train a selected group of specialist from the companies and these will become instructors for the companies.

The developed model will contribute to extension of several standards currently describing 2D situations in different applications domains. However the largest contribution will be to CityGML by providing formalism for underground modelling (CityGML is expected to be voted as OGC standard in June 2008). The researchers in this project will propose extension to the standard, when the research is completed. The researchers are members of the OGC working group (chair Timothy Case) discussing CityGML. This group is aware of the ideas and developments within 3DIM. Section GIS Technology is member of OGC with a voting status.

The results of the research will be presented at several international conferences as the intention is to present results at least at two international conferences per year and in one peer-reviewed journal every two years. Conferences of interest for this research are: 3DGeoInfo, Urban Data Management Society (UDMS), Spatial Data Handling (SDH), Association for Computing Machinery (ACM), International Society for Photogrammetry and Remote Sensing (ISPRS) and International Federation of Surveyors (FIG). The international peer-reviewed journals to be considered are International Journal of GIS, Computers, Environment and Urban Systems, GeoInformatica, etc.

4.4 Past performance

The GIS technology section is carrying out its research in close contacts with large Dutch organisations responsible for management of spatial information as well as vendors developing software tools. In the last years several projects have been completed, in which GIS technology has contributed to the development of spatial models (e.g. DTB-2000 for RWS, Land Administration Model for the Dutch Cadastre), information models (e.g. IMKICH, IMKL, OVIM, etc). One of the RGI projects, i.e. RGI-011 '3D TOPO' has won the prize of 'GIS innovation days 2007'for best research contribution. F. Penninga has won the prise of the Geo-info magazine for best paper for 2006.

4.5 Contracts

None

4.6 Patents

During the pre-research, no indications have been found with respect to any patents infringing with the deliverables.

5 Budget

Several companies developing software are interested in this research. Particular interest is expressed by Bentley Systems Inc. (Stephane Cote, head of the Research Department, Bentley Geospatial) and Snowflake Software (Ian Painter, CEO of Snowflake Software). These companies are contributing to the research by providing software for free to be used for developments and testing. Software available at SWECO and the University of Lund will be also freely available for research.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	TOTAL
Staff costs: (in k€)							
PhD student	22.424	24.549	26.676	28.526	29.528	30.528	162.231
Support staff				8.770	17.540		26.310
Sub-total	22.424	24.549	26.676	37.296	47.068	30.528	188.541
Non-staff costs: (k€)							
Equipment	5	1		4			10
Travel	2	2	2	2	3	3	14
Sub-total	7	3	2	6	3	3	24
TOTAL	29.424	27.549	28.676	43.296	50.068	33.528	212.541

The total requested budget is 212 514 euro. The staff costs are predominantly calculated for the work of Ludvig Emgård, who is going to be involved 8 months per year (67%) with the developments within this project. The support staff in the calculation includes the effort of a second researcher (at a post doc position), which will assists in the development and testing of the by writing specific code. The researcher will be involved 2 months in year 4 and 4 months in year 5. The funding requested for equipment is dedicated to hardware (computer and laptop) software (for example Maya, StudioMAX) not provided by the mentioned above companies, within the GDMC, Delft University of Technology, Lund University or SWECO. Several presentations in the Netherlands (for users and at national conferences) are planned at the beginning and in the third year of the research. The travel is calculated on the basis of presentations at international conferences and visits to other research groups outside the Netherlands.

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Appendix 1: Contact data of interested users

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Appendix 2: UML diagrams of current developments

A general view of the features included in 3DIM are shown in Figure 1. The model is tested in two DBMS implementations as shown below.

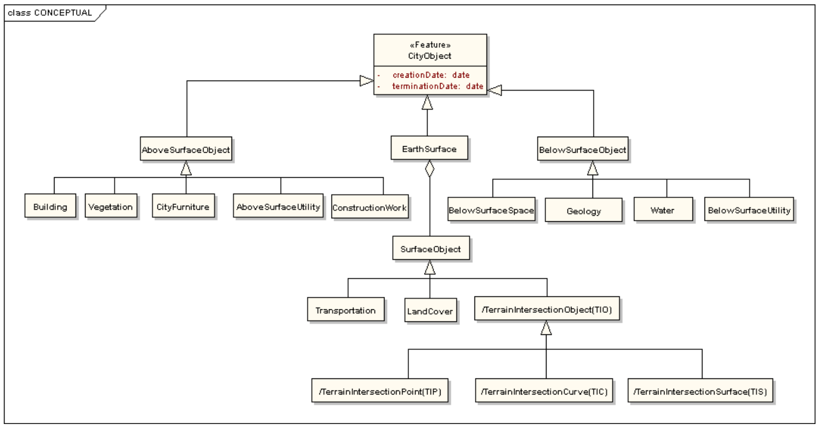

Fig 1. UML class diagram of top level feature hierarchy in the 3DIM (Emgård and Zlatanova, 2008a)

The first implementation alternative strictly separates semantics from geometry into two table groups. The common geometries are organised in four relational tables (point, curve, surface, earth surface) corresponding to simple geometry data types (point, curve, surface), one compound table giving maintenance of solids and supplementary tables for maintaining textures (Figure 2). The semantic entities are modelled as separate tables each referring to a semantic class and linked to tables containing the geometry (Figure 3).

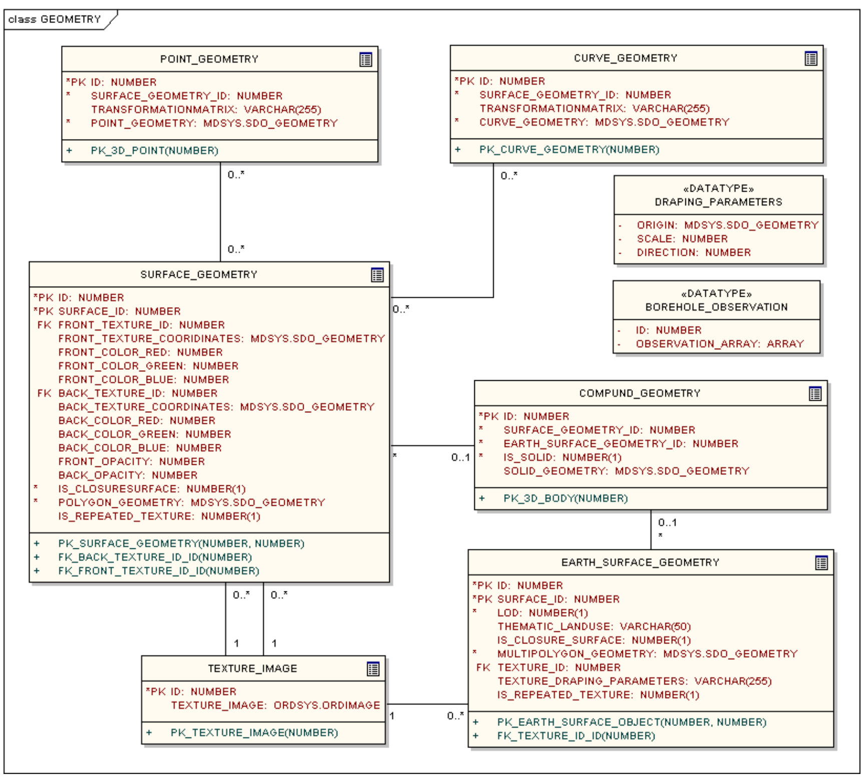

Figure 2: Spatial schema for database implementation according to alternative I (Emgård and Zlatanova, 2008b).

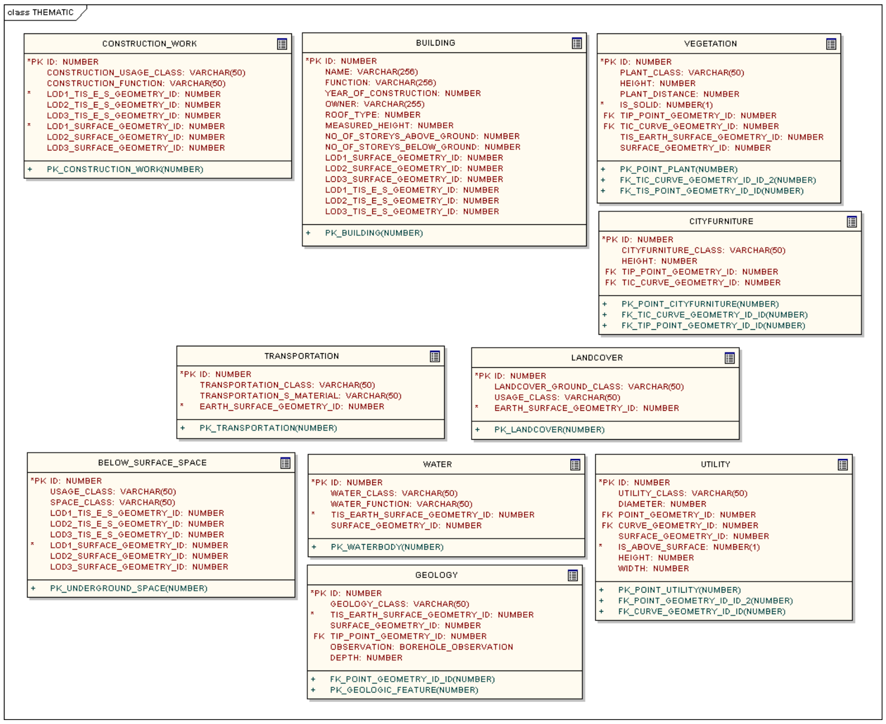

Figure 3: Spatial schema of the semantic tables in alternative I (Emgård and Zlatanova, 2008b)

The second implementation alternative is based on complete semantic sub-division where the geometry columns are integrated in the semantic tables (Figure 4). In this implementation, the geometry column may contain different geometries. Specific tables are defined for geometry only when explicitly required.

Figure 4. Spatial schema representing all tables in implementation alternative II (Emgård and Zlatanova, 2008b)