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Interoperability of Geothermal Data Models

Joachim Benner, Andreas Geiger, Karl-Heinz Haefele, Joerg Isele

Karlsruhe Institute of Technology, Institute for Applied Computer Science,
Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen

Joachim.Benner@kit.edu, Andreas.Geiger@kit.edu, Karl-Heinz.Haefele@kit.edu, Joerg.Isele@kit.edu

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ABSTRACT

It is common practice, that professionals use specialised software tools for their domains. In many cases scientific and/or industrial societies have accepted standards, often based on XML, in order to ease interoperability between software tools.

The car industry has been the protagonist for a product data model called STEP for the description of mechanical parts. For architects and the building industry the International Alliance for Interoperability (IAI) defined the building information model IFC (Industry Foundation Classes) based on STEP. On the urban level, which for instance will be in the focus while designing district heating systems, CityGML became a standard of the Open Geospatial Consortium (OGC).

There are a lot of other standards like WITSML for the drillers, SEGY developed by the Society of Exploration Geophysicists for storing geophysical data or GeoSciML which can be used to transfer information about geology.

All the geothermal aspects are too comprehensive for one semantic data model. Therefore applications are necessary to combine different semantic models without losing information. The paper presents an approach to integrate different kinds of spatial data which can be stored on local sources or can be accessed by web services. Data sources are for example city models, maps, urban planning data and geological data. Interrelations between the different models are set up by semantic and/or by the geospatial attributes.

1. INTRODUCTION

In May 2007 the European Parliament started the INSPIRE directive (Infrastructure for Spatial Information in the European Community). The intention is the re-use and commercial exploitation of Public Sector Information (PSI-Directive 2003/98/EG of the European Parliament). The current situation is branded of fragmentation of datasets and sources, gaps in availability, lack of harmonisation between datasets at different geographical scales and duplication of information collections [INSPIRE].

The intention is to realise a European spatial information infrastructure that can be delivered to everybody. It facilitates not only interoperability within public authorities but also approval procedures and public participation. Semantic data models are the key technology to realise the interoperability between different actors and domains. Representing the whole world in one model is too complex. Hence different semantic data models for different purposes have been developed and standardised over the last few years.

The spectrum of these semantic data models ranges from building data, city and infrastructure data up to geological data and consequently covers the sector of geothermal data.

Data analysis within one semantic data model is a problem many people are working on. Even more complex and in the focus of the activities at the Institute for Applied Computer Science is the data analysis over the borders of different semantic data models and the description of the influences between these models. The result of this research will be called "Geothermal Performance Modelling".

2. SEMANTIC DATA MODELS

Within the context of geothermal data several data models come into operation. The institutes focus on semantic data models[1] is restricted to neutral and open standards to ease the interoperability between different applications (see Figure 1). The following data models are only a small selection of available standards, but it is a first step to provide complete information to all participants:

- IFC (Building)
- CityGML, XPlanGML (Urban Planning)
- GeoSciML (Geology)
- WITSML (Drilling Technology)

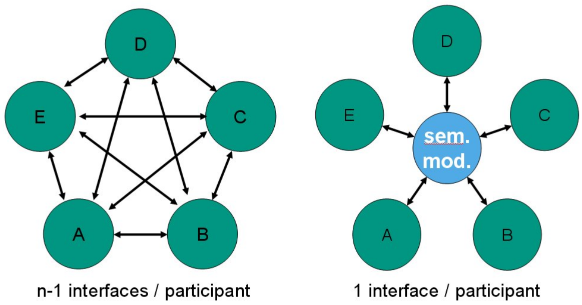

Figure 1: Reduction of interfaces through semantic data models.

2.1 Industry Foundation Classes (IFC)

The international alliance buildingSmart developed the Industry Foundation Classes (IFC, ISO/PAS 16739) for sharing information between project team members and software applications within the construction industry. IFC is an open standard for so called Building Information Models (BIM).

[1] A semantic data model in software engineering is a data modeling technique to define the meaning of data within the context of its interrelationships with other data. It is an abstraction which defines how the stored symbols relate to the real world. (close to Wikipedia)

The IFC model is able to represent information of different domains, like architecture, building services and facility management (see Figure 2), for the complete life cycle [buildingSmart 2008].

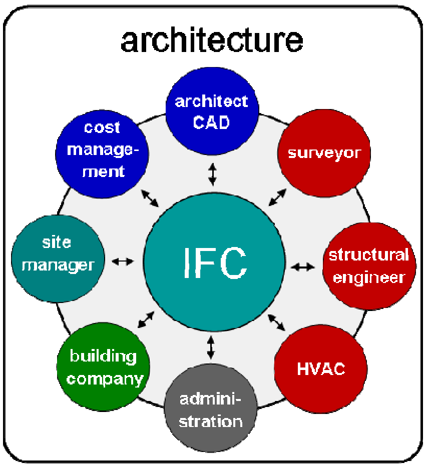

Figure 2: In an early phase of semantic data model development the intention was to reach interoperability within one domain.

The IFC model consists of objects, properties and relations. The building structure is typically based on project, site, building and building storey relationships. The building storey usually contains all building elements, like walls, windows, slabs and furniture. All objects can have standard properties, for example a wall can be load bearing and external. Between objects, relationships can be established. For example a wall can be "contained" in a storey, can be "connected" to another wall and can be a "boundary" of a space [Eastman 1999].

Figure 3 shows an example of a complete IFC model with 4 storeys and 21 spaces and with the corresponding building elements walls, slabs, roofs, windows, doors, stairs and railings.

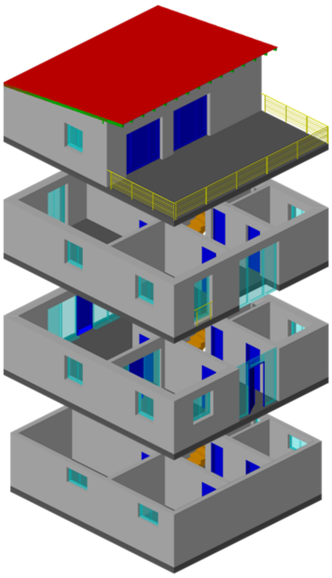

Figure 3: A complete IFC model with building elements (walls, slabs etc.) and building structure information (storeys, spaces etc.).

The IFC model relies on the ISO-STEP EXPRESS language [ISO 10303-11] for its definition and uses resources from ISO-STEP (e.g. ISO 10303-42, Geometric and topological representation).

For the data exchange an IFC model can be mapped in both a STEP physical file [ISO 10303-21] or a XML file [ISO 10303-28].

2.2 Semantic Data Models for Spatial Planning Applications

At the moment, there are two semantic data models relevant for spatial planning on urban and regional level: XPlanGML and CityGML. Both are derived from the XML-based standard GML-3 [OGC 2007] for the exchange of geographic data. GML has been specified by the OGC (Open Geospatial Consortium), a standardisation organisation for geospatial information systems. It was founded in 1994 and is a non-profit, international organisation engaged in the development of standards for geospatial and location based services.

2.2.1 Semantic Data Model for Urban Planning (XPlanGML)

The standard XPlanGML [Benner, Krause 2007] represents the planned use of a city area from a juridical point of view (see Figure 4). In contrast to CityGML (see chapter 2.2.2), the XPlanGML objects have a two dimensional geometrical representation. The standard is based on the regulations of the German urban planning law: Baugesetzbuch (BauGB), Baunutzungsverordnung (BauNVO) and Planzeichenverordnung (PlanzV).

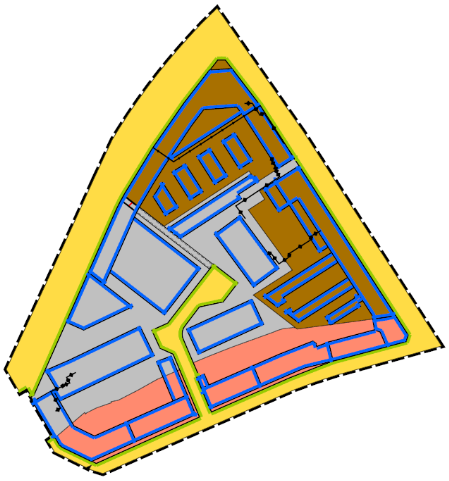

Figure 4: Visualisation of a XPlanGML based urban plan (Freie und Hansestadt Hamburg).

The XPlanGML objects and their corresponding attributes represent legal restrictions and regulations in using selected parts of a city for buildings or other purposes. Restrictions may be formulated geometrically (e.g. specification of the area where buildings are allowed) and/or attributive (e.g. specification of a maximal height, number of storeys or occupancy index of a building). If a specific regulation cannot be formalised by a set of attributes, integration into the XPlanGML data model as free text is possible. Optionally, this text can be related to specific parts of the planning area.

In the context of efficiently using geothermal energy, XPlanGML based planning data may provide important information on selecting an "optimal" site for a geothermal power station. Planning data on local and regional level especially contain information, which areas are specially provided, allowed, or forbidden as sites for energy production. By analysing the planning data of a certain municipality, the geographical distribution of the needed amount of heat from private housings and industry can be estimated. In case the residual heat of the power station shall be used, this information is necessary to select an optimal position for the geothermal site.

2.2.2 Semantic Data Model for Virtual 3D City Models (CityGML)

CityGML [OGC 2008] is an OGC standard for the exchange of virtual 3D city models (see Figure 5). CityGML represents important "objects" of a city like relief, buildings, traffic infrastructure, water bodies, vegetation or city furniture with their three dimensional geometry, their semantic meaning and a few basic attributes. The attributes cover classification, function and actual usage of an object. Certain classes e.g. buildings have additional attributes like the "year of construction" or the "number of storeys".

All CityGML classes can occur in 5 different "levels of detail" (LOD0 – LOD4). Each LOD corresponds to a certain degree of accuracy and complexity in the geometric representation and the semantic structuring. A LOD0 CityGML model only contains a digital terrain model representing the relief. In LOD1, semantic objects like buildings exist, but they have no thematic structuring and are roughly approximated geometrically by an extrusion of the building footprint. In higher levels of detail, the geometric representation is more and more refined, and a thematic structuring of a building is possible. A LOD2 CityGML building allows a classification of the exterior shell into wall surfaces, roof surfaces, ground surfaces and additional building installations. In a LOD3 model, these objects additionally can refer to openings like doors or windows. In the highest level of detail, a CityGML building may also have interior rooms, being composed of interior wall-, floor- and ceiling surfaces.

Figure 5: CityGML model of the historical city Ettenheim.

An important feature of CityGML is an inherent mechanism called Application Domain Extension (ADE) to extend the standard. By defining an ADE the set of attributes and relations of each CityGML class can be extended, and new classes being related to CityGML classes can be specified. This is especially important for defining data exchange formats for special applications, which need application specific objects and attributes. Currently, extensions of the CityGML standard for modelling subsurface objects and supply networks are being defined, which are important components for a geothermal based electricity and heat supply system. It has to be checked whether this application domain needs the representation of additional objects or additional attributes of existing objects.

2.3 Geology Science Markup Language (GeoSciML)

The "Interoperability Working Group" (IWG) of the "Commission for the Management and Application of Geoscience Information" (CGI) defines the needs for GeoSciML as follows. "It is becoming increasingly important to be able to query and exchange digital geoscientific information between data providers and users. Technological opportunities arising from the development of geospatial information standards are making such interoperability a viable proposition.

In order for there to be interchange of information there has to be an agreement on the nature and structure of the information to be interchanged. The simplest way of achieving this would be if all geoscientific data providers shared a common database structure. However, because we all already have "a lot of different "database implementations, and the information gathered and held by different providers is not exactly the same, this option is not possible. The solution is to agree a common conceptual data model, to which data held in existing databases can be mapped. Such a data model needs to identify the objects being described (e.g. "faults"), their properties (e.g. "displacement") and the relations between objects (e.g. "faults are a type of Geologic Structure"). Such a model can be described graphically using Universal Modelling Language (UML), an ISO standard.

Having agreed a conceptual data model it needs to be mapped on to an interchange format. The GeoSciML application is a standards-based data format that provides a framework for application-neutral encoding of geoscience thematic data and related spatial data. GeoSciML is based on Geography Markup Language (GML – ISO DIS 19136) for representation of features and geometry, and the OGC Observations and Measurements (O & M) standard for observational data. Geoscience-specific aspects of the schema are based on a conceptual model for geoscience concepts and include geologic unit, geologic structure, and Earth material from the North America Data Model [NADMC1 2004], and borehole information from the eXploration and Mining Markup Language [XMML 2004]. Development of controlled vocabulary resources for specifying content to realise semantic data interoperability is underway.

Intended uses are for data portals publishing data for customers in GeoSciML, for interchanging data between organisations that use different database implementations and software/systems environments, and in particular for use in geoscience web services. Thus, GeoSciML allows applications to utilise globally distributed geoscience data and information.

GeoSciML is not a database structure. GeoSciML defines a format for data" interchange, "and users or software developers have to provide a GeoSciML interface onto their existing data base systems, with no restructuring of internal databases required." [GeoSciML 2009].

Actually, the central scope of GeoSciML is interpreted information shown on geological maps (see Figure 6), and observational data from boreholes and field observations. The IWG explicitly encourages other initiatives to enlarge the conceptual model to other types of geoscience data. Two examples for such initiatives are Groundwater Markup Language [GWML 2009] and MineralOccurances [SEEGrid 2008]. KIT (Karlsruhe Institute of Technology) will start an equivalent initiative for geothermal data and invites other organizations to join the network.

Figure 6: GeoSciML example of a geologic unit [GeoSciML 2008].

2.4 Wellsite Information Transfer Standard Markup Language (WITSML)

The WITSML standard [WITSML 2008] was developed from the Energy Standards Resource Centre (energistics), which is an international not-for-profit membership organisation, to provide a seamless flow of well data between operators and service companies in the petroleum industry. The objectives are to speed-up and enhance the decision making and to reduce the costs.

In the heterogeneous environment, which is normally found in practice, the risk of conflicts to ensure a consistent repository is tremendous. The data flow contains also real-time processes for LWD (logging-while-drilling) and MWD (measurement-while-drilling). For that reason the WITSML data model represents a wide range of objects such as wellbore, mud-log, well-log and rig instrumentation (see Figure 7).

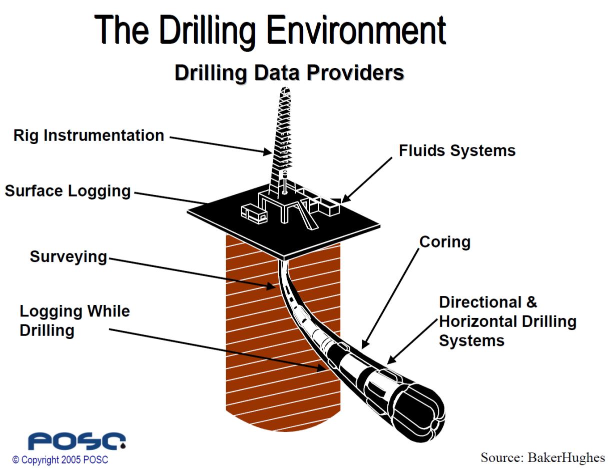

Figure 7: Typical objects of a WITSML model [Doninger 2005].

The project was initially developed by Statoil and by BP in 2000 and later by Shell. The first version was available in early 2003. The current active version is 1.4 released in December 2008. The technology behind WITSML is based on the internet standards (W3C, SOAP, WSDL, and XML) and has its own XML schema.

Beside the XML schema a set of profiles based on the Web Service Description Language (WSDL) has been developed. For an easier understanding what functionality from different servers may be used, three profiles are defined:

- Data transfer profile. A server that provides "near-real time" data from one or more wells while drilling and may also contain relevant data sets from associated offset wells.
- Data management profile. A server that can maintain a longer term data store and also support functionality in addition to the basic capabilities of the Data Transfer server.
- Archival profile. A server that is used to maintain a historical record of data in WITSML accessible format.

The WITSML data model covers all drilling related data. Currently this standard is driven and used in the petroleum industry, but it comes also into focus for an integral view on geothermal data.

3. OGC WEB SERVICES

In order to efficiently integrate distributed data in one application, standardised internet-based access methods are needed. For spatially referenced information, the OGC has developed specialised Web services.

Web services are defined by the W3C (World Wide Web Consortium) as "a software system designed to support interoperable machine-to-machine interaction over a network". In case of the OGC Web services this is a client-server connection using the internet based on the HTTP protocol.

In the application context of geoscientific data, the two most important services are the Web Map Service (WMS) and the Web Feature Service (WFS).

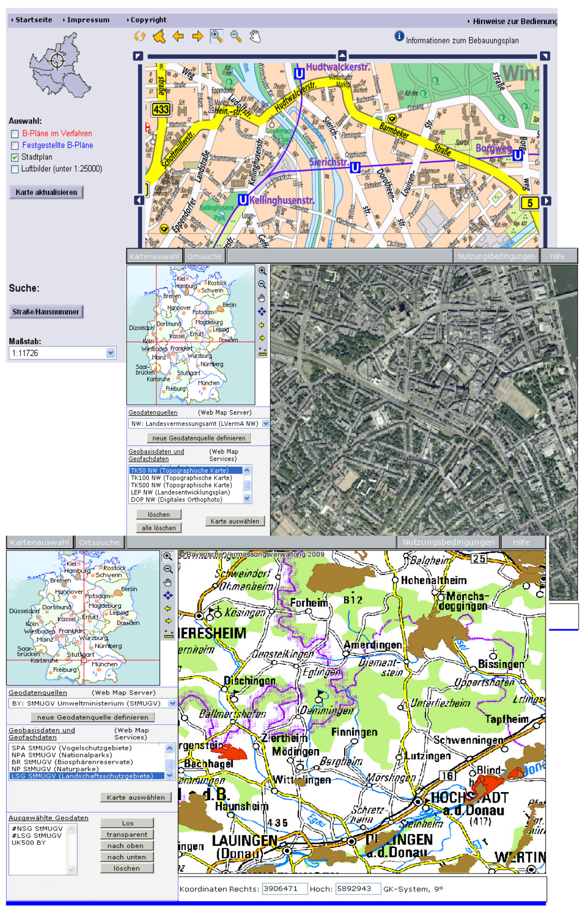

Figure 8: Georeferenced orthophotos and maps delivered by various Web Map Services.

3.1 Web Feature Service (WFS)

A WMS delivers access to geographic data by means of a pictorial (map) representation. This type of data is only suited for visualisation purposes. If the original geoscientific data are available as features and the client software needs to access these data, e.g. for analysis or interpretation purposes, a Web Feature Service (WFS) has to be provided.

This is another internet service standardised by OGC [OGC 2005], transferring vector data in GML format like CityGML or XPlanGML. Like the WMS, the WFS standard defines a number of operations in terms of XML-based requests and responses. The GetCapabilities request delivers metadata of the service, in response of a DescribeFeature-Type request the server provides the corresponding GML-3 application schema, and GetFeature requests for GML features (see Figure 9). The syntax of the GetFeature request allows a spatial or semantically filtering of features.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<wfs:FeatureCollection xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0"
                       xmlns:gml="http://www.opengis.net/gml"
                       xmlns:wfs="http://www.opengis.net/wfs"
                       xmlns:citygml="http://www.citygml.org/citygml/1/0/0" numberOfFeatures="2":
 <gml:boundedBy xmlns:xlink="http://www.w3.org/1999/xlink"
                xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <gml:Envelope srsName="EPSG:31467">
   <gml:pos srsDimension="2">5.967013359069824 45.829437255859375</gml:pos>
   <gml:pos srsDimension="2">10.488205909729004 47.806663513183594</gml:pos>
  </gml:Envelope>
 </gml:boundedBy>
 <gml:featureMember>
  <citygml:Building gml:id="Feature_1">
   <gml:boundedBy xmlns:xlink="http://www.w3.org/1999/xlink"
                  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <gml:Envelope srsName="EPSG:31467">
     <gml:pos srsDimension="2">5.967013359069824 45.829437255859375</gml:pos>
     <gml:pos srsDimension="2">10.488205909729004 47.806663513183594</gml:pos>
    </gml:Envelope>
   </gml:boundedBy>
   <citygml:creationDate>2007-03-01</citygml:creationDate>
   <citygml:terminationDate>2007-05-01</citygml:terminationDate>
   <citygml:yearOfConstruction>1985</citygml:yearOfConstruction>
   <citygml:roofType>Satteldach</citygml:roofType>
   <citygml:measuredHeight uom="m">7.00</citygml:measuredHeight>
   <citygml:storeysAboveGround>3</citygml:storeysAboveGround>
   <citygml:storeysBelowGround>1</citygml:storeysBelowGround>
   <citygml:storeyHeightsAboveGround uom="m">5</citygml:storeyHeightsAboveGround>
   <citygml:storeyHeightsBelowGround uom="m">2</citygml:storeyHeightsBelowGround>
  </citygml:Building>
 </gml:featureMember>
</wfs:FeatureCollection>
```


Figure 9: GML dataset delivered by a Web Feature Service.

4. SCENARIOS

As already mentioned in the introduction there are many cases in which people dealing with geothermal applications cross the border of their original domain. Many geothermal questions concentrate on geology. In many cases the heat exchanger may be the perfect interface between "underground objects" and "the use of the heat". Lots of other questions may only be sufficiently answered by extending the domain boundaries.

On a medium time scale software tools for "Geothermal Performance Modelling" are needed. These will be programs able to calculate and simulate the effect of minor changes in any system component on the overall geothermal system.

Two realistic scenarios from the Oberrheingraben, one of Germany's most promising regions for geothermal activities, may give an idea of the potential of such tools.

4.1 Extension of an Urban District Heating System

The south of the Oberrheingraben borders to Switzerland. In the north east of the city of Basel there is a small city with about 20.000 inhabitants called Riehen [Riehen]. In August 1988 they completed the first borehole with a depth of 1547 m which is used as the production well. The injection borehole is 1247 m deep. Since 1994 the geothermal plant feeds heat into the district heating system. Today the district heating supplies about 200 locations with heat. The thermal water comes with a capacity of 18 l/sec and with 64° Celsius. It is cooled down to 25° Celsius by two direct heat exchangers and by two electrical heat pumps. Due to these heat pumps the district heating system is run with temperatures higher than the temperature of the geothermal well. This eases the junction of the district heating system with heating installations of buildings that are not designed for modern low temperature cycles. Originally the pipe network was only about 5 km in length. Today it is expanded to 21 km.

Figure 10 shows a sketch of the Riehen district heating system. They use the geothermal plant for the base load. Gas-powered combined heat and power units produce the electrical energy for the heat pumps. Peak loads in cold winters are served by oil burners which are also used in case other systems cause problems as happened in late winter 2008 for instance. They also installed water tanks for the storage of some hot water in order to decouple production and consumption. The figure conceals that Riehen sells some base load to the German city Lörrach as long as it is not needed in Riehen.

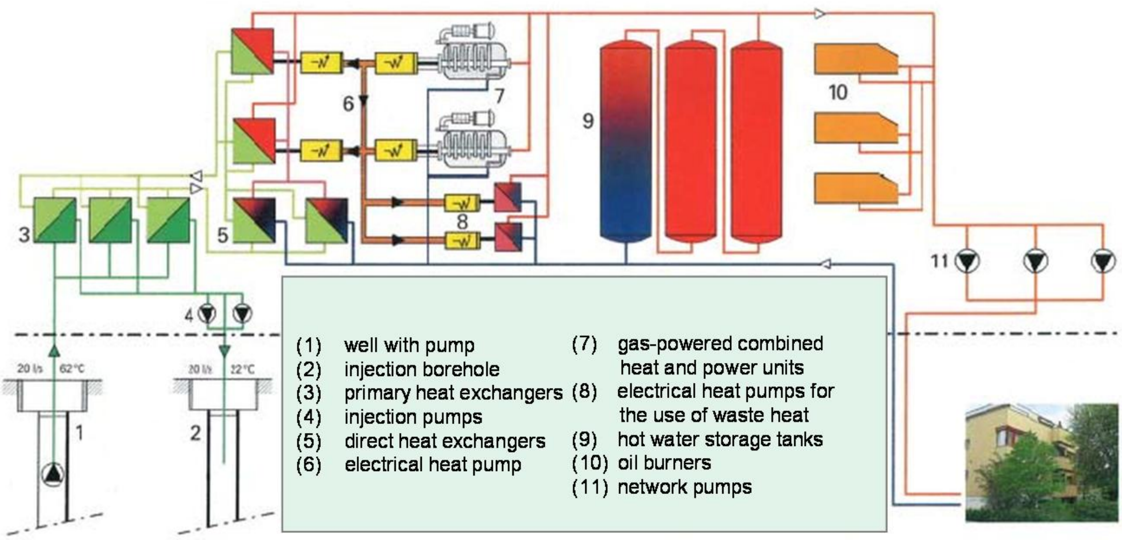

Figure 10: Sketch of the technical equipment of the district heating system in Riehen (Switzerland) [Gruneko 2009].

In 2005 the overall system in Riehen took 46% of geothermal heat, 42% of natural gas and 26% of oil to deliver 100% of heat, where they had 7% of losses in the district heating system and 7% of production losses.

There are other district heating systems in Riehen (see Figure 11) and it is decided to connect them to a network with a consumption of about 54 GWh/a. Afterwards the geothermal heat delivery will be twice as big as today. It will be enlarged from 10...12 GWh/a to 20...25 GWh/a. The output of the well will be increased from 18 l/sec to 22 l/sec [Schaedle 2009].

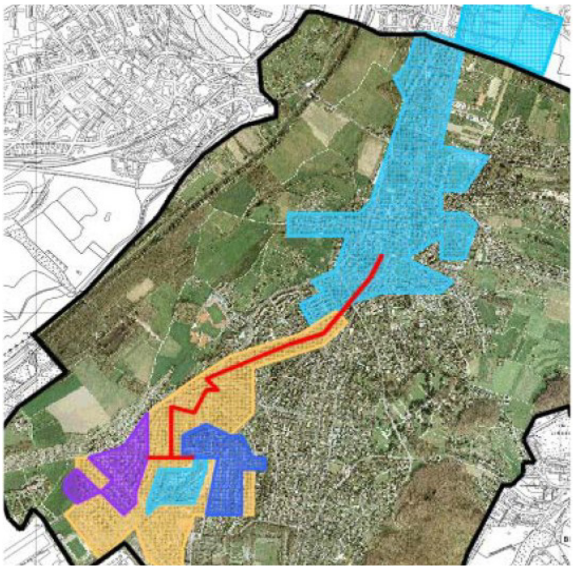

Figure 11: Overlay of different "maps" showing Riehen (different colours mark different district heating networks) [Schaedle 2009].

Very close to Riehen, in Basel, there is an EGS (Enhanced Geothermal System) project. While they stimulated their well in 2006, some earthquakes appeared with a magnitude of up to 3.4. This event frightened people and decreases the acceptance of the geothermal technology as a whole. Therefore it is an essential need for the industry and for administration to gain back some trust.

All these facts show how complicated it is to run a geothermal system in its optimum. It is unthinkable to reach this goal without the use of modern software. How about a "Geothermal Performance Modelling" tool optimising:

- the most economic resource distribution,
- a minimum consumption of oil,
- a maximum output of electrical energy,
- the best size of the water tanks

or giving answers to questions like:

- How will new customers influence my system?
- How far could the feed in temperature be reduced when some customers would modernise their buildings?
- What happens to the reservoir when the production is increased?

Unfortunately there is still much research work to do, before all the answers are given automatically. Nevertheless it is of great importance to merge data from different domains in a common viewer in order to ease the work of experts. Such accumulated information viewed in 3D will also help to make things transparent for worried citizens or interested customers.

4.2 Investigation of Structural Damages

In the small town of Staufen (see Figure 12) with a medieval townscape, only 35 km north of Riehen on the borderline to the Black Forest, they renovated the town hall. In order to save natural resources and as an example for the citizens they decided to use a heating system based on renewable energy. Seven boreholes were drilled in late 2007, each 140 m deep. U-tubes were installed as heat exchangers. A heat pump uses the warmth and provides heat in the required temperature range [Staufen].

Figure 12: Aerial view of Staufen [BZ B].

Only somewhat later, first cracks appeared in the wall finish of the town hall and in about 170 surrounding buildings. In the meanwhile you can stick a finger in some of the cracks. The archive of the town hall had to move out for static reasons. For some affected houses engineers plan building activities in order to secure the static.

What had happened? A survey report came to the conclusion that there is a "Gips-Keuper"[2] zone with a height of 75 m below the city. When it gets in contact with water, the anhydrite swells to plaster. This way the town is raised up to 1 cm per month. There is a coincidence in time and location of the catastrophe with the geothermal activities but the reason could also be one of the regular tectonic shifts below Staufen.

The town administration tries to help affected citizens with monetary support. There is an association that collects money for the conservation of the historic townscape. The local gas supplier tested its gas distribution system. So far there are no leakages. The administration of Baden-Württemberg published a regulation which stops drilling as soon as anhydrite or plaster is found.

Experts decided to drill again in Staufen. Cores explain the underground and may help to understand in detail what is happening. In spring 2009 they started behind the town hall. At the depth of only 17.8 m they stopped drilling because they found "Lettenkeuper"[3] that was expected at 150 meters

[2] It is one aim of the GeoSciML standard to provide the concept of "controlled vocabulary" for the correct definition of such terms. Since there is no simple translation and the authors are not geology experts, the German terms are used.

[3] Please see footnote 2

in a depth of 8 meters. Then they commissioned some 2D seismic and it was found that there is a tectonic fault zone of only 35 meters in width containing the swelling material. They shifted the drill rig closer to the original boreholes and tried again. The well is now equipped with several sensors. Groundwater is pumped out of the well to keep the anhydrite dry and to stop the raising of the city [BZ].

Up to now, there are no graphics available to the public showing a geological model underneath Staufen. Which non-professional will understand the description given above? It doesn't tell house owners how this correlates to their property. But also engineers would profit from a 3D model when they have to calculate the risk for buildings.

This is a good example of a situation where geology and detailed building information have to be brought together. IFC meets GeoSciML.

(There is a nice anecdote about the town: Staufen calls itself the "Fauststadt". Johann Georg Faust the central character of Goethes famous novel lived there about 500 years ago. Since silver got rare in the barons mines Faust was called to produce gold instead. In 1540 he died. They say he has had a contract with Mephisto and when it expired after 24 years, the devil came and got him.)

5. GEOTHERMAL PERFORMANCE MODELLING

5.1 Definition

"Performance engineering within systems engineering, encompasses the set of roles, skills, activities, practices, tools, and deliverables applied at every phase of the systems development life cycle which ensures that a solution will be designed, implemented, and operationally supported to meet the non-functional requirements defined for the solution" [Wikipedia 2009]. In this definition the term "non-functional" is used in the sense of "quality attributes".

Applying performance engineering to geothermal systems means to evaluate the quality of the desired solution by considering all significant parameters during the life cycle. A system usually covers several interdisciplinary fields. In the case of geothermal systems disciplines like geology, civil engineering, power plant engineering, supply engineering, urban planning, architecture and social disciplines have to find an optimal solution.

As a basis for geothermal performance engineering, data from all disciplines have to be integrated. This means data have to be collected without a loss of relevant information and linked by geospatial and semantic relations. This process will be called Geothermal Performance Modelling.

5.2 Concept

Interoperability between different software applications can be achieved by direct interfaces for each proprietary data format or by neutral semantic data models. The advantages of neutral semantic data models are the independence of software vendors and their software versions, the reduced number of data interfaces and the high quality of data exchange.

Due to the complexity of models the scope of semantic data models is limited to a certain application area. In different areas like construction industries (see chapter 2.1), urban planning (see chapter 2.2) and geology (see chapter 2.3) different models have been established. For each model applications are available to create, modify, visualise and use the model (see Figure 13 left).

If information from more than one model is needed, models usually have to be transformed into a suitable model. For example: if an urban planning application wants to use data from an architect, the IFC model has to be transformed into CityGML (see Figure 13 middle). Such transformation processes usually cause a loss of information.

In order to keep all information for geothermal performance engineering, different models have to be integrated in one application (see Figure 13 right). This means a specific application should be able to cover significant parts of more than one model without losing any information.

The focal point to achieve this is to design and implement a data structure, which is able to hold different concepts of data hierarchies, data properties and data relations. In addition such a data structure must be able to handle data with different reference coordinate systems and from local and web based data sources. In order to manage the data, the structure must be flexible enough to present a specific model in its own context and in the overall scene context. A special level of detail concept should be provided in order to reduce complexity.

While filling the data structure geospatial relations like a certain building is located at a certain geological underground have to be established as well as relations between objects of different models. In order to store the complete scene including the newly established relations between the models, a file format for storing data source (local and web sources) and interrelations between models has to be defined.

Finally the data structure should provide all input for geothermal performance engineering applications.

5.3 Pilot Application IFC Explorer

The IfcExplorer is prototypic software for integration, analysis, three dimensional visualisation and conversion of spatially referenced data. Originally designed for exploring the semantic building model IFC (see chapter 2.1), the software now supports different GML-based GIS data formats (CityGML with different ADEs, XPlanGML, rudimentary GeoSciML) and DXF. For GML based information, different sources belonging to different GML application schemata can be merged in one internal data model. Actually, CAD data are stored in a separate internal data model.

Under certain conditions, a transformation from a CAD data model into the GIS model is possible. By means of a geometrical generalisation, IFC models can be mapped on LOD1 CityGML models [Nagel 2007]. The transformation of DXF data into CityGML LOD2 Building, WallSurface and RoofSurface objects is possible, provided the DXF file has a specified layer structure.

The IfcExplorer can access file-based information and (for GIS-data) internet based information via Web Feature Services. Furthermore, three dimensional vector data can be overlaid with georeferenced raster information provided by Web Map Services. Figure 14 shows an example, integrating an urban plan (in XPlanGML-format), a 3D city model (in CityGML-format), and an orthophoto in a common 3D environment.

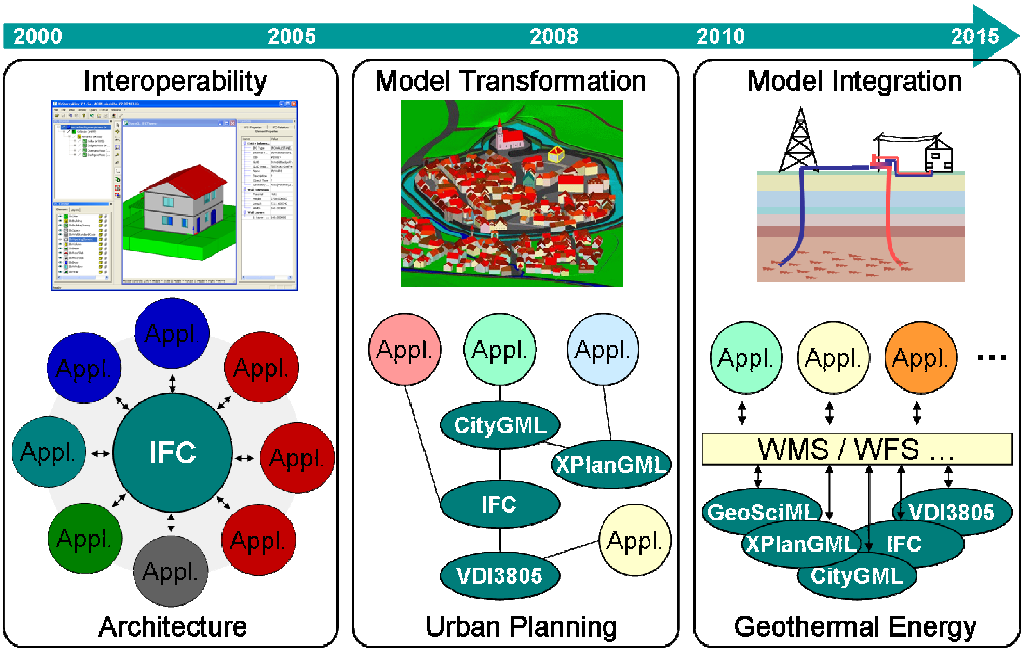

Figure 13: The 3 phases of semantic data model development.

The visualisation component of the IfcExplorer supports a broad spectrum of possibilities for an interactive exploration of the 3D scene. Viewing position and viewing angle of the scene camera can be chosen arbitrarily. The amount of objects visible in the scene can be selected on the level of classes ("show only buildings", "hide the relief") or on the level of individual objects. In a similar way, the graphical style of visible objects (colour, transparency, texture) may be determined by the object class or the value of a selected object attribute.

Figure 14: Integration of different data types in the IFC Explorer (Courtesy of Freie und Hansestadt Hamburg).

The example shown in Figure 15 is the very first attempt to integrate two different models in one environment without losing any information and to be able to interact and combine both models.

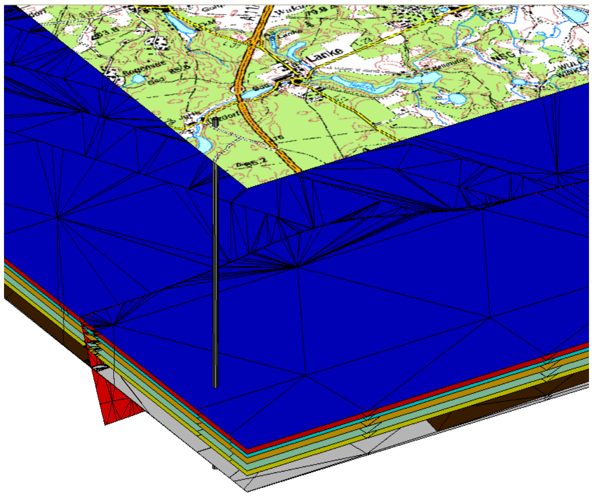

Figure 15: Geological data (DXF) and a corresponding map in the IFC Explorer (Courtesy of GFZ Potsdam).

6. CONCLUSION

A geothermal energy system is complex and involves a number of different disciplines. In some of the disciplines neutral semantic data models are established to store and exchange data between different software applications in the same domain.

If more than one model is necessary for performance engineering, data nowadays have to be transformed in a suitable model for the corresponding application, which tends to result in a loss of information.

The only possibility to avoid losing information is to integrate different models from different disciplines in one application. This integration then will be the basis for comprehensive geothermal performance engineering.

In order to demonstrate the potential of geothermal performance engineering, two realistic scenarios have been outlined and evaluated. The need for geothermal performance modelling as the base process for performance engineering has been explained and a future concept integrating data in an application without losing information has been introduced.

As examples four different semantic data models, typical for its domains, have been briefly described including their domains. The IFC model dedicated to the building construction industry was introduced for detailed building description including construction information. The CityGML and XPlanGML models were mentioned as examples for both the 3D planning and the consideration of legal aspects of urban planning. The GeoSciML model as a model for geoscientific data was considered to be the base model for specific geothermal data. Especially for drilling data, the WITSML model was reviewed.

Finally an overview of a pilot software application, developed at the Institute for Applied Computer Science, was given. This application is able to handle different semantic models separately. In a prototypic way it also handles two models (CityGML and XPlanGML) in a single environment without losing any information.

This application will be the future platform for realising the proposed concept of geothermal performance modelling.

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