MULTILEVEL INFORMATION MANAGEMENT BETWEEN DIVERSE DOMAIN MODELS IN GEOTECHNICAL ENGINEERING

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ABSTRACT

Current joint research activities aim at the development and validation of an information base providing right information at right time for the support of both regular construction and handling of exceptional situations in geotechnical engineering projects. A hybrid model- and resource-based information management system has been developed and tested in an application example in the frame of a large geotechnical engineering project in the city center of Berlin. An approach is presented to extend the system with a model management component to combine information elements from diverse domain models into one overall information model compound in consideration of fundamental mapping characteristics.

KEY WORDS

information management, information modeling, information integration, interfacing, geotechnical engineering.

INTRODUCTION

Geotechnical engineering like other engineering disciplines can be seen as an information driven discipline. The need of information recurs throughout all stages of construction, ranging from design, planning and execution to the use of the building. However, throughout its lifecycle different demands on the management of information and different levels of integration can be identified.

Information in construction engineering is in general very heterogeneous. Traditionally small and medium construction companies have a working environment which consists of a heterogeneous collection of engineering software applications and 'standard software'

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including office software for processing this information. However, ICT support is not yet as sophisticated as in other engineering industries (Jung et al. 2004) although the application of electronic document management technology experiences a quick growth, in particular in bigger projects (Björk 2003). Significant qualitative benefits can be reached in multi-partner projects applying centralized digital information management (Sulankivi 2004). Big companies apply heavyweight integrated software solutions which support the information processing throughout all phases of a construction project including project communication, workflow functionality, documentation and financial issues (like AEC/community, baulogis, BuildOnline and others).

MULTILEVEL INFORMATION MANAGEMENT IN GEOTECHNICAL ENGINEERING

To support particularly small and medium construction companies a multilevel information management system has been developed and tested in a first practical example. The information management system combines two approaches operating on different levels of information integration.

The first level is to manage information resources in a distributed project environment applying web-based technologies. Each single document as a container of heterogeneous information is managed by a semantically describing database. The information resources themselves remain physically at their point of origin in the responsibility of their authors.

However, for a comprehensive information management a simple document management does not appear to be sufficient. Therefore the second level is to integrate information that is contained in the aforementioned information resources into a system that supports the finding of information and raises the transparency. Moreover, frequently accessed information shall be provided to the engineer in a suitable manner without the obligation to access and open the documents containing it. This demands for the abstraction of typical engineering key information. An information model for geotechnical engineering has been developed on this level and complemented with an appropriate user interface.

RESOURCE-BASED INFORMATION MANAGEMENT

The first part of the multilevel information management system is provided by a web-based resource management system (Hildebrandt 2005). It was developed to support the sharing of heterogeneous information resources in distributed project environments and to overcome the problems arising from the traditional working processes working with different copies and versions of circulating information (information exchange).

The management of all kinds of (traditional) engineering documents (information resources) demands for the explication of their implicit and hidden information. To overcome the problem of semantic heterogeneity a single domain ontology is the base for the semantic markup of the information resources with descriptors. The ontology is flexibly adaptable for each project depending on special glossaries of the respective discipline and companies and the demands of involved partners.

The management of the resources is handled by resource entries stored in a meta-database. They contain the semantic markup, the format information and information about the physical location of the resource (URL). The resources themselves remain physically at their origin on any server worldwide in the responsibility of their authors. The resource management system is implemented as a web application (Java Servlets) running the database and handling the requests of the users.

The system is accessed from the client side by the web browser. Any equipment such as PC, PDA or even mobile phone (limited) can be used. As these instruments are mobile, access to the system exists at any time from any place. Basic functionalities include search mechanisms (according to the semantic markup), resource browsing (by tree structure), resource editing, integrated resource visualization (provided by special customizable applets, e.g. visualization of time series from data files), personal workspaces for registered authors, and bulletin board communication. An API is provided for integration in other systems.

This architecture has the advantage that the responsibility towards content and topicality remains with the provider of the resource. Furthermore it has the advantage that the presentation of the resource on the client side follows the MIME type supporting tools and thus is always familiar to the engineer. The users have an always up-to-date common information base.

MODEL-BASED INFORMATION MANAGEMENT

On the second level of information management the engineering information (objectives, tasks, finances, responsibilities, time-frame and organizational structure) permits the design of information models on a densely integrating level for rapid construction follow-up and fast reaction in emergency situations. An information model for geotechnical engineering has been developed integrating construction elements, building processes, monitoring, actors and organizational structure (Schley et al. 2004). The main objective for this information model lies in the support of handling emergency situations in geotechnical engineering. It is designed to contain key information only, since only few technical details about construction members and their states are needed for emergency handling. However, it turned out that this information model is applicable for the information management throughout the entire construction process. An alternative approach for an efficient information access in complex and detailed integrated product and process models through a navigational model is given by Reinhardt et al. (2004).

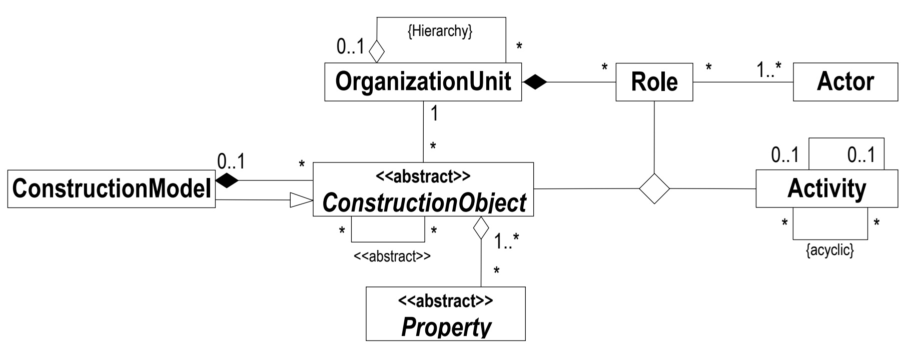

Figure 1: Excerpt from the geotechnical engineering information model type

The information model and its corresponding model editors are not intended to replace existing software packages and tools commonly used by the engineers. It is rather intended to be a supplementary instrument that fits into the engineer's working environment and provides a central point of reference concerning information management. A corresponding mechanism for interfacing with other sources of information is evidently essential.

The information model type (Figure 1) follows an object oriented approach and is described by the unified modeling language (UML). The abstract generalized model consists of three components. They represent the construction objects of the building (structure components, measuring devices, construction equipment, site facilities etc.), the construction process and the organizational structure. An extendable class hierarchy has been created to model typical geotechnical engineering construction objects like excavation, sealing slab, diaphragm wall, anchor, gauge etc. The construction object's properties are modeled separately with specialized property classes. They contain the actual key information.

INFORMATION MANAGEMENT PLATFORM

The proposed multilevel information management system combines both aforementioned approaches. The resource-based approach provides the management of all kinds of traditional documents usually shared during construction processes. Moreover it can handle heterogeneous information resources that change dynamically during their life time like all kinds of data files providing for instance measured data. The web-based resource management system also allocates communication and collaboration tools and makes it part of a web-based cooperation platform. The model-based approach provides the access to and the management of distinctive information, topological correlations and dependent information which cannot be recognized out of documents but which is essential for supporting the handling of emergency situations in geotechnical engineering. However, the underlying information model cannot give and is not designed to provide whole coverage of all information for construction management. Only key information is provided. The link between both approaches is managed by the information model. Special properties of construction objects, activities or organization objects contain links to resources, pre-formulated queries or dynamically formulated queries for the search mechanisms of the resource management system.

Navigation through information to access key information is crucial for decision making processes and crisis management. To support these needs a graphical navigator has been set up. It serves as central information editor for the entire information model presenting the construction project with its construction objects in a schematic generalized form by appropriate tools and editors. This allows for quick information retrieval and the recognition of spatial and temporal correlations to the engineer. The temporal context, provided by the process component of the model, displays the status of the building process at any time level of construction work. It also allows for comparisons of both the as-built and the as-planned states. Accessibility to information about the project status at current and any previous time supports decision makers to understand possible interactions between structure, soil, groundwater and activities as well as the development of failures and their reasons. The integrated tools contain links to the resource management system for further information not provided by the corresponding part of the information model.

APPLICATION EXAMPLE

The web-based multilevel information management system has been applied in the frame of a large geotechnical engineering project in the city center of Berlin. Main part of the project was the construction of a deep excavation with a total surface area of about 22,000 square meters, which has been executed within eight months only. The excavation was divided into four parts due to safety requirements as well as an efficient construction process in the required time schedule. One of the major problems for design and construction of deep excavations in Berlin is the very permeable sandy soil. The groundwater level is about four meters below ground surface and groundwater lowering is not allowed. Therefore wall-slab constructions are mainly used for deep excavations in Berlin (Savidis & Rackwitz 2004). Diaphragm walls with tie backs and jet grouting slabs have been used for the construction of the excavations. The excavation base level varies from 13 to 17 m in the four parts of the excavation pits.

A web-based Graphical Navigator together with a simplified model without process and organizational components has been used to manage data and information on the construction site. Main part is a resource management system using an ontology specifically related to the engineering project. The structure of the ontology was jointly developed and discussed with the project management and quality control personnel of the contractor.

A number of different classes of data and documents accrue during the construction phase of an engineering project. At the beginning it was decided to limit the class of documents within the information system to the following types: construction production documents for walls, slabs, anchors; plans; ground investigation reports; data and documents from several measurements during and after construction. A total of more than 8,500 documents were managed by the system. Figure 2 represents a snapshot of the information management platform.

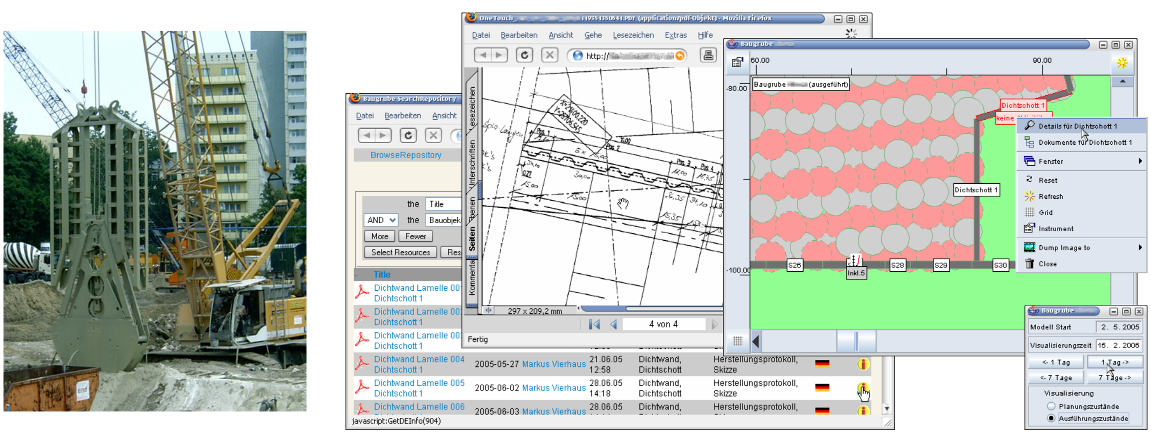

Figure 2: Construction site and information management platform

Very special and important in large geotechnical engineering projects is the use of measuring systems in the frame of the so called geotechnical observational method. The method itself can be traced back to the work of Terzaghi (Einstein 1991) and is now part of many geotechnical codes (like Eurocode 7). Main purpose of the monitoring is to control the soil-structure interactions during and after the construction process. It is necessary due to the fact, that a number of uncertainties are very difficult to cover in geotechnical design calculations. Therefore especially the data from these measurements, such as anchor forces, wall deformations, changes in soil density and ground water level inside and outside the excavation pits are very important for quality control and decision making on the construction site.

The information system was frequently used by the contractor's project and quality control personnel. In addition guest access was provided part time to sub contractors and consulting engineers. Questionnaires were developed and distributed to the users to get their feedback for the evaluation and subsequent improvement of the system. Evaluation of the questionnaires reflected the advantages of the use of that system in practice. After recent final completion of the excavations all data serve now as project archive and are used for further evaluation in research as well as practice.

INFORMATION MANAGEMENT BETWEEN DIVERSE DOMAIN MODELS

In general civil engineering projects involve many different models for specific purposes and with specific views on the same project (architectural models, structural models, geotechnical models, financial models, etc.). This leads to very much individualized software solutions and information models which frequently exist in parallel and independently from each other within companies.

The presented multilevel information management system for geotechnical engineering, designed for supporting processes of emergency handling in geotechnical engineering and proven in a first testing phase relies on diverse external domain models and even simple data sources like spreadsheet tables. Key information about the current state and the history of a construction project is extracted from those external sources and mapped into the geotechnical information model, providing quick and bundled information access. Detailed information is integrated as just providing links to parts of the external resources. The combination of various specialized external domain models together with the geotechnical information model into an overall model compound however does not result in one unique overall model of the whole construction project, since redundancies between diverse models violate fundamental characteristics of mappings. Such mostly unintentional redundancies most probably result in consistency problems.

Two approaches have been identified to define consistent integrated information models. One approach is to develop centralized core models, like IFC (IAI 2004) or in general building information models (BIM) (Tse, Wong & Wong 2005) for civil and building engineering, together with transformer components interfacing to the domain models. Such core models obviously define product model types for specific application domains. Traditional product model types map application domains into complex structures of simple object types, providing detailed as well as coarse information. The first disadvantage of such product model types is that an application domain has to be mapped more or less completely into a product model type before applying it as core model. The second disadvantage is that for almost every project environment only a small part of a given complex product model type is needed. The other approach is to select the model describing components from the various domain models and to manage the unavoidable redundancies in a way that one selected object will be treated as model component and the other (redundant) objects as dependant clones. This latter approach is applied within the integrated model compound, integrating the geotechnical information model and the specialized external domain models.

The integrated model compound management consists of two components: a transfer component and a management component. The transfer component as a middle tier (like Froese et al. 2000, but more generalized) supplies interfaces to and from the external domain models and the geotechnical information model and potentially required information transformers to adapt information within the transfer. Interfacing and transformation base on a generalized collection based core model. The management component maps and manages the object dependencies between the geotechnical information model and the external domain models in a way fulfilling modeling characteristics. It controls the components of the geotechnical information model, their link to their corresponding information components in the different external domain models, and the corresponding elements of the transfer component. As a side effect inconsistencies between different external domain models can be pointed out.

TRANSFER COMPONENT

The main intention of the transfer component is to serve as a middle tier between the geotechnical information model and the external domain models. For simplifying the interfacing and due to the heterogeneity of the external domain models, the transfer component bases on a generalized collection core model type together with collection reader and writer interfaces (Brüggemann & Liang 2004). The collection core model has been developed for a simple and efficient way to interface large amounts of heterogeneous engineering information between information models via a collection based middle tier. It provides object types according to the elementary set theory: *object* for wrapping single references, *collection* for aggregation of objects to sets, *tuple* as a container of ordered objects and *relation* as a collection of tuples. Furthermore a *structured object* is defined as a convenience object for wrapping multiple references and arbitrary amounts of primitive values (integers, doubles and booleans). The intentional lack of domain specific semantics makes this model type suitable for a simple and generalized information transfer between all kinds of engineering information.

The collection *reader* and *writer* interfaces perform the transformation from proprietary resources (domain models) to elements of the collection core model and vice versa. Optional collection *transformers* operate on the collection core objects. Readers, transformers and writers can be concatenated forming a transformation chain. The consistency of the concatenation in terms of collection objects is ensured with a simple XML language describing the input and/or output collection core objects of the readers, transformers and writers. The interface definitions are simple and thus transfer interfaces can easily be implemented for specific domain models.

MANAGEMENT COMPONENT

The management component basically realizes the integration of the diverse (partial) domain models into one unique information model ensuring the mapping characteristics of uniqueness. This is done by controlling the dependencies between original model (describing) elements and redundant clones (non-describing) using specific model element objects describing the links between dependant elements (Figure 3).

Within the aforementioned integrated model compound, the geotechnical information model is used as the internal operational core, i.e. it describes the entire structure of the overall model. However, it does not necessarily contain all model describing elements itself as origin. For practicability reasons (editing, responsibilities, etc.) it may contain clones of model describing elements, actually residing as original within external domain models.

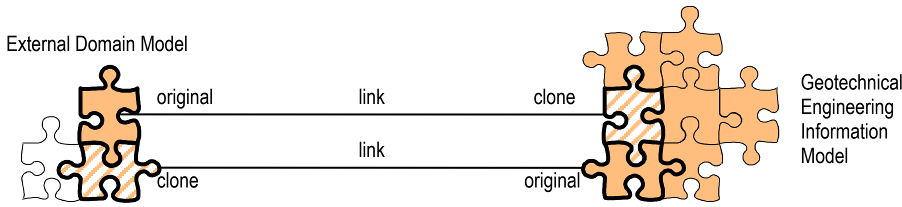

Figure 3: Model describing elements – original and clones

For linking the model element objects within the management component to appropriate elements of the transfer component, the geotechnical information model dynamically provides the meta information of its structure by the type and multiplicity of its object attributes and properties of relations between its objects (associated object types and multiplicities). With this structural information, appropriate writer interfaces for data import into the geotechnical information model and reader interfaces for data export[6] can be selected and together with transformer components transformation chains can be established.

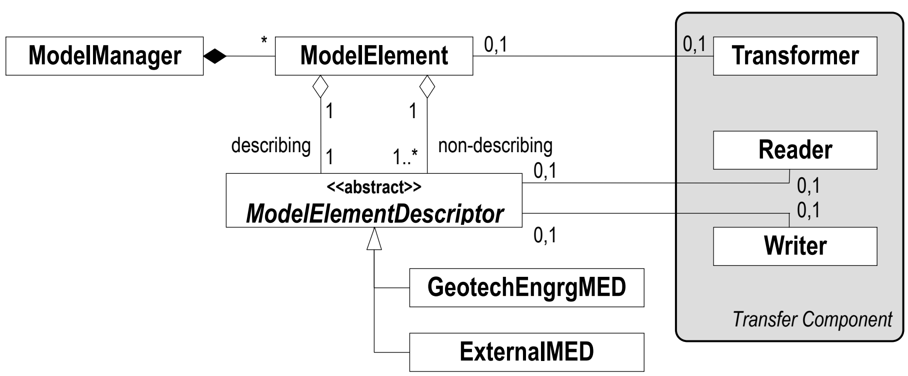

Figure 4: Elements of the management component

Basically, the management component provides a *ModelManager* that contains all managed *ModelElement*s of the geotechnical information model, i.e. all model elements that have a counterpart in an external domain model (see Figure 4). A (managed) *ModelElement* has one describing (either internal or external) and at least one non-describing (either external or internal respectively) representation. The actual representation is described by a *ModelElementDescriptor* (MED) which can be either a *GeotechnicalEngineeringMED* or an

[6] The semantics of "reading" and "writing" is defined from the view of the transfer component.

ExternalMED. The *GeotechnicalEngineeringMED* describes an element in the geotechnical information model (like *ConstructionObject*, *Property*, *Activity* …). An *ExternalMED* is a generalized description of an external model source, basically providing a URL for locating the model and a generalized format description. Interfacing to and from external model and geotechnical information model respectively is done by readers and writers from the transfer component, associated to accordant model element descriptors.

The following example demonstrates the principle of the transfer and management components. For setting up the aforementioned geotechnical information model various construction objects and according property objects have to be instantiated. In the information model an excavation pit's geometry is described by a depth value and a polygon, consisting of an ordered collection of points. CAD drawings usually provide this information in plan and section views. Figure 5 shows the principle of linking external model elements to the geotechnical engineering model.

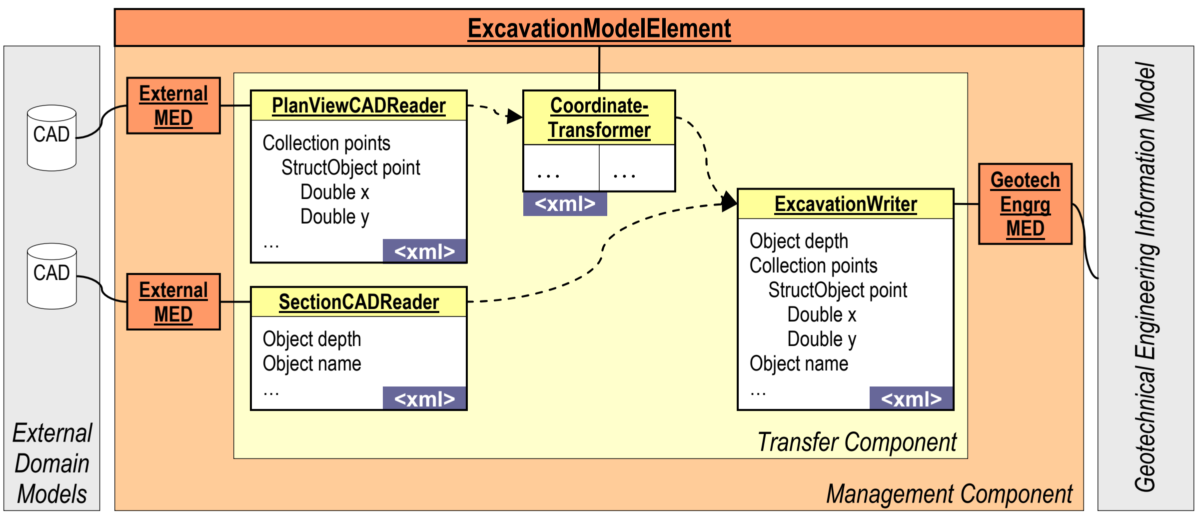

Figure 5: Principle of information management and transfer between diverse domain models

CONCLUSIONS

The approach to manage heterogeneous information for supporting regular construction and handling of emergency situations in geotechnical engineering with a multilevel management system has been outlined. The first level is used for loosely integrated information in document and file based information resources. The second level is the level of key information mapped in an information model. Both the information model and the resource management system are integrated in a web-based information management platform which has been tested in a pilot project. The pilot project provided important information for further development and improvement of model and system. Next steps include the implementation of customizable ontology and direct integration of measuring devices on site. This requires a reliable methodology for the integration of external model information into the presented geotechnical information model. A generalized approach for a model management combining different model describing elements into one overall model has been presented.

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