Network Based Co-operation Platform for Geotechnical Engineering

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Summary

This paper describes an approach to support co-operation of experts in heterogeneous geotechnical engineering project environments during both regular execution and handling of exceptional situations. A co-operation platform is introduced which is based on a generalized information model mapping key information about the construction project, the construction process as well as the organization structure. Several tools are provided to operate the information model in a network based environment.

1 Introduction

Engineering projects in geotechnical engineering, like tunnel driving in open excavations, require extensive co-operation of experts from different technical disciplines in distributed project environments. Web based working techniques and methods from modern information and communication technology are able to enhance this co-operation. As well as in other areas of civil and building engineering, design concepts in geotechnical engineering have to be adapted during execution. In geotechnical engineering, however, unforeseen problems and exceptional situations, such as the inflow of groundwater, are more likely to occur due to uncertainties of soil behavior. These exceptions may contravene with predefined construction sequences. They eventually require the setup of task forces, rapid decisions on short-term disaster handling, changes of construction sequences, and adaptations of supervisory, leadership and organizational structures within the project teams.

Current joint research activities in Cottbus and Berlin aim at the development and validation of an information base for the support of both regular construction and handling of exceptional situations. The basic approach is to create a generalized information model which provides only key information covering the whole execution of the construction project and to design appropriate tools and integrate them into a network based co-operation environment.

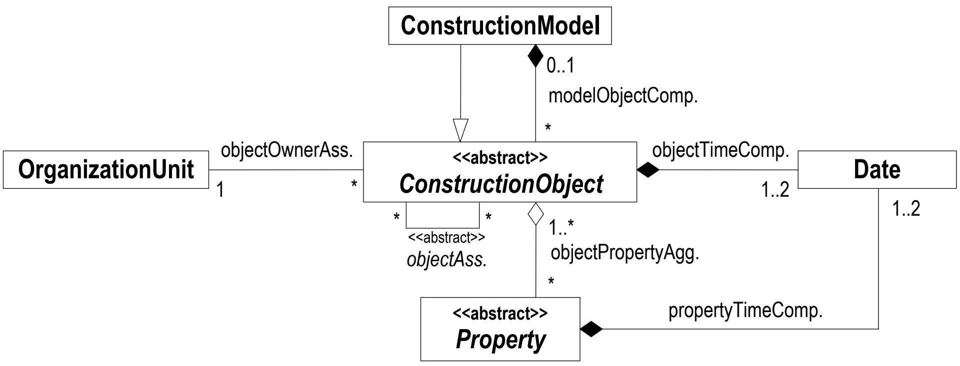
From around 1990 till now a lot of trough excavations (wall slab constructions) have been built in the central part of Berlin, in particular in the Potsdamer Platz area and the Lehrter Bahnhof site. In order to identify key information various trough excavations have been evaluated and analysed regarding both regular day-to-day work as well as damage events. Since in case of damage events assessment and determination of causes have primary significance, information concerning construction parameters and their measurement has been evaluated primarily. Among others the following sources of information have been used: construction documents such as construction logs for quality assurance, interviews with construction supervisors and site managers, German and European codes for geotechnical engineering, recent literature concerning trough excavations.

2 Information Model Type

The information model type for mapping information relevant for handling of exceptional situations follows an object oriented approach and is described with the modeling language UML. The abstract generalized model type consists of three components. They represent the so-called construction objects of the project, the construction process, and the organizational structure.

2.1 Construction Object Model Component

Construction objects are structural components, measuring devices, construction equipment, site facilities, and machines of the construction project as well as objects directly or indirectly interfering with the project like neighboring buildings or soil and groundwater bodies. A class hierarchy has been created to model typical geotechnical engineering construction objects like excavation, slotted wall, anchor, gauge, and pump. The properties of the construction objects are modeled separately with specialized property classes resulting in a highly flexible and adaptable information model. Property objects provide information about the planning and execution states of construction objects.



Association	Description
constructionmodelConstructionobjectComposition	Composition of construction objects in a construction model. Constraint: Although a construction model is a construction object, it is not a composed part.
constructionobjectTimeComposition	Association for mapping temporal validity of a construction object
propertyTimeComposition	Association for mapping temporal validity of a property object
constructionobjectPropertyAggregation	Association between construction objects and their properties
constructionobjectOwnerAssociation	Responsibility relation between construction object and organization unit
constructionobjectAssociation	Abstract association for mapping construction object topologies (has to be specialized for specialized construction object types)

Figure 1: Generalized construction object property model

Each construction object is part of a construction model. The construction model serves as a central model element and manages all construction objects. The construction object's temporal validity is given by an association to one ore two dates. The validity begins with the object's initialization. The time of initialization may not be before the model's initialization date. The construction object becomes invalid if the cardinality of the construction object time association equals two. That means no further changes of the construction object and its properties are allowed. Despite its invalidity the construction object must not be removed. It remains within the model for documentation purposes. The property's temporal validity is realized analogously.

In terms of object responsibility an association between construction object and organization unit exists. Responsibilities for the execution of building processes are modeled separately as described in the next chapter. The association between construction objects themselves is an abstract association mapping topological dependencies between specific construction objects. For concrete objects they are specialized explicitly. An example for specialized construction object types with their relations (specializations of the abstract construction object association) is shown in the following class diagram (Figure 2).

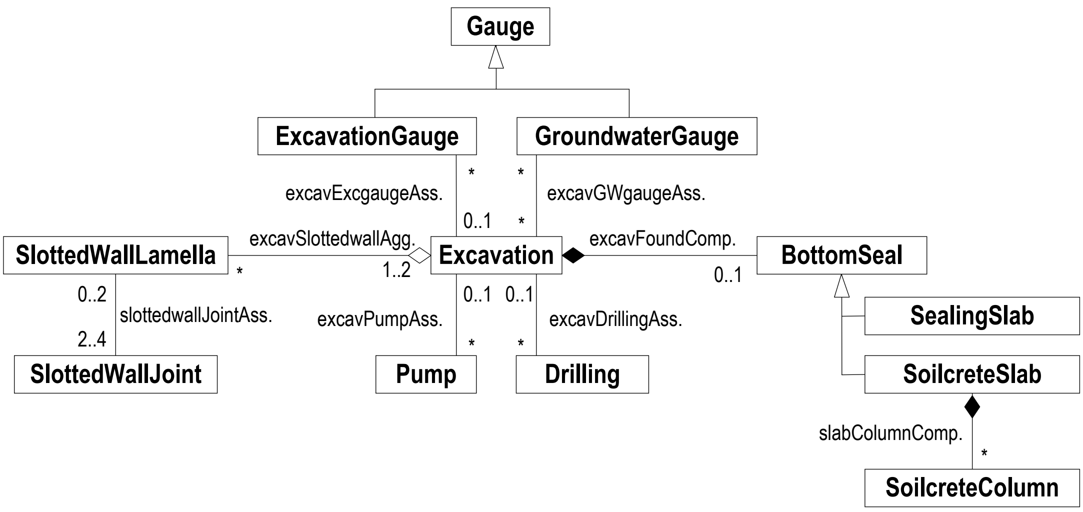


Figure 2: Specialized construction object types and their relations

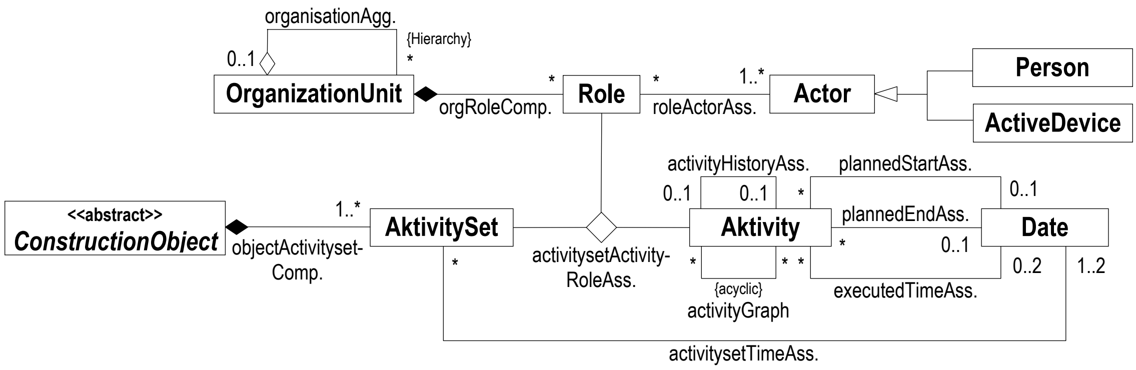
The first degree of specialization of the class property leads to the abstract classes geometry, material, mechanics, and construction. Geometrical properties describe position and extend of construction objects. The main focus on modeling properties lies on geometrical properties due to their relevance for the assessment of execution processes. They are divided into "primitive", universal geometries (point, line, polygon, polygonal prism, cuboid, …, also altitude for mapping geodetic altitudes) and complex, construction object specific geometries. In case of structural components (slotted wall, excavation, soilcrete slab, …) they map target and actual values of relevant geometrical information and define methods for comparison of target and actual values.

Material properties describe different materials with their parameters, like soil character or strength of material. The materials soil, concrete, cement slurry and steels have been modeled. Mechanical properties map stress and internal forces, in case of construction equipment and machines also their characteristic values. Construction properties give information about applied construction methods, norms, execution, and construction details. For the construction object type slotted wall for instance there is a construction property which describes the wall's execution in relation to other walls ("beginning", "running", and "closing"). In conjunction with the slotted wall joint's construction property (shuttering pipe, precast concrete element, flat joint element, joint tape) they influence the slotted wall's geometric property (like for instance the expected quantity of concrete).

In the generalized model type the property is associated to the construction object. Specialized construction objects are responsible for initializing necessary type specific properties. Necessary properties for a soilcrete column are for instance the soilcrete column geometry, a material property for the cement slurry, the target strength, the kind of execution, stress values (water pressure), and an item number.

2.2 Construction Process Model Component

Construction processes are mapped with activities and relations between them. Process states are not modeled explicitly since they can be derived from the knowledge of already and not yet executed activities.



Association	Description
plannedActivityStartTimeAssociation	Association of an activity to its date of earliest possible begin
plannedActivityEndTimeAssociation	Association of an activity to its date of latest possible end
executedActivityTimeAssociation	Association between an activity an zero to two execution dates
activityHistoryAssociation	Association between activities reflecting history of plan changes (substitution of activities)
activitysetActivityRoleAssociation	Ternary association between construction objects' activity sets, activities, and executing/responsible roles
constructionobjectActivitysetComposition	Assignment of activity sets to a construction object
activitysetTimeAssociation	Association mapping the temporal validity of activity sets
activityGraph	Set of directed edges of acyclic activity graph for mapping construction process

Figure 3: Process and organization model components

An activity is associated to two dates which represent in terms of critical path network earliest possible begin and latest possible end of execution. Furthermore an activity has a description and a planned duration of execution. Deducible values are dates of latest possible end and earliest possible begin. Zero to two other dates document the activity's actual execution. With no execution date associated the activity is in planned state (not yet started). One associated date makes it a running activity (commenced but not yet terminated). Completely executed is an activity when two execution dates are associated to it. In conjunction with the activity graph described later in this chapter a complete control and survey of the construction process is possible. Other properties are implicitly included in this model and can be generated automatically applying set algorithms and thus are documentable: the actual duration of execution, potential buffers in execution times, and delays of construction.

The documentation of plan changes can be relevant for the handling of exceptional situations. Hence no temporal and organizational changes on activities are allowed in this model. If an activity is affected by a plan change, a new activity is instantiated as a copy with adapted properties. The superseded activity is marked invalid and associated to the superseding one. This association provides former planned states for evaluation and assessment of exceptional situations.

The temporal sequence of activities is modeled by a directed acyclic graph. The graph contains all valid activities of the construction process with their predecessor/successor relations. In conjunction with the activities' planned times of execution the graph allows for the usual temporal operations on execution times, though activities already executed must not be changed. In conjunction with the activities' actual times of execution the temporal tracing and control of the construction process is realized. It is possible to determine which activities can/shall start, which activities are blocked by predecessors and which activities can/shall end.

While the activity graph contains all valid activities of the whole process, a so-called activity set contains all (valid and invalid) activities of a construction object. In analogy to activities activity sets are marked invalid under certain circumstances (plan changes, exceptional situations, …). However, for documentation purposes they are kept and superseded by new instances. Each construction object has exactly one valid activity set and any desired number of invalid ones. An activity set has one or two dates associated to it with the first date giving its begin of validity and the second one its end of validity, thus representing an invalid activity set. For the substitution of an activity set by a new instance the following rules apply:

1. The currently valid activity set becomes invalid and a new (valid) instance gets associated to the construction object.
2. For each activity of the old activity set:
   - If the activity is already executed, the same activity is added to the new set.
   - If the activity is currently running, a copy of the activity is added to the new set with both planned and actual start time of execution set to the planned start time of the primary activity. The original activity becomes invalid and associated to its successor via the plan history association.
   - If the activity is not started yet, the new set gets a copy of the original activity with all its properties. The original activity becomes invalid and associated to its successor via the plan history association.
3. For the activity graph all invalid activities are replaced by their valid successors.

Following the creation of a new activity set new activities may be added to it, for instance predefined procedures in case of an exception. A new scheduling may be necessary which can be done individually for each activity or automatically with the activity network.

An activity affects at least one construction object and is executed by at least one actor in a specific role. This is modeled with a ternary association between activities, roles and the construction objects' activity sets.

2.3 Organization Model Component

The organizational structure within a construction project is modeled widely independent from the other model parts. The organization model component is capable of mapping the prevalent organizational and responsibility structures of building sites.

The hierarchic structures, as determined by contracts, are represented with organization units. They can be real (company, division, department) as well as virtual units (joint venture, …). For one building project there can be several organization hierarchies independent from each other.

An organization unit is responsible for defining roles (project manager, foreman, worker, …). A role is associated to one actor or a group of actors who fill in this role. Activities at or with construction objects are executed by actors in a certain role. Since an actor can participate in different activities, a role serves as the context specific assignment of actor to activity, though differentiating between responsible and executing action. The specializations of an actor are human person and non human actor, the latter one being an autonomously acting device, e.g. for automatic recording and evaluation of measured data.

Figure 3 shows the class diagram of the process and organization model components. The organization model's relations are summarized in the table of Figure 4.

Association	**Description**
organisationAggregation	Association for mapping hierarchic organization structures
organisationRoleComposition	Relation between organization units and their roles
roleActorAssociation	Assignment of actors to specific roles.
contactableContactAssociation	Association for assignment of contact information to organization units, roles, and actors

Figure 4: Relations within the organization model component

3 Implementation Issues

The designed information model type as well as model tools and editors for presentation and processing of the information model have been implemented with their basic functionalities and verified exemplarily.

To meet the requirements for a flexible information management and an easy navigation within an existing model, the object relations are mapped explicitly. For this purpose an association model was implemented. It contains all 16 relations from the generalized model type as well as all specializations of the abstract construction object association mapping the construction object topology.

Object relations are implemented consistently by means of association objects. An association object is defined by the relation's arity as well as the roles, multiplicities, and types of the linked object sets. Corresponding to the arity it contains the ordered n-tuples of linked objects. The semantic restrictions of aggregations (whole-parts-hierarchy) and compositions (parts depending on existence of aggregate) are respected in specialized aggregation and composition objects.

The explicit mapping of object relations offers several advantages for information management:

- The information model's consistency is checked continuously by means of cardinalities.
- Type safe object relations are enforced.
- Manifold navigation and selection mechanisms are provided by operations on the set of associations as well as on the set of the associations' objects. Selection criterions take into account association roles, object types, objects and attributes. The latter ones can be evaluated by so-called selectors.
- The implemented classes are widely detached, hence better adaptable and extensible than classes with relations contained implicitly.
- Additional relations can be added without interference with existing classes. Thus distributed models can be combined easily.

4 Co-operation Platform

The co-operation platform for geotechnical engineering operates on the underlying information model and its linked models from involved disciplines. The platform provides several tools and editors classifiable into the following categories:

Tools and editors for construction object information. They handle the type specific properties of construction objects and their topologic dependencies. These tools provide continuous comparison of target and actual values on construction object base. A modular structure of these tools allows for an easy combination of desired tools and implementation for other type specific properties. A so-called graphical navigator as the central information editor plays the role as an overview component for the entire information model. It provides a representation of the construction project with its construction objects in a schematic form. This allows for a quick information retrieval and the recognition of spatial and temporal bearings to the user. The temporal context is displayed by a variable time control based on the current model time and an adjustable presentation time. Thus the construction project information is accessible for any planning and execution state with the respective property, organization, and process information providing means of documentation.

Tools and editors for process information. This group of tools is designed for tracing, control and editing of construction process information.

Tools and editors for organization information. They make organization hierarchies visible and editable easily. The definition and assignment of roles to their organization units as well as roles to actors and activities is made possible. Contact information assigned to organization units, roles and actors (persons) can be edited and instantly applied for the setup of communication channels (email, SMS, net based telephony). Links to construction object and process information are navigable.

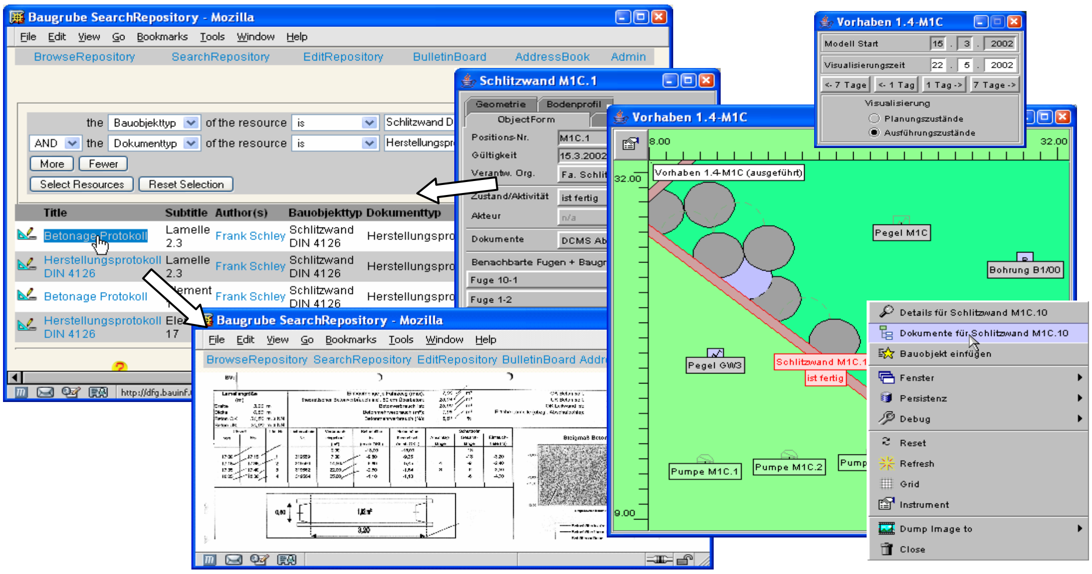


Figure 5: Graphical information navigator and other model editors

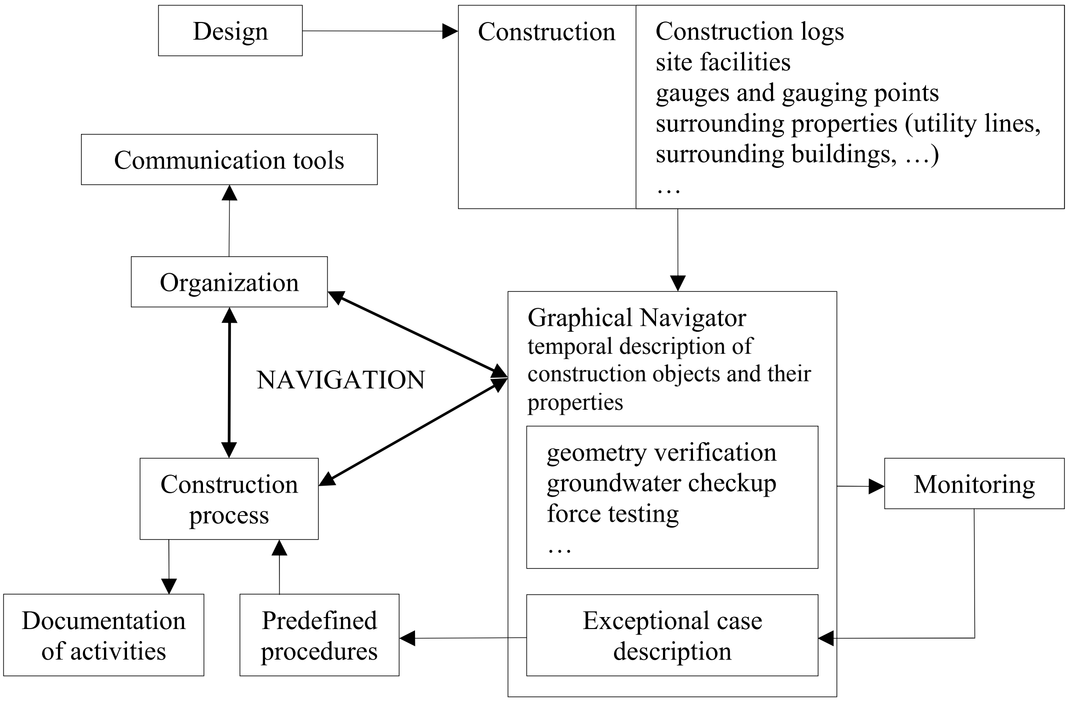


Figure 6: Flow of information in co-operation platform

Net based communication and co-operation tools. They include ICT based notification systems and mobile terminals for the access to the information model in a distributed environment.

Tools for connections to distributed external resources. By means of these tools measured data, drawing and design information are assimilated into the information model. Interfaces to other models are utilized where appropriate. Information contained in documents are linked to the model via a resource management tool (DCMS). It manages an arbitrary number of documents over the Internet by referring and marking them up with standard and project specific semantic markup types. Basic functionalities are search mechanisms, document browsing, integrated document visualisation, bulletin board communication, and possibilities to introduce new documents to be managed within the DCMS.

5 Conclusions

The information model and the model editors allow for their application in various scenarios during both regular construction and handling of exceptional situations. During regular construction it shall serve as the common information base for involved actors. It provides information about the execution process and the current, previous and planned state of several construction objects as well as the whole construction project. During exceptional situations it allows for an efficient and comprehensible decision making process involving all concerned actors. In addition to the possibility to sum up the situation quickly, decision makers can gather information about other possibly affected parts of the construction, the execution history of affected parts; they can analyze measured values and execution logs, evaluate possibly predefined measures and finally make decisions co-operatively about immediate measures.

The benefits of the network based co-operation environment lie in an improved and reliable shared access of key information in general and in a more precise problem identification, coupled with a more efficient, transparent, and time critical decision support in a close co-operation of all relevant experts. The underlying information model comprehensibly, consistently, and entirely maps the construction project, the building process and the organizational structure.

6 Acknowledgements

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