A data model for construction pits

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Modelling construction pits is time consuming and error prone. Information must be entered explicitly and checked manually. Data models are used to describe elements of a certain domain and relationships between them. To improve the modelling process a data model for construction pits has been developed. It captures foundation engineering structures and enables automatic model generation. The data model is implemented as C# class library and the resulting Building Information Modeling (BIM) models are generated using a plugin for Autodesk Revit. Based on the data model, knowledge based engineering (KBE) was introduced to support the modelling process, namely the Rete algorithm. Real-world tests were conducted, where the supported modelling process proved superior to traditional human design regarding design times and quality.

Keywords: construction pits, BIM, data models, knowledge based engineering

1 Introduction

BIM is changing and disrupting the architecture, engineering and construction (AEC) industry. The method has proven to be successful and has many advantages for all stakeholders. The BIM model is the heart of the method. Model quality defines the geometric and the informational detailing. In order to assure model quality, model checks are usually made in the planning and construction process.

Compared to other domains in the AEC industry the modelling process in foundation engineering is time consuming and error prone. Minor changes in the design can lead to high modelling efforts. The information in a model has to be defined and later checked explicitly by the designing engineer. Using a data model will improve these processes.

With a more efficient and intuitive modelling process the designing engineer is able to explore more variants and design an overall better solution. This leads to the following question: Can the modelling process for construction pits be supported by expert systems and if so, are there measurable advantages?

Using data models will help support the modelling process. Knowledge is implemented within the data model and allows its users to access and use the implicitly embedded knowledge. Furthermore, the instance of the data model is checked against a set of rules using an expert system. Since currently there is no data model for foundation engineering, a first step is to develop one.

The domain of construction pits within the domain of foundation engineering is very suitable as a proof of concept. Construction pits have no aesthetic requirements and are functional.

Their design is derived from the external constraints such as geology, water conditions and depth. They are composed of a combination of single elements. The amount of geometricly different elements is quite low and can be developed as a parametric element catalogue.

This paper begins with an overview of the related work that has been done. After a general introduction to the work done in the fields of parametric design and automated model generation the topics of data models and knowledge-based engineering (section 3) are described more thoroughly. In section 4 the case study of construction pits includes an overview of construction pit elements (subsection 4.1) and their relations (subsection 4.2) as well as the developed data model. A discussion can be found in section 5 followed by conclusions in section 6.

2 Related Work

Currently, many topics in the field of automated generation of models are already being applied in the construction industry. A basis for this are parametric components. Parametric components allow the user to control the geometry of the component via individual parameters (Shah and Mäntylä, 2019). This automates the modification process of the part. Geometric properties such as the length of a component can be modified via parameters. The basis for parametric components is the mapping of the geometry as a result of dependencies and conditions. In contrast to saving explicit geometry, where all coordinate points of the geometry are saved, saving parametric geometry saves implicit graph to create the geometry. When creating parametric components, construction knowledge about the components is required. Park (2011) describes how design knowledge can be anchored in a parametric object catalogue and thus shared with many users.

This implicit graph contains procedural steps, which describe the individual steps to be performed to obtain the resulting geometry. The inter dependencies of the components are mapped in a system of equations. According to Schultz et al. (2017), these dependencies consist of distances, angles or one of the following geometric conditions: coincident, co-linear, tangential, horizontal, vertical, parallel, perpendicular, or fixed. The system of equations is then solved by a geometric constraint solver (GCS) and the component is created (Fudos and Hoffmann, 2004). If the system of equations is not solvable, this indicates non-logical procedural steps.

By combining several parametric components, a partially automated model generation is implemented. In civil engineering this has already been already applied by the use of scripts. Software solutions such as Grasshopper for Robert McNeel and Associates Rhino[1] or Dynamo for Autodesk Revit[2] offer visual programming language (VPL) interfaces for creating such scripts. According to Ritter et al. (2015), VPLs are a simple way to customise solutions. By creating scripts, components are placed automatically according to certain rules, e.g. along a defined route. This automation is repeated any number of times with different input values. If the boundary conditions are the same, the result remains the same.

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[1] `https://www.rhino3d.com/`

[2] `https://www.autodesk.com/products/revit/overview`

Another application for semi-automated model generation is the post-modelling of two-dimensional planning documents. In the transition from conventional to BIM-based planning, the recognition of components and information in two-dimensional plans is interesting. Komorowski and Berkhahn (2004) present a neural Kohonen network, which serves the classification of components in plans. A model is then generated from the information obtained.

Vilgertshofer and Borrmann (2018) describe the automatic generation of a segment tunnel using graph theory. The aim is to support and automate the detailing of components with the help of a graph. The individual components are represented as nodes in a graph. In order to achieve a higher level of detail, a node in the graph, which represents a part of the entire component, is replaced by a subgraph. By rewriting the graph the primary rough model is refined step by step.

With the help of previous knowledge about the domain, the automatic model generation is implemented. This approach is summarised under the term knowledge-based modelling or expert system. The functionality and architecture of an expert system is described in Tripathi (2011).

3 Data models & knowledge-based engineering

Data models are used to store and organise data. A data model consists of entities and their relationships. An entity can have different attributes. Conditions and relationships can be checked within a data model. Since data is stored in a structured way, it allows to use KBE.

Data models for certain domains already exist in the AEC. Many authoring software use non-standard and native formats for storing BIM models. Not only the individual geometric elements are captured, but also the relationship to other geometric and non geometric elements. The industry foundation classes (IFC) ISO 16739 (2018) are an open and standardised format, which represents many entities and associations of building construction. The IFC model contains implicit knowledge. For example in the spatial structure of IfcWindow: a window is located within a wall. In the course of further standardisation in the construction industry, the IFC format is also extended (*IFC-Bridge - IFCINFRA*, 2019).

An example of the relationships between the components used in a construction pit is found in a bored pile wall. A bored pile wall consists of several bored piles. Since each bored pile is individually produced and documented, this granularity is indispensable. The individual bored piles are present in the model. However, the context of the bored piles is derived from the bored pile wall. The distance of the individual bored piles along the wall axis is defined by the axis distance. A change in the axis distance results in a change in the number of bored piles in the retaining wall. This information can not be derived from the individual bored pile, it becomes available in the context of the bored pile wall. This is only one of many examples of topological relationships of objects used in construction pits.

The acquisition of an construction pit in a data model offers enormous advantages for the creation, modification and testing of models. Furthermore, it is a first step towards a future partial or full automatic model generation. With automatic model generation, all boundary conditions are recorded in a machine-readable way, in addition to the rules of technology (standards, …). An optimal solution for the construction pit is then derived from the boundary conditions. In order to implement this, however, preparatory work still has to be done. A first step is the investigation of KBE, a branch of artificial intelligence. KBE refers to expert systems that access a knowledge database to solve complex problems. Expert systems consist of several components. In Singer (2014) an exact explanation of the individual components is given.

The extensive and interdisciplinary expert knowledge is recorded in a knowledge database. The knowledge needs to be transformed into a set of rules. This transformation usually works with the help of a knowledge transformer. The knowledge transformer does not possess domain-specific knowledge, but is able to map the rules within the knowledge-based system.

An automated alternative to manual knowledge transformation is the development of a knowledge acquisition interface. The knowledge acquisition interface replaces the knowledge transformer by automatically acquiring and transforming knowledge into rules. An automated acquisition of new knowledge is essential for the future administration of the knowledge database. The advantages are presented in Vlaanderen (1990). The interface should be intuitive and user-friendly. A VPL offers these features and can help transform knowledge into rules. In Ritter et al. (2015) the abstract representation is mentioned as an advantage of a VPL for persons without programming knowledge.

4 Case Study: Construction Pits

By the year 2050, 68 % of the world's population is projected to live in urban areas (*World Urbanization Prospects: The 2018 Revision*, 2018), making space a valuable asset. To create more, buildings do not only rise higher above the ground, but also reach deeper into the soil, relying on deep construction pits. Construction pits protect the construction from the surrounding ground and water, as well as they transfer loads. The planning and construction of construction pits is a complex task that combines competencies from various disciplines. Construction pits have no aesthetic aspect and are functional. The solution is derived from the various external constraints such as geology, final depth or water conditions.

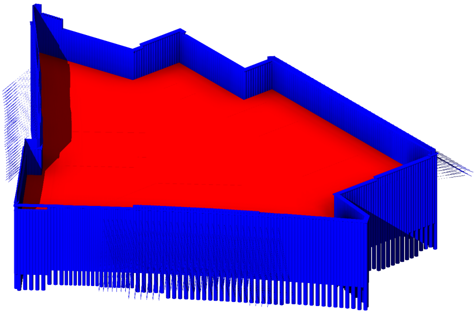


Figure 1: Foundation (red) and sheeting (blue)

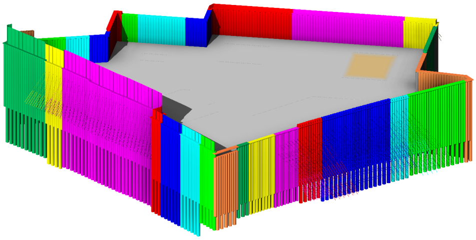
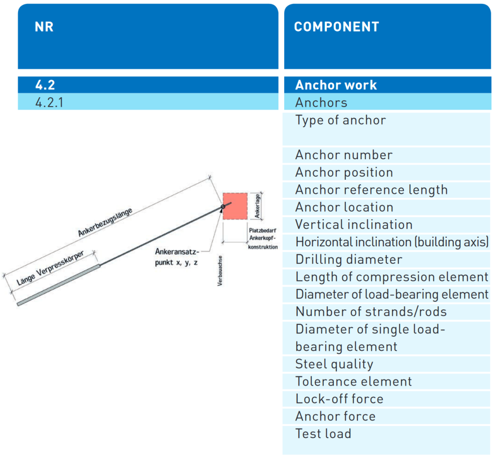


Figure 2: Different cross section types colour coded

A construction pit can be divided into foundation and sheeting (see Figure 1). Only the components of the sheeting were considered in this work. The sheeting consists of a combination of different components. Since the components do not vary excessively in form and function, the requirements are defined in a standardised way. Appendix 1 of *BIM in ground engineering* (2017) contains a list of objects in foundation engineering. The construction components (e.g. anchor, pile, ...) are combined and thus form the BIM model of the construction pit. The small number of components used in foundation engineering offers an optimal prerequisite for creating an object catalogue. In addition, the creation and management of such an object catalogue is greatly simplified by the standardised requirements on geometry and properties of the components.



NR	COMPONENT
4.2	**Anchor work**
4.2.1	Anchors
	Type of anchor
	Anchor number
	Anchor position
	Anchor reference length
	Anchor location
	Vertical inclination
	Horizontal inclination (building axis)
	Drilling diameter
	Length of compression element
	Diameter of load-bearing element
	Number of strands/rods
	Diameter of single load-bearing element
	Steel quality
	Tolerance element
	Lock-off force
	Anchor force
	Test load

Figure 3: Example: Anchor work and its associated properties from *BIM in ground engineering* (2017)

4.1 Objects

Six types of retaining walls were investigated in this work. In the future a more extensive examination will be possible. The structure of the combination of individual components as well as the classification into sheeting and foundation will not change. Table 1 lists the six types of retaining wall considered and two typical combinations in foundation engineering, also displaying the individual components required. The individual components are not part of the data model, but are visualised using the modelling software. The components exist in Implenia[3]'s object catalogue and could be used for this work. The data model is shown in Figure 5. The dark blue entities were treated in this paper. This is a pitfall-specific BIM data model.

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[3] `https://www.implenia.com/`

Lagging wall	- Beam - Bracing - Beam base
Pile wall	- Pile
Sheet pile wall	- Sheet
Slurry wall	- Slurry wall barrette
In-situ wall	- Shotcreting wall - Anchor
Anchorage layer	- Anchor
Combination: Pile wall & anchorage layer	- Pile - Anchor
Combination: Lagging & pile wall	- Beam - Bracing - Pile

Table 1: Investigated components

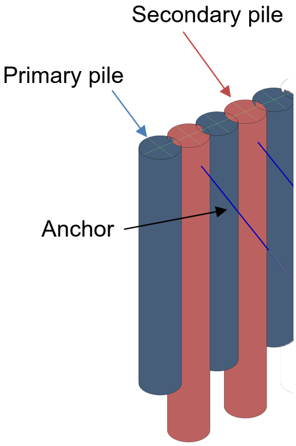

Figure 4: Visualisation of pile wall & anchorage layer

4.2 Relationships

As seen in Figure 2, the sheeting contains several elements of the cross section entity. As shown in Table 1, each cross section can consist of a combination of different retaining wall types. From the entity retaining wall, the subtypes anchorage layer, in-situ wall, lagging wall, pile wall, sheet pile wall and slurry wall inherit attributes and extend them. In Figure 4, the individual elements of an anchored pile wall were generated in the modelling software based on the design parameters from the data in the data model. The generation routines and data model were implemented in C#. A user interface was build, which resulted in a plugin for Autodesk Revit.

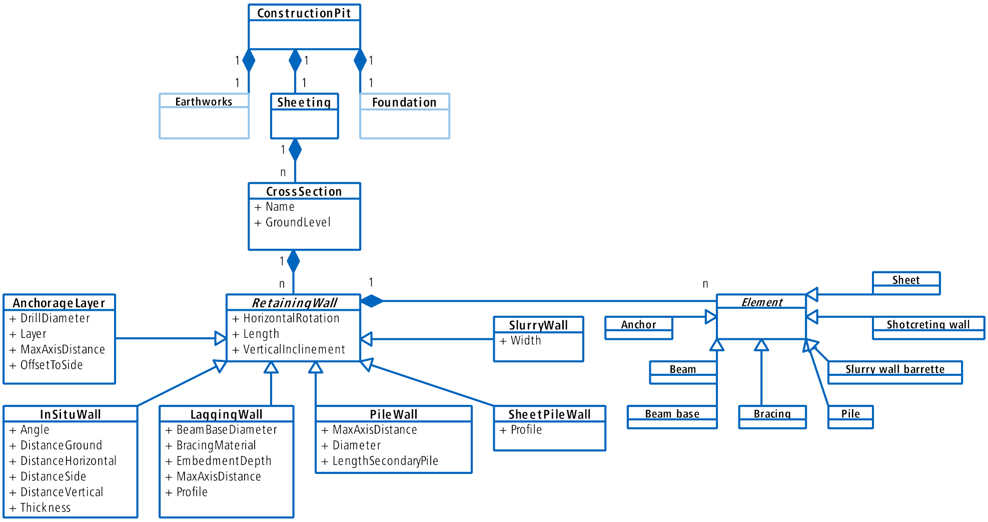

Figure 5: Developed data model for construction pits (Stauch, 2019)

5 Discussion

For the implementation, the components of the foundation engineering were first examined. Here a restriction was made and not all components, but a selection of sheeting components was selected. The investigation was mainly concerned with the topological structure of the components. An investigation of the component requirements, their structure and parametric has already been carried out at Implenia and has been incorporated into the existing object catalogue. Likewise, requirements for the information in the model are already described in *BIM in ground engineering* (2017). As a result of the investigation, a data model has been developed which maps the topological structure (subsection 4.2). This data model was implemented as a class library and the model generation from the data model was developed. The expert system was implemented based on the Rete algorithm. The Rete algorithm is described in Forgy (1990) and is a pattern matching algorithm. For the implementation the open-source solution NRules[4] was used.

In order to create a comparability between the model quality an objective evaluation method was presented. This method is derived from the intended use cases and the errors in the model. With the help of this evaluation method it was possible to make a comparison between the model quality of a model with and without support. In addition to the model quality, the modelling speed was also measured in order to determine an indicator of the time required.

The result of the comparison between a supported modelling and without it shows a significant increase of the modelling speed. The models are modelled up to five times faster. This results in models of the same or better quality. In the future, the use of a more complex, real model would have to be investigated. This makes it possible to observe to what extent subsequent changes in the design affect the modelling process. The support of the modelling process could bring enormous advantages in the administration of the changes to a section. The use of knowledge-based methods is possible and useful. The chosen algorithm is suitable for this. The required data is also implemented in the data model and is used for testing. The refinement of the rule set is possible by translating explicit, but above all implicit knowledge into further rules. To simplify the acquisition of knowledge, the possibility of a rule definition with visual programming language should be investigated.

For the investigation, only a small part of knowledge about the domain of foundation engineering could be recorded in the knowledge database. In the future it should be further investigated how knowledge can be captured and formalised. In particular, knowledge from design rules and regulations is usually already formally recorded and explicitly available. Such knowledge has already been examined in Luo and Gong (2014). A further investigation of automated model generation on the basis of boundary conditions is also interesting. In the long run, an automatic testing and adaptation of components to their boundary conditions would be interesting. For this purpose, however, they must be machine-readable.

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[4] `http://nrules.net`

6 Conclusions

Data models are used to model knowledge. Knowledge is mapped in the data model's entities, attributes and associations. Expert systems are able to check a data model against a set of rules. This process supports the user by automatically checking entered data against a rule set. Additional knowledge is made available in the form of a rule set.

For the domain of foundation engineering a case study has been done, to prove that a data model can be developed and checked against a rule set. Objects and relationships of construction pits have been modelled in a data model. Knowledge from the domain was mapped in the data model. The data model was implemented as C# library. From an instance of the data model a BIM model can be derived using a modelling software. The necessary functions to interpret the data model have been implemented. The model generation can be done semi-automatic. Modifications of the construction pit can be done on the data model and then imported and updated in the BIM model.

6.1 Acknowledgements

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[5] `https://www.implenia.com/`

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