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PATTERN-BASED GENERATION OF 4D-SCHEDULES FOR ROBUST CONSTRUCTION MANAGEMENT

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Abstract: The creation of construction schedules is a time-consuming manual process. While project planning depends on many tasks and parameters, the quality of schedules highly relates on the engineers' experience and the access to reliable, historical project data. While knowledge applied from software can assist an engineer, the main shortcoming of current tools is the separation in generating building information and construction process models. Proposed is a knowledge-based system that automatically generates 4D-schedules based on building information models. Patterns are used to generate a process model for repetitive work flows, such as placing formwork, reinforcing, and concreting. Pattern-enriched attributes, i.e. the topology of the building structure, are automatically applied to objects in the model. Resource allocation, such as varying the performance factors or the amount of work crews, becomes possible. Such analysis can still be evaluated and exported in the format of traditional Gantt-diagrams or color-coded 4D-schedules and the construction process model can be used for detailed scheduling, construction time control, and time-based quantity evaluations. The developed approach was validated for the concreting work of a 12-story tall office building under construction. Preliminary results indicate gains in accuracy and efficiency of the developed approach compared to the traditional scheduling process.

Keywords: 4D, construction schedules, Building Information Modelling (BIM), simulation.

1 INTRODUCTION

Construction projects are complex because of the involvement of the many trades that are working rather independently than jointly and the dynamic nature during project execution on site. The success of projects often depends on good planning and coordinating of a variety of important aspects upfront or before a project goes into the construction phase (Faniran et al. 1999). Modelling and simulation of construction processes have become a common practice in many organizations outside construction. They help in reducing project-related risks. Examples in projects are concerning budget, time, and quality (Song et al. 2006, Abourizk et al. 1992).

Though a detailed analysis of the complex processes in construction is not a common practice in many construction organizations, other industries, like the manufacturing industry, have realized its potential to improve productivity and efficiency (Tam et al. 2007).

Therefore, thorough process analysis needs to be done also in construction and beforehand any change can be implemented. Researchers argue that one of the most

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important aspects in the development of good simulation models that intend on improving construction efficiency, is to describe the dependencies between construction processes with realistic data (Halpin and Riggs 1992). Other experts say, construction process simulation or planning rarely happens in the field, because of little to no availability of realistic input or as-is data (Mikulakova et al. 2010, Günthner and Borrmann 2011).

On the other hand, the recent efforts in bringing digitalization to the construction industry and the application of modern information technologies to manual processes offer great potential for improving the mostly manual construction processes. According to Eastman et al. (2011), “BIM is one of the most promising developments in architecture, engineering, and construction (AEC) industries. With the BIM technology, an accurate virtual model of a building can be digitally constructed.” BIM-based risk management, clash detection, cost estimation, and 4D simulation have now become established features to support construction project management (Hartmann et al. 2012). BIM spans previously separated processes and serves the design, planning, and execution and all of its other phases (i.e., operation and maintenance) of projects (Borrmann et al. 2015). Though te current state-of-the-art in BIM methods envisions better planning, analysis, and control than existing manual processes, many organizations still struggle with its implementation (Melzner et al 2013).

The proposed methodology intends on improving the level of implementation of BIM by making field-ready application more practical. The following work contributes to the body of existing work the automatic generation of construction schedules by linking the advancements of object-oriented Building Information Modelling (BIM) and process patterns.

2 BACKGROUND

2.1 Building Information Modelling

The application of the Building Information Modelling (BIM) method is a worldwide trend in the construction industry. It is used to increase collaboration and flow of information ultimately leading to gains in productivity, reduction of project-related risks. Compared to traditionally ways of designing and planning a building project which mostly apply PDF file formats (i.g., 2D drawings and schedules) for the communication and documentation of information, BIM uses 3D-enabled information models. These contain objects with a rich set of properties. BIM allows a variety of applications such as trade coordination (i.e., via clash-detection), quantity take-offs, cost estimation as well as visualisation of construction sequences (often referred to 4D schedules) (Hanff 2014).

One of the major tasks during construction planning is to develop a project specific schedule. Many factors influence the process of scheduling. These factors are, for example, the number of available work crews, their performances factors, and the preferred choice of available construction methods. A construction schedule also shows the chronological sequence of operations organized at different levels of detail according to the considered project phases. Three levels of detail are normally used: framework schedule, coordination schedule, and detailed flowchart. The presented approach can be applied in all project phases.

2.2 4D-Scheduling

Schedules are displayed in most cases as bar charts (aka. Gantt chart). For large projects, Gantt charts are not very easy to understand. Comprehending the dependencies between the individual activities is often not obvious. To schedule the sequential flow and relationships between the activities so-called 4D-scheduling software programs or tools are used. Objects of a 3D model relating to an activity then are linked to the construction schedule (Figure 1). The planned sequence of erection the building can now be shown in a time-dependent visualization.

An observed advantage of 4D-visualizations is the communication between project participants. Furthermore, mistakes can easier be detected than in the numerous bars of a Gantt chart. Nevertheless, the creation of a 4D schedules or animated visualizations is not a standard practice on every project and neither required for tendering nor during the construction phase of a project. As researchers pointed out, input (as-planned) and feedback (as-is) data is crucial for planning realistic construction schedules (Huhnt et al 2010).

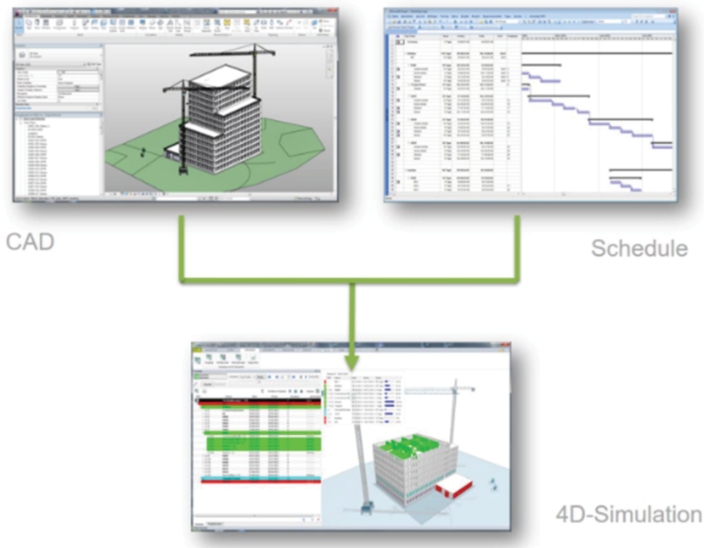


Figure 1: Method of traditional 4D-scheduling

2.3 Current Shortcomings

Construction planning includes scheduling and sequencing taking in consideration time and spatial constraints of a project. Traditionally, Gantt charts were used to plan construction activities. However, often single tools for such purpose do not cover the spatial conditions and mostly do not consider the project specific quantities. It is often the personal experience of the scheduler that comes into play as the most important factor for the quality of the final schedule.

In construction projects it is common that creating drawings, schedules, and estimates are separated planning tasks. Same or very similar data is needed for each of the task. Current 4D scheduling approaches separate the generation of a 3D model and the schedule. Both data sets are fused manually afterwards to create a 4D-schedule.

The developed approach automates this process by linking the building information model with process patterns and topological building structure. It guarantees a consistent schedule on a very high level of detail and quality.

3 METHODOLOGY

Construction companies, in particular smaller or medium business enterprises (SMEs) are typically one-of-a-kind businesses. Every building is built at once. Therefore, for simulation the construction processes, the model, including any of the input data, has to be created from the beginning. To minimize the effort in generating a model, standardized input data is necessary. For construction scheduling there are two main data sources that are needed: Information about the building including all objects and their quantities. Both data can come from BIM. Second, information about the sequences of activities is needed. This information will be derived from a so-called process pattern database (Figure 2).

Using process patterns for construction scheduling requires several pre-processing steps. During the pre-processing phase, the available information about the construction project and construction method needs to be analysed, prepared, and stored for further processing.

The modelling approach starts with the decomposition of a building into components. The manufacturing process, for example, is described in process-templates. The level of details of process patterns as well as the dependencies between activities can be chosen by the scheduler.

A tree representation of the construction sequence, ordered by building element type, allows the organization of the erection process. Process patterns are assigned to every element by pre-defined rule sets. For example, cast-in-place concrete walls are assigned to the process of building a concrete wall with several sub-activities starting with reinforcing and ending with stripping formwork or optionally required concrete surface finishing.

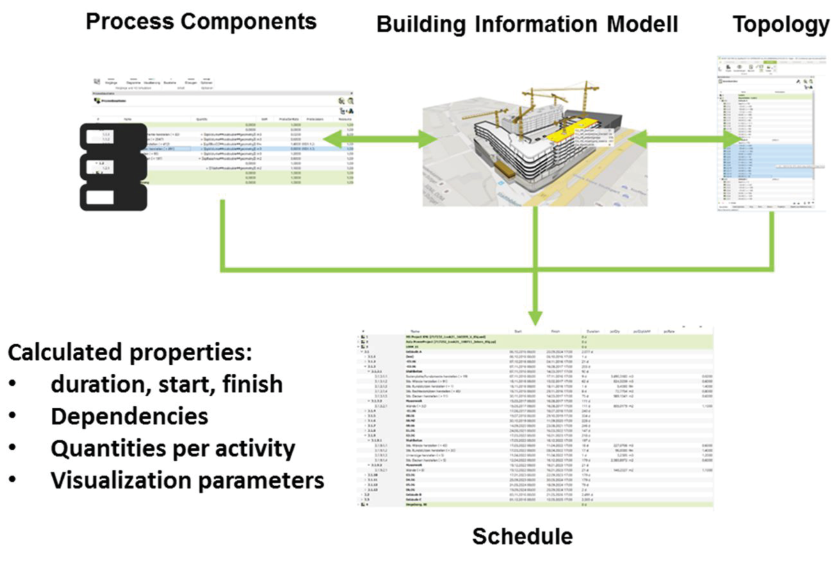


Figure 2: Framework of the rule-based scheduling process

3.1 Sub-Modell: Product Data

The input data for the generation of the schedule are project specific data that are generated from the building information model. This model provides the building with specific input data, foremost the building objects, hierarchical order, and quantities.

Building components are represented in an object-oriented context in this work. Accordingly, objects belong to a class with their respective properties. Building information models contain the geometric data, and furthermore information on the material type, final assembly location, weight, and other properties important practitioners who are concerned with constructability or quality issues. The building structure in construction projects generally is hierarchical, for instance floors, walls, slabs. Objects must be uniquely identifiable (Figure 3).

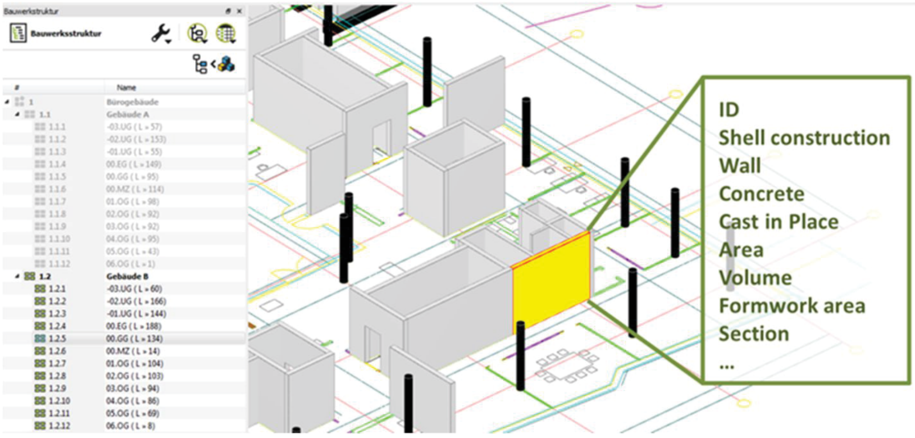


Figure 3: Definition of the building structure

3.2 Sub-Model: Process Components

The sub-model "Process Components" contains a database with process templates for all possible construction methods that can be applied to erect the object. It seems useful to introduce process templates to reduce the specification effort in modelling construction processes (Huhnt and Enge 2006, Melzner et al. 2012). Process templates help to systematize project-independent standard procedures. Individual processes can be structured with interrelationships to represent the entire system of activities. A process template defines a specific sequence of tasks and subtasks for producing a specific object of a building.

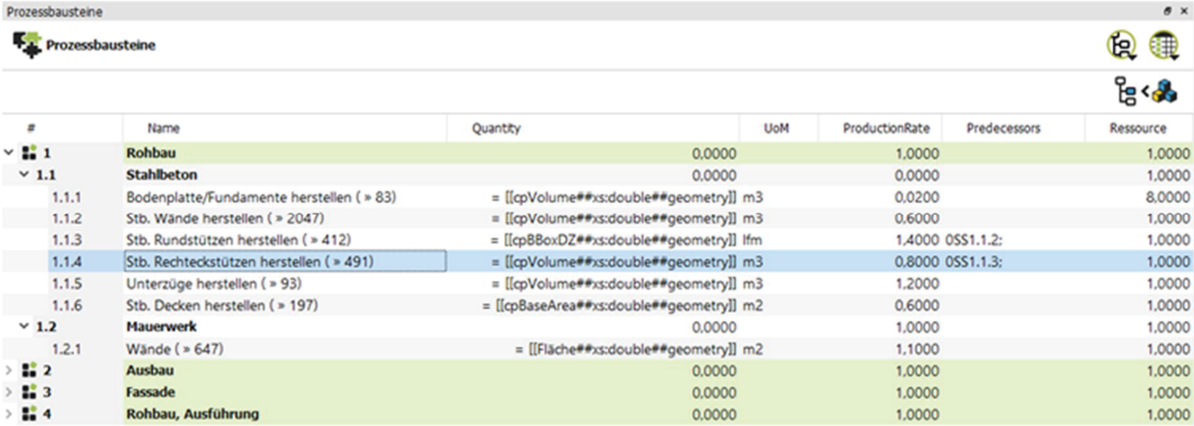
For example, for the erection of cast-in-place concrete elements a recurring work flow is applied. This work flow defined with the help of process pattern is reusable and stored in a process database.

The process template database stores all processes which are needed for construction. Each template consists of set of attributes that describe the processes (Table 1).

Table 1: Example of process template attributes

Attribute	Example
Name of activity	Build concrete wall
Formula for quantity determination	= [[cpVolume##xs:double]]
Unit of Measurement	m^3
Production Rate	5,5 m^3/h
Relationships	Start-Finish, Start-start, Finish-Start,
Task Visualization	Colour code

The process templates define the quantities, production rates, and predecessors as well as the options used in the resulting 4D-visualization (Figure 4).



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#	Name	Quantity	UoM	ProductionRate	Predecessors	Ressource
1	Rohbau	0,0000		1,0000		1,0000
1.1	Stahlbeton	0,0000		0,0000		1,0000
1.1.1	Bodenplatte/Fundamente herstellen (» 83)	= [[cpVolume##xs:double##geometry]]	m3	0,0200		8,0000
1.1.2	Stb. Wände herstellen (» 2047)	= [[cpVolume##xs:double##geometry]]	m3	0,6000		1,0000
1.1.3	Stb. Rundstützen herstellen (» 412)	= [[cpBBoxDZ##xs:double##geometry]]	lfm	1,4000	0SS1.1.2;	1,0000
1.1.4	Stb. Rechteckstützen herstellen (» 491)	= [[cpVolume##xs:double##geometry]]	m3	0,8000	0SS1.1.3;	1,0000
1.1.5	Unterzüge herstellen (» 93)	= [[cpVolume##xs:double##geometry]]	m3	1,2000		1,0000
1.1.6	Stb. Decken herstellen (» 197)	= [[cpBaseArea##xs:double##geometry]]	m2	0,6000		1,0000
1.2	Mauerwerk	0,0000		1,0000		1,0000
1.2.1	Wände (» 647)	= [[Fläche##xs:double##geometry]]	m2	1,1000		1,0000
2	Ausbau	0,0000		1,0000		1,0000
3	Fassade	0,0000		1,0000		1,0000
4	Rohbau, Ausführung	0,0000		1,0000		1,0000

Figure 4: Definition of the process components

The assignment between the process template and the building objects is executed by a pre-defined ruleset. The rule execution checks the objects' attributes against the template information, then assigns the process steps.

4 CASE STUDY

4.1.1 General Information

The proposed automated scheduling approach was developed as a new feature for the Building Information Modelling Software DESITE MD by ceapoint aec technologies GmbH.

An object-oriented 3D building information model of a 12-story office building was selected for the case study. The office building had a gross floor area of approximately 46000 m². The 3D model represents all structural element of the concrete shell structure such as foundations, beams, walls, columns, and slabs. The structural model contains of approximately 4500 objects. The objective of this study was to determine the practical benefits and limitations of the developed system.

W. MARKGRAF GmbH & Co KG was the contractor in charge of creating a model-based schedule and deriving accurate quantities for cost estimation. Furthermore, the final 4D schedule was used for extensive constructability planning, including worksite preparation and coordination.

4.1.2 Results

The added value for a scheduler is the developed querying function that automatically determines the quantities from the model and calculates the duration for every of the planned activities. The first attempt of the automated scheduling resulted in a 4D-visualation of 68 % of all of the 4500 objects in the planned building information model. The result illustrated in Figure 5 permitted a rough coordination schedule with 125 of the most critical activities. The availability of modifying object attributes led to a higher degree of automation. Therefore, quality models where objects have precisely defined attributes and which are created by following highly standardised modelling techniques are essential for the success of the developed method.

The developed automated scheduling approach has shown to assist the workflow and quality during construction planning. However, there are some current limitations and challenges. The framework requires a comprehensive knowledge about the construction processes and its subsequent activities. The gathering of all the necessary input information is a crucial point when generating quality results. While activities related to concreting work were investigated, further investigations have to be done in developing process templates for finishing works (or as determined by importance to the contractor).

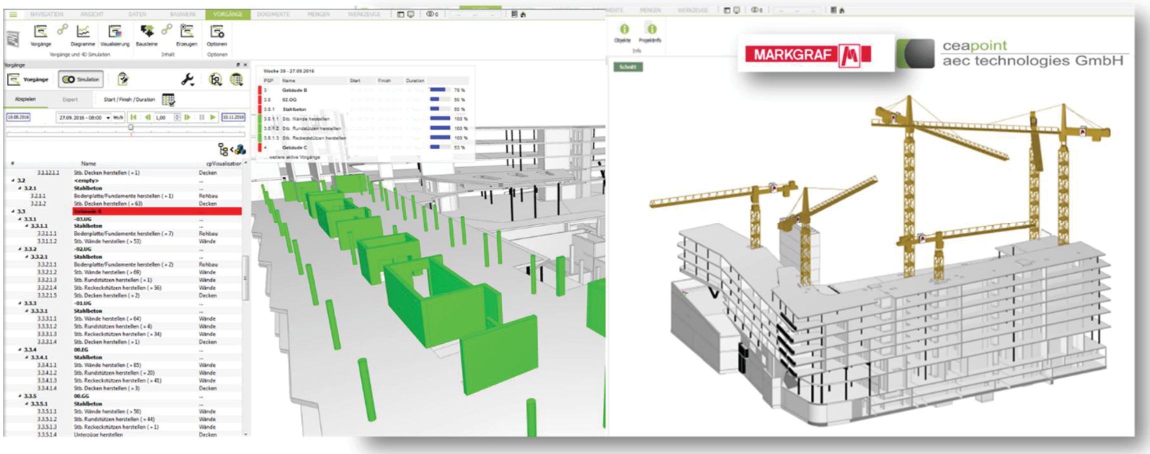

Figure 5: Generated schedule for shell construction

5 CONCLUSION

A new approach of automatically generating construction schedules was presented based on input data (construction sequences and historical estimates). The approach was implemented in a commercial software DESITE MD. Tests in practical applications allowed for the first time for the creation of a construction schedule that meets the requirements and constraints important to the construction practice. This includes the consideration of the building structure, the description of the processes and sub-processes of activities and takes into account the dependencies between these tasks.

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