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Performing Scenario Simulations in Construction by Using Standard Software

Durchführung von Szenariosimulationen mit Standardsoftware im Hochbau

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Abstract: The authors address the application of scenario simulation in construction from the application side. It is the point of view of the practitioner, who intends to apply process simulation for analysing the realisation phase of a construction process by using standard simulation software. The authors start from the classical application areas for process simulation in production and logistics and describe how the user in the construction industry can profit from scenario simulations taken from standard environment. Typical transfer problems are described as well as examples of simulation models are given to address practical limitations and chances based on the state-of-the-art software package Enterprise Dynamics.

1 Problem Statement

Generally it is expected that construction processes are optimised to a certain extent with regard to economical or time related figures. However, this is optimisation is very difficult because the underlying decisions are commonly based on incomplete information about the processes, their boundary conditions and also the interferences between the individual processes (Fiedler and Peldschus 1989). The parameters that govern construction processes are as a rule stochastical values which reflect the uniqueness of the construction in terms of weather and soil conditions, involved machines or personnel, etc.

In practice and for planning purposes estimates are taken which involve experiences acquired from earlier projects. However, it remains unclear if the results of such a planning fulfil the expectations towards the required degree of optimisation sufficiently. A potential solution to this problem can be seen in the use of simulation tools. In other industries (e.g. stationary industry) these virtual tools are inherent part of production planning. Application areas of simulation in the construction industry, however, have been shown by different authors, e.g. Voigtmann (2014), Berner et al. (2013) and Weber (2007). Whereas on scientific level the use of simulation in construction has been widely discussed, its application in practice is far behind.

Different authors report about the reasons for this situation and mention

- the lack of expertise in the companies to use simulation tools,
- the inadequateness of tools coming from the stationary industry in relation to the specific requirements of the construction industry,
- the enormous effort needed for the creation of adequate simulation models for the construction sector,
- the time needed for any adaptation of the simulation model to changes in the real system and
- the provision of valid input data for the simulation

as the main obstacles for applying process simulation tools in construction (Kochkine 2014; Kugler 2012).

In this paper the authors address the issue from the application side. It is the point of view of the practitioner, who is willing to apply process simulation for analysing the realisation phase of a construction process by using standard simulation software.

2 Literature Review

In the scientific literature many of the obstacles for applying process simulation to construction processes have been addressed by researchers. Standard software has been adapted by the provision of special toolboxes containing elements for the modelling of specific construction activities (Voigtmann 2014; Weber 2007). Some researchers developed new simulation tools focusing on individual problems of specific construction projects, e.g. Steinhauer (2007), Al-Hussein et al. (2006), Ruwanpura et al. (2000), Hajjar and AbouRizk (1999). Others attempted to address the question of data provision by linking simulation tools to CAD-software or by importing input data from building information models (Lu and Olofsson 2014; Wang et al. 2014; König et al. 2012; Kugler 2012; Xu et al. 2003). However, many of the scientific proposals have so far not been implemented in any commercial software packages. Especially for providing input data for the process simulation in construction, individual and hand-made solutions like spreadsheet processing programs are used for collecting and preparing the data (Kochkine 2014).

Weber (2007) describes an approach on the use of the simulation software Enterprise Dynamics for the simulation of construction logistical processes. The author uses 3D-CAD data to determine the material quantities of the construction site. These quantities have been connected to construction elements and linked with information of the time schedule. Weber creates a simulation model containing the logistical elements that are necessary to transport the calculated quantities of material to its place of use. By doing so the author uses simulation to test and evaluate different supply and warehousing strategies on a specific building construction site. The simulation runs and gives back throughput, waiting and idle times. The simulation acts as a support tool for decision making in the areas of site layout and logistics. Weber describes that the shortening of construction times by creating more parallel jobs on site requires higher coordination efforts. He argues that simulation tools in construction can be used as a means to increase productivity. The obstacles for the application of simulation tools are poor cost effectiveness, missing data input and others.

Pitsch (2011) reports that the challenges for commercial simulation tools for the application in one-of-a-kind processes are typical for the construction industry. He points out that especially the nature of one-of-a-kind processes is in conflict with standard tools which have more or less been developed for universal applications. Therefore standard simulation tools must be equipped with additional functions that allow an easy adaptation of its preset elements to the unique requirements of the processes to be modelled in construction.

Voigtmann (2014) reports on her research based on the use of the simulation software Plant Simulation (Siemens 2013). This has been expanded by the Simulation Toolkit Shipbuilding (STS package). STS provides predefined simulation objects developed for the modelling of shipbuilding processes. Finishing processes in shipbuilding are to a large extent similar to those of building construction. Voigtmann used a highly complex simulation program to model the logistical and technological construction processes in the finishing phase of a multi-storey office building. The dynamic simulation model that has been created extends the standard functionalities of the simulation software by the use of hard- and soft constraints (Beißert 2012), space management (Marx and König 2010), logistics control and others. Based on the number of parameters in the model and the individual range that each parameter can take the simulation time of the model changes dramatically. Voigtmann concludes that a sensitivity analysis of the impact of single parameters to the simulation time (time until completion of construction) can help limiting the total number of parameters as well as restrict the value range of each parameter. Voigtmann points out that this approach can contribute to some less complex simulation models and thus facilitate the application of simulation in construction.

Kochkine (2014) introduces a concept for process based production planning for optimisation purposes in construction. He argues that the simulation of production processes in construction is still challenging especially in the area of data collection, data import and model creation. Automated approaches which make use of building information models can be regarded as a chance to overcome some of the problems, but only for larger construction elements. Applying simulation to the finishing phase of construction projects which is governed by high construction costs, many small tasks (e.g. technical building services) and a relatively large number of different crafts on site is rather complicated to be suitable for practice.

Berner et al. (2013) discuss the use of simulation in manufacturing planning. They illustrate different applications based on Plant Simulation supplemented by the STS. It might be debatable whether the application of STS can be regarded as standard software because STS contains custom made simulation functionalities which facilitate the modelling in shipbuilding. However, by presenting the technical possibilities of simulation in shipbuilding, it gives a strong impression on how far the use of simulation in construction can go starting from a continuous enrichment of standard simulation tools. The following application areas of simulation in construction have been described:

- Determination of optimum work sections on a daily basis;
- Analysis of alternative operation methods;
- Determination of resource requirements and personnel;
- Analysis of different logistical concepts by considering the dynamic environment.

Considering the above mentioned application fields it shows that the use for process simulation is well described on the scientific level. The benefits of simulation tools have been clearly addressed. In technical respect different simulation programs are in use. By disregarding special simulators for isolated problems the use of conventional simulation tools in construction is discussed controversially. The potential for the application of process simulation as shown in scientific papers is still problematic if transferred to general purpose problems in construction. In order to address this issue a small series of simulation projects has been carried out which will be described in the following.

3 Use of Standard Simulation Tools

3.1 Introduction

3.1.1 Standard Simulation Software

The term "standard simulation software" as defined by the authors describes publically available software offered on the market, which can be used for the creation of multipurpose simulation models by using standard elements. The software should not be specialised on specific application fields nor does it have branch-specific solutions (Pitsch 2011).

There are two advantages by the use of standard software: 1st it offers broad application fields by providing a large set of standard elements. 2nd the software developing power can be higher because the number of clients from different applications can be considerably stronger. At first glance the software doesn't suit the requirements of a construction company because its prevailing problems are varying construction sites and conditions. Another disadvantage of using standard software is that the creation of individualised simulation models is more time consuming and requires higher adaptation skills of the simulation engineer than by using one-purpose simulation software.

A market review of simulation software for construction purposes did not detect a specific tool that can be classified as a standard in this field and which might be explicitly designed for modelling of construction processes already. In contrary, simulation tools were found that were coming from the stationary industry and which have been used in scientific applications for the modelling of construction processes already. These tools contain predefined elements which support modelling situations in the stationary industry and which show a high affection for adaptation to be applied in the construction industry.

3.1.2 Perspective

Basically a construction company has to take the make or buy decision, when deciding on technical tools and equipment. The company could either hire a consultant who offers simulation services or the company could purchase simulation software and provide it to its engineers as a planning support tool. Since project and production planning belongs to the core tasks of a company, the purchase option is most likely in the long run.

In the following chapters the perspective of the company's engineer is taken that has so far no experience with simulation but whose task it is to introduce it by the use of

standard simulation tools available on the market. The input to these chapters is gained from projects carried out at the Bauhaus-Universität Weimar in the term 2014/2015. The involved master students in civil engineering and construction management courses had so far no or only little theoretical background in simulation. They got the assignment to identify typical on site problems that could be tackled by the application of standard simulation tools such as Enterprise Dynamics. The students had to develop individual and team-oriented ways to get familiar with the software and to develop simulation models that were based on the standard functionalities of the software. Finally they presented the simulation results which were solutions for the identified problems in work planning.

The experiences gained during the project work as well as the results of these projects were thoroughly reported and documented. They contribute to a clearer perspective about the practical application areas and related challenges. The idea is that these project settings represent similar situations in practice by involving typical problems related to the work of construction companies.

3.2 Getting Started

After having acquired a simulation package the engineer in charge in the construction company usually finds himself in an isolated software environment which is not linked to the company's standard tools like computer aided design (CAD), building information modelling (BIM), enterprise resource planning (ERP) or network planning. This means that the data provision from construction projects or machinery pool into the simulation model must be performed by using the import/export functionalities of the corresponding software tools, or it must be generated manually with the simulation software. The engineer has to decide which information is needed and by which way (interface) it can be provided for a simulation model. Of course the engineer has to acquire some basic knowledge to learn how to perform a simulation study (theoretical knowledge) and he has to become familiar with the simulation tool as such (practical simulation knowledge) which might also include learning a new script language allowing the adaptation of the standard functionalities.

Furthermore the engineer who is using standard software will have to decide which standard elements can be used for modelling his real problem even if at first glance it appears inappropriate since they have been originally designed for a use in another application environment, most likely the stationary industry. An alternative could be that standard elements must be manipulated or new elements have to be developed and added to the library of the simulation tool.

The challenges of a first start with new simulation software in construction applications can be summarised as follows:

- Availability of qualified personnel to set up the simulation objectives and the modeling requirements (theoretical knowledge);
- Availability of qualified personnel to use a specific simulation software and to perform the simulation (practical knowledge);
- Generation or provision of input data to the simulation tool;
- Adaptation of standard simulation elements to the special needs of modelling construction processes.

Considering all these challenges the overall barrier to introduce simulation and develop a proper basis in a specific construction company for the use of simulation as a planning support tool is comparably high.

3.3 Simple Models for Construction Purposes

3.3.1 Overview

The projects that have been carried out at the Bauhaus-Universität Weimar were based on four different topics (table 1). The projects had been assigned each to 2 to 5 persons as a team and included theoretical studies as well as practical work with the provided standard simulation software. Enterprise Dynamics (software version 8.2.5 and 9) was used. During the work it has been individually assessed whether each task could be fulfilled by using and applying the standard elements and to what extent an adaptation of these had to be undertaken. Based on this assessment a recommendation was given whether the topic can be regarded as an appropriate application in construction companies that are willing to apply simulation but so far have not had experience with it.

Table 1: *Simple models for construction purposes*

No.	Purpose	Adaption of standard functionality by script language	Difficulty for simulation starters	Recommended application for use in construction
1	Setting up a transport chain for soil work	no	normal	yes
2	Material laying strategies by the use of 3D-BIM data	yes	high	no
3	Improving resource combinations	no	medium	yes
4	Modelling of logistical strategies	yes	medium	yes

Two of these projects and the experiences gained with them are presented here in detail.

3.3.2 Material Laying Strategies by the Use of 3D-BIM Data

This project focused on the connection between BIM and some standard simulation tool. The aim of the project was to elaborate how the 3D-coordinates of building components from a BIM model can be transferred into the simulation model. Within the simulation model it was intended to use the 3D-coordinates for transportation and material laying purposes.

The project started with the creation of a 3D-BIM model of a parking deck using Autocad Revit 2015 (fig. 1).

Figure 1: *Parking deck*

It was decided to simulate the asphalt laying on the park deck by identifying the positions of the existing concrete columns. The necessary task was thus the selection of the coordinates of concrete columns and the edges of the asphalt area.

Difficulties arose when trying to select these coordinates in Autocad Revit 2015 in order to export this information into a compatible format for further processing. As an alternative solution the 3D-Model was exported to AutoCAD 2015 where the position of the desired elements was selected (fig. 2) and exported into an MS Excel file.

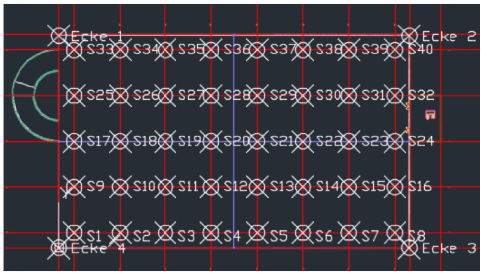

Figure 2: *Selection of columns*

The export into MS Excel was necessary, because the underlying coordinate systems in AutoCAD and in the simulation software were different, so that a conversion of the coordinates had to be performed. In order to improve the visualisation, a background drawing of the parking deck was inserted into the model layout. The creation of the paving material to be layed was simulated by using a source atom of enterprise dynamics library which was adapted in such a way that each square meter of the material to be delivered and laid receives an individual label from the excel file, which gave information to its final position. Figure 3 shows the model layout during the simulation run.

The created model provides a proper basis for a scenario simulation of different laying strategies. However, the efforts needed for the creation of such a model remain high. The experiences from a practitioner's point of view can be summarised as follows:

- Modelling work was time consuming;
- Coupling of different software system was necessary;
- Provision of data flow required comprehensive knowledge of software interfaces (exchange formats);
- The selection process of the required 3D-data need to be improved because up to now it requires a separate manual work step.

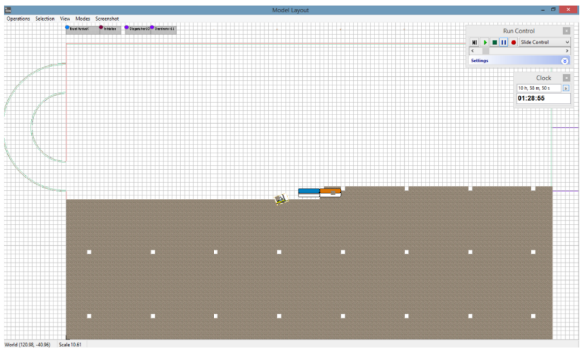

Figure 3: *Visualisation of material laying during simulation*

Considering the efforts needed for the conversion and transfer of 3D-BIM data into the standard simulation software at this stage of development the application cannot be recommended for construction companies that are at the beginning of applying simulation for their daily production planning.

3.3.3 Improving Resource Combinations

The main application of simulation in this project was analysing the combination between material requirements by workers and the corresponding logistical chain on site. It should be analysed how the site logistics must be organised in order to ensure a nearly 100 % productivity rate of bricklayers. In this project a ground plot of the construction site was used at the background picture for modelling purposes. The approach turned out to be suitable for a quick transfer of the site specific characteristics like roads, building structures etc. The project included the modelling of material delivery on site and the following transportation of the material to a smaller storage area near the entrance of the building. The ground plot (fig. 4) has been scaled to ensure the correct recognition of distances in the simulation model. Later the supply paths for transporters and workers have been placed onto the ground plot. These modelling elements are seen in figure 4.

Recommended values for production ratios (ARH-Tables) have been used to determine the material demands of professional workers at the different work locations. Scenario simulation has been carried out to determine the consequences for the logistical chain if the number of bricklayers is increased. By using a table calculation, is has been determined at which combination it is economically favourable to employ logistical personnel (less hourly wage rate) that focuses exclusively on logistical tasks in order to increase productivity of the bricklayers.

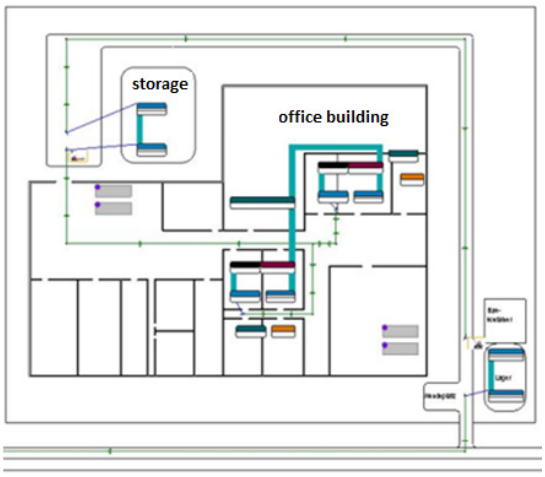

Figure 4: *Ground plot of construction site*

As a result of this application of simulation in the field of resource combinations, the experiences can be summarised as follows:

- Standard software supports this application well in a static system;
- Finding appropriate parameter values to model time realistic processes is time-consuming;
- The separation of logistical and technological (productive) tasks is difficult to model with standard simulation elements;
- The analysis of costs requires a comprehensive side calculation by using different time values measured during the simulation runs.

The use of standard simulation software in this application can be recommended. However, the modelling effort increases drastically when increasing the complexity by considering more types of material, different teams of workers and the dynamical environment of the construction site. Furthermore it turned out that the management of relevant parameters within the simulation model must be considered at an early stage. This can be achieved for example by implementing an interaction form or by hosting the parameters in an easily accessible calculation table.

4 Discussion and Conclusion

After having demonstrated various possibilities of applying simulation, Berner et al. (2013) have raised the question how long it will take the construction industry to use simulation for its production planning. Considering the results of the simulation projects that have been shown in this paper and the reviewed literature, there is a clear answer: the application of simulation tools to support production planning in construction will find its way into practice if

a. the entry barriers to use simulation tools have been lowered,
b. the integration of the tools within the corporate data management and IT infrastructure is given;
c. the data provision and data import is enhanced;

d. the time frame for development and verification of simulation models is shortened;
e. the approach of applying these tools in real projects will follow a formalised procedure.

Referring to a) and considering that the construction industry in Germany is highly fragmented by small and medium sized companies and engineering consultants, the economic barriers to use simulation as planning support tools are still fairly high. The task to perform a sound simulation study to support planning processes requires specially trained personnel which must have both, knowledge about simulation and construction works. It is obvious that an investment into simulation and modelling is rather undertaken in larger companies than in traditional small and medium sized companies. This is presumably also the reason why theoretical or prototypical concepts for the use of simulation in construction have not yet been implemented in the available tools by the software industry.

Referring to b) and c), it is not to be expected that simulation tools will be useful when operated in completely separated environments of the company's IT infrastructure. This requires connecting simulation with the existing planning and management tools. Then practitioners will not have to spend additional time for continuously aligning simulation systems with the existing information technology. Simulation tools are a powerful environment for a bidirectional processing together with traditional planning results. Suggestions to improve construction planning have to be transferred back into the traditional planning tools (time planning, BIM, ERP) and can then be considered during execution. A central connection or integration of standard simulation tools is therefor required.

An automated adaption of the simulation model refers to item d). Different changes of resource base or in design must be made possible without exceeding the required modelling time. Furthermore an optimal level of detail must be found that reflects the character of the construction project and shortens simulation time. In fast changing projects am in-depth simulation approach might be outdated because the chosen parameters and assumptions aren't valid anymore.

The application of simulation by practitioners requires additional formalisation of the steps to be executed with simulation tools as referred by item e). This means that a general approach on how to integrate a simulation tool in construction planning should be provided, which also functions as a guideline. This approach should include instructions on how to proceed related to different standard situations.

The one-of-a-kind character of construction projects often requires a thorough evaluation "from scratch" when designing simulation models as planning support tools. The main tasks for further research are to develop concepts for the integration of simulation tools as well as the further development of standard simulation elements that allow an easy adaptation to changed conditions on a specific site. Simulation software must approach itself closer to standard software applications in construction or even become an integral part of it. To overcome the existing hurdles for a successful application of standard simulation tools by construction companies is for many companies on the market currently still regarded as rather high.

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