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BIM AND SEQUENCE SIMULATION IN STRUCTURAL WORK – DEVELOPMENT OF A PROCEDURE FOR AUTOMATION

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ABSTRACT

Sequence simulations are a very useful tool to increase the visibility of workflows, to identify potential conflicts in advance, to improve the communication between different trades and to assign tasks accurately. Hence, the entire construction process can be executed in a more efficient manner – saving time and costs. Building Information Modeling (BIM) enables the linking of schedules and 3D CAD models. This is widely understood as 4D-simulation. However, in practice the process of data entry is time-consuming, making the employment of this procedure cost-prohibitive. As consequence, it has not yet been established in practice. 4D-simulation has yet to show any noticeable simplification or improvement to the planning and scheduling process.

The goal of this paper is to support the development of a procedure which automates the generation of a construction schedule from the data of a standard BIM model. Firstly, a demarcation of research will be done, as there are already several research approaches in the field of 4D simulation. Secondly, a system analysis of structural work will be executed in order to identify requirements for the procedure. An important criterion is that the construction schedule can be formulated and adapted in all project phases.

Building on the results of the systems analysis, a process model can be formed in which the activities of a construction schedule can be constructed as a universal and project-independent template. For each of these activities, attributes are established which exactly describe the associated components of the BIM-model specific to any particular project site. The attributes of the activities from the process model must be tested for consistency with those from the BIM model. A case example is demonstrated to validate the developed procedure.

• KEYWORDS

Building Information Modeling (BIM), 4D-simulation, Scheduling, Visual Management, LPS

• INTRODUCTION

Since BIM has been applied in the construction sector for several years, positive synergies between Lean Construction and BIM have become obvious. Remarkable

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improvements are expected all across the lifecycle of a project. Therefore, the implementation of BIM in construction projects is progressing quickly. Significant benefits are expected when BIM and Lean Construction are implemented together. (Sacks et al, 2010; Dave et al, 2011; Bhatta and Leite, 2012; Hamdi and Leite, 2012; Gerber et al, 2010; Toledo et al, 2014).

One approach is the use of 4D simulation in combination with the LPS (Gonzalez 2012; Bhatla and Leite, 2012). It is important that project participants understand the construction processes and progress in order to achieve compliance with schedules and planning results. 4D simulation can ideally be used for virtual first run studies and to visualize Gemba and project content in order to improve and accelerate project understanding. Thus, 4D modeling improves coordination of the different trades and allocation of resources. The consequences are reduced waste and variability, as well as a more stable workflow.

Unfortunately, the use of 4D-models is currently often limited to basic 4D-simulation at a macro level. A project is usually only simulated with the level of detail of a master or phase schedule (Dave et al, 2011). A more detailed depiction of a project with a refined schedule requires an intensive manual linking of tasks, durations and dates with the BIM objects in order to represent all dependencies. This is very time-consuming and therefore a noticeable improvement in the planning and scheduling process has yet to be realized (Harris and Alves, 2013). Hence, 4D simulations have not yet been established for day-to-day use in construction projects. To achieve this, the use of BIM and 4D simulations has to be facilitated. Automated and standardized procedures are required in order to rapidly generate and evaluate construction plans and scheduling alternatives with 4D simulations (Bhatla and Leite, 2012).

The aim of the approach depicted in this paper is the development of a procedure to automatically create an initial construction schedule based on a BIM model in order to accelerate and facilitate 4D simulation, thus improving the scheduling process and the assignment of resources to activities. Project-independent process templates are sought based on a universal definition of the structure, components and attributes of a 4D model in the field of structural work. The aim is to replace manual work with automated procedures as far as possible.

• RESEARCH – CONSTRUCTION SIMULATION

A number of investigations has been conducted in the field of construction simulations in order to automate and facilitate scheduling. According to the approaches of many researchers, a description or formalization of construction processes is crucial to achieve a certain degree of automation.

Research on automated schedule using object data is dating back at least to the 1970s, e.g. CYCLONE (Halpin, 1977). This work as well as other early work in construction simulation has been the foundation for recent research, e.g. object-orientated process simulation, CPM-Networks or discrete-event-simulation by using object-orientated programming (Tommelein and Odeh, 1995; Zozaya-Gorostiza, 1989; Liu and Ioannou, 1992 etc.). Important research questions when applying these theories to current approaches are the automatic definition and integration of semantic information or how to extract attributes contained in the BIM-model while regarding technical and organizational dependencies.

One approach for automated scheduling is the use of process templates. In this context, the construction process is described as a sequence of activities and component status. For this purpose, the building has to be broken down into components to be assigned to categories afterwards. The basic principle here is that each category has a predefined set of status variables to describe the manufacturing process of a single component. Thus, the execution of an activity requires a specific component status, resulting in the associated component status. This approach is not CAD based (Huhnt and Enge, 2007).

The abovementioned approach has been extended to a CAD based scheduling. The method enables the creation of schedules by using the data contained in the CAD model. Furthermore, the non-geometrical information in the CAD model determines the construction method. The results are valuable for better scheduling, but not suitable for use on construction sites, due to the fact that the schedule is depicted in a table and not in a bar chart or work breakdown structure. It is also not possible to automatically verify whether all the contained components from the CAD model have been considered for the scheduling; a manual completeness check is required (Kugler, 2008).

Another approach is the constraint based scheduling, which has been specially developed for structural work and finishing. A distinction is made between hard and soft constraints. These constraints define dependencies between objects within a simulation environment. The hard constraints (e.g. technological dependencies) must be complied with in order to depict a process. Soft constraints, on the other hand, describe strategic dependencies. They don´t need to be complied with completely. This approach enables the generation of various execution strategies (König and Beißert, 2008).

A Case Based Reasoning (CBR) system presents an alternative option in model based scheduling. Here, reapplying and adapting proven solutions from similar previous projects can solve new design problems. The CBR cycle passes through its four phases: retrieve, reuse, retain and revise. The idea is to store every solved case in a case platform, separated by problem and solution. Hence, the most similar solution for a new problem can be found and applied (Hartman et al., 2012).

Another research project presents a solution for creating both schedules and 4D simulations based on the data stored in a CAD model. According to this research, 4D simulation is usually only used for the visualization of construction processes and the linking is mostly done manually. Further research is required in order to significantly speed up a 4D simulation, thus improving its cost-benefit relationship. Provided there is a logic suitable for extracting data to define processes and durations, an automated linking between the CAD model and the schedule is possible (Tulke and Hanff, 2007).

However, all approaches are difficult to handle & haven't been developed holistically in accordance with the BIM method. This prevents application and acceptance in practice.

• ANALYSIS OF FUNDAMENTALS

• STRUCTURAL WORK

In the planning and construction of buildings, the work is packetized and divided. This is done in order to facilitate the tendering and contracting of projects or parts of them. However, a uniform structure cannot be found. It is possible to differentiate between structural work, mechanical, electrical and plumbing (MEP), finishing and the building envelope. A finer structure can be expressed in trades or work sections, based on the traditional branches of industry. This paper focuses on structural work. For the procedure to be developed, it is assumed that the structural work consists of the construction of the foundation and the supporting structure. Associated trades are brickwork, concrete work and reinforcement work.

GEOMETRIC STRUCTURE

The structure is one of the first things that have to be considered in a construction project. A Work Break-Down Structure is a useful tool to define the scope of a project and to break the work down into work packages. (Berner et al, 2013) The WBS is the basis for all other plans, e.g. resource plans or schedules. Hence, a WBS enables adequate planning and management of a project. A WBS also adopts the basic structure of the BIM model. The better a model is structured in the beginning; the less effort is required to generate a 4D Simulation (Dave et al, 2013). For the work with a BIM model, a geometric-based structuring approach seems to be the best approach. Figure 1 demonstrates two possible variants to structure a project.

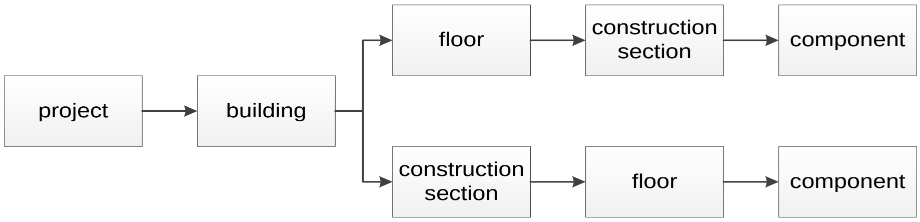

Figure 23: Structure of a building in structural work

• TECHNICAL DEPENDENCIES

The decomposition of a building into its components is essential for a consideration of its technical dependencies. There is a manufacturing order of the components in order to erect a building. Technically, first the foundations, then the walls and finally the ceiling are built. This information can be used generally and independently from an individual building, because this order is universal. A closer look demonstrates that a single component is composed of a number of parts and crucial applications, e.g. concrete, formwork and reinforcement. The information on technical dependencies will be used in the process model.

• ORGANIZATIONAL DEPENDENCIES

Organizational dependencies are generally difficult to model, especially when formalizing these dependencies independently of a project. In practice, these decisions are made subjectively, repeatedly reconsidered, and possibly also changed over the course of a project. The main focus relating to the organizational dependencies in a construction project is the production cycle, which arranges cycle elements. A cycle element can be defined in different ways; e.g. construction section, floor, or a combination of both. The definition of a cycle element differs from project to project and depends largely on the level of detail of the schedule. The working direction of the cycle elements also needs to be defined (Fig. 2).

The variants “horizontal” and “vertical” are seldom used due to economic aspects. For instance, the abovementioned variants require more formwork elements than the “diagonal” variant. A lack of formwork elements causes waiting times and interferes with the construction process, thus causing waste. On the downside, an abundance of formwork elements leads to increased costs without improving the construction process.

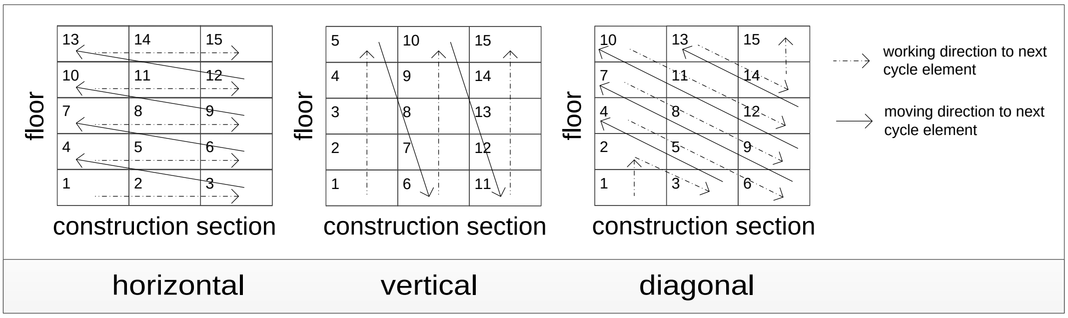

Figure 24: Working direction of cycle elements

- **REQUIREMENTS FOR THE PROCEDURE**

The procedure is developed according to the requirements described below.

1. Adaptability: In order to ensure a dynamic and flexible procedure, changes should be automatically adjusted in the 3D model and scheduling.
2. Generality: General structures and naming conventions must be considered. Project-specific construction schedules have to be generated. The automatic linkage of the construction schedule with the 3D model should be based on a general logic.
3. Usability: Existing commercial 4D software systems should be used in order to avoid unnecessary problems or interfaces caused by new or multiple systems.
4. Correctness: The mapping of components and their attributes with the individual processes of the process model has to be unambiguous and correct. This is essential for the automated generation of the schedule and for creating the 4D animation.
5. Completeness: All components contained in the 3D model have to be linked to the process model. If one or more components cannot be linked, these should be identified through a verification process.

• PROCEDURE

• PROCESS MODEL

A process model is generally used to describe and define how processes should look, and represents an anticipation of a universal valid construction process. Its elements consist mainly of processes and their relations to each other. A single process maps an activity (e.g. construction of walls) within the construction process. Its relation to other processes represents the given order (e.g. first construction of walls then construction of ceilings). Expertise in scheduling and modeling is needed to prepare a process model. It is recommended that the crucial processes be defined in close collaboration between the scheduler, the BIM manager, and experts from the corresponding trades.

By implementing the abovementioned dependencies, both technical and organizational, a procedural structure results (Fig. 3). In order to map the process model to a specific project, each process needs to be identified by a number of attributes. Thus, components of a BIM model can be addressed in order to activate the corresponding process (see "automatic generation of sequences"). To generate a schedule, it is helpful to reduce this number of attributes as much as possible. Attributes that contain information to building physics (e.g. insulation values) are not relevant, because these have no direct impact on the schedule. There must be a standardized definition of attributes for each process to ensure a successful scheduling. Attributes which represent the topological location of the component and their categorical designation are important. Regarding the topological location of a component, attribute values for "building", "construction section" and "floor" are required. The categories "ceilings", "foundations", "structural columns" and "walls" must be used to describe components within structural work. At the end, the developed process model can be used as a template for scheduling. Creating the process model requires a lot of effort but only needs to be done once for a project or company. The procedural structure can also be modified and adapted, e.g. changing the working direction of the cycle elements.

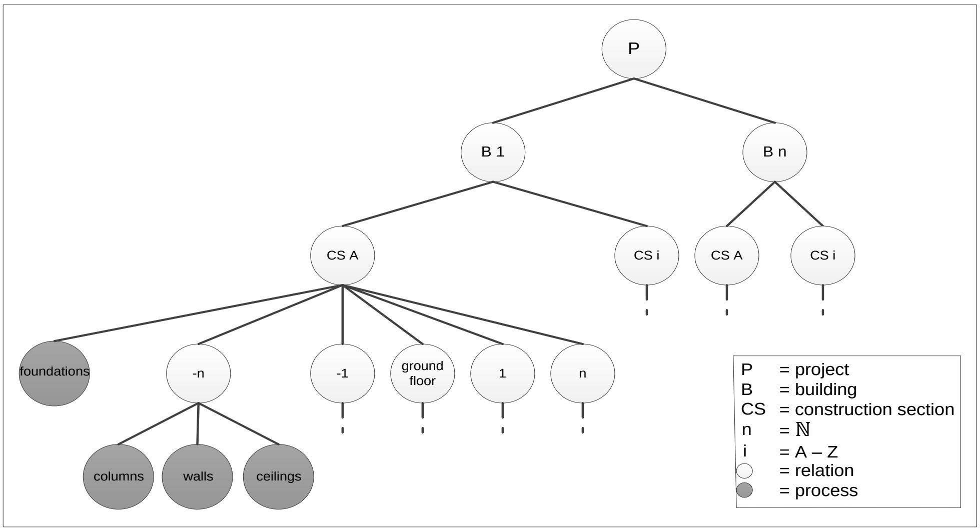

Figure 25: Process model presented as graph

- **BIM MODEL**

A BIM model is a 3D representation of a building enriched with information. In the procedure developed, project-specific information is stored via attributes in the components of the model. In contrast, the process model contains general information; the attributes of the processes are predetermined. A requirement of the procedure is that the attributes of corresponding processes and components match. Applying a standardized BIM library for a guaranteed consistency of attributes is recommended. A standard naming procedure for all components and attributes is required. The attribute names and values must be selected clearly and concisely. Table 1 illustrates that.

Table 1: Necessary attributes in a BIM model as sample

	attribute name	**attribute value**
topological location	building	1, 2, 3, n
	floor	-n, -1, 0, 1, n
	construction section	A, B, C, ..., Z
categorical designation	category	ceilings, foundations, structural columns, walls

- **DEPICTION OF PROCEDURE**

The Procedure, with its main components, the BIM and process model, is explained below.

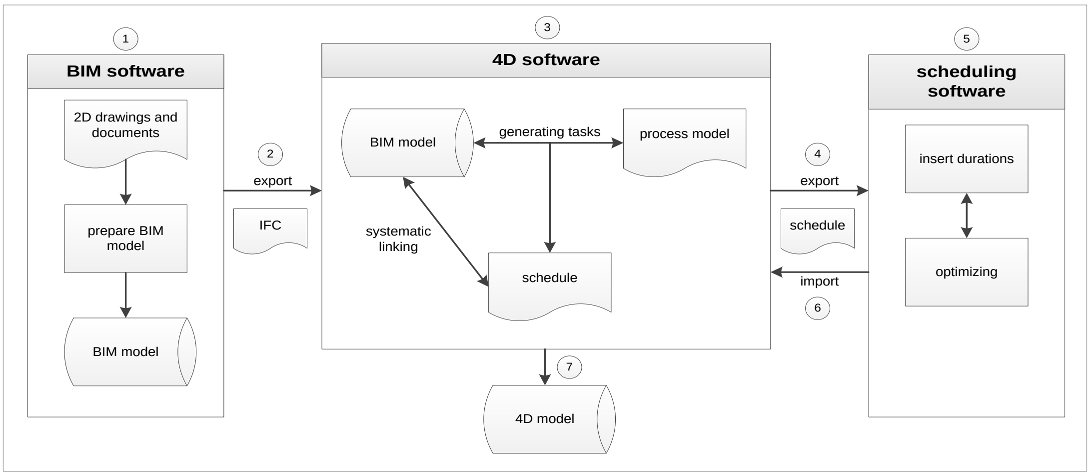

Figure 4: General workflow of the BIM based procedure

A BIM based CAD software, a 4D software and a scheduling software are required for the procedure. The procedure contains of the following steps:

1. A BIM model is created using input data, such as 2D drawings, documents and specifications.
2. Subsequently, the BIM model gets exported into the 4D Software. A neutral exchange format (Industry Foundation Classes IFC) is used. Any proprietary data format can be used alternatively if required.
3. The 4D software is mainly used for two purposes: firstly, tasks are automatically generated based on the imported BIM model using the process model. However, time durations or optimal sequences are not defined. Secondly, tasks are systematically linked with objects/components of the BIM model.
4. The incomplete schedule is then exported to a scheduling software. The required data format differs depending on the chosen scheduling software.
5. The schedule still has neither task durations nor an optimized sequence of tasks. This will be done manually in the scheduling software. The schedule can be optimized based on performance factors, available resources and experience. Any additional information known at this time may be added. Resources cannot be assigned automatically yet. Adjustments require a manual update.
6. The optimized schedule is imported back into the 4D software.
7. Even after Step 5 (optimization), the schedule has the same links to the BIM model as before. In contrast to classic scheduling, no new links are created, nor are old ones changed. In the last step, the 4D model is produced.

• AUTOMATIC GENERATION OF SEQUENCES

In this section, the automatic generation of sequences (Step 3 in Fig. 4) is shown in greater detail. The BIM based approach is based on a comparison of the attributes stored in the process template with the attributes in the BIM model. The order of processes is based on the organizational and technical dependencies of a construction process. For each process, attributes are defined to ensure an assignment to the corresponding components. Attributes (geometric and non-geometric attributes) are a prerequisite for the identification of and matching processes and components.

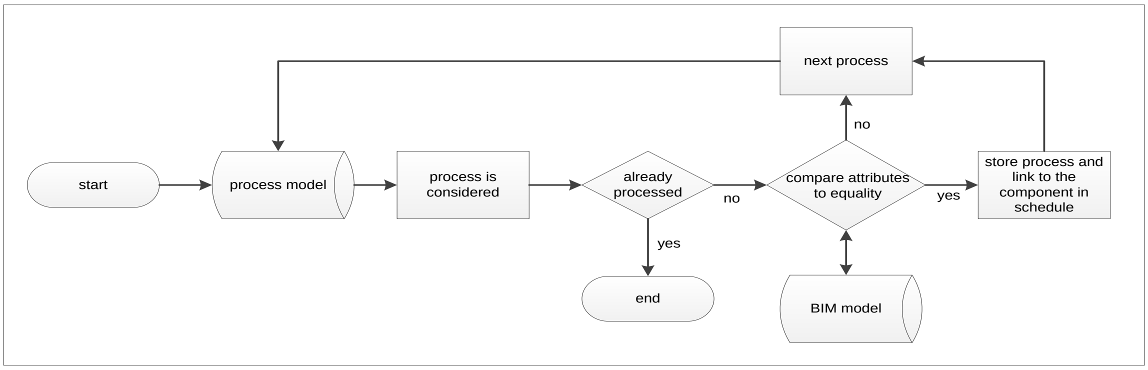

Figure 5: Workflow of automatic generation of sequences

The attributes in the process model are compared and checked for equality with the BIM model task for task. This is done in a numerical or alphanumerical order. If there is a match, the task is stored in the schedule, and a dynamic and adaptable link between component and task is created. Tasks and components are linked via a unique identification number. If a task has no corresponding component, the next process gets checked. The processes in the process model are checked sequentially until all processes have been checked. Processes with no corresponding component in the BIM model will be ignored. In this case, the processes are either not needed, or the attributes are missing or false in the BIM model. Then these attributes need to be edited in the BIM software manually. Only tasks with a link are displayed in the schedule.

• EVALUATION

An industrial project which comprises the structural work of three buildings, each with three floors and a total of six construction sections, was selected for testing. The aim was to get both an initial schedule and an automated linking in the 4D model. It was necessary to emulate the abovementioned automation to generate sequences, because this functionality is not yet part of common 4Dsoftware. This could also be implemented as an add-on in a 4D software solution. Existing functionalities of the software solution used enable the search for components according to defined attributes. Like that a single process within the process model was mapped. This step was repeated for any process to map the process model successively. As a result, a selection of processes and their corresponding components was displayed. Afterwards, the outcome was transferred into scheduling software for optimization. As a result, an initial schedule was generated, linking the schedule and the BIM model. The schedule was checked for correctness and completeness. All tasks were correctly identified and placed in the correct order. All components from the BIM model were included. The demand for adaptation was examined by modifying the structure of the construction sections – the modifications were automatically displayed in the BIM model. A schedule and its related dynamic links could be automatically generated and updated.

• CONCLUSIONS & LIMITATIONS

A simultaneous implementation of BIM and Lean Construction can improve construction processes significantly. The use of 4D simulation in combination with classical lean tools such as LPS is very promising. The draft depicts a procedure to automatically create an initial construction schedule based on a BIM-model in order to facilitate 4D simulation. Process templates are required based on a universal definition of the structure, components and attributes. It is possible to automatically link and update the process- and BIM-model. 4D simulations can be generated more easily, although specific dates, durations or adjustments still have to be addressed individually. An automated quantity take off as well as calculation of durations and resources is not part of the procedure. The focus was structural work from the perspective of a general contractor - other trades and project participants need to be regarded as well. Furthermore, a deeper consideration of details and processes below the current level of detail of the developed procedure is required. The BIM-method requires very structured and disciplined work. First projects show that more effort is required in early phases of a project in terms of accurate modelling, decision taking and providing required procedures and databases (e.g. a process model and its attributes). New professions emerge, and the project participants collaborate in a different way – new processes and roles are required. Thus, the implementation of the BIM-method requires a lot of effort in the beginning. That might be a barrier to adopting the BIM method and the proposed procedure depicted in this paper. More research is needed to address the abovementioned limitations and to demonstrate the expected efficiency gains.

• REFERENCES

Berner, F., Kochendörfer, B., Schach, R. (2013). Grundlagen der Baubetriebslehre 2 - Bauleitplanung, B.G. Teubner Verlag, Wiesbaden

Bhatla, A. and Leite, F. (2012). “Integration Framework of BIM with the Last Planner System” 20th Annual Conference of the International Group for Lean Construction (IGLC-20). San Diego State University, San Diego

Dave, B., Boddy, S., Koskela, L. (2011). “Visilean: Designing a production management system with Lean and Bim.” 19th Annual Conference of the International Group for Lean Construction (IGLC-19), Lima

Gerber, D, Becerik-Gerber, B., Kunz, A. (2010). „Enabling Lean with IT.“ 18th Annual Conf. of the International Group for Lean Construction (IGLC-18). Technion, Haifa

González, A. (2012). A Proposal for Implementing the Last Planner System Supported by 4D Technology at the Building´s Structural Concrete Work Stage. Civil Engineering Thesis, University of Chile, Santiago de Chile

Halpin, D. (1977)."CYCLONE – A Method for Modeling Job Site Processes." J. Constr. Div., ASCE. 103(3)

Hamdi, O. and Leite, F. (2012). “BIM and Lean Interactions from the BIM Capability Maturity Model Perspective: A Case Study.” 20th Annual Conf. of the International Group for Lean Construction (IGLC-20). San Diego State University, San Diego

Harris, B., Alves, T. (2013). "4D Building Information Modeling and Field operations: An exploratory study." 21st Annual Conf. of the International Group for Lean Construction (IGLC-21), Fortaleza

Hartmann, V., et al., (2012). "Model-based Scheduling for Construction Planning.“ 14th International Conference on Computing in Civil and Building Engineering, Moscow

Huhnt, W., Enge, F., (2006). "Can algorithms support the specification of construction schedules?“, ITcon Vol. 11

König, M., Beißert, U., (2008). "Constraint-basierte Simulation von Bauprozessen.“ Tag des Baubetriebs 2008, Bauhaus-Universität Weimar, Weimar

Kugler, M., (2012). "CAD-integrierte Modellierung von agentenbasierten Simulationsmodellen für die Bauablaufsimulation im Hochbau.“ Schriftenreihe Bauwirtschaft I 22, Dissertation, Kassel University Press, Kassel

Liu, L. and Ioannou, P., (1992). "Graphical Object-Oriented Discrete-Event Simulation System, Proceedings of the 1992 Winter Simulation Conference

Sacks, R., Koskela, L., Dave, B. and Owen, R. (2010). "Interaction of Lean and Building Information Modeling in Construction." J. of Constr. Eng. and Mgmt.,136(9)

Toledo, M., et al. (2014). "Using 4d Models for Tracking Project Progress and Visualizing the Owner´s Constraints in Fast-Track Retail Renovation Projects" 22nd Annual Conf. of the International Group for Lean Construction (IGLC-22). Oslo

Tommelein, I. and Odeh, A., (1995). „Assembly of Simulation Networks Using Desig, Plans, and Methods." J. of Constr. Eng. and Mgmt., 120(4)

Tulke, J., Hanff, J., (2007). "4D Construction Sequence Planning – New Process and Data Model.“ 24th International Conf. on Inform. Technology in Constr., Maribor

Zozaya-Gorostiza, C. et al. (1989). "Knowledge-Based Process Planning for Construction and Manufacturing, Academic Press Inc., San Diego