Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.

IMPORTANT CONSTRUCTION CONSTRAINTS IN CONSTRAINT SIMULATION

Sebastian Hollermann

Institute for Construction Engineering and Management
Bauhaus-Universität Weimar
Marienstraße 7
D-99423 Weimar, GERMANY

ABSTRACT

This paper identifies construction constraints for a constraint simulation of a construction flow. Therefore the construction environment and the methodologies of scheduling in construction are analyzed. Typical characteristics of construction schedules are classified. The relationship between different activities or between activities and building elements or between different building elements are examples for identified classes. With these characteristic construction schedules of real construction projects are analyzed. The results of this survey of construction schedules and the identified strategies of construction methods are presented in this paper in order to understand the process of scheduling. Based on that, the results of constraint based scheduling simulation can be improved a lot. Additionally, the reliability of construction schedules can be improved. Thru the productivity in construction can be increased.

1 INTRODUCTION

Eastman and Sacks (2008) explored that the productivity of the construction industry in the United States of America does not increase like the total productivity of the United States of America.

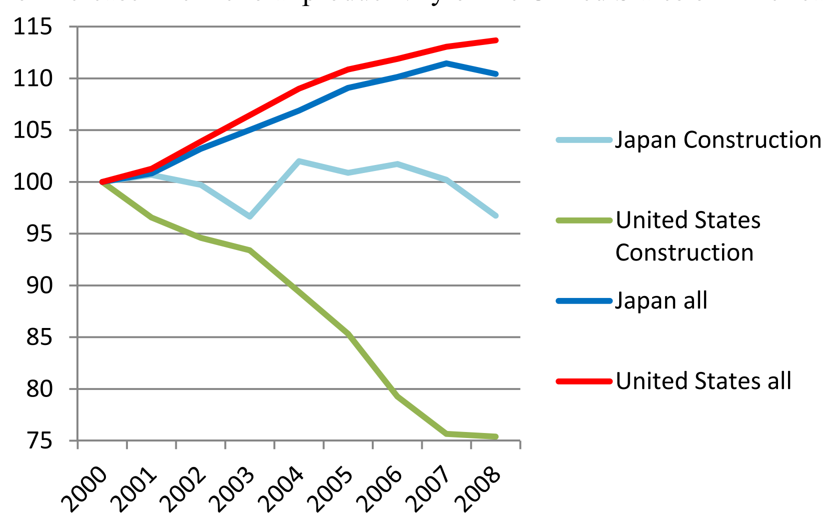


Figure 1: Labor productivity index (OECD, STAN Indicators).

Figure 1 shows that, although the total productivity and the productivity in construction sector in Japan differ like in the United States of America. New technologies such as computers are the mayor reason for this increase of productivity per working hour in the last twenty years. In the United States of America and in Japan the total productivity increases. However, the productivity in construction decreases in the United States of America. The productivity in construction sector in Japan has a smaller decrease, but seems to stay almost on the same level.

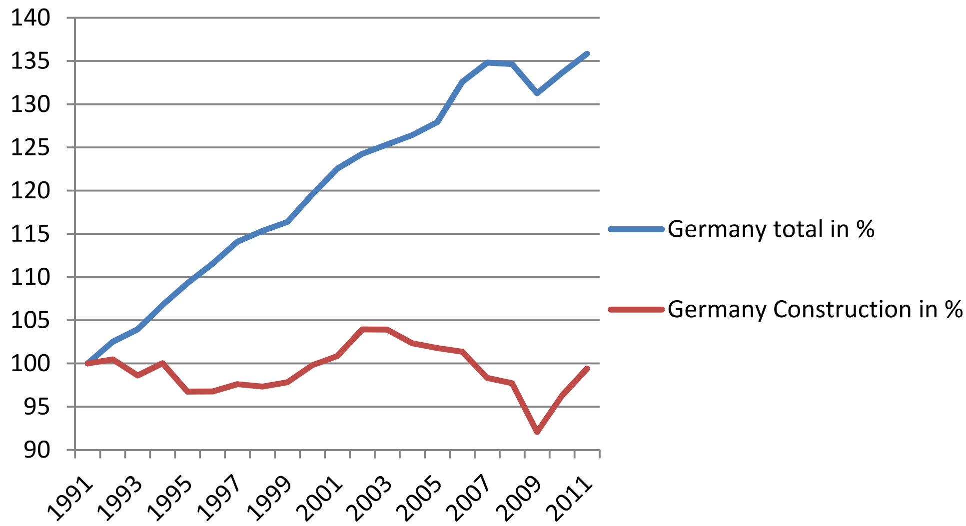


Figure 2: Labor productivity index (Statistisches Bundesamt, 2011).

This trend in the development of productivity in construction compared to the total productivity seems to be the same for a lot of countries in the world. Figure 2 shows the same trend for Germany like it is for Japan. This indicates that, new technologies like the use of computer in work planning in construction has not yet given significant benefits to the construction industry.

There are three major reasons why it is in the construction industry more complicate to improve the productivity. The first reason is the size of construction companies. Figure 3 shows that most of the construction companies are very small. That means new technologies has to be implemented into a lot of small companies. For small companies it is very expensive and time consuming to change their processes. Especially if the new processes still need improvements.

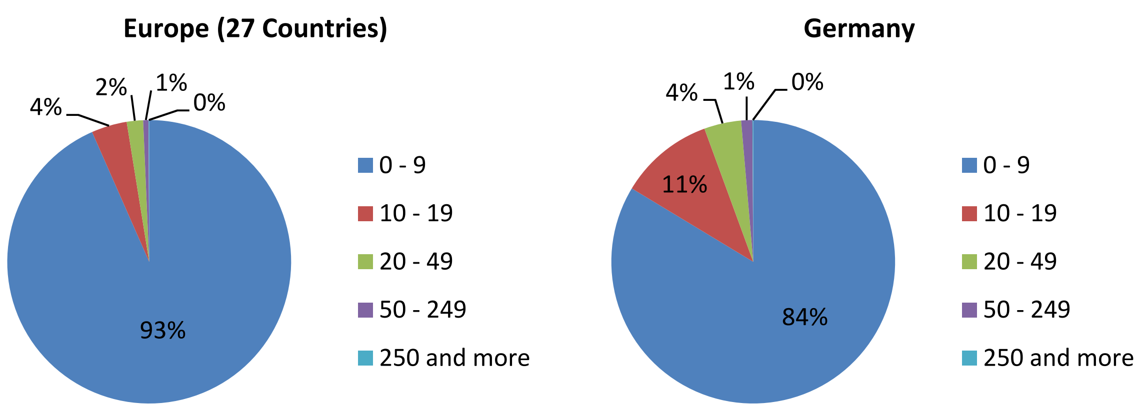


Figure 3: Size of construction companies in Germany and Europe by employees (Eurostat 2010).

The second reason why it is in the construction industry more complicate to improve the productivity is the product. In construction each product are one of a kind. That means according to ASIM in Bargstädt (2013):

- production only according to external customer order
- target setting by external customers and according to individual customer requests
- simultaneous planning and realization
- frequent and permanent changes
- permanent lack of information, thus necessary requirement for extensive structures for communication
- changing working environments
- high flexibility in terms of production site and ways of production
- considerable degree of manual processing
- poor automation
- quality problems due to novelty of product and high requirements at first go
- fixed and mostly critical delivery date

The third reason why it is in the construction industry more complicate to improve the productivity is the understanding of all process. A lot of different companies and parties from different fields have to work together, however the work processes and the processes of planning and especially scheduling are different. Therefore, this research is surveying the methods and the results of scheduling in construction.

2 SCHEDULING

2.1 Methods of scheduling

The construction work planning has to consider the construction flow, resources and costs (Figure 4). The result of work planning is the project flow and is commonly display in a time schedule such as a bar chart. The duration of a process is depending on the construction flow and the availability of resources. Different material has often only impact on costs. Construction method has impact on the construction flow, resources and costs.

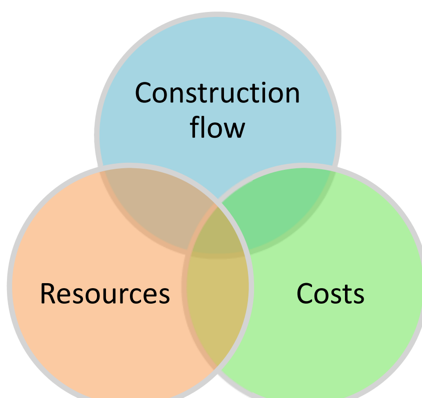


Figure 4: Construction flow planning.

For scheduling different methods can be used. Figure 5 gives an overview about operation research with the different scheduling methods. Most common in construction is the Critical Path Method of the scheduling network diagramming techniques. In practice, simulation is not very often used for scheduling. Linear programming requires special software and knowledge about the methodology. To build a model for simulation is still too complicated and time consuming, especially for small construction companies as discussed in Chapter 1 and Figure 3.

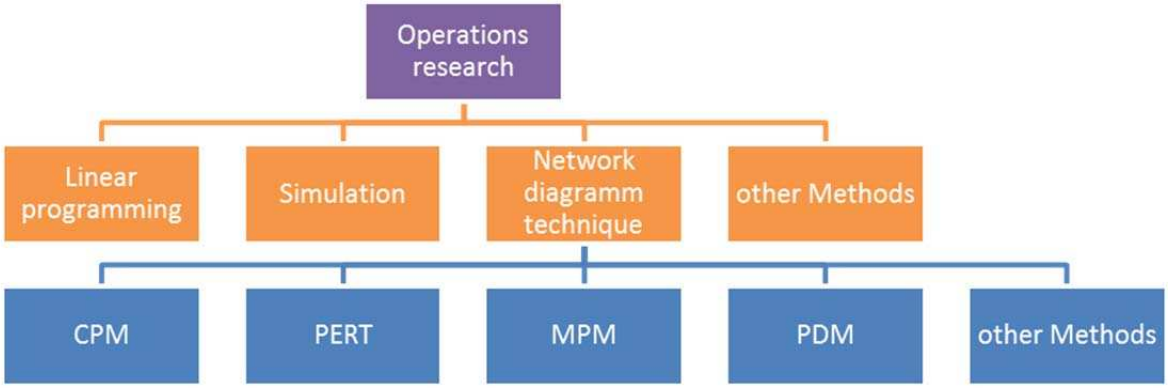


Figure 5: Operations research according to Krause et al. (2011).

The different scheduling techniques shown in Figure 5 require different information input. However, the different scheduling techniques consider different information. As Table 1 shows, most of the common scheduling techniques do not consider the availability of resources. They assume that enough resources are available at all time. However, this is not the case for small construction companies. The schedule baseline is for almost all scheduling techniques generated based on the schedule and therefore not considered during scheduling. The constraint simulation is a methodology which considers resources during scheduling.

Moreover, for construction flow planning it is important to consider the process sequence and the process duration. The common scheduling techniques like Critical Path Method (CPM) and Metra Potential Method (MPM) are using deterministic values for the process duration and the process sequence. The Program (or Project) Evaluation and Review technique (PERT) already can us stochastic values for the process duration. The PERT is not often used in scheduling construction projects. The only scheduling technique which considers stochastic process duration and a stochastic process sequence is the constraint simulation.

Table 1: Methods of scheduling.

	Duration	**Process sequence**	**Resource**
CPM Critical Path Method	deterministic	deterministic	-
MPM Metra Potential Method	deterministic	deterministic	-
GA Genetic algorithm	deterministic	stochastic	-
PERT Program (or Project) Evaluation and Review Technique	stochastic	deterministic	-
GERT Graphical Evaluation and Review Technique	stochastic	stochastic	-
PDM Precedence Diagramming Method	deterministic	deterministic	-
Constraint Simulation	stochastic	stochastic	X

The constraint simulation as scheduling technique is because of the methodology especially suitable for construction projects. One of a kind projects in construction with their changing environment requires a flexible process sequence of a schedule and a stochastic process duration. The constraint simulation can consider resources because it can solve the resource-constrained project scheduling problem (RCPSP). To identify dependencies and the logical constraints in construction project is needed for all scheduling techniques.

In these days, a computer supported creation of a schedule is because of the handling standard for all construction projects. Further, an object-oriented time scheduling helps to structure a project logically. Because of the fact that, common product models like a Building Information Model (BIM) are object-oriented and computer supports the way of object-oriented modeling too. An object oriented product model and a connected object oriented schedule like it is possible with the Industry foundation standard (IFC) ensure consisted data in a project.

2.2 Relationships in construction schedules

The goal of scheduling is to identify activities, sequence them and calculate their duration. The sequence of activity is depending on the relationship between the activities. The CPM, MPM, PERT and PDM Methods are focusing only on relationships between the sequenced activities. The constraint simulation has to focus on all relationships as constraints for the flexible and dynamic scheduling simulation of the process sequence. The relationships between activities can be:

- Finish to Start (FS)
- Start to Start (SS)
- Finish to Finish (FF)
- Start to Finish (SF)

These relationships could in furthermore be modeled with leads and lags (Project Management Institute 2008). There are three categories of process relationships in a construction project as shown in Figure 6. Logical once can be formalized and they depend on the technology, on standards or on the product. Furthermore, the user can add individual or project specific relationships. The availability of resources add although further relationships. This is known as resource-constrained project scheduling problem (RCPSP).

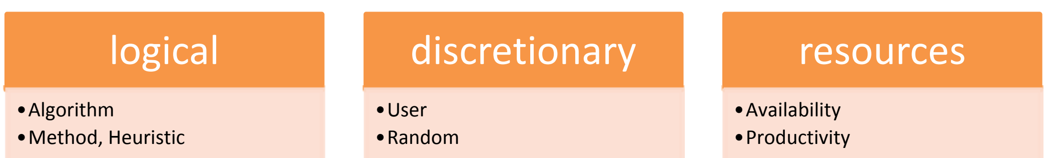


Figure 6: Categories of process relationships (Hollermann and Bargstädt 2012).

Beside the relationships between activities, the activities in a schedule have as well relationships to building elements. The different kind of relationships between processes and building elements is described in Table 2. The relationship between processes and building elements in a construction schedule is depending on the construction method, work section and the Level of Detail (LOD). One activity could represent several building elements or just one building element. Furthermore one building element can have a relationship to several activities in a schedule.

Table 2: Relationship between processes and building elements.

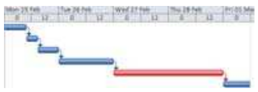
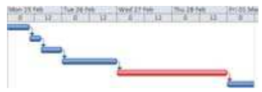
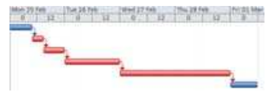
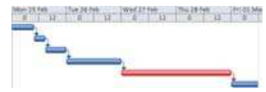
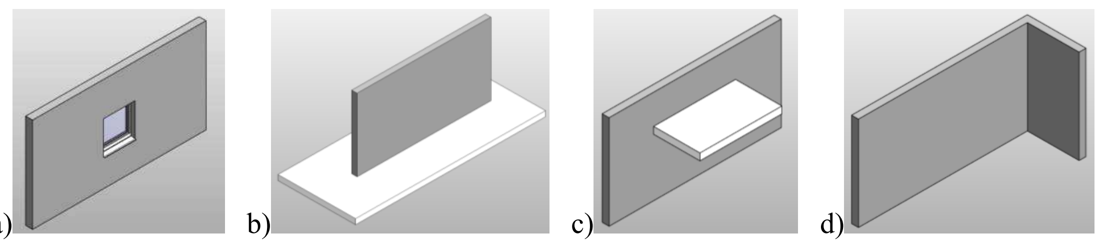
process : building element			
1:n	**1:1**	**m:1**	**1:0**
 	 	 	

Table 2 shows as well the possibility, that a process has no relationship to a specific building element. An example for that would be the allowance for construction, tendering or waiting for an approval of drawings. But in general, tendering or approval of drawings are a 1:n relationship between one activity and several building elements.

For scheduling most of the dependencies has to do with the relationship of building elements to each other. Examples for topological relationships of building elements are shown in Figure 7. These examples indicate already how difficult it is to describe these relationships. Johnson et al. (2004) analyzed different methodologies of generating a process sequence, based on building elements. They analyzed methods by building element type, by elevation, by Joint Configuration and by Tracing from Foundation. But the results of these four methods were not satisfying enough.



a) b) c) d)

Figure 7: relationships between building elements.

De Vries and Harink (2007) developed another method to identify the relation between building elements. Therefore he moved each building element a couple of centimeter to all direction and analyzed if there is an intersection with another building element. The validated results of this research seem to be really practical to identify relationships between building elements. However, what relationships in scheduling are really important for a schedule are not identified yet. Therefore, real construction projects have to be analyzed.

2.3 Construction flow strategies

For a construction normally several schedules are possible. Each alternative has his own characteristic. Therefore, for scheduling a construction project a strategy is needed. The basic dependencies as they are shown in Table 3 are strategies for sequencing processes. The methodologies analyzed by Johnson et al. (2004) and the developed methodology from de de Vries and Harink (2007) are examples for these basis dependencies by topology. Other examples for basic dependencies are: big elements before small elements, by building element type, by material type, by volume, by dimension, by elevation, by level, by distance, by orientation, from left to right, from center to the sites, from the back to the front, by amount of needed resources and by material quality.

Table 3: Basic dependencies according to Bargstädt (2013).

basic dependencies	principle examples for sequencing
geometric coordinates	Sorted according to x-, y-, z-, φ-, r-direction
delivery-oriented	first-in-first-out, last-in-first-out, etc.
time-oriented	long durations before short durations or vice versa
calendar-oriented	respecting fixed dates, excepting holidays, outside of breeding season etc.
interior element geometry	Interior work before exterior work

More advanced strategies are shown in Table 4. These more advanced dependencies are characterized by giving a priority to a process to start. This is part of solving the resource-constrained project scheduling problem (RCPSP). Other examples for giving a priority to a process are depending on weather, logistic aspects and availability of workspace.

Table 4: Advanced dependencies according to Bargstädt (2013).

advanced dependencies	principle examples for prioritization
properties of work items	simple parts before complicated parts
properties of work performance	activities causing dust or soiling come first
properties of work environment	activities requiring dry environment come first
granularity of work items	coarse work phases come before fine phases
properties of work after treatment	activities requiring drying or other curing processes come first

For choosing a process which fulfills all constraints of sequencing to start with, a strategy or a combination of strategies mentioned above could be used. Furthermore other algorithms, a case based reasoning, position on the activity list or a random chooses could be used. Which strategy is most common or important for construction project is unknown. Therefore it is needed to identify and analyze construction strategies in real construction projects.

2.4 Building Information Model-based work preparation

Based on models of a construction project different reports or analyses can be done. By linking models together like the multi model container presented in the mefisto research project (Scherer and Schapke 2011) more detailed information of a project are in a consistent way available for reports and analyses. These linking of models are the idea of Building Information Models (BIM). The Industry Foundation Classes (IFC) already includes the object-oriented product model and the time schedules.

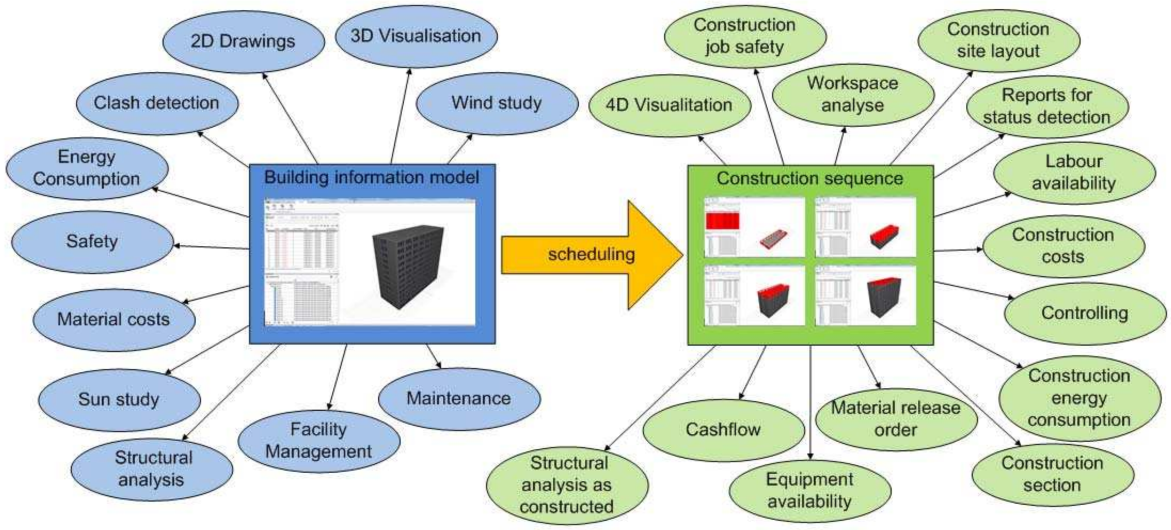


Figure 8: Project management based on a Building Information Model (BIM).

Many reports and analyses like structural analysis, bill of material costs, sun studies, 2D-drawings and clash detection are based on the object-oriented product model (Figure 8). If the Building Information Model is linked with the construction flow model more analyses and reports can be done. Figure 8 shows, that reports and analyses of 4D-Visualisation, construction site layout, labour and equipment availability, construction energy costs and construction costs needs information about the product **and** the schedule. A lot of reports and analyses as shown in Figure 8 are based on the relationship between building elements with each other, processes with other processes and building elements with processes. Therefore, the relationships in the construction flow of real construction projects should be identified, analyzed and graded.

3 CONSTRAINTS IN CONSTRUCTION

3.1 Analyze of construction schedules

In this research project twenty six time schedules from Germany, Sweden, Norway and Austria are analyzed. These construction projects are from different construction types, but not from single family houses and tunnels. All schedules are created during work planning and are adjusted to as build. The analyses of each time schedule is based on the schedule itself and an expert interview with the site management about the schedule and the construction site.

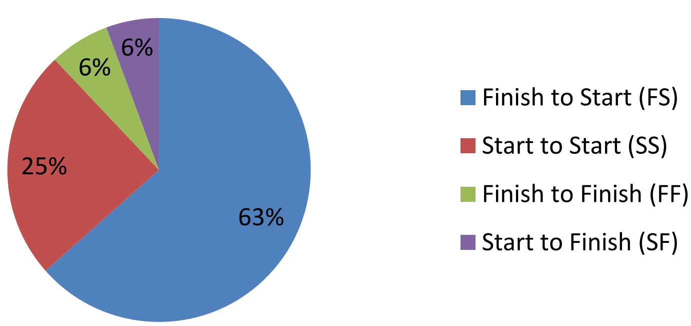


Figure 9: Relationship between activities in construction schedules.

By analyze the construction schedules we identified the Finish to Start relationship as the most common relationships between activities in construction. The result is displayed in Figure 9. But through the expert interviews the released that almost all of the Start to Start, Finish to Finish and Start to Finish relationships are not correctly modeled in the schedules. They often are Finish to Start relationships. The result of these schedule survey is that approximately over 85% of the relationships between activities on construction projects are Finish to Start relationships.

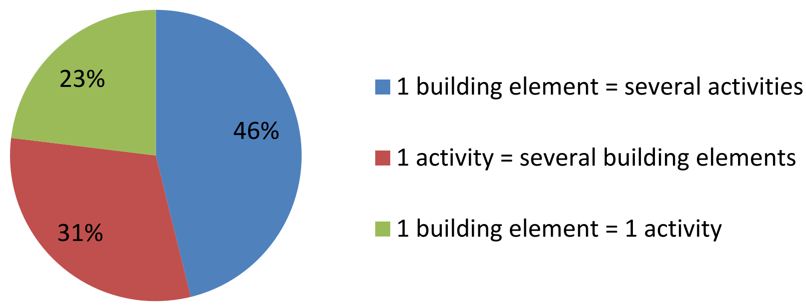


Figure 10: Relationship between processes and building elements.

The relationship between building elements and processes as described in Table 2 was for the analyzed construction schedules as shown in Figure 10. Most of the building elements have a relationship with several activities in a schedule. This indicates, that construction schedules care about the technology constraints of the construction methods.

3.2 Relationships in construction schedules

The finding of the described research was that there is no strong relation between the amount of processes in a construction schedule and the kind of building or the size of the building. Typically a construction schedule fits on one page (DIN A3, A2 or A1). The reason for that is according to the expert interviews to have a good overview of the project flow on one page. A schedule of a construction has in average 135 activities. Figure 11 show that most of the construction schedules has between 51 and 100 activities.

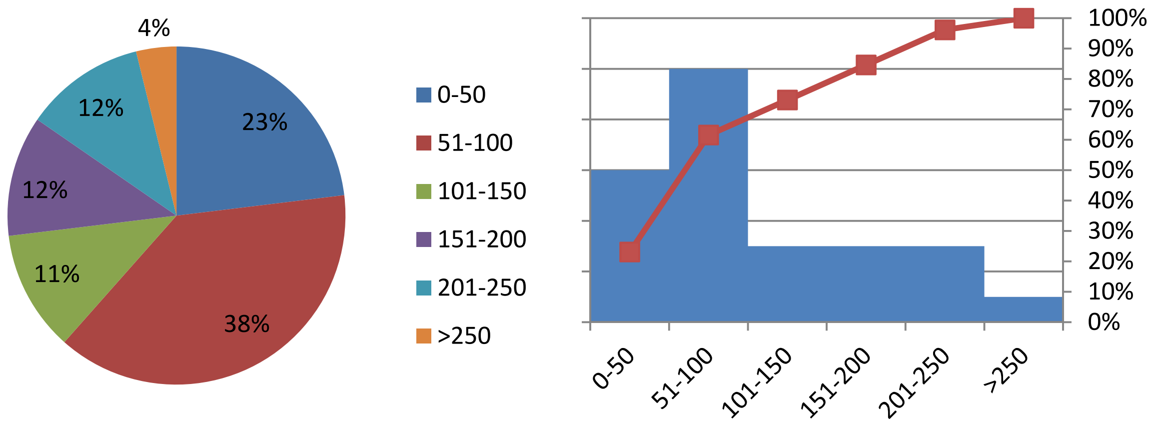
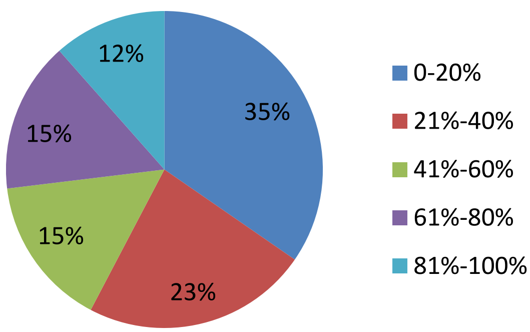


Figure 11: Activities per time schedule.

38 activities are in average on the critical path. Figure 12 shows that 35 % of construction time schedules have 20 % or less activities on the critical path. Furthermore 58 % of construction time schedules have 40 % or less activities on the critical path and 73 % of construction time schedules have 60 % or less activities on the critical pass. That indicates that in construction projects a lot of activities can be done parallel and are flexible.



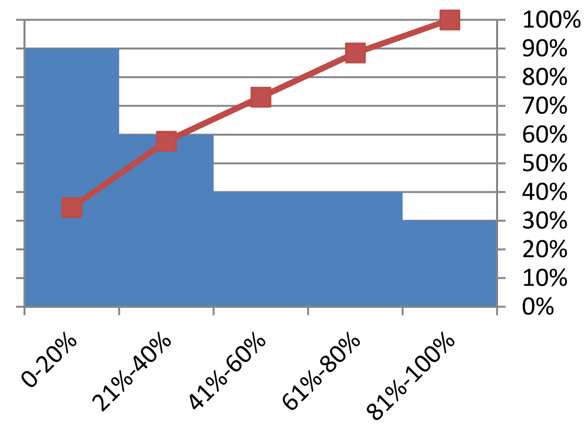
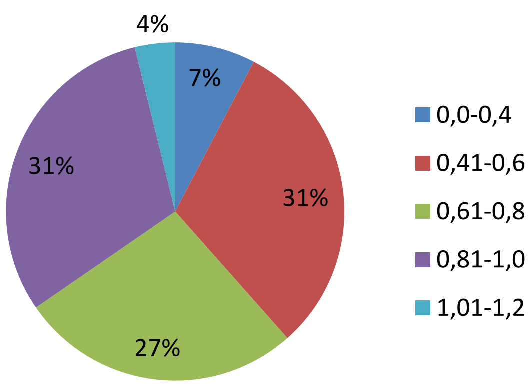


Figure 12: Activities on the critical path.



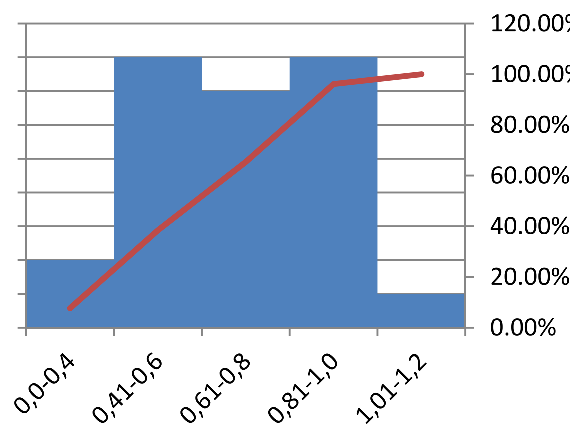


Figure 13: Ration dependencies / activity.

For a better understanding of relationships in construction projects, the dependencies and activities in a schedule are analyzed. A activity has in average 0.65 dependencies in construction schedules.. Figure 13 shows that most of the construction schedules has less dependencies then activities, only 4 % has more dependencies then activities. In the expert interview a lot more dependencies which are not in the construction schedules could be identified. To support construction scheduling it is because of changes in the construction flow important to care about all relationships.

3.3 Constraint simulation

For a construction several alternatives are possible. Therefore, a simulation of the construction flow helps to find a good solution in a virtual environment. For simulating a construction flow the relationships has to be considered. Constraint-based simulation was developed by König and Beißert (2008) and considers different constraints Beißert (2012). This paper shows which relationships in construction schedules are considered today. Figure 14 propose a process of constraint simulation based on a building information model. Similar to practice, it starts with the modeling of the product and adds constraints such as construction methods with their resources and geometrical relationships. Based on that, constraint simulation experiments can be done. The simulation experiments have to consider important and real dependencies to create a reliable schedule alternative. Therefore this research has analyses real construction schedules and identified relationships in construction schedules. Construction schedules based on a Building Information Model can be used for creating reports and studies. Furthermore these construction flow model can be used for a 4D Visualization of the construction flow. Should a study or the 4D Visualization identify, that relationships are missing, is it easily possible to at this constraints and run the simulation again to get a other alternative schedule. Furthermore during execution changes can be add through new constraints and the new schedule can be simulated. In the same way users can add personal or project specific constraints at all time. From the expert interviews we recognized that in practice the construction companies starts the process of scheduling with simple relationships and they later on add special relationships. In the same way works the proposed process of constraint schedule simulation in Figure 14. These way of working helps although young and inexperienced engineers to understand the impact of relationships to a construction flow and get experience through that.

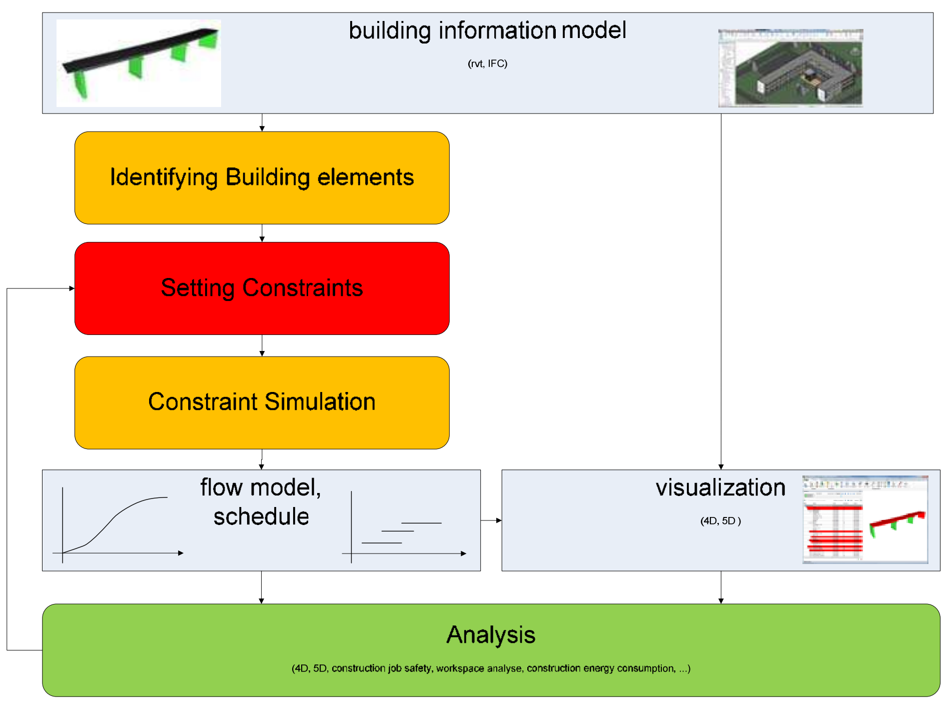


Figure 14: Constraint schedule simulation based on a Building Information Model.

4 CONCLUSION AND OUTLOOK

This paper shows, what relationships in construction projects are common. Furthermore this paper gives an overview how schedules are structured today. In today´s construction schedules only 0,65 dependencies per activity are modeled. Most of the real dependencies are not modeled. For a constraint based schedule simulation of a construction project much more dependencies has to be modeled. This paper identifies geometric and technologic relationships as dependencies which have to be added and considered in a constraint based schedule simulation for a construction project. In a next step the schedule survey and expert interviews will be extended to more schedules from projects all over the world to identify more in detail which relationships are important, how to formalize the generation of constraints and whether there are differences between Countries or project types.

REFERENCES

Bargstädt, H.-J. 2013. "Transferring BIM Information into Respected Work Orders". CSCE 2013, Québec.

Beißert, U. 2012. "Constraint-basierte Simulation zur Terminplanung von Ausführungsprozessen".Dissertation, Weimar .

Eastman, C. M., and R. Sacks. 2008. "Relative Productivity in the AEC Industries in the United States for On-Site and Off-Site Activities". *Journal of Construction Engineering and Management* 134(7): 517–526. DOI: 10.1061/(ASCE)0733-9364(2008)134:7(517).

Hollermann, S., and H.-J. Bargstädt. 2012. "Work Planning based on a Building Information Model". *International Conference on Construction Applications of Virtual Reality*, Taipei, Taiwan University Press.

Johnson, S., P. von Buelow, and P. Tripeny. 2004. "*Linking Analysis and Architectural Data*". *ACADIA Fabrication Conference*, Cambridge and Toronto, Ontario, University of Waterloo School of Architecture Press.

König, M., and U. Beißert. 2008. "Constraint-basierte Simulation von Bauprozessen". *Schriften der Professur Baubetrieb und Bauverfahren, Nr. 17* (2008), Page. 17–36

Krause, T., J. Martin, W. Kuhlmann, J. Pick, U. Olk, K. H. Schlösser, W. Streit, and N. Winkler. 2011. "Zahlentafeln für den Baubetrieb". Wiesbaden, Vieweg + Teubner.

Project Management Institute 2008. "A Guide to the Project Management Body of Knowledge." Newton Square, Pa, Project Management Institute.

Scherer, R., S.-E. Schapke, R. Scherer, S.-E. Schapke, R. J. Scherer, and H. Tauscher, Eds. 2011. MEFISTO. Dresden, Inst. für Bauinformatik.

Statistisches Bundesamt 2011. Volkswirtschaftliche Gesamtrechnungen, Inlandsproduktsberechnung Detaillierte Jahresergebnisse. Wiesbaden.

Vries, B. de, and J. M. Harink. 2007. "Generation of a Construction Planning from a 3D CAD Model". *Automation in Construction* 16(1): 13–18. DOI: 10.1016/j.autcon.2005.10.010.

AUTHOR BIOGRAPHIES

SEBASTIAN HOLLERMANN is an civil engineer in the Institute of construction engineering and management, Bauhaus-Universität Weimar. He is doing his dissertation in construction management. Before moving to academia, he accumulated several years of construction site management experience for bridges. He received an engineering degree from the University of Applied Sciences Münster, a journeyman's certificate of the Chamber of Crafts, Vechta, Germany, and a research grant of the German Academic Exchange Service for a research about shear connectors for timber concrete composite bridge constructions, Joensuu, Finland. His email address is sebastian.hollermann@uni-weimar.de.