

BIM-based Construction Site Layout Planning and Scheduling

Kevin Schwabe¹, Stephan Liedtke², Markus König³, and Jochen Teizer⁴

- 1) M.Sc., Research Associate, Chair of Computing in Engineering, Ruhr-Universität Bochum, Germany. Email: kevin.schwabe@rub.de
2) M.Sc., BIM-Consultant, DeuBIM GmbH, Düsseldorf, Germany. Email: liedtke@deubim.de
3) Dr., Prof., Chair of Computing in Engineering, Ruhr-Universität Bochum, Germany. Email: koenig@inf.bi.rub.de
4) Dr., Team Leader, Ed. Züblin AG, Stuttgart, Germany. Email: jochen@teizer.de

Abstract:

Site layout planning is performed before the start of construction to allocate and arrange important resources, for example, the location of temporary facilities, the flow of materials, and the safe positioning of equipment. The availability of construction resource information a priori, such as existing site environment and infrastructure, temporary object geometry, and interconnected dependencies are essential for successful site layout planning and efficient project handling. However, site layout planning is hardly ever updated in detail once construction starts because the time-dependent nature of such information in the dynamic construction environment changes frequently and consequences of change can only be assessed manually. Sequencing site layout plans according to progress in the construction schedule is important to optimize for safety and productivity performance. Therefore, formulating a dynamic construction site layout model underlies the specific resource characteristics that are available as well as the dynamic changes that are expected to happen during operation. Another important issue is the compliance of rules and standards. Verifying rule compliance nowadays is performed manually. Automated rule checking would be of great help to prevent human error and ensure a safe working environment. The goal of this work is to demonstrate the development of the interface between construction site layout objects in Building Information Modeling (BIM) and the construction schedule by using a neutral data exchange format (Industry Foundation Classes, IFC). The current state-of-the-art in construction site layout planning is reviewed. Requirements for BIM-based site layout planning are defined. An IFC-extension is introduced to allow for BIM-based site layout planning. A novel concept and the prototypical implementation of rule checking is used to assess quality of the model-driven site layout plan. Visualization gained through 4D (3D+time) progress of construction site objects is demonstrated using a realistic construction site. The various benefits from BIM-based vs. traditional construction site layout planning are explained.

Keywords: construction safety, equipment positioning, logistics, material flow, site layout design and planning.

1. INTRODUCTION

The process of site layout planning describes the design and allocation of site equipment such as tower cranes or containers. Every decision during this phase needs to find a balance between maximum safety and minimum cost. Due to the complex and dynamic nature of this manual process wrong decisions and errors can occur that have negative consequences not only for the health and safety of site personnel. The decision making follows specific rules, standards and best-practices. Evaluating and checking these rules is very time-consuming and requires a lot of experience in this field.

The construction industry is currently experiencing a change to a more digital construction planning process mainly with the help of Building Information Modeling (BIM). The BIM method is used to provide all necessary information of a specific building project from the planning phase up to facility maintenance with the help of an intelligent 3D-Model. This can be achieved by expanding the geometrical information (3D) of the model with additional information. To implement an integrated digital planning, the site layout should also be integrated into existing BIM models. A BIM-based site layout planning not only provides a 3D-model of site equipment, where 2D site layout plans can easily be derived from, but also considers 5D information for time scheduling and cost estimation. Combining and storing all building information in a common data environment will lead to a consistent data management and prevent economical and health related risks.

In this paper a BIM-based site layout planning concept is proposed. Requirements for predefined parametric BIM-objects for site equipment are evaluated. Rule-based algorithms (rule checking) for an automated site layout evaluation are prototypically implemented. Furthermore, a representation of dynamic site equipment in the neutral data exchange format IFC (Industry Foundation Classes) is introduced, which can be used for 4D animations.

2. RELATED WORK

A meaningful outlook for a possible concept for BIM-based site layout planning requires a look into the work that has already been accomplished in this field. Therefore, a literature research was performed. An overview of this

literature research can be seen in Table 1. Keywords that relate to the topic of site layout planning were defined to identify significance. The most significant keywords and their frequency of appearance are visualized by the colors green (often), yellow (rare), red (never) and orange (in other context). The overview shows only a limited number of publications. It neither includes papers that have identical content with one of the mentioned papers nor those published before 2009. Most of the previous work related to site layout planning was already referenced in the publications mentioned in Table 1.

Ning et al. (2011), Pradhananga & Teizer (2014) and Yahya & Saka (2014) use optimization algorithms to find the optimal allocation of site equipment in a 2D site layout plan. Other optimization and simulation approaches, which use 3D or 4D technologies, are published by Astour & Franz (2014), Andayesh & Sadeghpour (2014), Cheng & Kumar (2014) and Olearczyk (2015). All of these papers considering site layout optimization or simulation contribute to be a valuable benefit to an automated site layout process, but are always one step ahead. This means that they assume a given design situation, where the necessary site equipment is already selected. Another assumption is the existence of constraints for the optimization or simulation process. But the origin of these constraints and which rules or standards they base on is not specified. Astour & Franz (2014) describe a process where simulation takes place within the BIM environment and suggest a site equipment database and collection of rules and constraints. A precise description or introduction of these databases is not mentioned in any of the research. Cheng & Kumar (2014) derive the parameters for the dimensioning of site equipment from the construction schedule linked with the 3D-model. Dividing the volume of a 3D building element by the scheduled completion time provides a peak consumption per day. This can be repeated in every construction phase, so that the dynamic nature of a site layout can be taken into account. Although they lack the mentioned prior step they will have a major impact on how automated BIM-based site layout planning will be designed. Hollermann & Bargstädt (2014) concentrate on the representation of site equipment in a 4D animation. They also propose a parametric site equipment database, so that dynamic site layout planning can be performed. In addition, the resulting 4D model can be visualized in a stereoscopic multi-user system.

Altogether, simulation and optimization of site layouts represents the most significant part in previous research. The necessary development of databases of parametric site equipment models and rules or constraints is assumed, but not specified any further. This leads to being one step ahead of what needs to be done in the first steps of BIM-based site layout planning.

Table 1. Overview of literature research

	Eastman et al. (2009)	Ning et al. (2011)	Hollermann & Bargstädt (2014)	Astour & Franz (2014)	Pradhananga & Teizer (2014)	Yahya & Saka (2014)	Andayesh & Sadeghpour (2014)	Kim & Teizer (2014)	Cheng & Kumar (2014)	Olearczyk et al. (2015)	Zhang et al. (2015)
2D		x			x	x					
3D			x							x	x
4D			x				x	x			
BIM	x		x	x				x	x		x
Site layout		x	x	x	x	x	x	x	x	x	
Site layout plan											
Rule checking	x							x			x
Geometrical rules											
Safety											x
Simulation/optimization		x		x	x	x	x		x	x	
Crane simulation										x	
Workspace modeling								x			
Time/change							x		x		
often rare never in other context											

The automated and systematical evaluation of rules is called *rule checking*. Rule-based algorithms evaluate a given situation for rule compliance with the help of rule languages. The rule language transcribes existing textual rules and best-practices into an algorithmically readable form. Automated rule checking is considered highly attractive but still in early stages of research. Eastman et al. (2009) provide a general overview of rule checking in building designs. They describe, compare and assess existing rule checking systems and present ideas for further rule-based applications. Their work does not explicitly cover rules for site layout planning, but the summarized workflow will serve as a template for further rule checking implementation. Their statement, “Parametric tables are an intermediate step between ease of use and the generality and power to define and implement any relevant rule” will be considered with particular attention. A second statement, “The work presented here deals with post facto applications of rules to a design. However, rule checking evaluation can also be applied during and supporting design development” will be treated similarly. Applied rule checking is presented by Kim & Teizer (2014) and Zhang et al. (2015). They apply rules that consider occupational safety to a 3D model. After the rule checking causes a conflict the implemented algorithms provide proposals for possible solutions. The proposed solutions are

derived from standards and best-practices. This approach takes rule checking to the next level, because it does not only consider true or false as a result.

3. CONCEPT

Significant advantages that come with BIM-based processes are parametric 3D modelling and optimized data management. The 2D site layout plans needed in the field can easily be derived from the 3D model. Adding and retrieving additional information to and from the model prevents the common problem of loss of data throughout the planning phase of a building. A special feature of site layout planning is that allocation and dimensioning of site equipment is performed under strict compliance of rules and standards. With the help of BIM information the evaluation of these rules could be automated. Interactive approaches to rule checking, where decision making is supported by rule-based algorithms, can help to avoid economical or health related risks.

Therefore, we propose a novel concept for interactive site layout planning, which can be seen in Figure 1. There are three data sources which provide the main input information to create a BIM-based site layout model. The digital building model provides the geometric and semantic information. Parametric models of construction machinery or site equipment need to be developed so that an easy access during site layout planning phase can be guaranteed. A further database containing a comprehensive set of rules for the positioning and dimensioning of site equipment enables the automated rule checking. The interactive exchange between the 3D-model and the schedule allows reading and writing time-dependent information. With this information the 4D animation can be performed. The process results in the creation of site layout plans, the enabling of parametric cost calculation and the provision of data for logistics planning.

The proposed interactive rule checking concept is depicted in detail on the right of Figure 1. At first the site layout designer chooses a required site equipment element type, for example *tower crane*. For this element type the supporting software automatically searches the site equipment database for a specific element that satisfies all associated rules in the rule database, for example a *Liebherr 1250 HC 40* crane. After an element is found the designer will be able to place it on the site, while placement rules are checked. This process is repeated until all necessary site elements and rules are successfully checked.

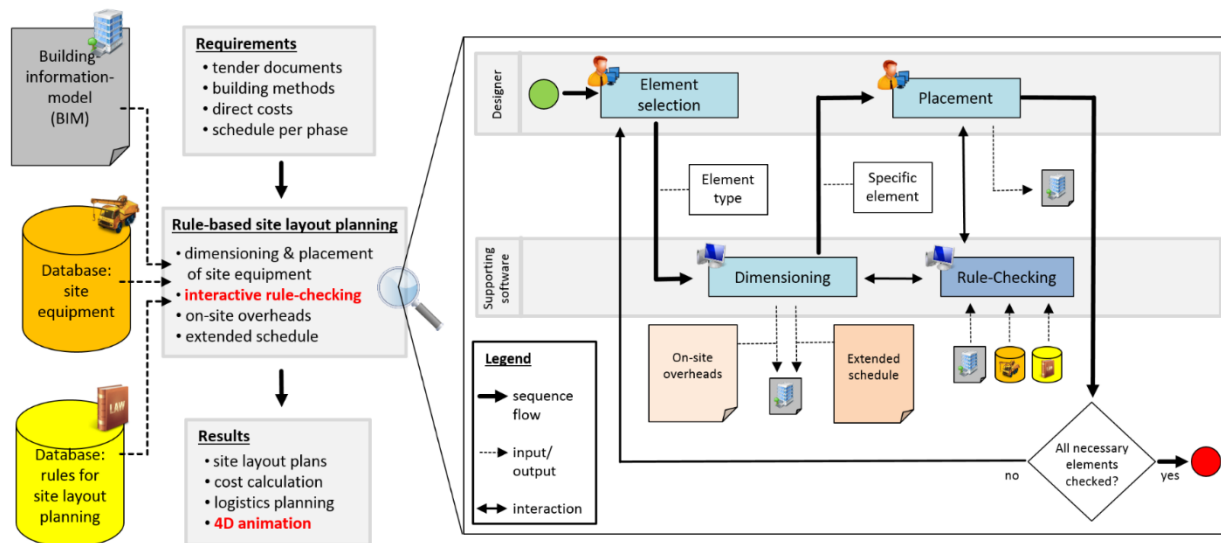


Figure 1. Process scheme for interactive site layout planning

3.1 Parametric site equipment

By using pre-defined object catalogs, the creation of digital models can be significantly simplified. In our concept we are using a parametric object catalog for defining site layout elements. For example, a tower crane template has several parameters like *crane boom length*, *hook height* or *maximum load capacity*. An example of parametric site equipment implemented as an Autodesk Revit family can be seen in Figure 2. The site equipment database can either be a unique database for each construction company or a globally accessible online database. It should include the following elements:

- large equipment (construction machinery, cranes, etc.);
- social services and office equipment (containers, sanitary facilities, etc.);
- traffic areas and transportation routes (construction road, storage areas, etc.);

- supply and disposal (electricity, garbage containers, etc.);
- construction site safety (site fence, scaffolding, etc.);
- temporary pit system (excavation support, slope, etc.).

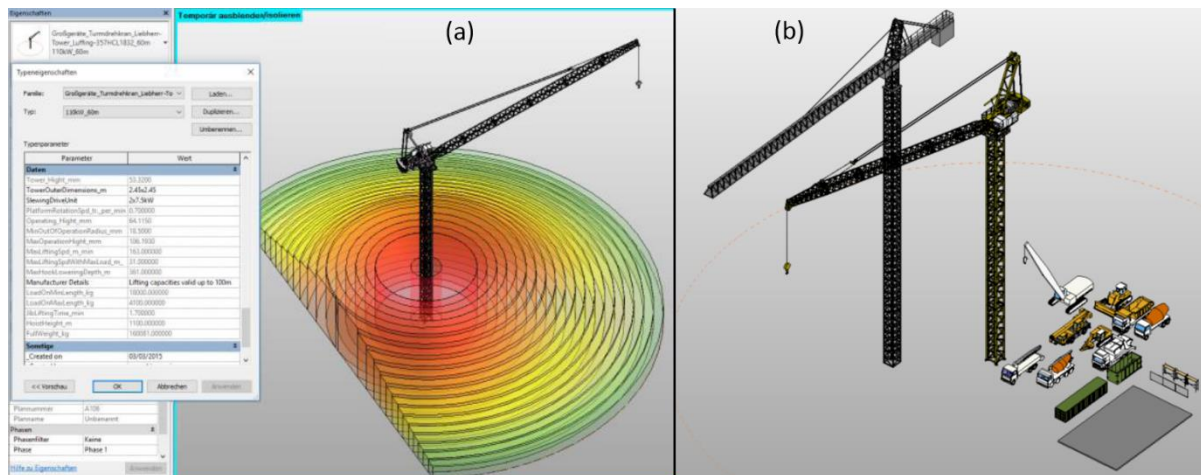


Figure 2. Examples of parametric site equipment

The site layout model should be exchanged as well as all other information between the involved project members. For this purpose, open data formats, e.g. the IFC format (buildingSMART, 2013), should be essentially used. Currently, the IFC format does not yet include a representation of site equipment entities. Therefore, an extension of the IFC format has been developed in order to transfer important elements and their properties between different BIM software systems. The IFC extension can be seen in Figure 3.

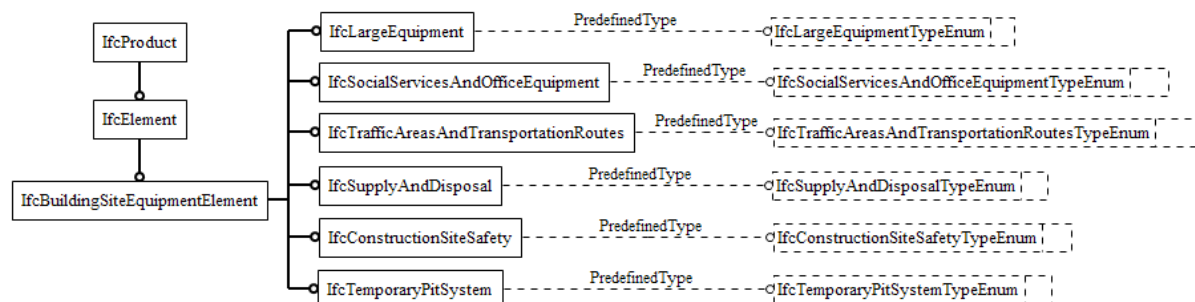


Figure 3. Representation of site equipment as IFC entities

3.2 Interactive rule-checking

During site layout planning certain rules need to be considered or checked. Eastman et al. (2009) structured the procedure of rule checking in the BIM-environment into the four following steps:

- rule interpretation,
- building model preparation,
- rule execution and
- reporting of checking results.

The first step deals with the actual rules. Rules and standards can be found in written form, hardly readable for computers. Therefore, the naturally written rules must be transcribed into an interpretable computer language. The second step enables adequate object filtering. This means the search for a particular set of keywords that can be uniquely assigned to a certain object. For example, the element mentioned in the rule must have the exact string representation as one of the element parameters. If the parameter does not exist, rule checking will not be possible.

During the model preparation the user must make sure that all necessary elements and parameters have reasonable values. In step three the actual rule check takes place. All rules are imported and checked. Possible conflicts must be added into the data structure in order to make the information available in the next step. The last step takes the conflict information from the rule execution and presents them to the user. There are two mandatory types of

reporting of checking results. The first one is the textual report of information. The second one is the visual display of conflicting elements. For example, if there is a geometrical clash detected between two elements, the textual report will give the element names and ids and the visual display will select or isolate both elements in the model viewer.

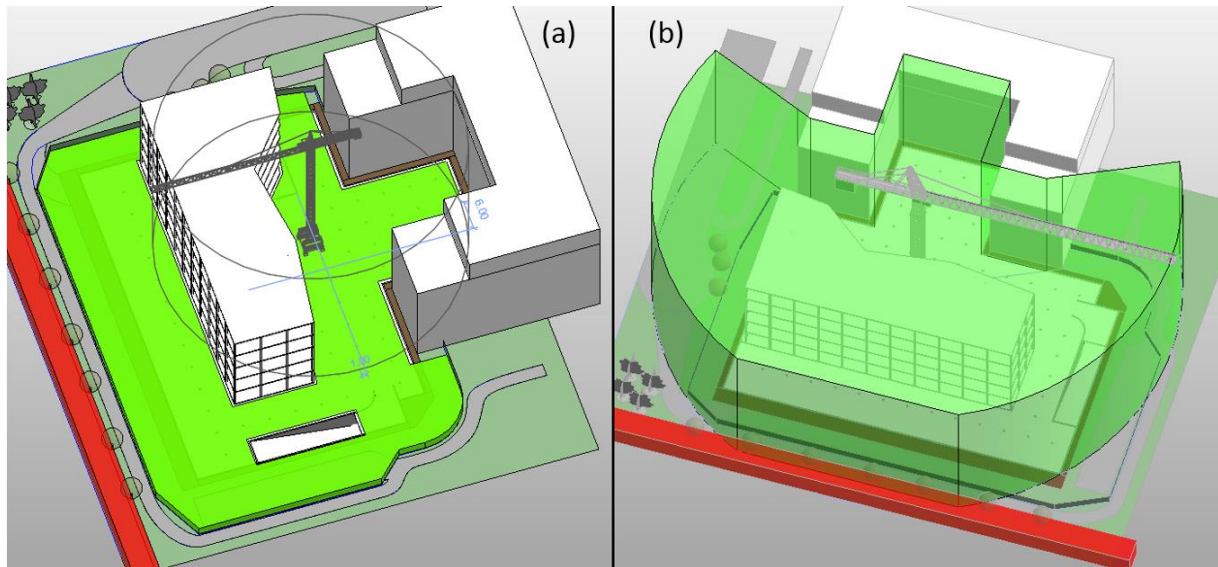


Figure 4. Examples for interactive rule-checking

This procedure represents the subsequent rule-checking. It checks rules after a design is finished. Eastman et al. (2009) state, “The work presented here deals with post facto applications of rules to a design. However, rule checking evaluation can also be applied during and supporting design development.” This means that design decisions can also be made by applying rules beforehand. Thus, a decision is made knowing that it will not cause any conflicts, because the design software evaluated and proposed possible decisions in advance. For this the software needs comprehensive knowledge about the geometry of the actual model and a rich database which includes all rules and site equipment models.

Figure 4 shows two options of preprocessed interactive rule checking. In Figure 4(a) the available placement area of a tower crane is depicted. For example, rules that dictate a safe distance between certain objects or rules that prevent placement on inclined surfaces will be taken into account. The green surface is the result of applying all rules that limit the placement of the crane at the same time. In Figure 4(b) applied rules cut the tower radius in order to find an appropriate spot for a material storage area. In this case rules that list elements where loads must not be hoisted over will be considered.

3.3 Scheduling site layout equipment

Apart from the geometrical information, time-dependent data plays an important role in site layout planning. Cost calculation and logistics planning require a very strict and precise scheduling. Linking the 3D model with schedule data results in a 4D data model. This can be used to visualize the construction process in a 4D animation. Hence, a violation of its integrity can easily be detected. Because the animation cannot take place inside the design software, the model, including site equipment elements, need to be exported into an independent data exchange format, e.g. the IFC. Time-dependent information is normally represented by tasks with a start and end time. For site equipment elements we developed a process pattern consisting of the three tasks installation, operation and dismantling. Durations of installation and dismantling are defined in the site equipment database. The duration of operation is derived from the schedule.

The dynamic nature of site layout planning occasionally forces temporary facilities to be moved. For example if a building is scheduled to be built in two consecutive sections, the tower crane will be moved from one section to the other. This procedure cannot be processed in a 3D model. Even in a 4D model it can only be achieved by using two individual crane objects. The problem with two objects is that they can occur as two individual cranes during cost calculation, although only one single crane is actually in use. In this case the process pattern mentioned above can be used again to indicate a position change. An IFC extension enabling time-dependent placement and multiple positions is currently under development. A prototype of the IFC extension can be seen in Figure 5. The entity *IfcTimedPlacement* associates with existing entities for object placement. The entity *IfcTask* is used to represent

schedule data (e.g. start and end time).

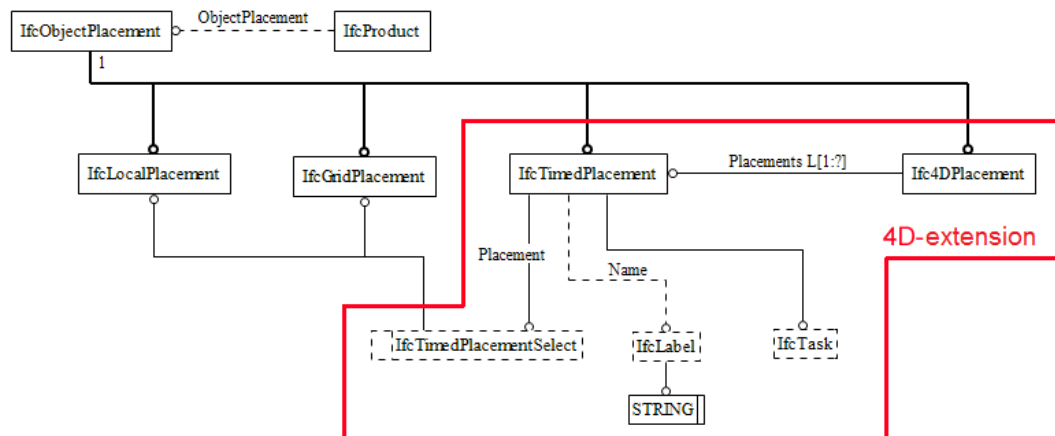


Figure 5. Prototype 4D-extension in IFC

4. CASE STUDY

The concept of BIM-based site layout planning has been prototypically implemented using a realistic construction project. Rule checking and 4D animation are performed. Figure 6 shows the resulting 3D model of the construction site in Revit and the AddIn developed to perform simple rule checking tasks. The example consists of a five story office building and some surrounding terrain and urban cityscape. The rule checking implementation includes two example rules. The rules can be displayed and configured by using a table. Keywords or values in each column are the parameters for the implemented rule-based algorithms. This tabular approach was chosen because Eastman et al. (2009) stated, “Parametric tables are an intermediate step between ease of use and the generality and power to define and implement any relevant rule.” The first rule represents the example rule ‘*Containers may not be placed within the load pan radius of tower cranes*’. The keywords in italics indicate the information needed for the rule transcription. The second rule transcribes another example rule ‘*All building elements must be within the reach of tower cranes*’. Further rules will be implemented.

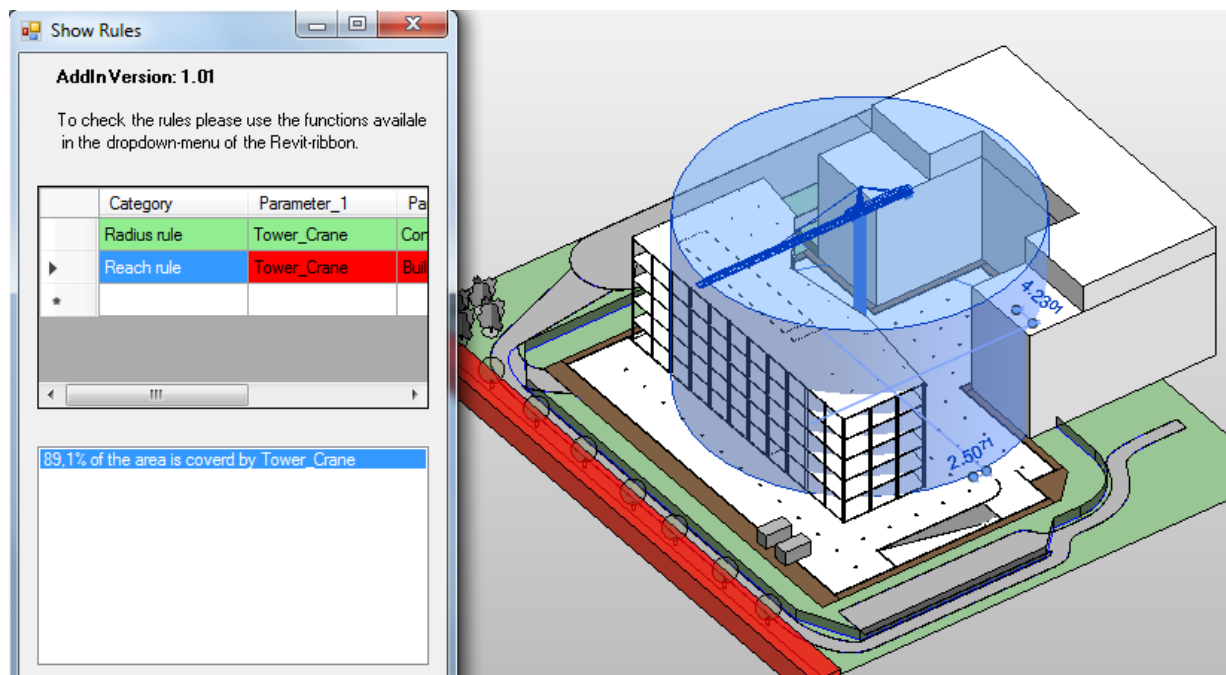


Figure 6. Rule execution: conflict appearance

For validating the rules a site layout was created using two different site equipment objects. Figure 6 shows a tower crane and a container. The radius of the tower crane is represented by a semitransparent cylinder. The first rule

execution indicated one positive (green row) and one negative (red row) checking result. A click on the red row in the rule table reveals the list of conflicts in the text field below. The conflict report states, “89.1% of the area is covered by Tower_Crane”. The rule check returns *false* and changes the table row color to red because 100% of the building area must be covered by tower cranes. Clicking on the conflict text selects all involved objects, in this case the tower crane. Now the designer can relocate or replace the site equipment objects and perform the rule check again. If all rules are marked green, the designed site layout has full rule compliance.

When the site layout design is complete the site layout model can be exported as an IFC file. The site equipment is represented in the proposed IFC extension. Importing the IFC file into a 4D animation software enables the connection between the 3D model and schedule, so that the 4D animation can be performed. Figure 7 shows the 4D animation in the software Autodesk Navisworks including parametric site equipment elements.

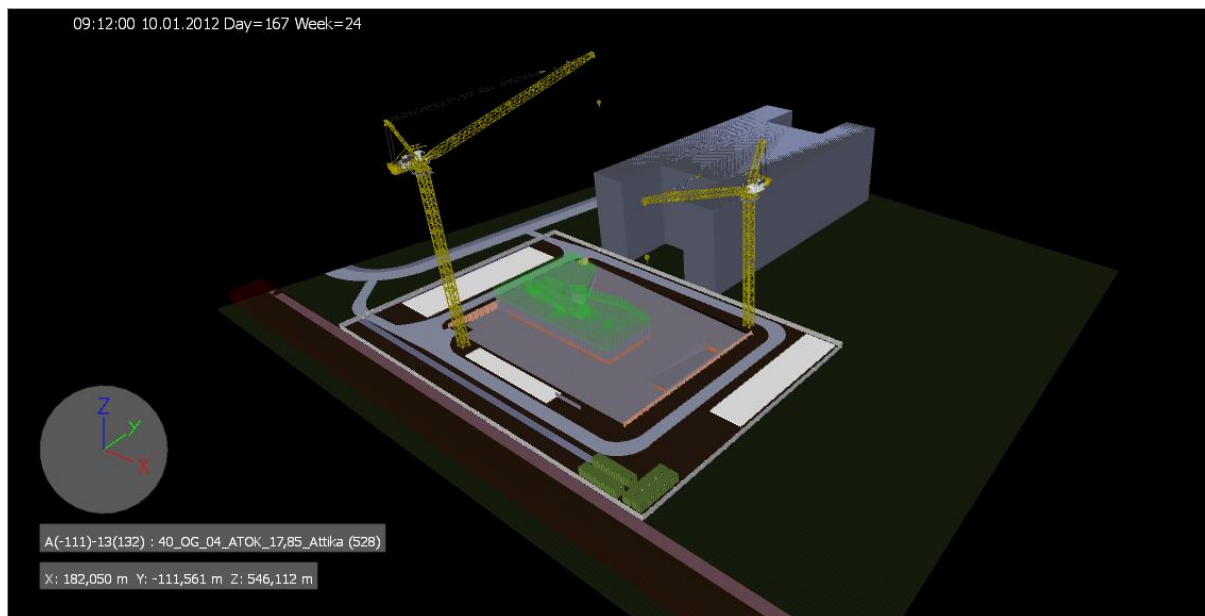


Figure 7. 4D animation in Autodesk Navisworks

5. DISCUSSION

The rules implemented in this research raise no claim to be exhaustive. They were simplified to give an overall impression of possible rule checking solutions for site layout planning. Furthermore, the implemented algorithms show no interactive or predefined rule checking solution, but the subsequent rule checking can be processed, where a given situation is checked after a design step is complete. However, the rule implementation is not yet tested with respect to the interactive method, taking into consideration that a calculated proposal for a design solution which suits all rule requirements needs exact knowledge of the amount of rules concerning the given design task. Although the use of the Revit API enables rule checking after each design decision, it is not the perfect choice. The large amount of BIM data in the Revit model results in lengthy computing time. Restricted or limited functions for specific objects in the Revit API leave the implementation to be counterintuitive. A solution would be an external software dealing solely with site layout planning, rule checking and design optimization.

6. CONCLUSIONS

In this paper a concept for BIM- and rule-based site layout planning is presented and demonstrated. Considering the intuitive 3D-environment and the application of a comprehensive parametric rule and site equipment database, the improvement of dimensioning and allocation of site equipment becomes obvious. Especially the development of interactive rule checking approaches throughout the design phase can further improve the site layout planning process. The automated rule checking and 4D animation will result in fewer errors so that costs can be saved and human health protected. 5D information including site equipment data in the BIM-model will lead to a better data management and prevent data loss before construction start. This enables an easier access to dynamic site layout planning during construction phase.

Future work should address the development of a rule database and site equipment catalogs. The rule database must be structured to fit a designated rule language. The use of existing rule languages or the definition of a new rule language in this context must be addressed. Performance enhancement of the rule implementation or the

development of an external site layout software solution will contribute to the application of open-BIM. Another contribution to open-BIM is the registration of the proposed IFC extensions. Especially the embedding of schedule information in the BIM model will result in a consistent management of time-dependent data.

REFERENCES

- Andayesh, M. and Sadeghpour, F., (2014), The time dimension in site layout planning, *Automation in Construction*, 44, 129-139.
- Astour, H. and Franz, V., (2014), BIM-and Simulation-based Site Layout Planning, *COMPUTING IN CIVIL AND BUILDING ENGINEERING ©ASCE 2014*, 291-298.
- buildingSMART, (2013), Retrieved from website: <http://www.buildingsmart-tech.org/ifc/IFC4/final/html/>, accessed on July 15, 2015.
- Cheng, J. and Kumar, S., (2014), A BIM Based Construction Site Layout Planning Framework Considering Actual Travel Paths, *The 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014)*.
- Eastman, C., Lee, J., Jeong, Y., and Lee, J., (2009), Automatic rule-based checking of building designs, *Automation in Construction*, 18, 1011-1033.
- Hollermann, S. and Bargstädt, H., (2014), 4D Site Installation Planning in Virtual Reality for Multi-user, *COMPUTING IN CIVIL AND BUILDING ENGINEERING ©ASCE 2014*, 777-784.
- Kim, K. and Teizer, J., (2014), Automatic design and planning of scaffolding systems using building information modeling, *Advanced Engineering Informatics*, 28, 66-80.
- Ning, X., Lam, K., and Lam, M., (2011), A decision-making system for construction site layout planning, *Automation in Construction*, 20, 459-473.
- Olearczyk, J., Lei, Z., Ofrim, B., Han, S., and Al-Hussein M., (2015), Intelligent Crane Management Algorithm for Construction Operation (iCrane), *The 32nd International Symposium on Automation and Robotics in Construction and Mining (ISARC 2015)*.
- Pradhananga, N. and Teizer, J., (2014), Congestion Analysis for Construction Site Layout Planning using Real-time Data and Cell-based Simulation Model, *COMPUTING IN CIVIL AND BUILDING ENGINEERING ©ASCE 2014*, 681-688.
- Yahja, M. and Saka, M., (2014), Construction site layout planning using multi-objective artificial bee colony algorithm with Levy flights, *Automation in Construction*, 38, 14-29.
- Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C., and Teizer, J., (2015), BIM-based fall hazard identification and prevention in construction safety planning, *Safety Science*, 72, 31-45.