4D Site Installation Planning in Virtual Reality for Multi-user

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ABSTRACT

The site installation for a construction site should be optimized for the environment, the construction itself and the construction methods. To support the process of site installation planning a perspective projection in combination with head tracking of the participants in the planning process is helpful. By this, clashes between the construction and site installation equipment can be avoided. However for planning a site installation the different perspectives of involved parties at the same time are needed. But in a perspective projection one cannot point out things so that others can see what is pointed at, because all get the same perspective projection. Therefore a multi-user environment with perspective projection is helpful. Furthermore the interaction between different experts is needed to find the optimum. A perspective projection in combination with head tracking for multi-users can solve this problem. Since quite some time product models like building information models can be visualized in virtual reality. Only placing the objects of site installation within this BIM model is not enough because a typical construction site changes dynamically during the construction time. Therefore a product model linked with a time schedule to 4D construction model is needed as base for the planning of the construction site. Based on that, the site installation can be developed according to the requirements of the construction process. Furthermore, the objects of site installation have to be modeled with their parameters. Thus movements and processes flows can be check.

INTRODUCTION

Work planning of construction projects is dealing with preparing the complete construction process to build a construction. Building elements are generated by processes to produce them. The processes' sequence is depending on different constraints which describe the interdependencies. The process duration is depending on the construction method and the availability of resources. The environment also has a significant impact on the execution of the construction process. Therefore the design of a site installation is an important factor. The location, size and parameters of site installation elements are depending on the construction, on the construction environment and on the construction method. Therefore a planning environment is needed, which encompasses all these factors and at the same time gives a realistic imagination of the construction flow and all its elements within the site installation. This allows involving also participants in the planning process, which have different backgrounds.

SITE INSTALLATION PLANNING

Site installation of a construction site consists of site installation elements like machines, equipment, temporary constructions and supply utilities. Furthermore, the site installation has to support the construction process. Site installation must be compared with a permanent factory, with the exception, that it is only a temporary working place for some months or a few years.

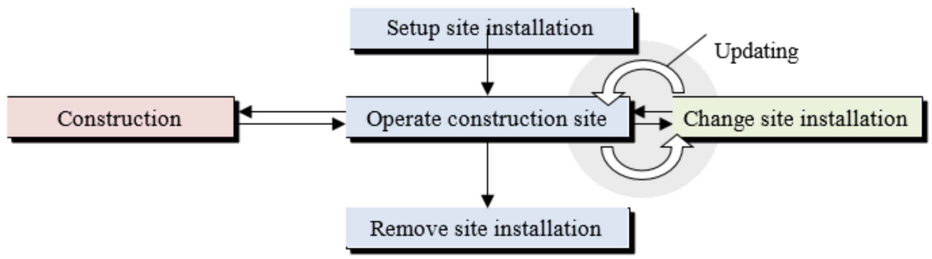

Figure 1. Site installation (Bargstädt and Steinmetzger, 2010)

Planning, acquisition and setup, operation and removal are the main phases of site installation. Furthermore, the site installation has to be adapted during construction time, if different processes require different site installation elements. The conversion of a site installation is an activity within the construction flow. Thus the construction flow model and the site installation model are linked with each other.

Furthermore the site installation is depending on the construction. There are three different types of construction: one-point sites like high-rise building and towers, line-oriented sites like tunnels, roads and waste water channels, and spread-out sites like development area, water dam, factories, shopping malls and surface mines. Figure 2 shows an example of a sketch for a one-point site installation.

Different regulations and laws have to be considered for the planning of site installations. Traffic flow arrangements and job safety regulations are the most frequent. The major impact factors for site installation are identified as being:

- Type of construction project (design, construction, etc.),
- Size of the construction project (dimensions, construction materials, etc.),
- Production-related factors (design, construction methods, equipment),
- Material flow (type, quantity and weight of the material, their storage requirements),
- Local conditions (construction site environment, water and electricity supply, soil conditions, etc.),
- Construction time (milestones, handover) and
- Execution period (calendar-related, relevant weather conditions)

Today site installations are displayed on 2D drawings as shown in Figure 2 and Figure 3. Other than in Figure 2, Figure 3 shows a more detailed site installation. Several parameters of site installation elements like lifting capacity of the crane and range of the concrete pump are illustrated. Also an overview drawing of the surroundings and an explanation for symbols are given. And the drawings show the title block with general information as author of the plan, date of issue etc.

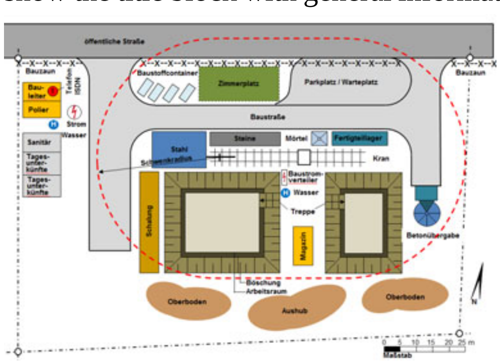

Figure 2. Example for a site installation

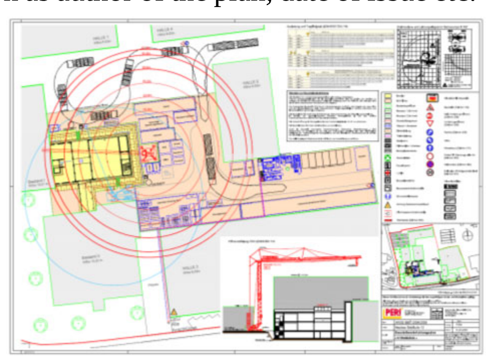

Figure 3. Examples for a site installation plan (Source: PERI GmbH)

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Yet this work procedure is stationary. It focuses only on one given moment of the construction flow, but it neglects the constantly changing site environment. Therefore a methodology is needed which considers the construction flow as well. Currently different models for the construction, i. e. a building information model and another model for the time scheduling are available. Through linking of these models, a 4D-Model of the construction flow can be generated. 4D-models of the project support the process of modeling the construction flow (Hartmann and Fischer, 2007) (Tulke and Hanff, 2007). However these models do not consider all the temporary elements of the site installation. Furthermore they do not consider the requirements for site installation elements, which result out of the construction process. Therefore, the site installation planning should be modeled in parallel with the construction flow. Thus, the site installation elements have to be modeled as objects and with their parametric behavior. In this research three different categories of site installation elements are identified. Figure 4 shows these categories and gives examples of the corresponding site installation elements.

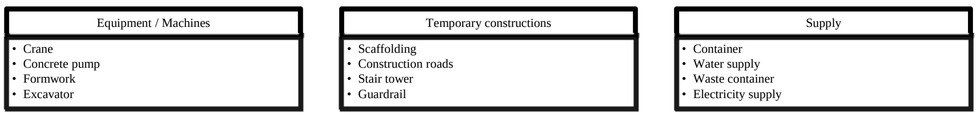


Figure 4: Examples for site installation elements

BUILDING INFORMATION MODELLING

Building Information Model. A building information model is an object-oriented, three dimensional product model. The geometrical shape, the position and orientation is described by parameters. A building information model can include other information besides geometric information. Material could be such an attribute of an object. Requirements for an integrated product model are described in (Abeln, 1995).

The three dimensional building information modeling has benefits for the construction projects (Abeln, 1995). Building a BIM is object-oriented construction modeling. In several countries standardization of BIM is going on, for example in the US. The supplementary information is attached to the model at the right place. It can easily be communicated in this context. Different messages can be conveyed by using different perspectives or layers of the building information model. This kind of modeling is well established (Eastman, 2011), (Weygant, 2011), (Jernigan, 2008).

Kaminski analyzed the capability of BIM in infrastructure projects (Kaminski, 2010). Liebich analyzed the changes through BIM for the planning processes and job descriptions (Liebich *et al.*, 2011). A more detailed analysis of the implications which BIM brings for civil engineers, is given by Strafaci (Strafaci, 2008). Kohls shows how to use BIM as a base for a construction flow simulation of building construction (Kohls *et al.*, 2010).

The Industry Foundation Classes (IFC), developed by building SMART (International Alliance for Interoperability, IAI), is a neutral and open specification for building information models. It is registered as the international standard ISO 16739. The base class IfcProduct relates to a geometric or spatial context of objects. The IFC base class for processes, IfcProcess, is subdivided into tasks, events and procedures.

4D – Construction flow. The Mefisto research project proposed using BPMN (Business Process Model and Notation) models as a formal description for construction processes. A process-based simulation library can be established. Process templates can be used to break the project schedule down into more levels of detail (Scherer *et al.*, 2010). The proposal requires a Build Information Model, which is manually linked with a project schedule and with other information about available resources.

Within the research project of Mefisto, Benevolenskiy et al. discussed the ontology-based model and the use of process patterns and rules in the configuration of construction processes (Benevolenskiy *et al.*, 2012). Therefore, they develop a process configurator. It provides the defined ontology specifications, an initial knowledge base of process patterns, basic process rules and a set of construction process rules for the subdomain “structural concrete works”.

Huhnt proposes a process pattern for a more detailed construction flow model (Huhnt and Richter, 2010). The construction process must be modeled with its activities and events. Process patterns are linked to building elements for 4D visualization. A 4D visualization of the schedule helps to check the workflow. A methodology to break down a building into components and to assign processes is shown in (Huhnt *et al.*, 2010). Different colors help to understand the contents of the 4D visualization.

For 4D visualization, a three dimensional object-oriented product model must be available and linked to activities of schedule. A construction flow animation based on BIM is called 4D BIM. The objects in an object-oriented construction model have additional attributes for the start, end and duration of each process. By use of a time slider the different objects appear according to their scheduled execution dates.

4D SITE INSTALLATION PLANNING

Perspective projection in combination with head tracking. 3D television and stereo display are perspective projections with a fixed point of view. Therefore the perspective projection is only right for one single perspective. In all other points the perspective is wrong and the stereoscopic effect does not appear. Head Tracked systems can adjust the perspective to the individual view point. But when several users are using such a system at the same time, all will have the perspective of the head-tracked user as shown in Figure 5.

If all users would have the same perspective like in Figure 5 they could not point at some specific coordinate to each other because their fingers would not meet in space. Therefore, every user should be head-tracked, as shown in Figure 6. This stereoscopic multi-user system has been developed by Kulik et al. (2011).

A group-to-group interaction is possible through the coupling of two or more of these multi-user systems (Beck *et al.*, 2013). As a result face-to-face meetings in a virtual environment are possible. Furthermore site-by-site coupling and exploring in a virtual environment as one group but placed in different places in real world are another application of such a system. For the planning of site installations the independent navigation is most interesting, because different groups of works can place their needed site installation elements at the same time like on a construction site. If the site installation from one group affects the work of another group of workers, in such a virtual environment this would be immediately detected and could be changed to a better or not conflicting solution. The detection of problematic site installations and processes which affect others can not only be used during planning but also as a training environment. For the placing of site installation elements in space there is need to point out to others in space where it should be placed.

In this research the building information models are used to be shown as a perspective projection. The file formats ifc and cpixml are used with the construction model. To show the construction model with the multi-user systems, the models have to be converted to obj files. Building information models are object oriented and therefore can be converted to a scene graph.

Object oriented site installation planning. Objects of site installation have different parameters. Performance, geometry and working range are examples for parameters of site installation elements. Figure 7 shows the parameters for the working range of an excavator.

Figure 5. Single-user head tracking perspective projection

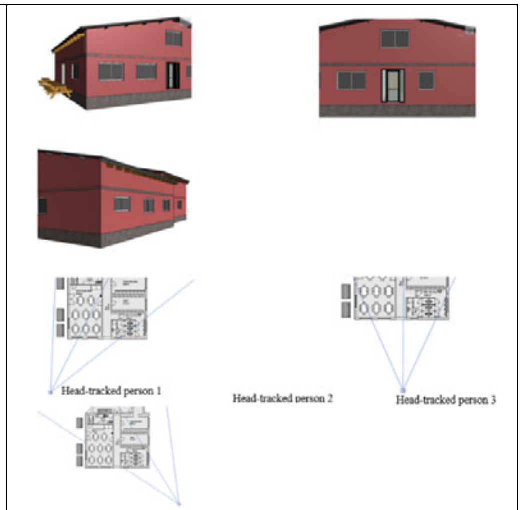
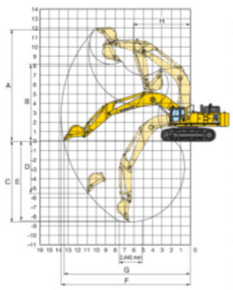


Figure 6. Multi-user head-tracking perspective projection



	MODEL	PC800LC-8	PC800-8
	Boom length	8,0 m	7,1 m
	Arm length	3,6 m	2,9 m
A	Max. digging height	11.955 mm	11.330 mm
B	Max. dumping height	8.235 mm	7.525 mm
C	Max. digging depth	8.445 mm	7.130 mm
D	Max. vertical wall digging depth	5.230 mm	4.080 mm
E	Max. digging depth of cut for 2,44 m level	8.310 mm	6.980 mm
F	Max. digging reach	13.660 mm	12.265 mm
G	Max. digging reach at ground level	13.400 mm	11.945 mm
H	Min. swing radius	5.985 mm	5.645 mm
	Bucket digging force (ISO)	40.500 kg	48.000 kg
	Arm crowd force (ISO)	33.300 kg	38.100 kg

Figure 7. Work range parameters of an excavator (Source: KOMATSU, www.komatsu.eu)

For site installation planning the information about working range, geometry and performance has to be modeled. Figure 8 and Figure 9 show examples for such smart objects of site installation elements. The geometry and material of the site installation elements is modeled like building elements. The working range is displayed as colored area.

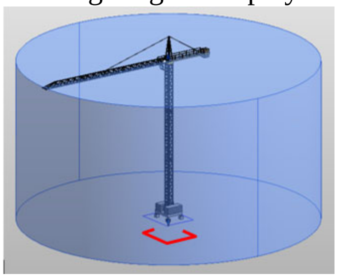


Figure 8. Visualization of site installation elements

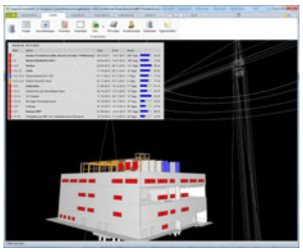


Figure 9. Visualization of site installation elements in a construction flow model

Site installation objects can be displayed in a construction flow visualization, as shown in Figure 9. Furthermore, for site installation planning it is necessary to place site installation elements in space. Therefore the user has to point out in space. To point out where in space elements shall be positioned, is especially important if a group of users work simultaneously on-site installation elements in space. Furthermore site installation elements have to be placed in space according to the processes of the construction flow which is in progress. With the linking of site installation elements to the construction flow in a virtual reality, clashes between different site installation elements and between site installation elements and the ongoing construction can easily be avoided, because several perspectives can be easily checked. Therefore real size perspectives are very helpful.

The stereoscopic multi-user system supports the transfer of information from planner to supervisor and worker as well as to the client and other third parties. Drawings, however, require an understanding of what the points and lines mean. The proposed stereoscopic multi-user system does not require a special knowledge of interpreting. This is a major advantage for a stereoscopic multi-user system in communication and planning of site installation, because in the process of site installation planning different parties with very different construction experience are in involved like the client, authorities, third parties and suppliers.

The design process of the site installation is based on the BIM construction model and on the construction flow in a 4D-visualization. Several common methods are known for the planning of the construction processes. These methods assist in solving questions like which and when a process starts or which kind of site installation to choose and where to place these elements. As shown in Figure 10 the possible methods of construction planning can be randomly, rule based case based, by constraint simulation and beforehand (pre-election) or interactive by a user. Furthermore combinations of these methods are possible. Most common in construction planning is the method, that a user just designs it beforehand. But in a virtual environment, as proposed in this paper, other methods like based on constraints or in an interactive environment seem to be more powerful.

4D site installation. By linking smart objects of site installation to a construction flow, the processes and building elements are linked to the site installation elements. In Figure 11 a sequence of a construction flow model together with the construction

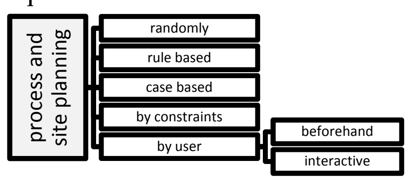


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Figure 10. Methods of construction planning

and time schedule is linked with the site installation elements. The visualization of the site installation elements in the construction flow is realized like the construction flow by showing, hiding or highlighting the site installation elements in the scene graph (obj-file). The links of processes to building elements and the links of site installation elements to processes and building elements are stored in an xml-file. The time schedule is stored in a separate xml-file. The objects of site installation elements can be stored as separate obj-files or can be included in the co

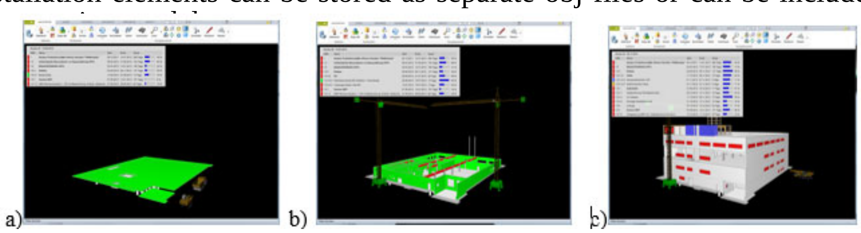

Figure 11. Construction sequence

Then the site installation can be interactively developed in the stereoscopic multi-user system. In the described virtual environment the construction flow can be visualize. When a construction process requires a site installation element this will be shown in a list. Then, users can choose this site installation object and place it in space. The place in space and the time when it gets installed are stored in the xml-file. Whenever the site installation element will be moved or removed, this information will also be stored in the xml-file. The xml-file is a resource schedule for the site installation. Thus for site installation elements a resource graph can be generated.

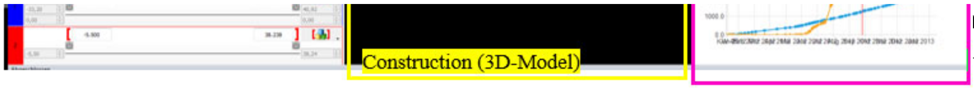

Figure **12**. This construction control panel gives an overview about the important information of the construction flow. Therefore it has to display:

- Processes not started
- Processes ready to start
- Processes in progress
- Processes finished
- Resources
- Recourse graph
- Construction (3D-Model)
- Building elements not started
- Building elements ready to start
- Building elements in production
- Building elements finished
- Properties

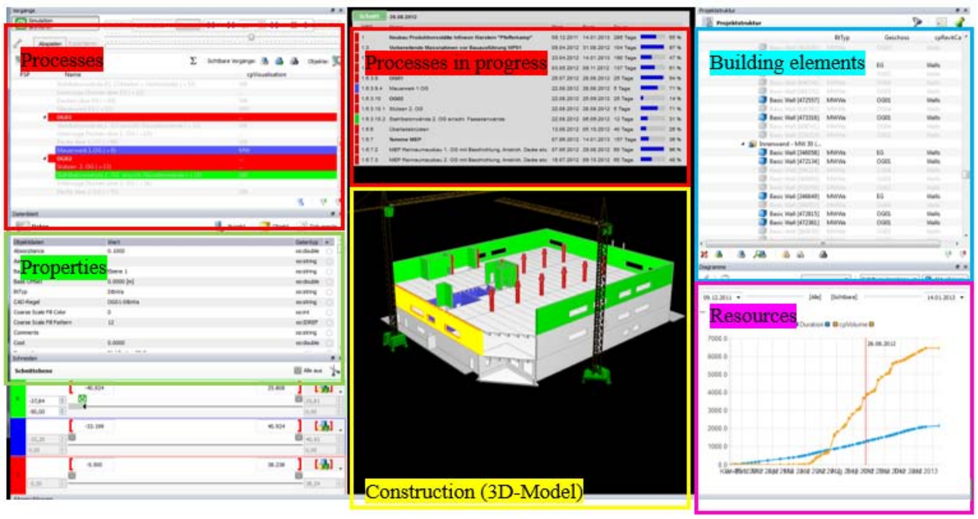

Figure 12. Construction control panel

Working on this construction control panel and by means of the stereoscopic multi-user system, an interactive site installation planning is possible. Tools for interacting with building elements in the stereoscopic multi-user system are developed by Argelaguet et al. (Argelaguet *et al.*, 2011). In this research, however, it is shown, how the construction control panel is integrated into the stereoscopic multi-user system. The object-oriented way of modeling then allows an allocation of all site installation objects.

CONCLUSION AND OUTLOOK

In this research a product model is linked with a time schedule to a 4D construction model and visualized in a stereoscopic multi-user system. This environment supports the process of planning of the construction site. Based on that, the site installation can be developed according to the requirements of the construction process. Therefore the objects of site installation have to be modeled with their parameters. Furthermore site installation elements can be allocated in the virtual environment during the 4D construction flow visualization. Clashes between site installation elements and with building elements can be detected in the virtual environment. As it is required in professional construction, these analyses can be done by working in groups of different parties, where every person will have his individual perspective on the project.

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