BIM-and Simulation-based Site Layout Planning

H. Astour[1] and V. Franz[2]

Department of Construction Management, University of Kassel, Germany
[1]h.astour@uni-kassel.de, [2]vfranz@uni-kassel.de

ABSTRACT

In the course of the research project, a prototype system has been developed at the Institute of Construction Management in the University of Kassel, Germany. The developed system performs its task in two phases: BIM-based (BIM: Building Information Modeling) generation of 3D-site layout plan, and simulation-based evaluation of the site layout plan. BIM-based generation of site layout plan takes place within a BIM environment based on an optimization methodology for automated dimensioning and locating of the site facilities. This methodology depends on geometry data of the building and obstacles at the site. It also depends on the equipment which is available for the project, the number of staff, the construction methods to be used, as well as the necessary safety measures at the site. For the sake of generation process, a 3D-parametric library has been developed; the elements of which are used as basic components for the site layout plan. The degree of utilization of the site equipment is determined in the "simulation-based evaluation of the site layout plan" phase. For this phase, an agent-based simulation model has been developed. This model is capable of simulating the behavior of all elements on the site and the interaction between them and their environment. The required data for the simulation is read from the BIM environment and input via the built-in and self-developed user interface within the BIM environment. This paper describes the site layout planning problem and the previous efforts to solve it by using computers. It also illustrates the necessity for effective site layout planning system and clarifies the system architecture which is developed for this purpose.

INTRODUCTION AND BACKGROUND

The site layout planning during all the construction phases has to ensure high productivity by the optimization of material flow and the efficient use of high-cost equipment on the site. Short and fast transport routes, clarity, efficient use of technology and a safe work environment ensure the success of a construction project. However, the success of a construction project often requires the solution of complex issues related to the construction site, taking into account the local conditions and factors, technical feasibility, in addition to cost and time (Schach et al. 2011). That means, many decisions must be taken in the planning of construction site (e.g., the number of labor forces and equipment to be used or the location and dimensions of the storage areas, etc.). The complexity of a construction project and a lot of interlocked factors influencing complicate optimal planning of the site facilities.

Consequently, many simplifications are made in the work preparation phase, which often neglect the necessary factors to make a right decision. This increases the risk of wrong decisions and their negative economic consequences. Therefore, it seems more reasonable to concern the usability and profitability of the construction site facilities to be used in advance (Schach et al. 2011).

Due to the complexity and the number of factors involved, computers are considered as an efficient tool to help site planners in their task. (Sadeghpour et al. 2006). Over the last few decades there have been a lot of research studies to plan the construction site virtually using software-tools. An extensive literature on this field is described in (Zhou et al. 2009 or He et al. 2012). These approaches classified based on the used mathematical optimization algorithm. In addition, some of the approaches which used combinations of technologies follow next. Irizarry et al. 2012 combined geographic information system (GIS) and Building Information modeling (BIM) to optimize the location of tower cranes on construction sites. Horenburg et al. 2010 integrated the building site equipment into the event-based simulation. In this approach the site layout has to be drafted manually, whereas the simulation results provide more information, such as specific storage locations or capacity utilization of the equipment over the time. He et al. 2012 developed a 4D site layout planning system based on Monte Carlo method to solve space issue in the construction sites. The system calculates the transportation and work execution distances and times for each piece of equipment and worker. Nguyen 2013 has presented an automated approach to dynamic site layout planning, which integrates building information model schedule, genetic algorithm, RFID-RTLS (radio-frequency identification- Real-Time Location System) and physical construction component. The outputs of this system are real-time and schedule tracking and site layout plan.

Most of these previous approaches tend to simplify the site layout planning problem in order to achieve a practical solution. In general, it can be said that, planning the elements of the construction site facilities cannot be done systematically and sequentially. Instead, the conflict between the dimensioning and locating of the various elements must be taken into account (Töpfer 2001). The problem in many previous researches is that the size or the shapes of the site facilities assumed have to be previously defined. They have a fixed number of facilities and limited shapes and orientation. Therefore, they are not flexible enough to take all the changing factors on the construction site, including time into consideration.

Hence the purpose of our research project is to develop a system for planning the building construction site, which satisfies the following conditions (these conditions are based on Lennerts 1996 and 1999. They were revised and supplemented.):

- Interaction with the user by the use of simple interfaces to capture the complexity of the construction site.
- 3D-visualization of the construction site layout during the construction phases.
- Taking into consideration the real dimensions and shapes of the site facilities.
- Reducing of the data to be inputted for the definition of the construction site by integrating with other software solutions (BIM/CAD).
- Sensitivity analysis: this means the quantification of a given construction layout with different parameters.

- Focus on tower cranes which are the major transporters of the materials at the site of building construction.
- Reducing the possible risk of collision in multi-tower crane operations by a corresponding height separation of tower cranes.
- Safety consideration (e.g., safety zones around construction area and facilities etc.).
- The possibility to use the developed system also for special building construction sites (e.g., restrictive spatial conditions like in residential areas).
- Evaluation of the logistic behavior of the site, site equipment and their interactions with the environment during the execution as well as checking the smooth movement of material flow, taking into account the possible collisions.
- Simple modification or extension of the proposed optimal solution with the possibility to integrate the user's experience in a simple way.

The system, which this paper presents, tries to meet the above conditions by linking BIM-building model, the construction process model and the site facilities model. Afterwards, as a whole they have been used as a base for simulation study to evaluate the behavior of all elements on the site and the interaction between them and their environment.

The paper explains the developed approach by introducing the system architecture. In addition an overview of the system components is presented. This paper ends with a short conclusion and a list of challenges as a further work.

SYSTEM ARCHITECTURE

This work is built on the results of a research project with the theme "CAD-integrated simulation modeling for the construction process simulation in building construction" (Kugler 2012). In this research an agent-based simulation model was generated from a building model, which is created in an object-oriented CAD-system, in combination with a construction process model. The needed geometric data and the quantities of materials are read from the building model, whereas construction process model that describes all construction methods, activities and their dependency relationships is stored in a separate database. The simulation model is described in the section *simulation-based evaluation of the site layout plan*.

Figure 1 shows the architecture of the developed system. It is based on a system that has been presented by Kugler 2008. The further approach of the present work, which is shown in dark color, is to expand the existing system to a site facilities model, so that it can be used to produce optimal site layout plans and to determine the degree of utilization of the used equipment and labor force over the duration of the project. For this purpose, the construction process model database and the simulation model in the old approach have been adapted in order to take the right logistic behavior of the site into account.

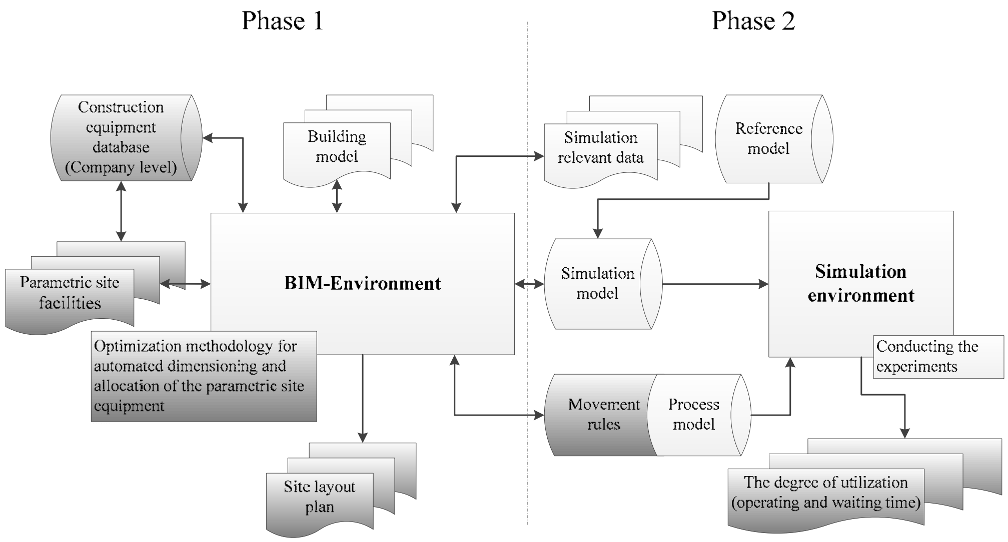

Figure 1: System architecture

Figure 1 illustrates how the system performs its task in two phases: BIM-based generation of 3D-site layout plan (phase 1), and simulation-based evaluation of the site layout plan (phase 2). The two phases are explained in the next two sections.

BIM-based generation of 3D-site layout plan. General 3D-parametric objects (parametric library) for different project phases were developed within Autodesk Revit BIM-Platform to represent the site facilities. When using general objects, the main dimensions can be changed and the 3D appearance can be improved by selecting a suitable 3D surface material for the case. These objects contain not only the dimension parameters but also all other related technical and cost parameters. The corresponding parameters can be automatically selected from the construction equipment database (company level) and assigned to the related objects in the parametric library. The construction equipment database contains all parameters of elements which are owned or might be leased by the firm. Every element in the database has a status which determines if it could be used in this project or not. The selection of parameters from the database for the dimensioning of the elements as well as the uploading and locating of these elements in the BIM-environment Autodesk Revit occurs automatically using an optimization methodology. Figure 2 represents the used optimization methodology, which consists of three sub-models: *Capture of the site-geometry*, *generation* and *Pipe and Filter*.

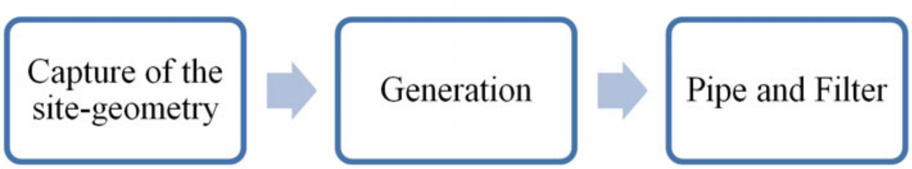

Figure 2: The model of optimization methodology

The sub-model *Capture of the site-geometry* is shown in Figure 3 as a Unified Modeling Language (UML) class diagram. This sub-model is responsible for reading the needed data from the BIM environment. It is given by the definition of the geometry of building, fence (or the boundary of the site) and the potential obstacles (e.g., tress or existing buildings) at the site. If the BIM environment contains only the building model, the developed system has tools to create 3D fence and obstacles quickly. Within this sub-model the geometry of the building, fence and possible obstacles are read from the BIM-environment and transferred to the sub-model *generation*.

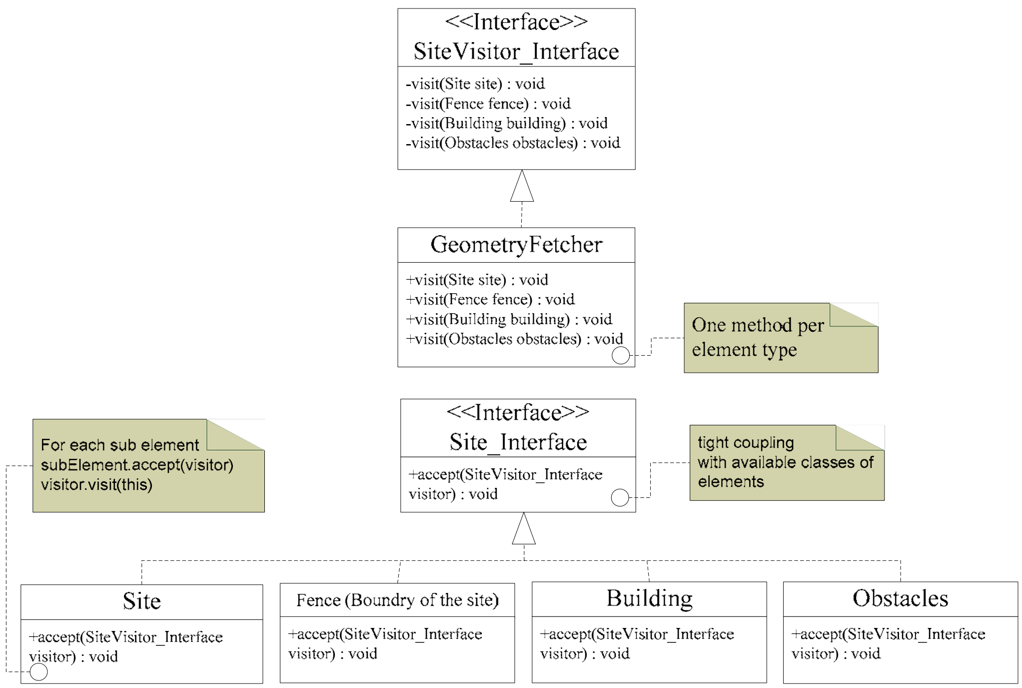

Figure 3. Sub-model: Capture of the site-geometry

The sub-model *generation* is responsible for the generation of the safety distances and zones, the building excavation and the possible locations of the site facilities. This sub-model has the same structure as the sub-model *Capture of the site-geometry*. Within the generation-process, the created safety distances and zones, the geometry of the generated building excavation as well as the coordinates of the possible locations of the site facilities are read and transferred to the sub-model *Pipe and Filter*.

Pipe and Filter is an architectural pattern. It provides a structure for systems that process a stream of data (Buschmann et al. 1996). In our system the sub-model *Pipe and Filter* is responsible for filtering of the coming data to select the optimal or near-optimal locations and dimensions for the site facilities. A filter is a processing step. Each filter has data input and data output. In the filter, the incoming data is converted. During the conversion, parts of the data can be removed, added or replaced (see Figure 4).

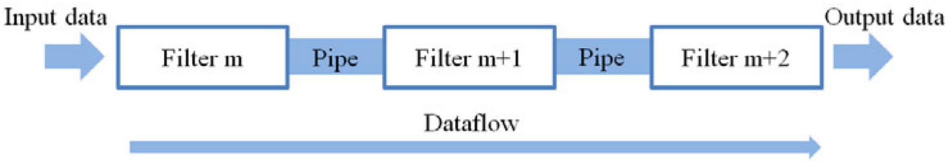

Figure 4: Pipe and Filter

The filters in our system contain the criteria which are necessary to determine the optimal or near-optimal locations and dimensions of the site facilities. A pipe is a connection between the individual processing steps (filters) to transfer the data between them. In this research, the objective function is essentially an equation expressing how well the criteria fulfilled. As an example for these criteria, the criteria related to the location of tower crane are mentioned (e.g., the crane has to be close to center of gravity of the building mass, keeping a safe distance to the building excavation, sufficient space for assembly and disassembly of cranes, all storage areas must be covered by the cranes etc.). These criteria are saved in the system and can be reused, adjusted or changed depending on the construction project and user requirements. After determining the appropriate locations, the corresponding parameters are selected from the database to determine the dimensions of the parametric elements. The selection of these parameters is based on a series of criteria, which depend on the geometry of the construction site, the needed capacities and the used construction methods. Examples for the criteria to determine the dimensions of the tower crane: The cranes have to cover their entire work areas; the crane has to have the required lifting capacity etc.. With the defining of the project phases the site layout plans for different phases can be generated.

Simulation-based evaluation of the site layout plan. In this phase the parameters of site facilities and the building data (geometry and quantities of materials) are read automatically from the BIM environment. This process has a significant advantage since it reduces the amount of the necessary simulation-data, which has to be manually inputted (Chahrour 2007). The logistic data, which define the tower crane movement rules such as priority rules in multi-crane operations (Astour et al. 2013) and the different type of loads, that can be lifted by different means of transport on the site, have to be manually entered within the BIM environment. The data of the construction process model, which describes the construction process and which is stored in an external database, is transferred with the site facilities parameters, the building data and the logistic data in the simulation environment. The objective of the simulation study is to evaluate the logistic performance of the created site layout plans over the project duration. The output of the simulation study is the degree of utilization of the site elements (mainly the tower cranes and the corresponding labor forces). Based on the simulation study, the need for certain equipment over a certain period of time can be determined. In addition, the number of required labor forces over the project duration can be laid down.

The original simulation model has been developed by Kugler 2012. The selected simulation environment "SeSAm" (Shell for Simulated Agent Systems) (http://simsesam.de/) is a software tool, which has been developed at the institute of computer science at the University of Würzburg, Germany. With this tool multi-agent simulation models can be created. The simulation models created in SeSAm are saved in XML-based data structure. This facilitates the access to these models from a BIM environment. A simulation model in SeSAm consists of *agents*, *resources* and *world*. The *agents* represent all active components of the system such as site machinery and labor forces. The passive components, such as the building components (walls, floors etc.), the materials and the obstacles are displayed in the *resources*. The *world* defines the spatial range of agents' movements. A *situation* is a configuration of the *world* with a given number of resources and agents (see Figure 5).

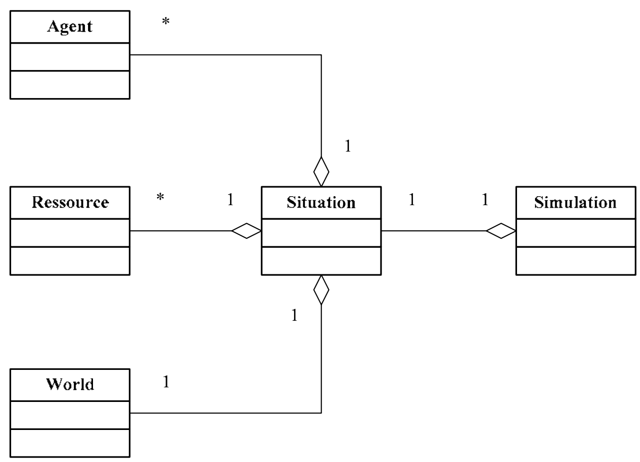

Figure 5: UML class diagram for a simulation model in SeSAm (Kugler 2012)

The modeling of the behavior of the agents is carried out in SeSAm using UML activity diagrams. An activity may consist of different actions. The implementation of the actions and conditions are performed in SeSAm under using predefined functions that can be combined. The conditions between the various activities determine the time at which an agent switches between two different activities. The properties of the agents and resources are mapped into variables. For more information about the simulation model refer to Kugler 2012 and Astour et al. 2013.

CONCLUSION

In this paper the system architecture of a BIM-and simulation-based site layout planning for building construction projects has been presented. The system combines the advantages of BIM for the comprehensive parametric and 3D viewing of the site with the simulation advantages in order to evaluate the logistic performance of site layout plans, which is created within the BIM environment.

A first prototypical system has already been implemented successfully. Building on the experience gained from the prototypical implementation a more user-friendly system, that can be used for planning the site layout of a variety of building construction projects will be developed later. Also, the whole system needs to be validated.

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