

3D-Planning of construction site equipment based on process simulation

T. Horenburg, J. Wimmer, S. Kessler, W. A. Günthner

Institute for Materials Handling Material Flow Logistics, Technische Universität München, Germany

Abstract

Current approaches in planning building site equipment evaluate static periods, e.g. construction phases. As a consequence these states provide a rudimentary optimized layout plan, however without considering the material flow and corresponding interactions in a precise form. Due to dynamic processes, which could obstruct the material flow, an adaption of the equipment layout during individual construction phases is indicated as essential.

The specified approach implies a simulation based planning of the site equipment, which also considers layout-relevant actions during construction phases. By designing a sophisticated toolkit with intelligent objects for material flow and equipment, a new practical method to establish a building site is provided. The planning is set up with common, plan-based procedures; a 3D-model of the equipment is generated automatically by inheriting information from the intelligent objects mentioned above. To visualize possible collisions, the applied configuration is embedded into a 3D-model of the building site, which indicates the current progress of construction.

Apart from these advantages, the current layout can be validated in terms of an efficient use of functional surfaces, such as storage areas or routes of transportation. By designing the equipment within the simulation environment instead of using 3D-CAD, it is possible to perform a precise analysis of the material flow. Due to user-specified attributes, which vary dynamically over time, objects of site equipment adapt autonomously to the material flow of different construction phases. Hence objects request and release equipment areas dynamically, dependent on the current progress of the workflow.

The integration of building site equipment into the event-based simulation provides a basis for an optimized material flow. The approach enables the construction engineer to manually draft a layout, whereas the simulation generates more specific information, such as specific storage locations or capacity utilisation of the equipment over time.

Keywords: Construction Site Equipment, Layout Planning, Simulation, 4D

1 Introduction and related work

The equipment of a building site as a link between planning and realisation assures high productivity by optimizing material flow and efficiency of expensive machines. So far the planning of the building site equipment is done at the draughting board, with realistic replica or in 2D-CAD. Layout planning as well as resource scheduling is based on heuristic principles and the experience of the person responsible.

There have been approaches in research, however, to plan the building site virtually using software-tools and create transparency for later processes within work preparation. The development of the important site-internal material flows is simulated in order to validate the material flow for an existing layout. This concept is based on inflexible processes without managing available resources (Weber, 2007). Another approach consists in dimensioning objects of building site equipment using rule-based algorithms and loading them into a 3D-model. A basic layout is to be determined, which can be optimised subsequently according to the specific material flow (Lennerts, 1999). Yet another concept is to manage resources and areas for repetitive floors in multistory projects based on a project plan (Thabet and Beliveau, 1997). Further research determines the layout of tunnel projects using a genetic algorithm, which evaluates hard and soft constraints to realise an optimal arrangement of the equipment objects (Zhou et al., 2009).

Approaches existing so far consider static periods, such as approximate construction phases. Hence there is a new status of the building site equipment created for each phase, which facilitates a macroscopic optimisation of the layout, however, without considering individual material flows. Due to dynamic processes, which compromise an unobstructed material flow, it becomes necessary to adapt the layout during individual construction phases.

2 Proposed solution

The approach presented in this paper implies a planning of the building site equipment within the simulation environment, which considers layout-relevant actions also during construction phases. Based on a module library including intelligent objects of material flow and equipment, it is possible to establish a building site with the usual, plan-based and practically tested method. A 3D-model of the building site equipment is automatically generated and is integrated into the model which represents the current building progress. The layout of the equipment combined with the workflow and the building site model serves as basis for the simulation, which results in an optimal construction sequence for building site processes (Beißert et al, 2008). Figure 1 shows the developed concept for equipping a building site with an integrated simulation based evaluation.

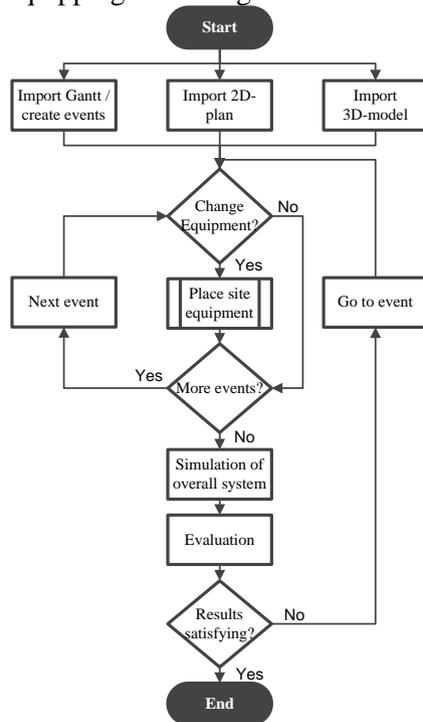


Figure 1: Flowchart of the entire process

2.1 Import of data in the simulation environment

Since the site equipment is to be implemented in simulation, it becomes necessary to import all spatial and temporal coherence of the building site. In order to create a complex building from different elements, an interface had to be developed, which analyzes the structure of the building in a CAD-system and assigns it to the simulation. Every individual element has to be temporally adjustable. The structure and the position of the elements related to the origin of the entire building site are controlled within the CAD application and can be exported as an XML-file. This includes information of position, rotation and the path for every building element leading into the deepest substructure level. The XML-file is imported into the simulation and assigned to a hierarchical and object-orientated building structure. A 3D-building site model, which represents the surrounding of the building site and its basic conditions, is imported together with the building.

A 2D-plan is also necessary in order to guarantee the planner the spacial coordination on the building site and to allow the plan-based work describe above. Therefore an empty plan with a ground plan, an outline of the building and the blocked areas are imported into the simulation model.

Bar charts or Gantt-diagrams are often used for project management of large-scale construction projects. Individual operations are assigned and become verifiable using these charts and diagrams. Therefore an interface in the simulation environment had to be created, which generates a functional bar chart out of an exported XML-file.

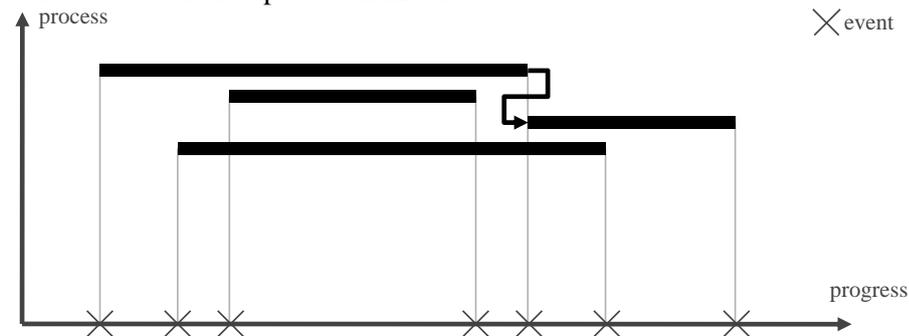


Figure 2: Definition of events in Gantt-charts

Events are created within the imported Gantt-chart, which define the individual construction phases (represented in figure 2). These events are located each at the start and end of every process step, as single material flows are often completed at this point. Hence the accuracy of planning the building site equipment correlates with the accuracy of the general project plan.

Changes or delays in the building process require therefore no new planning of the equipment – provided that a bar chart with the actual dates exists. Interferences in the building process, caused by the layout of the building site, do not occur, because the planning is dependent on the progress of the process and not on fixed dates.

2.2 Module library of intelligent objects for the building site equipment

Besides the imported models and the project plan a library of intelligent objects for building site equipment is provided. Further attributes, such as time and costs of the equipment, 2D- and 3D-CAD-models and functions of common building site equipment are stored for every simulation object. For instance an inventory management is already integrated for the storage spaces. Additionally, the objects are adjustable during time. Changes in size and position can therefore be represented, which is particularly interesting for variable areas such as storage spaces.

For every event generated by the project plan it is possible to place and parameterise objects from the library on the building plan. The different attributes refer to typical characteristics of the particular object such as size and capacity of storage areas or the rotational and lifting speed of cranes. In this

approach the building site is to be equipped based on a 2D-plan and set up depending on delivery and storage strategies. A 3D-model is parallelly used for the equipment of the building site and the entire layout is updated automatically as soon as a module of the library is integrated. It is therefore possible to perform a three dimensional verification of the equipment objects without additional effort and expenses. The current configuration and attributes are recorded and the next event is activated, in which individual objects can be added, modified or deleted from the layout.

The allocation of space at the time assigned by an active event is performed by the planner. This offers the opportunity to use diverse tools for optimizing the layout (Yeh, 1995) and to transfer the ascertained draft into a simulation programme. During the periods between events, idle space is available for the resource management and can be allocated respectively. Different procedures are generated on the building site according to the objects' individual parameters and material flow, as objects request and deallocate equipment areas dynamically, depending on the accomplished process step. The mounting location, for instance, is a dynamically adjustable object. It is therefore possible, depending on the location the material is consumed, to reserve or create an area for temporal storage and to deallocate after mounting. This dynamic behaviour extends the concept of space-based scheduling (Thabet and Beliveau, 1997) mentioned above by considering realistic material flows.

The applied approach utilises the planner's expertise to generate a reasonable building site equipment and adds a transparent analysis of the effects on the construction progress to reduce complexity.

2.3 4D-visualisation and process simulation

The 3D-model of the building site as well as the 3D-objects of the equipment are displayed in the simulation environment. Thus dynamic processes of the building site equipment are visualised in 4D and an overview of the site's equipment target state during the entire construction phase is generated. Moreover, the building site equipment is an important input parameter for the simulation of building processes. Several construction processes are driven by the building. The essential activities are created from the building structure with predefined design patterns and can be assigned to the simulation using preprocessing tools (Wu et al, 2009). The project schedule links these activities including their individual start and completion times with the building site equipment. Times for mounting and dismounting building site equipment, which are also embedded as attributes of the intelligent objects, can be used for a more detailed simulation.

2.4 Results of process simulation

The validation of the building site equipment represents an important element of this paper's concept. Based on the process simulation significant evaluations such as capacity utilisation of equipment objects are generated separately for every construction phase. For instance, the fill level of storages is recorded, the capacity of overloaded areas can be extended and the utilisation of machines is optimised. As a result of implementing the construction site equipment to the simulation environment – unlike common CAD-systems – various analyses of material flow such as Sankey-diagramms or bottleneck analysis are feasible. The current layout is validated according to an optimal material flow and efficiency of individual functional surfaces by a sufficient number of simulation experiments. The visualisation of realistic material flows enables a clearly arranged planning, in which effects of layout modifications can be easily analysed.

3 Results

The presented method of solution to improve the building site equipment is realised in Siemens Plant Simulation. The result is a module library for an efficient 2D/3D planning of building sites.

3.1 Implementation of the module library

The library contains individual modules that can be combined with other modules via defined interfaces. The library as well as the modules can be expanded. The implementation is exemplarily realized for specific objects such as storage and installation areas, construction roads, tower cranes and containers. The modules are functionally embedded in the simulation and controlled by easily comprehensible dialogs. The building area is managed by background routines, so that areas can not be occupied simultaneously by several processes. Figure 3 demonstrates the overall concept.

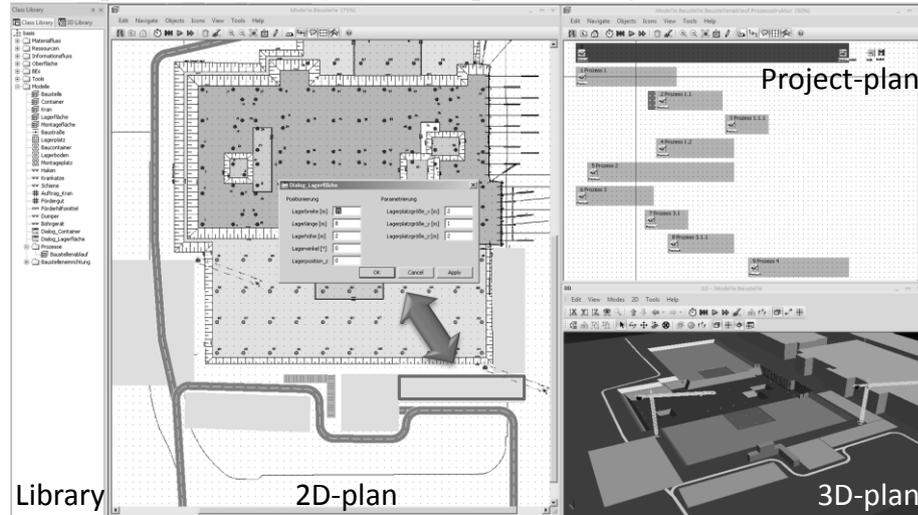


Figure 3: Equipment of the building site using the module library

For every event of the imported Gantt-chart the building site equipment can be adapted and the respective layout configuration is recorded. During simulation experiments the equipment objects are specified according to the determined layout and the current event. Modules already used at an earlier state are updated so that the content of occupied storage spaces is still available after adapting the layout. If storage or construction areas are completely removed from the layout, the simulation will issue an occupied storage space and rearrangement processes can be planned respectively.

3.2 Case study

The functionality of individual modules is already verified at a demonstrative building site. Figure 4 shows the building site which has particularly dealt with earthworks and deep foundation processes.

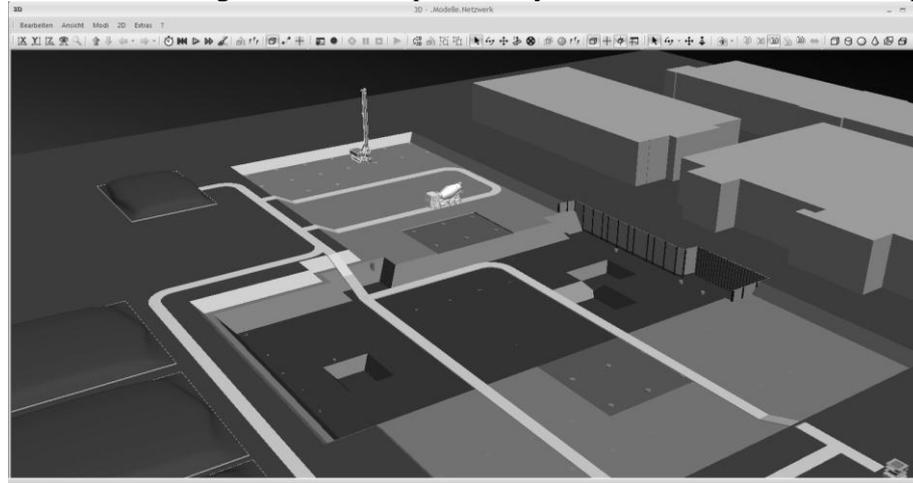


Figure 4: Evaluation of earthworks

The dimensioning of road layout and storage areas for earthwork processes at each individual construction phase was specifically important. Consequently, the utilisation of large equipment (excavator, dumper) and the storage space available could be verified. The automatic 3D-visualisation illustrates the processes simultaneously and creates clarity and transparency.

4 Conclusions

The integration of the building site equipment in a simulation environment does not only serve as preparatory module for the process simulation, but is also basis for an unobstructed material flow at the construction site. The approach introduced above provides a tool to plan the construction site layout manually depending on the accuracy of the project plan, the precise layout results from the simulation according to the required degree of detail.

Furthermore it is conceivable to integrate algorithms for optimising layouts into the simulation tool, e.g. CRAFT (Meller and Bozer, 1996), which results in a layout of production areas at optimal costs. An implementation of a genetic algorithm (Zhou et al., 2009) is reasonable for the planning of the temporary equipment objects. It is also possible to consider security-relevant aspects by integrating specific rules into the simulation tool.

5 Acknowledgements

The research presented in this paper was carried out within the ForBAU project which is funded by the Bavarian Research Foundation (Bayerische Forschungstiftung).

References

- BEIßERT, U., KÖNIG, M. AND BARGSTÄDT, H.-J., 2008 Execution strategy investigation using soft constraint-based simulation. In: *IABSE Conference, Information and Communication Technology (ICT) for Bridges, Buildings and Construction*, 2008, Helsinki, Finland
- LENNERTS, K., 1999. Entwicklung eines hybriden, objektorientierten Systems zur optimierten Baustelleneinrichtungsplanung (ESBE). *Bautechnik* v. 76, Issue 3 & 4
- MELLER, R. D. AND BOZER, Y. A., 1996. A new simulated annealing algorithm for the facility layout problem, In: *International Journal of Production Research*, Issue 6 pp. 1675-1692
- THABET, W. AND BELIVEAU, Y., 1997. SCaRC Space-Constrained Resource-Constrained Scheduling System, *Journal of Computing in Civil Engineering*, Issue 1 pp.48-59
- WEBER, J., 2007. *Simulation von Logistikprozessen auf Baustellen auf Basis von 3D-CAD Daten*, Dissertation, Universität Dortmund, Dortmund, Germany
- WU, C., BORRMANN, A., RANK, E., BEIßERT, U. AND KÖNIG, M., 2009. A Pattern-Based Approach for Facilitating Schedule Generation and Cost Analysis in Bridge Construction Projects, In: *Proc. of the 26th CIB-W78 Conference on Managing IT in Construction. Istanbul, Turkey, 2009*.
- YEH, I.-C., 1995. Construction-site layout using annealed neural network. *Journal of Computing in Civil Engineering*, Issue 3 pp. 201-208
- ZHOU, F., ABOURIZK, S.M. AND AL-BATTAINEH, H., 2009. Optimisation of construction site layout using a hybrid simulation-based system, *Journal of Simulation Modelling Practice and Theory* 17 348–363