Towards collection, processing and use of actual data for process simulation during construction

Horenburg T., Wimmer J., Günthner W. A.
Institute for Material Handling, Material Flow and Logistics, Technische Universität München, Germany
Borrmann A., Dori G.
Chair of Computational Modeling and Simulation, Technische Universität München, Germany

Construction projects in urban areas imply multiple activities on limited work space and hence lead to interferences and delays depending on the quality of the planning. Due to the increasing competition in construction industry an immediate reaction to these problems is crucial. This paper introduces a comprehensive approach for construction planning utilizing process simulation and VR-visualization to address the issues mentioned. By monitoring the construction progress actual state data is generated to update simulation parameters and corresponding results for future construction realization. Therefore a detailed concept was developed to process the various types of raw (actual) data in order to receive information about the construction progress. Furthermore this paper introduces a design for simulation and visualization environments to interpret actual data. Hence temporal and spatial collisions can be detected before execution and profound measures taken respectively.

1. Introduction and motivation

The scheduling of civil engineering projects is a major challenge. For the economic construction an efficient schedule is necessary which is balanced among the individual processes. In this context, a variety of processes have to be temporally and capacitively harmonized. Furthermore unexpected factors, e.g. weather, changing soil conditions, supply bottlenecks, and also residents and building owners often interfere with the planning and handicap the construction process in an early phase of the project. The detailed schedule at the beginning of the construction project becomes obsolete and has to be rescheduled within the shortest possible time taking into account the current situation on the basis of an uncertain data base. So far, this task is entrusted to the skill and rationality of the construction manager, who has to reschedule immediately in order to avoid cost intensive idle time of machines and human resources.

To better support this re-planning during execution, this paper introduces a novel approach to enable a sophisticated planning which using the technique of discrete-event simulation for predicting the progress of construction projects, while at the same time integrating actual data gathered by different automated and semi-automated methods. Accordingly, the proposed approach comprises the follow steps:

- Gathering and processing of actual data
- Implementation of simulation experiments based on actual data
- Analysis of critical construction processes with kinematics simulation and collision detection

The discrete event simulation (DES) allows predictions of the subsequent construction process based on known boundary conditions (resources, time and spatial dependencies). In research, DES has already been used for a long time, but solutions are missing that integrate various types of real-data obtained from construction processes. So far, the simulation experiments conducted are not based on the actual construction progress and respective constraints, but on initial assumptions. Hence simulation results are not reliable for future states as soon as these assumptions happen to be wrong during construction.

Furthermore the changing layout is particularly problematic for the determination of spatial collisions. For a correct analysis, the correct spatial condition of the building and the site equipment has to be available at the time of execution. This information can be determined with the DES and transferred for analysis to an appropriate kinematics software.

2. Related Work

The possibilities of a simulation during construction have been considered so far only sporadically. Ailland and Bargstädt (2010) analyze the use of actual data for the implementation of simulation studies. Marx and König (2011) model the current geometric condition on the construction site in the DES with three-dimensional geometric constraints. The framework COSYE however is a generic platform, which facilitates collaborational development (re-)using various data sources (AbouRizk et al., 2011). Based on the same High Level Architecture Azimi integrates actual data by monitoring the construction progress via RFID resulting in a construction control system with visualization (Azimi et al. 2011). The area of construction visualization in fact is already widely investigated (Koo and Fischer, 2000; Kamat and Martinez, 2002; Jongeling et al., 2008; Doulis et al., 2007). Yet simulated construction processes are often not considered for visualization and therefore collisions between static and dynamic components are not detected. A major problem within this area of research is the correct prediction of future states for such investigations.

The application of mobile computing in construction and its respective methods are evaluated by Chen and Kamara presenting a framework for on-site information management (Chen and Kamara, 2011). Known methods for geometric registration of the current construction progress are based on the compilation of photographic, photogrammetric, or laser scanning pictures (Memon, Majid and Mustaffar, 2005; Shih and Wang, 2004; Bosché, 2010; El-Omari and Moselhi, 2008; Kim, Son and Kim, 2011). Non-geometric methods of recording actual data include the tracking of the material flow to and on the construction site, for example, via RFID (Yoon, 2006; Hammad and Motamedi, 2007; Helmus et al., 2009; Klaubert, 2011). For the collection and transfer of production data of machinery a standard was introduced by the AEMP (2010) which, however, does not adequately support determining the performance of the equipment. A system for automatic data acquisition is introduced by El-Omari and Moselhi, which integrates different monitoring technologies such as laser scanning or RFID and progresses the gathered data for project management (El-Omari and Moselhi 2011).

On construction sites, however, are plenty of potential data sources giving information required for the actual state of construction progress. Therefore an approach to gather relevant data, combine the different technologies to determine the current progress and to update the simulation respectively is developed.

3. Our Approach

Especially the Construction managers and planners must be able to react quickly on changing conditions during construction and thereby assess the consequences of their actions more effectively. Therefore the approach introduced in this paper visualizes the predicted construction progress by combining the technologies of DES and virtual reality (VR). The

DES determines the construction progress and temporal collisions between the various processes at any future state. Based on this input the VR technology is able to visualize the geometry and monitor critical processes, such as the assembly of large precast elements. By the transparency gained from the combination of DES and VR the planning can be improved before, as well as during the execution stage and cost intensive errors will be avoided in subsequent construction processes. Furthermore the simulation technique allows optimizing the utilization of machinery and controlling the current construction progress.

Civil engineering in urban areas is particularly suitable to apply the technique of process simulation during construction phase, since there are various activities to be executed in limited space which often results in overlaps and delays. In addition, these sites often represent a traffic obstruction and respective inconvenience to the residents, so that a consistent process not only involves benefits in terms of cost but also helps to reduce the duration of the impact on the surrounding of construction sites.

Figure 1 shows three essential parts for the implementation of the simultaneous construction simulation which are based on an existing initial planning.

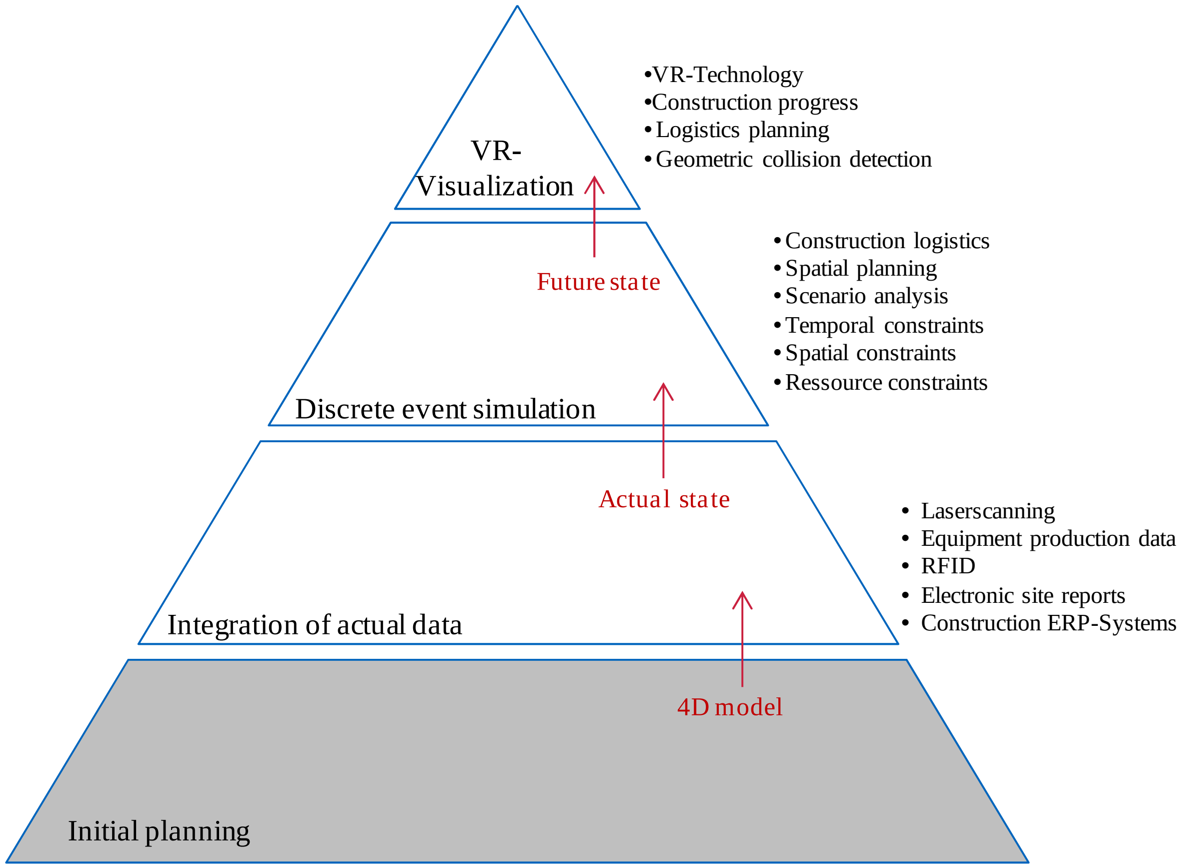


Figure 1: Focus and structure of research

The approach is based on an automated gathering, processing and integration of actual data from the construction activities. Sources might be laser scans, machine data, ERP-systems or well-structured manually supplied information. Special focus is on simple, efficient and preferably automated capture of the current state in sufficient accuracy. A parametric 4D model of the construction process is the basis for the representation of the actual state. All input variables should be examined for their qualification and required accuracy. Especially in the field of machine data, the quality of individual information is analyzed. This facilitates a robust forecast for the completion of individual construction phases.

On the basis of the predicted construction progress, future activities of the building process will be simulated. Simulative rescheduling during construction is possible and interferences between processes can be detected respectively. Therefore the relevant information requirements need to be structured and the level of detail of the civil engineering processes has to be defined. In addition, a concept for handling with processes that are actually in execution but not finished yet is evaluated for concurrent simulations. Spatial bottlenecks are detected in simulation experiments and the general availability of mounting locations can be ensured using methods of path planning. As introduced above, a bidirectional interface between process simulation and 3D model is developed, which transfers the current progress to the simulation and visualizes its results.

The planning state determined by the DES supports the early analysis of difficulties in the construction process. Therefore, a portable robust VR system is under development, which is designed for a direct use on construction sites. With this system the site conditions for all future processes will be generated and critical processes will be analyzed. The simulation returns the positions of the individual elements (main machinery, building container, roads ...) at the designated time; the 4D model, however, provides the geometry of the building and the environment. Analogously, visualizations for demonstration purposes can be generated for any future date.

Integration of actual data

At first the integration of actual data is examined with respect to the question which of the various existing sources on the construction site can be used to simply and efficiently record the current status of the construction progress. In Figure 2 the different sources for the gathering of data are depicted.

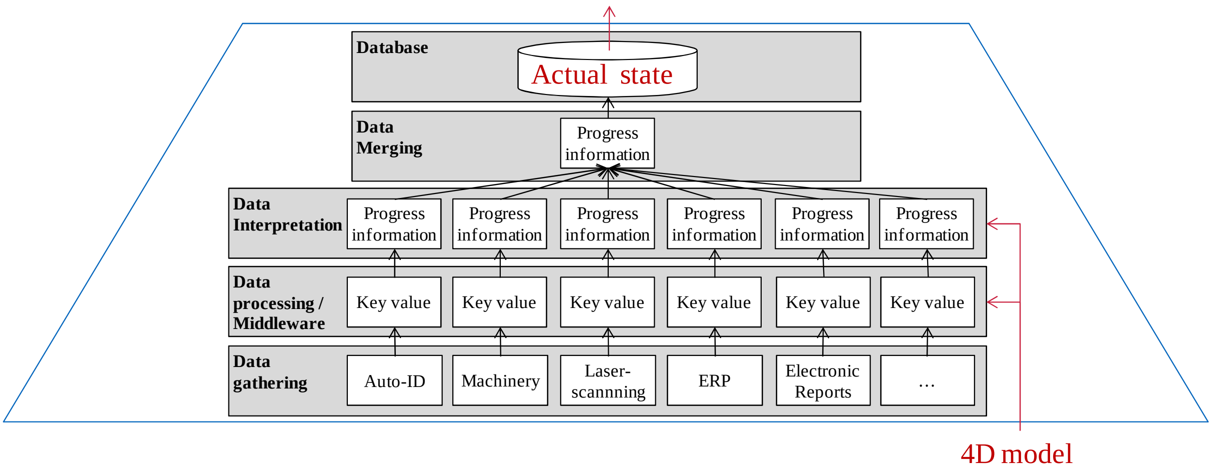


Figure 2: approach for data gathering and processing

Data acquisition as well as the creation of a valid simulation model is very time consuming resulting in high costs (Martinez and Ioannou, 1999). For this reason models are generated from generic modules and – especially in the field of simulation using actual states – data is gathered preferably with automated methods. Hereby cost intensive times for model-updates are reduced. Yet it is the decision of the simulation expert to update changes manually if required, e.g. the availability of resources in a hardly predictable environment of construction works. In combination with different approaches to monitor the construction progress a significant prediction about future activities can be met.

Auto-ID systems such as barcode or RFID can be used to identify different items on the construction site such as precast elements. In combination with mobile devices also additional information can be assessed. (Klaubert, 2011)

The determination of the mass flows during the excavation of pits can be realized by means of laser scanning and GPS tracking of the transportation machinery. Against this background it has to be investigated, how point clouds generated by laser scanning and the movement profiles of the various machinery can be converted as effectively as possible into earth masses.

Also the relevant construction machinery determines the current progress. In foundation engineering mainly drilling rigs and trench cutters are of interest as they provide data on the current production. Thus, even different soil layers are detected by the sensors of these specialized machines.

Yet this (raw) data of all different sources can not directly be used to update a related 3D model during a construction project and derive new plans. Likewise plan corrections or the parameterization of simulation are not possible immediately. Hence a processing of raw data is fundamental to create useful information on the construction progress.

As shown in Figure 2 in our concept the collection of actual data is divided in four different steps. Firstly data is collected from different sources like machines or laser scanners. This data has a high volume but cannot be directly used to monitor the construction progress.

Example: All excavators on an earthworks site have sensors which are measuring the position of the excavator, the angle between superstructure and undercarriage and also the angles of the boom every second. This continuous data stream is sent via telematics to the back office.

Hence in a second step the gathered data from every source is processed to key values. Often several data streams of the same source or even different sources have to be combined to process these key values.

Example: Boundaries are defined for all sensor data of the excavator. If the angle between superstructure and undercarriage changes more than 30° in one direction and the height of the bucket, that can be calculated out of two additional sensors on the boom, increases more than 2m, we expect that the excavator has made one duty cycle. The properties of the bucket (SAE-volume) and the bulk solid (filling and decompaction factor) deliver the volume hauled each duty cycle. The multiplication of the duty cycles and the bucket size yields the overall volume hauled by this excavator.

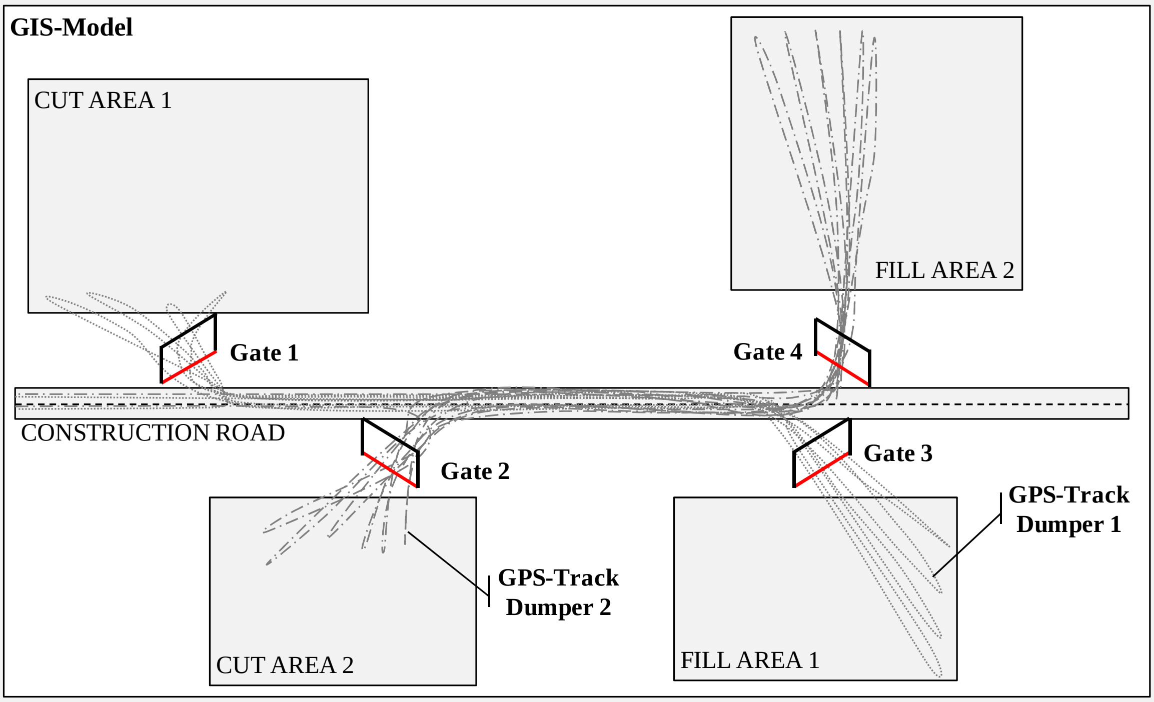
In a third step the key values are further combined with the 4D-model and the initial planning to receive a measure for the construction progress.

Example: To assign a process of the 4D model to the key values, the position of the excavator is compared with the areas in the 3D-model. If there are several possible processes the data is assigned manually. The overall volume, that have to be excavated, is also defined in the 4D model. So we know the progress of the specific earthwork process with the data from the excavator.

If there exist several sources with information concerning the same construction process this information has to be merged in a last step. A rule based system therefore has to decide which information is more reliable and more accurate.

Example: There is different information about the progress of an earthwork process from a laser scan, which has been processed to a specific excavated amount. In the rule based system the laser scanning information is defined as more accurate than the information of the excavator. So the laser scanning information is handed on as the actual state of the construction site.

Especially the processing of the raw data to key values for the measurement of the construction progress is usually not easy. For this reason a gate-based application for processing GPS-data has been developed as shown in figure 3.



Key Value Table

Truck	Dumper 1				Dumper 2			
Segment	**Gate 1 to Gate 1**	**Gate 1 to Gate 3**	**Gate 3 to Gate 3**	**Gate 3 to Gate 1**	**Gate 2 to Gate 2**	**Gate 2 to Gate 4**	**Gate 4 to Gate 4**	**Gate 4 to Gate 2**
Segment time 1	2:30	1:45	1:49	1:36	…			
Segment time 2	1:46	…	…	…				
…	…							
Segment time n	…							
Times passing a segment	**4**	**…**						

GPS-Tracking Application

Figure 3: Gate-concept for processing GPS-tracks to key values for the construction progress

The GPS-module delivers the position of a dumper in user-defined intervals, for example every five seconds. To create a key value out of this data stream, the number of hauling cycles, virtual gates are placed in the application on a GIS-model of the construction site.

Every time the GPS-data stream of a dumper passes a virtual gate the data stream is split and a segment time is calculated. If a dumper first passes a gate positioned on the access to an excavation area and then a gate at a dump area, we assume that the dumper has transported material between these two areas. From the data sheet of the dumper and the soil parameters of the excavation area the transported mass in every hauling cycle can be derived. By taking all available transport machines into account, the overall mass movement on the construction site can be computed. On this basis the progress of the earthwork processes can be determined.

Since not all necessary actual data for planning and simulation can automatically be analyzed from machines, laser scanning and Auto-ID systems, there must be also a way to create data manually - but in a structured form - and to integrate the respective information into the simulation. For this purpose programs for digital site reports or costing and billing programs have to be enhanced for an extraction of their structured data.

In order to update the simulation to the actual state the Level of Detail (LoD) of the gathered progress information has to be considered in relation to the LoD of the discrete event simulation. There are three cases that have to be handled:

- LoD actual data > LoD simulation: the collected data shows the progress of a part/subprocess of the regarded construction activity in the simulation
- LoD actual data = LoD simulation: The actual data is a measurement for the progress of a the regarded activities
- LoD actual data < LoD simulation: The actual data shows only the progress of a higher process level

Considering these level of details a simulation model is generated, which is able to run various experiments based on the informative value of the input (actual state data).

Discrete event simulation

The possibilities of data collection on civil engineering sites are examined in the first part of the project. This data is used to update a simulation model that includes the current progress of the construction project and thus creates the basis for rescheduling.

In the discrete event-based simulation system a hierarchical approach is used to reduce the pre processing time. Less relevant standard processes are modeled as duration, cost or timecritical processes in a very detailed, realistic model. A project schedule can be imported to provide a rudimentarily sequence of the construction processes which are modeled with Gantt modules in the simulation environment. Besides the process duration which is imported from the project schedule, information about the change in the building progress is required. If necessary, operations are transferred to a higher level of detail. This results in several subprocesses, where all necessary information to run a process module are added in the simulation. This includes the local placement at the construction site, the required resource types and materials. In the highest level of detail the process is further broken down into its basic activities. Therefore additional process parameters and corresponding visualization information are necessary.

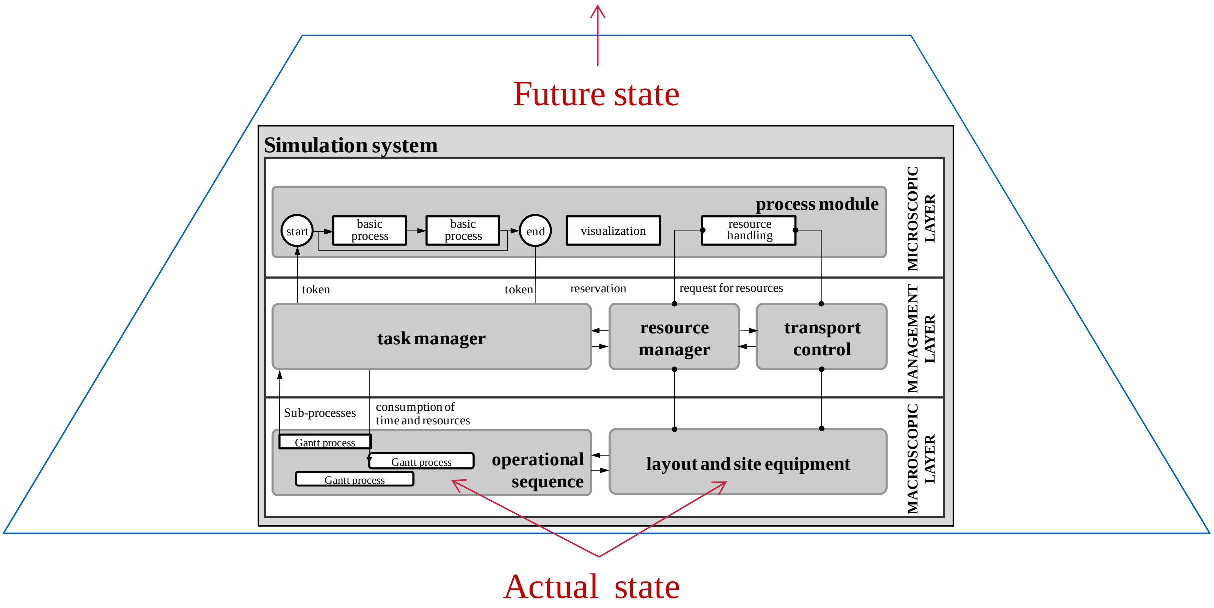


Figure 3: Internal interaction of the different modules in the detailed process simulation

Figure 3 shows the interaction between the developed simulation modules. Gantt modules start a process in relation to its predecessors or from a fixed date. If a process is not further detailed, it is modeled as a time consumption, which can trigger at the beginning and at end of a state change in the building progress. The time consumption can be enhanced with a statistical component for a Monte-Carlo simulation. Thus a probability distribution for the end of each construction process and for the completion date of the overall project can be determined. In case of a further detailing, the required information on the subprocesses is stored in each Gantt module. When starting a Gantt module the sub-processes are sorted and executed by the sequence management module if all necessary preconditions are met. Therefore the resource management checks the availability of all resources required and reserves them for the process module respectively. If then all predecessors are completed, preconditions are met. The sequence management generates a process module and passes all information on a token.

The implemented process modules are divided into the three areas:

- state machine
- resource handling and
- visualization

In the state machine (the highest level of detail) the token runs through various basic activities, whereas each start and finish of an activity generates a new state. Individual activities can be passed several times, but may also be skipped depending on the parameters and the overall environment of the process module. The resource handling is allocating and deallocating material, workforce, equipment and space to each basic activity. Once a resource has arrived at its defined destination, it will be processed. The process continues and the token will be forwarded to the following basic activity correspondingly. Furthermore, the process visualization module rotates or translates 2D and 3D objects to represent the current process state as well as the progress of the construction.

With the generalized module structure various processes in a construction site can be combined. The modules have standardized interfaces, so that further activities can be implemented in the module library. The module library is built object-oriented, custom attributes, such as and 3D objects are stored local in each module. The simulation library is designed for a combined 2D/3D visualization, to use it by means of communication between the different stake holders on the construction site.

Thus various scenarios are analyzed with the generated, highly detailed simulation model in order to support the production planning during construction. At this stage of investigation, different approaches for generating execution sequences and optimizing the machine utilization will be considered and finally be tested in a case study.

VR-visualization

The third part of the project concentrates on the representation of the virtual planning. The developed VR application should best be operated directly on the construction site, so that current plans can always be visualized and alls persons involved can discuss the respective problems. Therefore the areas of interest regarding visualization are to identify considering the different participators in construction projects.

Furthermore the possibilities of VR systems to perform geometric collision analysis are investigated. Such analyzes are intended to assess collision feasibility studies on spatially complex construction processes. Thereby the modeling of movement profiles for construction machinery and the site conditions at the determined state are examined within the VR environment. This is realized by implementing convenient interfaces for the 3D-model as well as for discrete event simulation. The simulation provides the dates and locations of individual elements (appliances, building container, roads, etc.) at a given time. The geometry of the building or the excavation and the environment is extracted from the 3D model.

4. Conclusion and Outlook

Construction projects in urban areas imply multiple activities on limited work space and hence lead to interferences and delays. The introduced concept for the simulation during construction addresses these problems. The approach enables a consistent process by visualizing the effects of interferences and reducing the effort in consequent rescheduling. Therefore the current progress has to be determined and integrated into process simulation. Future site conditions can thus be modeled and used for kinematic analyzes or for visualization purposes. Developed methods and solutions will be validated in case studies providing real construction site data. Especially the robustness of the technologies in daily work operations and the acceptance of those involved in these technologies will be evaluated. The results support the evaluation and improvement of the developed prototype.

5. Acknowledgements

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