INTEGRATION OF SIMULATION DATA FOR CONSTRUCTION PROJECT PLANNING USING A PROCESS-BASED SIMULATION FRAMEWORK

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ABSTRACT
This paper presents the recent developments of the process-based simulation toolkit, which aims to support planning of construction projects through rapid development of simulation models and efficient integration of simulation input data from various data models. The paper focuses on the integration of simulation input data for the basic project data, namely: product model based on IFC standards (ISO 16739), process models based on BPMN notation, planning and resources data. It discusses and presents the latest research work and the prototype implementation through two study cases.

Keywords: construction process management, simulation data integration, reference process modelling

1. INTRODUCTION
Simulation methods have been used to optimize and improve the planning quality in many industry sectors like manufacturing and logistic since long time, and they are integrated as an essential part of the whole design and planning process. However, in the construction industry, the use of simulation methods for planning has not been widely adopted and it is usually limited to analyse and solve problems in an ad-hoc manner (simulation study or simulation-on-demand) at certain times of the project life. The application of simulation techniques for construction projects is a very promising but also a challenging field of research (Lucko et al. 2008). Creating reliable and reusable simulation models is very complex, combined with high costs of software licenses and personal training for in-house simulation. While great advances have been made in construction simulation over the past few decades, adoption by industry has lagged, for three potential reasons: simulation is not accessible, it cannot handle the complexity of modern construction projects, and the benefits are not immediately obvious (AbouRizk 2011).

Therefore, providing a convenient simulation tools and collaborative platforms to integrate the huge and complex projects data with low-cost entry for construction industry is crucial to promote a wider adoption of simulation in construction industry.

As a part of the national German leading research project MEFISTO (www.mefisot-bau.de) a Construction Simulation Toolkit (CST) has been developed. It aims to accelerate the process of creating simulation models for construction and logistic operations during the planning and operation phases of construction projects.

In general it aims to support the planning process in order to reduce the total duration and cost of construction projects and avoid any conflicts during the construction phase by improving the planning quality and utilization rates of resources. The simulation model should help the project manager to verify the feasibility of a given schedule with a combination of different resource constraints or different building design alternatives or construction methods.

The toolkit is created on top of the simulation software Tecnomatix Plant Simulation from Siemens PLM Software. It provides a set of reusable simulation components with a simple user interface for rapid building of process-based simulation models for planning projects with resource and activity calendar constraints. The CST framework has a modular structure and consists of a set of simulation reusable components. Figure 1 shows some of simulation components in CST which can be used to create and customize simulation models rapidly.

![Figure 1: The modular structure of simulation models built with CST](image)

The implementation of the CST toolkit is generic and can be used for different kind of projects and domains. This is a result of separating the core simulation components which are applicable for any simulation domain and the domain specific components (product model, resource, and process models). CST uses formal BPMN process models to define the logic of construction operations. It integrates also most of the important construction project information and can be used for a rapid and effective development of simulation models. The concept of using a formal
process models and mapping them to simulation model in addition to a description of the system structure has been presented in (Wagner et al. 2010) and (Ismail et al. 2011). This paper focuses mainly on the data integration between the simulation framework and other project data models. Section 2 gives an overview about data integration for Building Information Model (BIM), process model and planning data. The modeling of resources is discussed briefly in section 3. Finally, two study cases are presented in section 4 in order to illustrate and highlight some of the framework applications. The main contributions and innovative aspects of this research are:

1. Using formal business process models based on BPMN notation to capture and organize the knowledge in construction domain and providing the ability to transform these models into a simulation process directly.
2. Addressing interoperability problems through integration of most important simulation input data from CAD/BIM design and planning software.
3. Coupling the logistic and production operations in one unified simulation environment in a mixed micro and macro levels of details.

2. DATA INTEGRATION BETWEEN BASIC MODELS

One of the top reasons to keep using simulation inside the construction industry for real projects limited is the huge amount of information which must be collected for each simulation study in a certain degree of quality to ensure realistic results. The one of a kind character of construction projects leads to a one of a kind simulation study. A big effort was made in our work to solve the problem of data integration and maximize the reuse of available project data. This was achieved through: (1) Adopting the most used standards for both of building information modeling (product model in AEC) and process modeling, namely the Industry Foundation Classes (IFC) and Business Process Model and Notation (BPMN), (2) Implementing import and export interfaces to integrate the simulation study input and output data within the planning workflow.

2.1. Integration of BIM data model

The integration of building information data for any simulation study is one of the most challenging and time consuming problem for real construction projects. Some reasons for this problem are:

1. The quality and level of details of BIM models do not usually match the simulation requirements (e.g. missing information about the base quantities and materials of building elements, or the hierarchy structure is not defined correctly)
2. The freedom of modeling in practice without considering the constructability aspects especially in the architectural models. It usually leads to common problems, for example having some walls extended over many stories, or having a wrong type of building elements.
3. The wide range of BIM authoring tools with inefficient support of IFC standards.

CST as a generic simulation toolkit allows the user to define the data structure of the product model in very flexible way; on the other hand it adopts the IFC data model (ISO 16739) as the most supported format among BIM authoring software for automatic integration between BIM and SIM model.

The data model server project IFCWebServer (Ismail, 2011) was developed in parallel to CST toolkit in order to enable extracting all the necessary information from BIM models effectively. The data extraction and mapping to simulation model were achieved by using predefined queries/filters and data validation rules. The results of the queries can be saved as XML files and imported easily into the simulation model.

Figure 3: Information flow between BIM and SIM models

2.2. Integration of process model data

In our approach, Business Process Model and Notation (BPMN) is used to create semantic and graphic process models for various construction operations. BPMN models consist of simple diagrams constructed from a limited set of graphical elements. This makes it easy to learn and understand for both, business users as well as developers.
Flow Objects are the main elements to define and control the behavior of a business process. The basic modeling elements of BPMN which can be used inside the simulation process templates are:

- Start/End events
- Task and sub-process
- Sequence flow
- Gateways: Parallel Fork/Join, Data-Based XOR
- Conditional and default flow.

Process models will be imported into a process catalog as ‘ready to use’ Reference Process Models (RPM). The process catalog includes reference process models for the best practices of various construction processes that are reusable across different construction projects in addition to their data definitions of resources and productivity factors.

The process catalog includes models for the best practices of various construction processes that are reusable across multiple projects with their data definitions of resources and productivity factors. The knowledge accumulation enables a continuous improvement of the catalog.

The process templates can be as simple as having one single activity or a set of serial activities which run sequentially without any kind of control flow or very complex ones including loops and conditional gateways which may result in skipping/repeating some activities. In order to create reliable simulation model, one needs to carefully examine every detail of the construction process and identify the major events and processes that will be presented in the simulation model (Akhavian et al. 2011).

In CST the user has the freedom to move the logic and the dependencies between different tasks to be a part of the input data for each simulation model or to be included inside process templates. However this may lead to one of the following extreme situations:

1. A very detailed project schedule with a simple process templates for each task
2. A very simple project schedule consisting of few tasks with a high level of abstraction combined with very complex process templates

Both cases must be avoided to get the most out of the simulation model in the sense of ease of use and the flexibility of answering as many as “what if” scenarios. It is mainly the responsibility of the user to maintain balance between these options according to the simulation goal and the availability of data. Figure 4 shows as an example of a good balanced process template for erecting a wall for three construction methods: Precast, In-situ concrete and as bricks walls.

By using this template there is no need to use three different templates and link them explicitly to each wall as part of the simulation input, which reduce the time and efforts to prepare the simulation data. The definition of resources and duration value/formula for each single task can be embedded inside the BPMN process template or maintained in separate database.

2.3. Integration of planning data model

Another important domain of information is planning data model, which connects the other basic models together in form of project schedules or what is called “Task list” inside the CST framework.

The start point of planning any project is to establish a list of all the activities which have to carry on in order to deliver the expected result with a certain quality taking into account the limits of time and resources. The most common methods to describe and visualize this list are Gantt charts, activity networks, and PERT diagrams combined with the critical path analysis method (CPM). Using simulation technique as an additional tool to support the planning, offers a lot of benefits to improve the outcome by:

- The duration of any activity will be calculated dynamically during the simulation taking in account the real combination of resources which have been used to do the work and the exact quantities of work from the product mode.
- Integrating the uncertainty factors of resource productivity, quantities and duration calculations.
- Allowing the planer to test the output of many “what if” scenarios rapidly.
- Assist in taking immediate corrective actions in case of unexpected changes during the construction phase.

CST support importing/exporting project schedules from/to Microsoft Project software and offers a handy way to break the project schedules one or more levels down automatically by using special process templates, which serve as a recipe to describe the steps and logic
of activities needed to complete the work with each task in the high level schedule.

3. MODELING OF RESOURCES
The modeling of resources inside the simulation model and the interaction between tasks and available resources is very important to ensure the correctness and reliability of simulation results. A simple data model was defined to describe the resource requirements of each activity in a generic way. This model allows defining the minimum set of necessary resources and their (min, max, default). Table 1 shows an example of the required resources definition for the activity “Concrete Work” in the Wall erecting process model.

Table 1: Resource definition for the activity “Wall ConcreteWork”

<table>
<thead>
<tr>
<th>Resource From</th>
<th>Resource To</th>
<th>Condition</th>
<th>default/min/ma x amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Concrete_Sink</td>
<td>Class= &quot;C25&quot;</td>
<td>Volume</td>
</tr>
<tr>
<td>Worker</td>
<td>WorkerBusy</td>
<td></td>
<td>3 2 5</td>
</tr>
<tr>
<td>Pump</td>
<td>PumpBusy</td>
<td></td>
<td>1 1 1</td>
</tr>
</tbody>
</table>

Most of traditional planning methods and tools assume that required resources for any activity will be allocated at the start of the activity and released at the end and also assume that the same resources will be used to complete an interrupted. In our approach the dynamic allocation of resources during simulation bypasses these assumptions and resources can be reallocated when they are not necessary any more needed to complete the activities.

CST framework includes the following standard resources:
- Building material: concrete, steel
- Equipment: Formwork panels
- Construction machines: Tower crane, concrete pump, trucks
- Human resources: workers with qualifications
- Construction site facilities: Storage areas, transport roads, entrance and exit gates

The resources inside the simulation model can be defined as abstract objects or as detailed simulation modules. Figure 5 shows the representation of the tower crane object as an abstract resource (top) or as a detailed simulation module with extra functionality to calculate the duration of transport precisely and support 2D and 3D animation.

4. CASE STUDIES

4.1. Case Study 1: Generic planning model
The first case study is a textbook activity network adopted from (Talbot and Patterson 1979). This study case was presented in (Shih-Ming Chen et al. 2012) using an intelligent scheduling system (IIS) in order to find the near optimum resource distribution for different project objectives. The project objective of this study case is assigned to be the minimum project duration. The activity network consists of twenty activities with equal priorities using six resources with daily availability constraints (Fig. 6).

The shortest project duration was 45 days which is 4 days shorter than the best result obtained from widely used commercial software using CPM method.

![Figure 6: Activity network for the first study case](image)

![Figure 5: Simulation modules for tower cranes in different level of details](image)
In this case study we are presenting how to use CST as a generic simulation framework. The definition of activities (duration, resource requirements) and the generic resources have been entered as direct input. Figure 7 shows the simulation model of this case. It consist mainly of 2 inputs components: Task list and Resource pool and three output components: Process pool, Gantt diagram, and a Project monitor to watch the utilization of resources.

Figure 7: Simulation model for case study I

In this example the start time of all activities has been set to zero and the relationships between tasks and the definition of their resource requirements have been entered directly inside the “Task List” component. The resources R1-R6 defined inside the “Resource Pool” as generic resources and their daily resource limits have been set according to the table in Fig 6. The daily and weekly work time settings have been adjusted to ignore the default weekend days and daily work time. The shortest project duration we got after 100 simulations run was 45 days which is the same compared to the result obtained from IIS. Figure 8 shows the simulation results as Gantt chart and the resource utilization diagrams.

Figure 8: Simulation result of the study case I

4.2. Case Study II: Multi-Story Office Building
The second case study is a simulation model for 18-story office building. This sample project is based on a real project in Germany and was chosen as a reference project in the MEFISTO project. The goal of the simulation study for this sample project is to analyze and compare different planning options and “what if” scenarios. Some of the applied scenarios for this sample project are:

1. Showing the effect of changing the amount of any available key resource on the total duration of the structural work for one story or the whole building. This could be done for example by changing the number of workers, cranes, or formwork panels.

2. Comparing the resource utilization rates and the expected win or lose in the construction duration for two planning options (1) Each story consists of one working section and all workers are qualified to do any kind of structural work. (2) Each story consists of two work sections and the workers are divided to different teams with specific qualifications.

3. Generate detailed construction schedules based on primary schedules and visualize the construction work progress.

In this project a process catalog of all construction activities (formwork, steelwork, concrete work, etc.) for the walls, columns, and slabs was created including the definition of resources.

The graphical representation of the BPMN models made it easy for all participants to understand how the simulation works. The modular structure and the flexibility of the simulation components allows with a minimum effort to analyze a lot of simulation scenarios using the same simulation model and finally deliver the simulation results in different formats as Gantt charts, 2D animation, 4D Simulation.

Figure 9 shows for example the effect of changing the number of workers (10–40 worker) on the total duration of the structural work for two stories, the utilization rates and the concrete consumption for the case of 12, and 24 workers. The result of this study case showed the advantages of using simulation technique effectively to solve a lot of planning problems which is not possible using traditional methods. Figures 10 and 11 show a part of the simulation results as 2D animation and 4D model.

Figure 9: Effect of changing number of workers
The full supplementary materials related to this case study and other simulation projects can be accessed online at: http://bci52.cib.bau.tu-dresden.de:3000

5. CONCLUSION AND FUTURE RESEARCH

This paper presented the development of a process-based construction simulation toolkit with a focus on the data integration between the basic models and the resource modeling. Two sample cases are presented to validate and explain the concepts behind the development and the possible applications of this toolkit. This research attempts to spread the acceptance and application of simulation technique to support the planning of real projects by allowing the rapid deployment of simulation models. Future work should focus on the integration with other models like the cost and risk models and also on the interaction between the production and logistic operations.

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