Process Design Tools for the AEC Industry

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Introduction: "Uebung macht den Meister" (practice leads to mastery)

Engineers and builders continually build models in their heads, on paper, with wood, glue and cardboard, and with the computer. The models enable them to imagine what could be, to assess a situation or scenario, and to communicate their vision of a future state and reasons for its desirability to others. Over the last few decades, significant progress has been made to model aspects of a building or structure with computer tools. Computer-interpretable models representing the product (building) and supporting a number of analyses and visualizations are on the horizon. For example, for structural engineers it is today commonplace to build a computer-interpretable model of a structure to analyze its fitness for a specific purpose. For many other engineers involved in the delivery of a project, few or no tools exist to support the design activities in their domains. This is especially true for construction managers whose task it is to design the production process. As part of the set of models needed to describe and evaluate a proposed design, this paper focuses on the need to develop process design tools and a corresponding process modeling language and visualization and interaction functionality tailored to the AEC industry.

Current commercial software tools do not generate or work with a computer-interpretable process model that supports process analysis and visualization. Put another way, in their computer models structural engineers can fail as often as they want prior to committing to a design, and they can use the same models to show others why something works or does not work. Construction process designers do not have tools that allow them to do that. Therefore, they have to pretty much get it right the first time. From watching sports teams, symphony orchestras, or ballet ensembles we all know that it is highly unlikely that a team of specialists will succeed in doing everything right the first time. Music and ballet ensembles have vocabularies that allow them to orchestrate or choreograph the performance of a team. They can also practice (simulate) a performance, trying out several approaches. In the AEC industry, it would of course be much too expensive to practice with the real thing. The only practice (rehearsal) we can do is with models, and computer models are for the foreseeable future the only models that can potentially support the demands of the multi-disciplinary and multi-stakeholder design and construction processes in our industry. However, much remains to be done to allow practitioners to build computer models of AEC products and processes much faster and more economically than the real products and processes and to share and display these models efficiently and effectively.

Motivating example: "I'll get back to you" or "We can't change that now"

At a recent construction site meeting I attended, one department of the owner's organization wondered whether it might still be possible to add a fountain to a pond, which was part of the site development plan. The pond was already under construction. The project manager and the owner team had to weigh the following questions:

- What would the schedule and cost impact on the construction of the pond and the adjacent facilities be if the design were to be changed as quickly as possible?
- What would the schedule and cost impacts be if the construction of the fountain were done after the current construction activities on the pond were completed, but before the pond was filled with water?
- What would the schedule and cost impacts be if the construction of the fountain were done after the currently approved project scope had been completed.

During the project meeting, nobody was able to explore and explain any of these three scenarios in a satisfactory and constructive way. I even doubt that everybody in the room clearly understood the current status and plans of construction, the scope of work entailed in adding the fountain, the difficulties that would be encountered if the fountain had to be added to the scope of work right away, etc. For example, the barcharts and 2D drawings did not illustrate clearly the work already in place, the work currently going on, the work planned for the next three weeks, and the various kinds of relationships between work processes and project stages. Furthermore, the tools used to document the construction process did not support any of the analyses necessary to give insights into the pros and cons of each of the three scenarios. Without such insights it was essentially impossible for the owner team to decide whether they should just forget about the fountain or whether it might actually be relatively cheap and easy to add it. Without being convinced themselves of one or the other scenario they could not really approach top management to allocate funding for this scope change.

To give the owner representatives the feedback they needed, the project manager would have needed a tool to model the work processes involved in adding a fountain at various stages of the current scope of work. The tool would have also had to support analyses and visualizations of the effect of the added or changed work on the existing schedule and budget. All he could do was to draw on his experience to guide the owner team towards the most economical scenario. In essence he advised the owner team that "it was too late to change the design now" and incorporate the construction of the fountain right away. He promised "to get back to them" with respect to the tradeoffs between the other two scenarios.

Research Needs: "Life would be so much better if …."

In my experience situations like the one described in the previous section occur on all projects. It is difficult to decide what one wants if one cannot understand the implications of choosing alternative A versus B. One of the analyses that is often needed to make a well-informed decision is the impact on budget and schedule. To a large extent, this impact depends on the production process and its design. This is where I see the need to develop a process vocabulary. This process vocabulary should allow construction process designers to describe, model, analyze, and visualize the construction processes and their relationships and relevance to the project design (product), the project's organization, resource allocation, etc. The resulting model should allow decision makers and other stakeholders to gain an appreciation for the risks and tradeoffs of each scenario.

The process vocabulary will need to model work methods, activities, temporary structures, and resources (to name a few concepts). It would also need to provide ways to model the spatial and temporal aspects and relationships of these concepts. The efforts of the North American project management domain group in the IAI have produced a good set of model components (types of objects) and relationships to describe plans, schedules, estimates, and resource usage for a project. The components in the model are largely representative of current practice. As discussed, current practice does not explicitly consider the process aspects of a project in a computer-interpretable form. For example, when a scheduler creates a schedule for a sequence of work in CPM format, she needs to abstract or simplify all sequence constraints to logical (temporal) constraints. The spatial relationships between the work, although typically considered when making a schedule, and the reasons for a particular precedence relationship are lost. A process vocabulary would have to allow practitioners to model the dynamic spatial and temporal aspects of work on AEC projects.

The challenge for such a vocabulary is that it needs to be general so that it applies to all (or at least many) types of projects. Yet it needs to be able to support very project-specific and unique situations. Most of the research work to date (including my own) has focused on providing partial domain-specific solutions and has not been tested on full-scale projects. I am interested to find out what abstractions will lead to a vocabulary that allows practitioners to work at several levels of detail, to quickly build the large models they need to represent a real project, and to rapidly understand each others' process models.

At a brief charette on process design at the annual workshop of CIB's group W78 (Information Technology in Construction) the participants identified the formalization of the following concepts as important for such a process vocabulary:

- Hierarchy (project information exists at many levels of detail)
- Purpose, rationale and constraints (without giving the user a way to formalize the purpose of a model and the rationale for a particular solution including it's related constraints, the computer will not be able to make much "sense" of the information in a process model, which leaves all the work to update a model to the user)
- Inputs and outputs, boundaries of a process
- Relationships (among other reasons, relationships between processes are based on information, resource, time, and space dependencies)
- Metrics (formal metrics and corresponding analysis algorithms are needed to determine whether a process is cheap, fast, safe, resource balanced, executable …)
- Views, queries, coding, classification (users always need new ways of looking at project data)

The participants felt that the representation of process models needed to be improved. They felt that CPM schedules, bar charts, Petrie Nets, and IDEF diagrams were not sufficient. Furthermore, they suggested that particular emphasis should be given to the formalization of all types of dependencies at various levels of detail and to consistency mapping between levels of detail.

The main benefits of more formal process models would be to

- understand the present better
- envision the future
- improve constructibility
- manage resources more efficiently and effectively.

Personal background: "Why do I care?"

My experience of working for a subcontractor for bridge projects motivated me to study how to improve the interface between design and construction. On most projects in which I was involved, designers had made decisions about the design configuration without consulting with construction. This led to designs that were expensive, time-consuming and sometimes unsafe to build. During my Ph.D. I focused on developing a constructibility checker for concrete structures represented in 3D CAD models. The work showed that, without an explicit notion of time, it is difficult to give meaningful constructibility feedback. This led to my work on 4D models. By linking a 3D model and a temporal model (schedule), the designer's and the contractor's perspectives are part of the same model and have to be reconciled. However, current 4D models are not based on a process vocabulary and do not support computer-based analyses with respect to cost, safetey, risks, etc. In addition to the work on process modeling, I am also interested in improving the visualization and interaction functionality for process models. The 4D CAD link on my homepage http://www.stanford.edu/~fischer provides brief descriptions and links to current projects in my research group and gives further background to this position paper.

Acknowledgments

I have greatly benefited from discussions with colleagues and students at CIFE, members of the North American project management domain group of the IAI, members of the Lean Construction Institute, and participants in the charette at the most recent workshop of CIB's W78 group (Information Technology in Construction) in Vancouver, Canada.