Generating Sequences of Construction Tasks

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ABSTRACT: Construction processes require preparation phases where among others the sequence of construction tasks has to be developed. This sequence of tasks cannot be transferred automatically from project to project. Specific peculiarities of projects need to be considered so that individual follow up charts need to be set up. In practice, follow up charts are developed that describe the sequence of tasks in different levels of detail. The quality of these follow up charts depends on the experiences of construction managers. Software tools do not support the development process of these charts; they document the result, the follow up charts themselves. Therefore, completeness and logical correctness of these charts can only be checked by inspection. This paper presents a modeling technique where the sequence of construction tasks results from a task-oriented specification. Each construction task is modeled individually by describing its preconditions and its results. The interdependencies between the tasks are calculated from the task-oriented specification based on relational algebra. The task-oriented specification consists of a description of the prerequisites and the results of each task. All interdependencies are calculated based on this specification. A specific topological sort algorithm based on graph theory determines the sequence of tasks. The advantage in using the presented modeling technique is that logical correctness and completeness can be guaranteed. A practical example is presented.

1 INTRODUCTION

Construction processes in civil engineering are characterized by specific peculiarities. Their complexity does not allow for specifying an overall process model that is valid for and can be adapted to each project. In addition, an optimal construction process cannot be derived based on optimal partial processes only. It is well know from mathematics that local optima do not guarantee for a global optimum so that optimal partial processes do not guarantee for an overall optimum as well. Also low detailed descriptions of processes cannot be used to generate high detailed process models. It can be shown in mathematics based on hierarchical graphs that high detailed processes can be mapped onto low detailed processes. The inverse procedure, mapping low detailed processes onto high detailed processes, is not defined. There is no mapping rule that can be used to derive high detailed processes from low detailed ones.

As a consequence, construction processes need to be prepared individually. Especially the sequence of tasks needs to be worked out for each project. Construction processes are so called ad-hoc processes; and it is also known in other disciplines like software engineering that ad-hoc processes need to be prepared individually.

In civil engineering, work plans document agreements and rules for the execution of projects. These work plans cover descriptions of tasks, responsibilities, deadlines, budgets, and also the sequence of task is described as target values for the execution of construction processes (cp. DBV (1998)). Of course, software tools are used to specify schedules. But the use of these software tools has serious disadvantages. The user specifies tasks and their duration. In addition, interdependencies can be modeled. However, there is no necessity to specify all interdependencies, and the number of interdependencies is in general so high that the effort of specification is unacceptable. As a consequence, not all interdependencies are documented. In general, subsequent modifications are necessary, and existing interdependencies might influence the modifications. If these interdependencies are not documented, they might be lost so that incorrect schedules will be the result.

The present paper discusses an approach specifically focused on construction processes where all interdependencies between tasks are captured. However, the interdependencies between tasks as well as the sequence of tasks need not be specified by the user, they are calculated based on some task-oriented user input. Each construction task is modeled individually. Beside construction tasks, components are considered that are built or modified during the execution of the project. The user has to specify relations between tasks and components, for instance the components that are created during the execution of a task. Based on this input, interdependencies between tasks are calculated and a sequence of tasks is determined.

The advantage of the presented approach is the availability of the theoretical background that is used for calculating the interdependencies between the tasks and the sequence of tasks. Specifying interdependencies between construction tasks is not the duty of a construction manager any more. Like in structural analysis, a construction manger specifies some input, and he has to evaluate the results, in this case the sequence of tasks. This requires a rethinking in the area of construction management. The logic of construction processes is determined, and its correctness and completeness with respect to the user input can be guaranteed.

2 MODELING TECHNIQUE

As an assumption, construction processes can be described by

- components,
- construction tasks, and
- relations between and in construction tasks and components.

A building can be described by its components, and the presented modeling technique requires all components to be named.

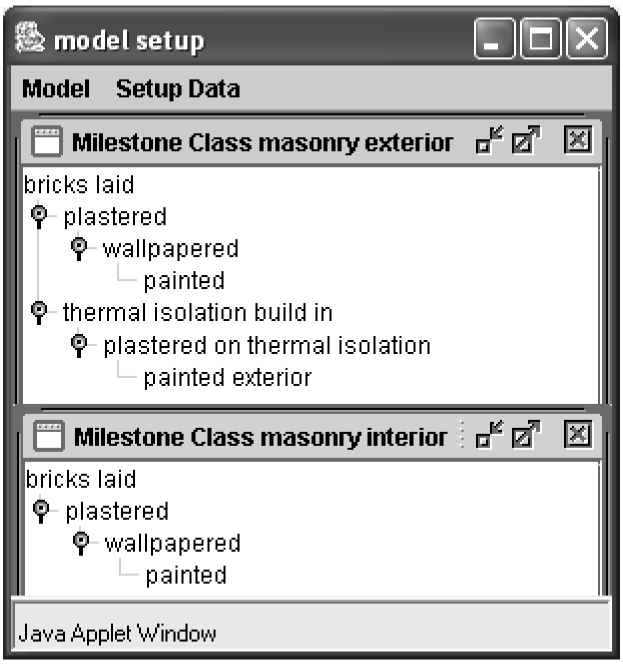


Figure 1. Milestone classes

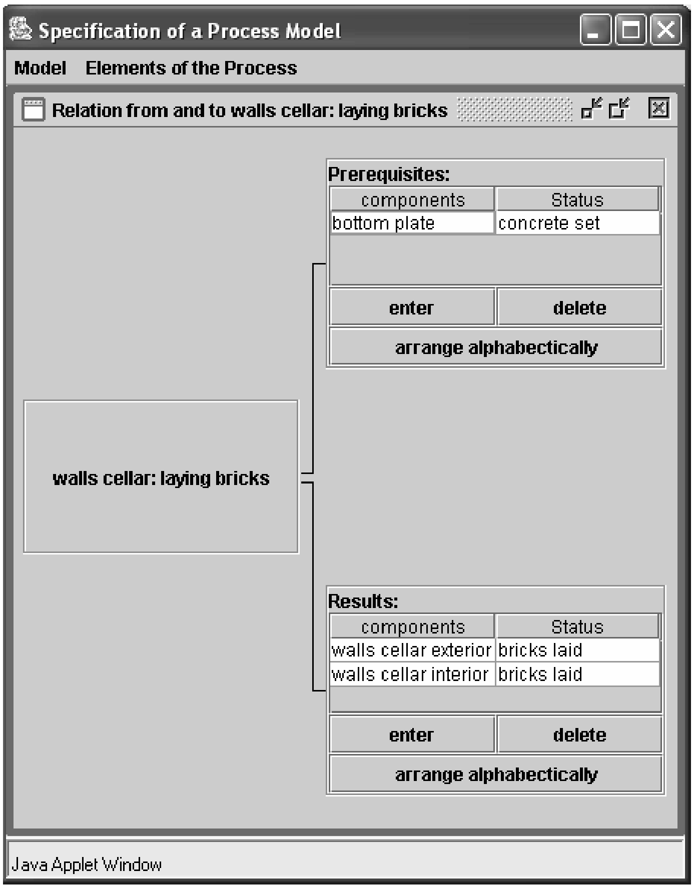


Figure 2. Specification of relations between components and tasks

In general, components will have several states during the execution of a project. For instance, the bricks of a wall are laid first, than the wall is plastered, and than it is wallpapered and painted. Milestone classes are introduced in the modeling technique to describe the states of components. These milestone classes are specified for different types of components. In general, components have different surfaces whereas each surface will have different states. This is considered in the modeling technique, and trees are used to specify the states and the sequence of states for types of components.

Figure 1 shows two examples of milestone classes. The states of all surfaces of interior masonry pass through the same states. Therefore, this milestone class consists of a sequence. Exterior masonry needs a thermal isolation outside and the identical states like interior masonry inside.

The presented modeling technique requires all construction tasks to be named. Two relations between tasks and components need to be specified. One relation describes the prerequisites for the execution of a tasks, the other relation describes the result. Both, the prerequisites and the results are components in a specific state. Figure 2 shows an example. The task “wall cellar: laying bricks” requires the bottom plate in the state “concrete set”. As the result, the exterior and interior cellar walls achieve the state “bricks laid”.

3 THEORETICAL BACKGROUND

In a first step, relations between tasks are calculated based on the specified relations between tasks and components. Two rules are evaluated for this purpose:

1 Consider a task T that has a component C in state s_r as a result: All tasks that have the component C in state s_i as a result where s_i is in the milestone class of C on the path from s_r to its root have to be executed before task T.

2 Consider a task T that has a component C in state s_p as a prerequisite: All tasks that have the component C in state s_i as a result where s_i is in the milestone class of C on the path from s_p to its root have to be executed before task T.

Based on these two rules, relations between tasks are calculated the describe tasks that have to be executed before other tasks.

The relations between tasks can be sorted topologically if they do not cover a cycle. Cycles can occur if a task T1 requires a component C1 in state s1 and has a component C2 in state s2 as its output whereas another task T2 requires C2 in state s2 and has C1 in state s1 as its output. Such a situation is shown in figure 3. These conflicts can be solved if the affected tasks are executed in parallel. The affected tasks that have to be executed in parallel can be replaced by a major task so that cycles can be avoided.

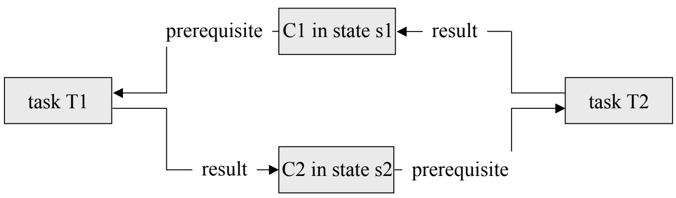


Figure 3. Cycle in a construction process

In general, several solutions can be determined as a sequence of tasks where all relations between tasks are considered. A topological sort algorithm based of the breadth-first-search is chosen for the determination of the sequence of tasks. This algorithm guarantees the lowest number of logical steps, and each task is inserted at the first logical step when it can be executed (cp. Pahl Damrath (2001), Turau (1996)). Such a solution needs to be evaluated by a construction manager. The algorithm considers interdependencies calculated from the relations between tasks and components only. Further interdependencies might exist, e.g. the availability of special equipment does not allow the execution of specific tasks in parallel. Such interdependencies are not jet considered so that the calculated sequence of tasks can only be regarded as a proposal. It needs to be edited, and a construction manager can select another solution from the solution set. Each sequence of task that covers no cycle is a valid solution. Cycles can be checked based on topological sort algorithms as presented in Turau (1996).

4 EXAMPLE

The modeling technique has been tested using realistic examples. Figure 4 shows some construction tasks that have been modeled. Figure 5 shows some components of a building. The calculated sequence of tasks is shown in figure 6.

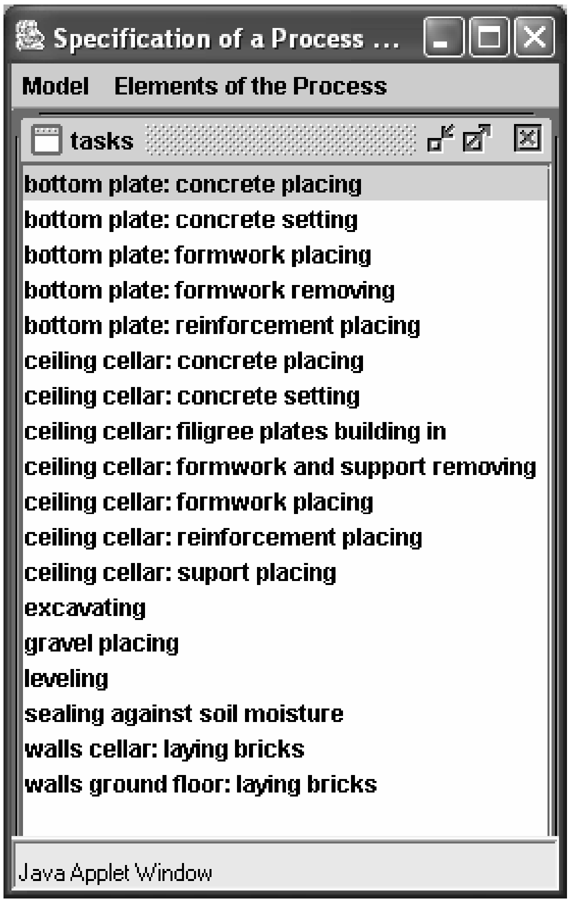


Figure 4. Construction tasks

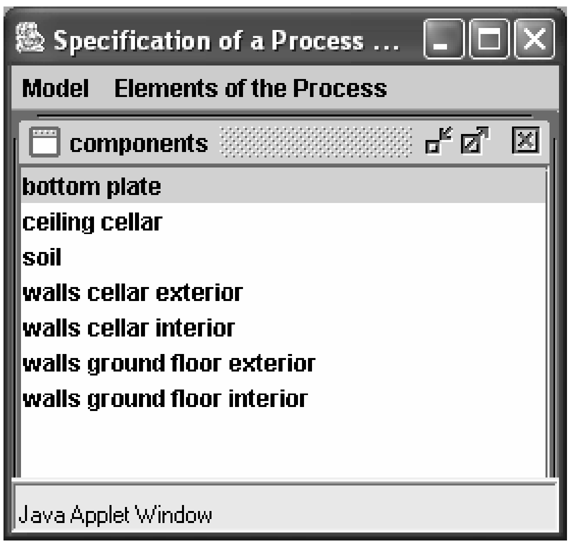


Figure 5. Components

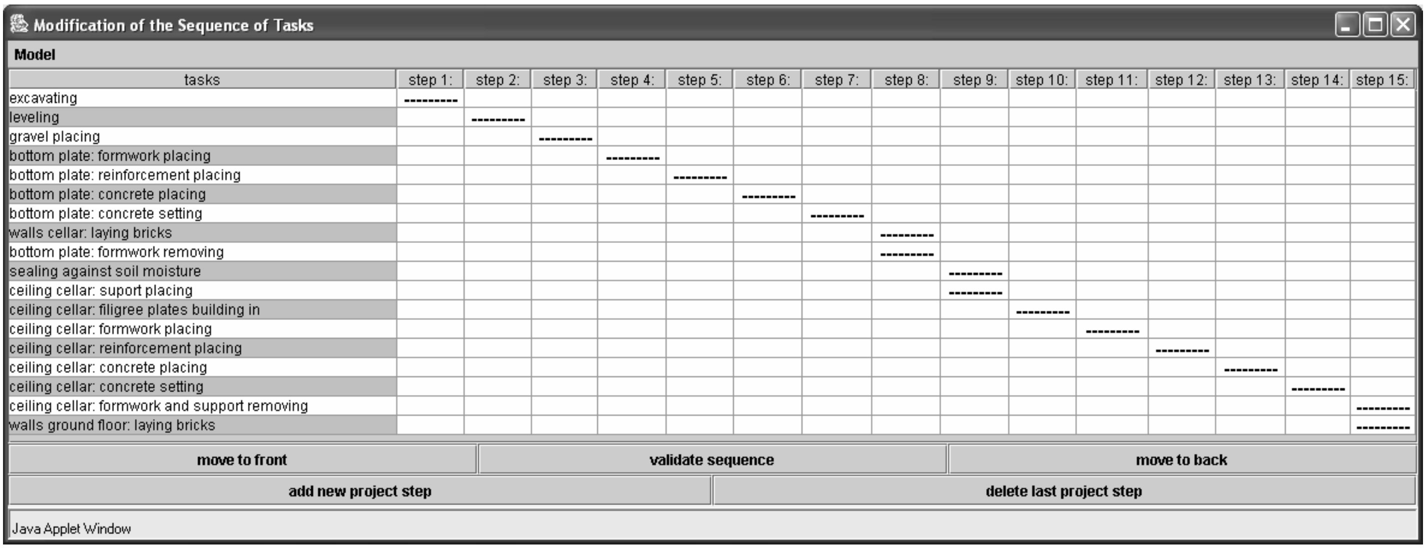


Figure 6. Calculated sequence of tasks

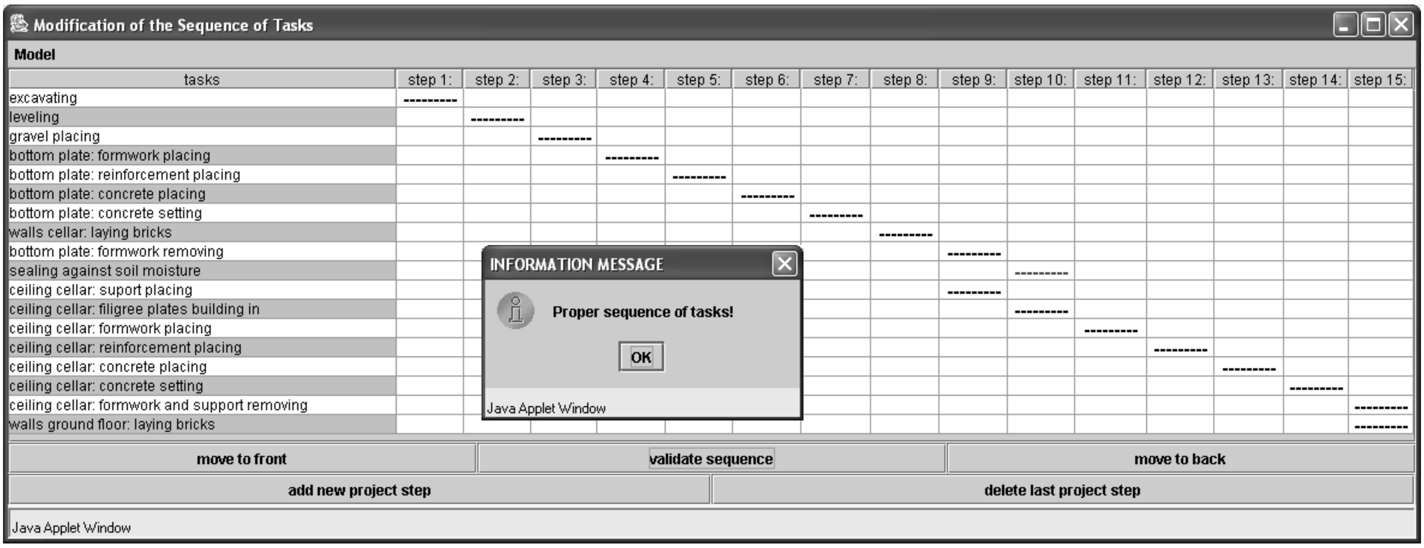


Figure 7. Modified sequence of tasks

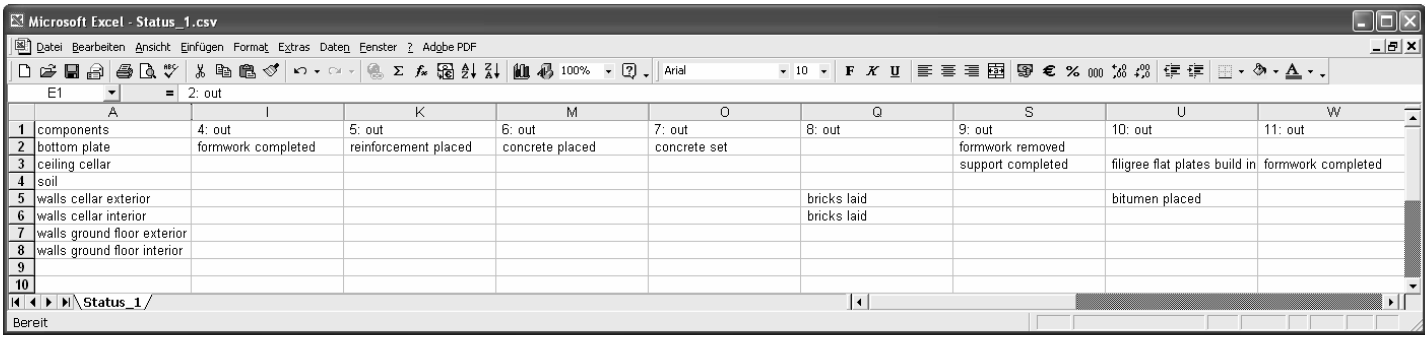
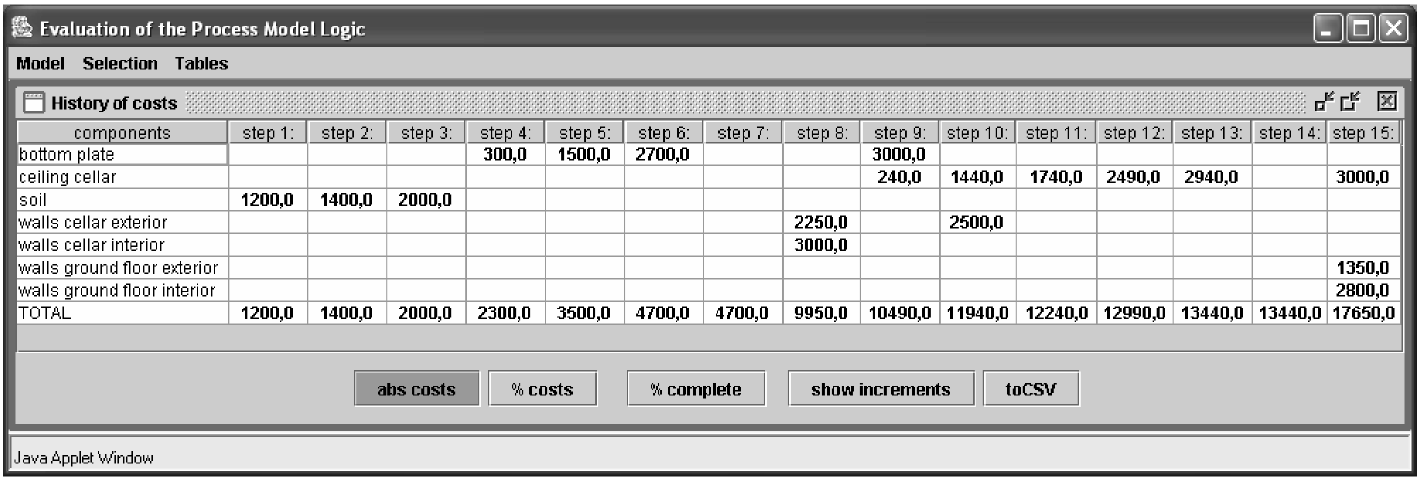


Figure 8. History of components

The sequence of tasks can be edited. Tasks can be moved backwards or forwards. It can be checked whether the modified sequence of tasks is valid. Figure 7 shows a modified sequence of tasks. Two tasks have been moved backwards. These tasks do not have any direct successors so that there is no conflict with existing relations between tasks. The modified sequence of tasks is valid.

The sequence of tasks can be evaluated. Figure 8 shows an extract of the history of components. The states are shown for specific project steps only. The displayed values are the states of the components that are achieved at the end of each project step.

The example presented in figures 4 to 8 covers a small number of components and tasks only. Realistic projects in civil engineering consist of several hundreds of tasks and components. Print outs are necessary for the evaluation of these processes, and in general several pages with a size of DIN A 0 are necessary to present the sequence of tasks and the history of the components.



components	step 1:	step 2:	step 3:	step 4:	step 5:	step 6:	step 7:	step 8:	step 9:	step 10:	step 11:	step 12:	step 13:	step 14:	step 15:
bottom plate				300,0	1500,0	2700,0			3000,0						
ceiling cellar									240,0	1440,0	1740,0	2490,0	2940,0		3000,0
soil	1200,0	1400,0	2000,0												
walls cellar exterior								2250,0		2500,0					
walls cellar interior								3000,0							
walls ground floor exterior															1350,0
walls ground floor interior															2800,0
TOTAL	1200,0	1400,0	2000,0	2300,0	3500,0	4700,0	4700,0	9950,0	10490,0	11940,0	12240,0	12990,0	13440,0	13440,0	17650,0

Figure 9. History of costs

5 WEIGHTING

The determination of the logic of a sequence of tasks as described in section 3 is a first step in preparing construction processes. The sequence of tasks can be evaluated so that the planned history of the components can be determined. The planned history of the components can be regarded as basic information concerning the quality that has to be achieved. However, project management requires three different types of information:

- quality,
- costs, and
- deadlines.

Costs and deadlines can be included into the modeling technique by weighting components and tasks. Components in specific states are the products of construction activities. Achieving a specific state requires financial effort. This can be expressed by weighting each component with its individual price.

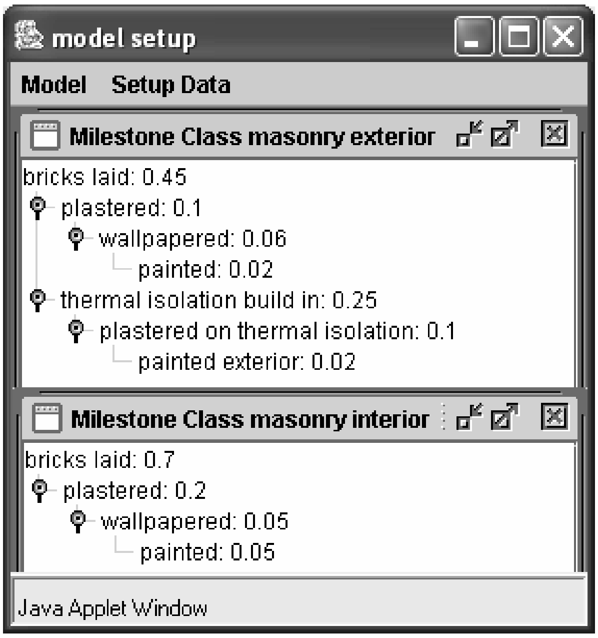
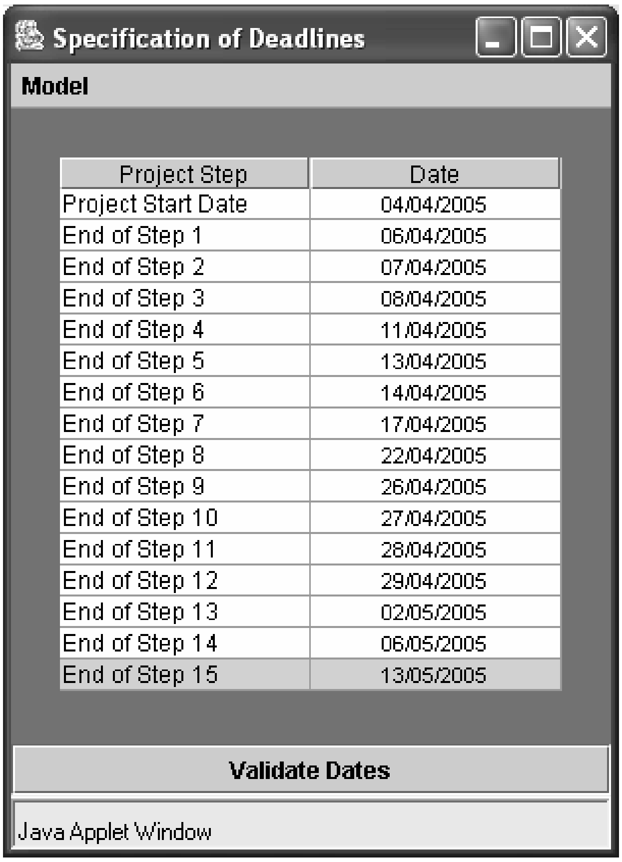


Figure 10. Weighted states

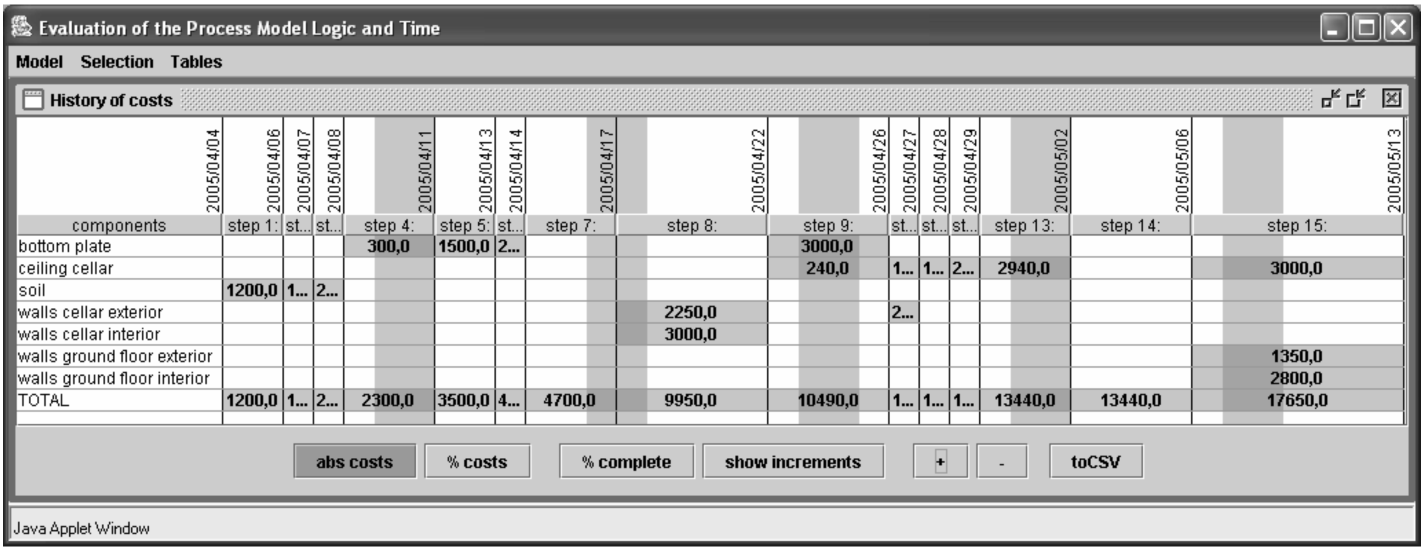
As part of the milestone classes, percentage values can be specified that describe the effort that is necessary to achieve a specific state. Figure 10 shows these values for the milestone classes that have been developed for components of the type “masonry exterior” and “masonry interior” (see figure 1). As a consequence of weighting components with their prices and states with a percentage rates, a history of costs can be determined. Figure 9 shows an example.

Deadlines can be specified for the beginning to the project and for the end of each project step. Figure 11 shows an example. As a consequence, the sequence of tasks and the history of components, and costs can be mapped onto the time scale.



Project Step	Date
Project Start Date	04/04/2005
End of Step 1	06/04/2005
End of Step 2	07/04/2005
End of Step 3	08/04/2005
End of Step 4	11/04/2005
End of Step 5	13/04/2005
End of Step 6	14/04/2005
End of Step 7	17/04/2005
End of Step 8	22/04/2005
End of Step 9	26/04/2005
End of Step 10	27/04/2005
End of Step 11	28/04/2005
End of Step 12	29/04/2005
End of Step 13	02/05/2005
End of Step 14	06/05/2005
End of Step 15	13/05/2005

Figure 11. Specification of deadlines



2005/04/04	2005/04/06	2005/04/07	2005/04/08	2005/04/11	2005/04/13	2005/04/14	2005/04/17	2005/04/22	2005/04/26	2005/04/27	2005/04/28	2005/04/29	2005/05/02	2005/05/06	2005/05/13
components	step 1:	st...	st...	step 4:	step 5:	st...	step 7:	step 8:	step 9:	st...	st...	st...	step 13:	step 14:	step 15:
bottom plate				300,0	1500,0	2...			3000,0						
ceiling cellar									240,0	1...	1...	2...	2940,0		3000,0
soil	1200,0	1...	2...												
walls cellar exterior								2250,0		2...					
walls cellar interior								3000,0							
walls ground floor exterior															1350,0
walls ground floor interior															2800,0
TOTAL	1200,0	1...	2...	2300,0	3500,0	4...	4700,0	9950,0	10490,0	1...	1...	1...	13440,0	13440,0	17650,0

Figure 12. History of costs mapped onto the time scale

Figure 12 shows an example; the history of costs is mapped onto the time scale. The presented modeling technique results therefore in all basic information that is necessary to be known at the early beginning of a construction project, quality, costs, and deadlines, can be generated and derived from the logic of construction processes.

6 CONCLUSIONS AND OUTLOOK

The presented modeling technique is a first step in modifying the use of information technology in the area of preparing construction processes. At present time, information technology is used to document target values for construction processes that have been generated on human experience only. Of course, algorithms are available, for instance to determine critical paths, however, the use of information processing needs specified processes and does not support the development of these processes. This usual way of using information technology is prone to errors, and it is inefficient.

The presented modeling technique supports the development of processes. It distinguishes between the logic of a process and the weighting. In a first step, the development of a correct and consistent logic of the sequence of tasks and the history of the components is supported. In a second step, the process is weighted with deadlines and costs. The results are target values that cover the three most important information for an efficient project management: target values for quality, deadlines, and costs.

An equivalent modeling technique has been developed for engineering planning processes. This technique has been successfully tested in real engineering projects (cp. Huhnt & Lawrence (2004)). Practical tests of the presented technique for construction processes are in progress.

The use of the presented modeling technique results in further questions and tasks.

The distinction between the logic of a construction process and its weights requires efficient techniques to guarantee for complete and consistent weightings. For instance, costs need to be assigned to all components of a building. Interdependencies between disciplines need to be considered. Cost information need to be checked, and consistency has to be reviewed.

Complete weightings open the way to optimization problems. Several solutions are valid for a sequence of tasks. Overall optimization techniques need to be investigated to select “the best” sequence of tasks.

The presented modeling technique makes use of specific relations only. For instance, restrictions in the use of personal or equipment are not considered. Expanding the presented technique to consider further restrictions and constraints is a challenge and has to be investigated in future.

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