

ADAPTABLE PROJECT SCHEDULE PLANS USING CHANGE TEMPLATES

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Abstract. *The uncertainty existing in the construction industry is bigger than in other industries. Consequently, most construction projects do not go totally as planned. The project management plan needs therefore to be adapted repeatedly within the project lifecycle to suit the actual project conditions. Generally, the risks of change in the project management plan are difficult to be identified in advance, especially if these risks are caused by unexpected events such as human errors or changes in the client preferences. The knowledge acquired from different resources (past projects, experts etc.) is essential to identify the probable deviations as well as to find proper proactive/reactive solutions to the faced change risks. Hence, it is necessary to have a knowledge base that contains known solutions for the common exceptional cases that may cause changes in each construction domain.*

The ongoing research work presented in this paper uses the process modeling technique of Event-driven Process Chains (EPCs) to describe different patterns of structure changes in the schedule networks. This results in several so called “change templates”. Under each template different types of change risk/ response pairs can be categorized and stored in a knowledge base. This knowledge base is described as an ontology model populated with reference construction process data. The implementation of the developed approach can be seen as an iterative scheduling cycle that will be repeated within the project lifecycle as new change risks surface. This can help to check the availability of ready solutions in the knowledge base for the situation at hand. Moreover, if the solution is adopted, CPSP, “Change Project Schedule Plan”, a prototype developed for the purpose of this research work, will be used to make the structure changes of the schedule network automatically based on the change template. What-If scenarios can be implemented using the CPSP prototype in the planning phase to study the effect of specific situations without endangering the success of the project objectives. Hence, better designed and more maintainable project schedules can be achieved.

1 INTRODUCTION

Construction is a project-based industry. Each construction project can be considered unique as the boundary conditions, the project team, the used techniques, and the agreed upon products are different from a project to another. Moreover, although construction projects are executed using deterministic management plans, the uncertainties and dynamic changes faced in this sector are bigger than in other industries. This can be ascribed to the following reasons:

- Many assumptions in construction projects have to be made based on incomplete information. Such assumptions may be wrong and consequently can endanger the progress of the project.
- Some used methods in construction project management may increase the uncertainty and consequently the potential change risks, such as the fast track method which uses as well incomplete information.
- The boundary conditions under which a construction project is assumed to be done are changeable. For example, if the project will be executed over a span of many years the legislative, environmental, or economical conditions may change.
- Different alternative execution methods can be used to construct the same product. The choice between the variants is a matter of decision making. Taking the proper decision is not always certain as it is related to the experience, methods, and information the decision maker has.
- Manual tasks have a large portion in most construction processes. The execution of these tasks is strongly related to the human performance. This is in turn affected by different factors, such as age, state of mind, physical health, attitude, emotions etc. Consequently, the error-rate within the construction processes is relatively high.

All these issues cause that many construction projects may be afflicted with change risks¹ and consequently will not go as planned. Hence, some project management plans (schedule, cost, resources etc) need to be adapted repeatedly within the project life cycle to suit the new project conditions.

In this paper, a high-level description of patterns of change, named “change templates” is presented. These templates are described using the business process modeling technique of the Event-driven Process Chains (EPCs) [1]. They are used to support schedule plan changes in construction projects. Under each one of these templates different types of “change risk-resolution” pairs can be categorized. Each project results in a product that consists of several sub-products, and each one of them can be represented in a process that produces this sub-product. To support the reuse of such processes within different projects a process should be comprehensive enough to contain all known alternative execution methods that can be used to lead to this sub-product. Moreover, a reusable process should contain all known exceptional cases that may occur through the progress of the process and their known responses. A high level description of such reusable processes is introduced also in the paper using reference process modeling concepts and the developed change templates. The implementation of a reference process uses an ontological knowledge base that contains the known information about this process.

The paper starts with an overview about the change-related literature in AEC as well as a classification of the process-oriented changes. After that, the main concepts of Business

¹ A **change risk** means here the uncertain event that its consequences or treatment will cause changes in the structure of the schedule network plan of the process/project.

Process Modeling “BPM” are illustrated and the used BPM technique of EPCs is explained in brief. Afterward, one of the developed change templates is introduced. Also, a simplified example, using the CPSP prototype to integrate the changes in the process schedule and showing how to apply change templates for reference process modeling purposes, is presented. Then an ontology model representing the concepts of the desired Process Reference Model “PRM” is illustrated. The paper is concluded with an outlook of the further work needed to complete the suggested approach.

2 BACKGROUND

2.1 Change literature in AEC

In the literature on change management it is stated that changes are inevitable in construction projects even if comprehensive project studies have been made, [2, 3, 4]. Changes in a construction project may occur at any phase of a project and can affect different project management plans. The effect of changes in the post-fixity phase of the project is severe as the management plans have been adopted and have been partially executed. To make changes in a project plan, modifications in the project contract/ specifications may be needed using change orders, or even an extra contract, i.e. contract addendum. Most of the research work done related to change management in AEC discusses the legal aspects of changes, i.e. from the building law perspective. Other researchers have tended to focus on the general factors and characteristics of the risks that lead to changes, their causes, their consequences and their management. Accordingly, several risk and change management standards have appeared, [5, 6]. Nevertheless, Change management in AEC has been also the focus of several IT developments in the last two decades. For example, Ahmed et al. [7] have developed an integrated environment for computer-aided engineering that integrates a global database, several knowledge modules, and a control mechanism to systemize object changes. Also, a change management system was proposed by Mokhtar et al. [8] for managing design change in a collaborative environment. The model is capable of propagating design changes and tracking past changes. Another information model based on object oriented concepts was introduced by Karim & Adeli [9]. Based on this model, “CONSCOM” a software system was developed which covers construction scheduling, cost optimization, and change order management. An information model to facilitate the design coordination and management of design changes was introduced by Hegazy et al. [10]. Important dependencies between building components were represented by this model to help identify the ripple effect of changes between components. *Managing Change and Dependency in Construction Projects* (MCD) was a three years research project (2001-2004) in England [11]. It had the scope of developing a change management toolkit to assist the project teams to learn and improve their change management skills in predicating and managing changes. Furthermore, Motawa et al. [12] introduced the work “Stability” concept to describe the possibility of changes in construction tasks. This concept was presented within a fuzzy-based change management system aimed at predicting the likelihood and the impact of changes.

2.2 Levels of changes

Process-oriented changes can be found on different levels in the construction projects. As a project consists of several processes and each process has several tasks, the changes are considered to be in three levels, i.e. the project, process, and task changes.

- Project changes: these changes can affect the duration of the project, the project budget, or even the expected product of the project. As an example, if the duration of the project will be shortened, changes in the relationships between its processes (parallel instead of sequence) may be done if applicable. Otherwise, the duration of one of the processes correspondingly will be shortened which means that some adjustments to the task relationships within the process or to the task attributes (duration, cost etc) should be done.
- Process changes: changes in the expected sub-product of the process, problems encountered through the process execution, or changes on the project level can lead to changes in the process. These changes may lead to change the task attributes, task relationships, or even the tasks themselves within the process. Consequently, a planned task in the process may be canceled/ substituted or a new task may be inserted.
- Task changes: the changes on this level mean to change the attributes of the task. This affects mainly the duration and cost attributes. Duration changes include start or end time of the task or even both of them. A change in the task duration can affect the corresponding process duration if the task is on the critical path of the process or if the float reserve on its path is not sufficient.

2.3 BUSINESS PROCESS MODELING

Business Process Modeling “BPM” can be defined as the human activity of creating business process models.

Business process concept

In general, a construction project as a product needs at least one process to construct it. The processes that represent a construction project are related to each other in the project management plan in a way that serves the available technological and logical conditions of the project, e.g. the time frame, the budget, the resources, etc. A business process is a specific order of tasks, determined by the set of project conditions, across time and place to achieve a determined sub-product in the project. Each sub-product represents the end state of a process and a start state for one or more other processes.

Business process model

A business process model is the result of mapping the current (as is) or a future (to be) state of an organization’s business process. The modeled business process can be either a real-world business process as perceived by a modeler or a conceptualized business process. Nevertheless, a process model involves an abstraction from a business process including only the relevant aspects which serves a certain modeling purpose. There are in the BPM domain many modeling techniques suit different requirements of the organization in different management levels. As examples of such techniques, Business Process Modeling Notation “BPMN” [13] and Event-driven Process Chains “EPCs” [1] are popular techniques used to model business processes. According to Mendling and Nüttgens [14], business process models are used in two different contexts to benefit business processes within an organization:

- Business analysts use process models for documentation, optimization, and simulation of business processes.
- Information system analysts use process models on the middleware tier to glue together heterogeneous systems.

In our work business process models are used for the creation and the optimization of business reference models those represent schedule networks of construction processes. They are used also to describe how exceptional events can change the structure of a schedule network in the shape of templates. These templates can be integrated in the reference model to show all the exceptional cases those can appear in the course of the process execution.

Business reference model

A business process model is considered as a reference model when it will streamline the design of a particular model by giving a generic solution that can be tailored according to the needs each time it will be used, [15].

The use of reference models is not new in project management. Although reference models in this field are called templates or checklists, they serve to some extent the same purpose. They refer for example to risk templates, work breakdown structure templates, organizational charts, or project schedule network templates, [16]. An organization can continuously optimize their templates based on their application and usefulness in prior projects. Process reference models PRMs can be used to speed up the preparation of the process, to reduce the likelihood of missing important details, and to increase the consistency of the results. A prerequisite for the effective reuse of a PRM is a comprehensive description of its application context. The application of a PRM may comprises (1) its' selection from catalogues or bibliotheca, (2) its' adaptation to the project context as well as (3) its' integration and utilization in the project management plan.

With regards to the decomposition of the model and the degree of adaptability various forms of reference models reuse can be distinguished. In Sharmak et al. [17], four approaches to reusing reference models were presented:

- Analogical reuse that imposes no restrictions on the use of reference models.
- Rule-based Configuration in which the reference models comprise explicit rules for their adaptation.
- Generic Configuration in which the possible adaptations of reference models, such as their specialization and instantiation are defined by the methodology.
- Composition that combines multiple reference models in a superordinate one.

The deterministic perspective of a process model

In the practice of construction project management, deterministic schedule plans are used to control the progress of construction projects. On the contrary, it is common in BPM to have alternative paths (using OR, XOR connectors). To use such a business process model as a part of a construction schedule plan, a deterministic instantiation of the process model is needed. This can be done by separating the process model to all the alternative models that do not include any (XOR, OR) connectors, i.e. deterministic models. After that, the alternatives should be evaluated based on the critical project criteria, e.g. time, cost etc, to choose the most suitable one to the current project conditions; see figure 1. In the case that the conditions upon which the first alternative solution was chosen have been changed, then this alternative may be replaced by another alternative which is more suitable to the new conditions. Whether the adopted alternative was a new one, then the process model has to be updated by including the new alternative into it, i.e. the process model will be enhanced to a more comprehensive one.

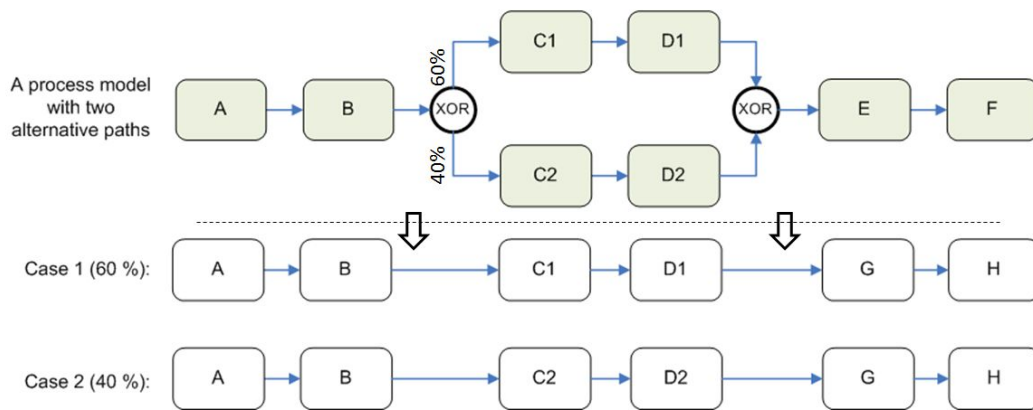


Fig.1: the separation of a process model to its deterministic models

2.4 Event-Driven Process Chains (EPCs)

EPCs offer the possibility to model business processes considering different business perspectives (organizational, data, functional, service). EPCs also enable the modeling of alternative, conditional-ruled elements and therefore reference modeling is also possible. The rules to decide when and how to tailor the model are set in advance using configurable EPC elements. For more information about EPCs and its extensions refer to [1, 14, 18].

Essentially, The EPCs technique was not arbitrary chosen in this work but because of the following reasons:

- EPC has an event-driven architecture and therefore a construction process state is based on events in the production life-cycle. This makes it suitable to represent a change risk as deviation event in the business process model and accordingly the adopted action is modeled as a response to the plan deviation event. Such kind of representation is not possible in the usual project scheduling methods.
- The EPCs technique supports configuration, as it has some specification to represent configurable elements within a process model. Configuration here means that some elements in the model can be included or excluded based on predefined rules. As plan deviations are uncertain events that may occur and not, so they and their responses should be modeled as configurable parts in the BRMs. Such a configurable part will be adopted if a deviation event will occur and will be skipped in normal situations.
- The EPCs technique was initially introduced as a modeling concept to represent temporal and logical dependencies in business processes [1]. Therefore, EPCs can be seen as a Precedence Diagram Method (PDM) with some advantages due to suiting IT requirements, databases etc. Hence, it is applicable to model schedule networks. Moreover, the EPCs technique can be extended using extended EPCs constructs to include the organizational units and other resources that participate in each task.

3 OBTAINING PROJECT MANAGEMENT DATA FROM AN EPCs MODEL

The EPCs method has an XML-based interchange format called EPML developed by Mendling and Nüttgens [14]. EPML is still not supported on a wide software range; Cuntz and Kindler [19] developed an EPC simulation tool that uses EPML as an interchange format. Furthermore, EPML is supported by the professional BPM tool Sementalk. EPML builds on EPC syntax related work and reflects experience from the specification of other XML vocabularies

in its design principles. The structured data within an EPML file describe and organize only the graphics-related information in an EPC model. The comprised data are structured in an EPC root element which has two attributes, i.e. EPC Id and the name attribute. This root element serves as a container of a set of EPC control flow elements. Functions, events, and arcs are children elements of the root element <EPC>. All these elements have <graphics> child elements to describe their positions and their dimensions. A flow element as a child of the arc element describes the relationships between the elements of an EPC model. This is done using two, source and target, attributes having the id values of the corresponding elements (see figure 2 left). The information stated in an EPML which can be helpful for project management purposes is actually not much. The name of each task and the dependencies among the tasks are the only information that can be useful. The task description is an important data which should be included in the EPML as such a description can be assigned on the model level and adapted as needed on the instance level, i.e. within the project. On the contrary, it is logical that the cost and the duration values of each task are not available in an EPML as their values must be decided on the instance and not the process definition level. The cost and the duration values of each task are related to the quantities of units to be executed, the available resources, the time frame, and the budget offered in the project. CPSP prototype is a project management tool developed at the Institute for Construction Informatics, Dresden University of Technology for the purpose of this research work. It includes some project management methods, such as Gantt charts and Critical Path Analysis. Furthermore, it can perform a comparison between different versions of the project based on the task dependencies. This prototype can import an EPML file which describes a deterministic business process model as a starting point of the project management. After that, the missing data can be completed according to the project conditions. The resulting project schedule can be saved in a relational database, as shown in figure 2.

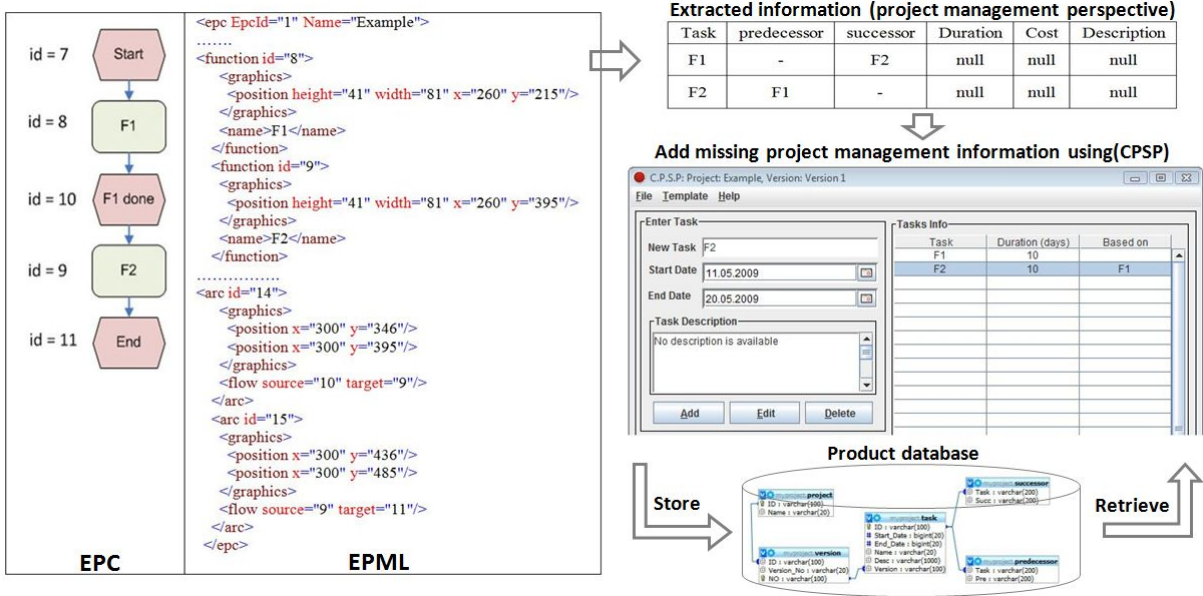


Fig. 2: The extraction of scheduling-related data from an EPML file using CPSP prototype.

4 SUGGESTED CHANGE TEMPLATE BASED APPROACH

In our approach the EPCs technique is suggested for the creation and optimization of business reference models that represent process templates for construction schedule networks. Also it is used to describe how exceptional events change the structure of a schedule network in

the shape of templates. Such change templates, can be used as a part of any reference model. Based on each change template a schedule change procedures can be built which in turn can be used within a project management software tool to help automate the change steps in a schedule network.

Based on the constructs of the EPCs technique, several change templates have been suggested to cover the schedule changes on the process level, see section 2.2, in construction projects, for more information about the developed templates refer to [20]. These templates are divided into two groups: (1) proactive and (2) interruptive change templates. In this paper only one of the proactive templates, the insertion template, will be discussed in detail as an example of the overall templates.

4.1 The insertion template

This template represents a post-fixity case in which an adopted action is done before the risk evolves to a real problem, and definitely before the affected function “Activity (n)” starts, see figure 3. Basically, there are two possibilities to continue the process that have to be examined here. In the case that the risk is not expected to occur, i.e. the probability/ impact is below the thresholds, the path which includes “Activity (m)” will be skipped. This is the normal situation when the planned activities will be executed without any change. However, if the change event is approved, then the change response “activity (m)” will be included in the process. Such approval of the process will be obtained if the risk event has a considerable probability/ impact on the targeted activities according to the agreed tolerance thresholds. This is done by the responsible team, e.g. the owner, the owner representative, the contractors etc.

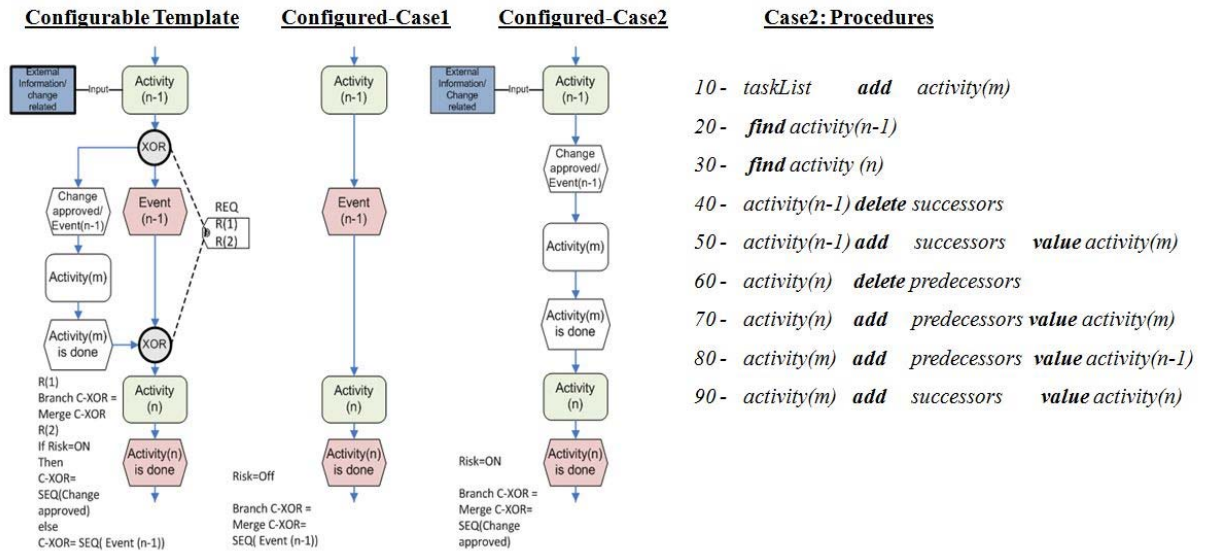


Fig. 3: Insertion template and its configured variants

The whole configuration alternatives are controlled by If-Then statements. These statements are specified as configuration requirements, which will control on the one hand the EPC model correctness after configuration. On the other hand, it will control the right path choice according to the Risk (ON, OFF) cases. The response is expressed here in general as one function named “Activity (m)”. This function can be refined to the necessary level of detail as a hierarchical EPC function.

The configured case (Case 2) of the change template can be achieved in a schedule network by using the procedures shown in figure 3 right. These procedures were implemented in the

CPSP prototype to enable inserting a new task only by defining its predecessor tasks. Hence, the structure changes of the schedule network will be done automatically instead of the common manual adjustments needed by common management tools.

A more general case can be obtained when a new task will be inserted after several tasks instead of one task only. Additionally, if the activity (n-1) has not only one successor but several, all these successors will be successors to the inserted activity (n) and the activity (n-1) will have only activity (n) as a successor. In the case that more than one response is available to deal with the situation at hand, a decision making analysis should be made to choose the most suitable variant.

4.2 Using the insertion template in a real example

In the simple example presented below, it is assumed that a project contains several construction processes that have to be executed within a given time and cost frame. These processes are connected to each other in a way that serves the general conditions controlling the project. One of them is the process of constructing a retaining wall. In the design phase it was decided to construct it as a cantilever retaining wall using reinforced concrete. The dimensions of the retaining wall and other design specifications determine the work quantities needed to be executed. Accordingly, the cost and the duration of each task within the process plan are assigned. However, in the construction phase and before starting the backfill task it was found that the design did not provide a drainage system behind the wall to reduce the hydrostatic pressure and therefore improve the stability of the wall. According to the project manager such a drainage system will be needed as the ground water level in that area is high in winter. After communications with the design team it was clarified that the hydrostatic pressure had not been considered in the calculations. Hence, this design gap had to be repaired by inserting a drainage work task in the process. This insertion is considered proactive here as the error was discovered before making the backfill. Otherwise, it will be needed to remove the backfill, make the drainage system, and after that to backfill again, which is obviously much more complicated. After the new task has been planned, the process cost and duration have to be recalculated accordingly and the effects on the project cost and duration have to be studied. When the new task is approved, it can be inserted within the process and executed. The insertion of the new task “Drainage work” means that some relationships have to be changed between the existing tasks. The new task can be inserted in the schedule network of the process using the insertion dialog of the CPSP prototype, as shown in the figure 4. The needed dialog inputs are (1) the name of the predecessor task(s), (2) the attributes of the new task (name, start date, end date, and description), and (3) the insertion reason.

According to the needed tasks, the variants, and the exceptional cases that can be found in the construction process of a cantilever retaining wall, a PRM that represents this process can be designed. In the figure 4 right, a very simplified reference model is presented. Excavation, reinforced concrete foundation, reinforced concrete wall and backfill are the essential tasks that cannot be skipped within this process. The “Shoring” task is represented within an insertion template and linked to the main process model. The “Shoring” task may be included in the case of unstable excavation, or excluded if in the site there is only a backfill area. The “Drainage work” task is linked also using an insertion template to the reference model. By considering all known cases in the business process model, it will be comprehensive enough to be considered a PRM. Consequently, the possibility to miss an important detail will be decreased in the case that the related PRM is used in the detailed design and construction preparation phases.

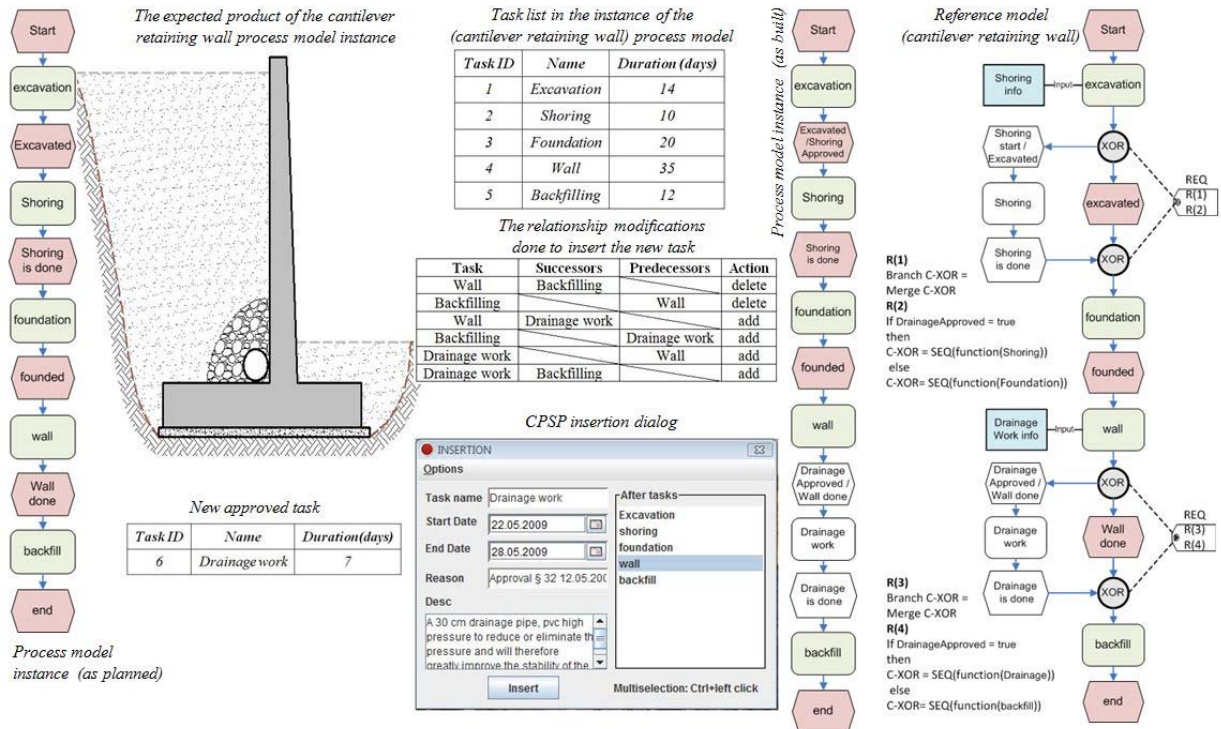


Fig. 4: The insertion of a new activity in a cantilever retaining wall process

5 REFERENCE MODELING BASED ON AN ONTOLOGY MODEL

In our approach, the PRMs are modeled using EPCs elements. Configurable EPCs constructs play a main role in the description of a PRM as some elements in the PRM can be adapted in a model instance based on their predefined constraints. Up till now, there is no business process modeling tool that supports the use of configurable EPCs constructs in a EPCs process model. C-EPCs can only be found in the literature regarding their graphical and XML-based notations, as well as their formal transformation to normal correct EPCs elements, [14, 18]. The needed concepts and constraints of the intended PRM within a construction domain can be realized using the concepts of ontological engineering [21]. Using an ontology as a knowledge base populated with data to represent PRMs has several benefits. Firstly, process models have the drawback that an essential part of their semantics is bound to natural languages; this allows much room for interpretation. Clearly defined semantics for process models can be achieved by instantiating the elements of a business process model from the concepts of an ontological knowledge base [22, 23]. Secondly, a PRM represents the repository of data about a specific construction process. This data will be stored in the ontological knowledge base, thereby enabling advanced queries when retrieving information which may even infer facts that are not explicitly created by the modeler of the PRM [21]. Thirdly, in semi-formal process models, like EPCs models, non-standardized arbitrary names are used. Referencing the model elements to concepts of the ontology will enrich each element with a full semantic context including a range of attributes, an inheritance hierarchy, references to related concepts, constraints for their usage and rules to insure model consistency. Fourthly, a semi-formal process model instantiated from a PRM as a deterministic model enriched with ontology-based information can be mapped to formal modeling languages such as BPEL [24].

Figure 5 shows a simplified ontology model representing the concepts needed in a PRM and the relationships between these concepts. In this ontology model, each construction process produces a certain product using an execution method. Generally, more than one alternative execution method can be used that leads to the same product. Each one of these execution methods consists of several tasks. The relationships between these tasks in the execution method are determined using two attributes, predecessors and successors. These two attributes have the task class as data type. Some of the tasks in each execution method are essential as they cannot be skipped, whereas other tasks are not, see section 6.2. The configurability attribute with its Boolean data type controls this feature, e.g. a task with a *false* configurability value is an essential one in the execution method. Furthermore, each task may be associated with some known risks/problems. Each one of these problems in turn can be solved using some solution. To integrate the developed change templates in the ontology model of the PRM, a change template is assigned to each solution. This is shown in the relation “use” which has the “Solution” concept as a domain and the “Change Template” concept as range. The last concept has the Insertion change template as a sub class which in turn has the attribute predecessor with data type “Task”. The solution of a specific construction problem will follow a specific change template, e.g. the Insertion Template has a value of the attribute predecessor equal to the task that the solution will be inserted after it.

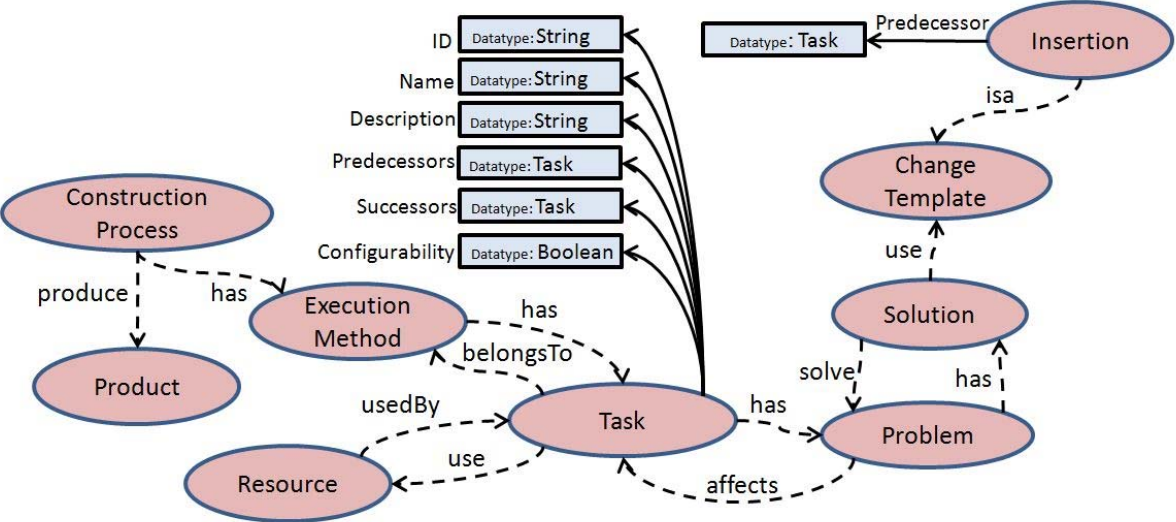


Fig. 5: A simplified ontology model of the suggested process referencing approach

6 CURRENT IMPLEMENTATION

The developed approach can be represented as an iterative scheduling cycle that will be repeated within the project lifecycle as new change risks surface, see figure 6. The main components of this cycle are (1) a reference knowledge base containing different PRMs; some of them will be used to design the needed project schedule plan, (2) a project database containing the product information and including the instances of the adopted adapted processes from the reference knowledge base. These instances are related to each other according to the project conditions. As well as, (3) a service tool that controls and manages the knowledge base and the database using some dedicated functions, e.g. query, save, update, retrieve etc. Currently, the work on the second component, a product relational database, and its control and management through the third component, the CPSP prototype, is already finished. The ontology services

based on the presented ontology model in the previous section still need to be done. This shall be accomplished by extending the same used prototype. As changes occur, different versions of the project schedule are the consequences. The ability to compare different versions of the schedule plan based on the task dependencies is one of the important aspects achieved in this work to (1) evaluate different scenarios in the planning phase as well as to (2) document the deviations in the planned progress of the project schedule.

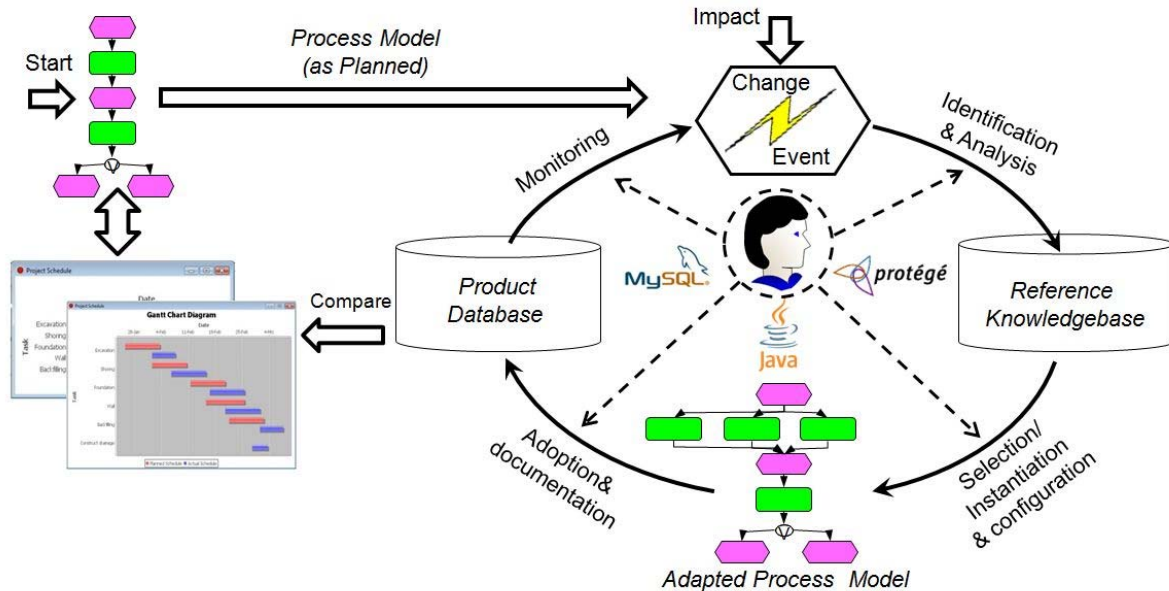


Fig. 6: the iterative scheduling cycle of the presented approach

7 CONCLUSIONS

In this paper we have discussed the implementation of the developed change templates by using as an example the Insertion Template. The benefits of such templates to automate the adjustments of the changed schedule networks were also described. The product of the project is an aggregation of different sub products. Each one of these sub products is done using a construction process. Therefore, the schedule network can be considered as an assembly of different construction processes. As a need to reuse the gathered construction knowledge encapsulated in the construction processes, the concept of a construction PRM which is comprehensive and configurable was also introduced in this work. Using PRMs in AEC can help to speed up the planning process, to insure getting more consistent plans as well as to accelerate the adaptability of the changed plans by offering ready solutions.

The presented approach can be used in the planning phase as well as in the execution phase of the project. In the planning phase it is used to build the schedule baseline by adopting, adapting, and instantiating each needed PRM and then links these PRMs together. Moreover, in the planning phase What-If scenarios can be implemented to study the effect of specific situations without endangering the success of the project objectives. Consequently, it will support the project team in anticipating and evaluating potential changes and their impacts. Hence, better designed and more maintainable project schedules can be achieved. In the execution phase it can be used to provide ready solutions to the faced problems as well as to automate the adjustments of the schedule networks.

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