Considering Project Risks in Reference Modeling of Construction Processes

H. Pruvost, A. Benevolenskiy, S.-E. Schapke & R. J. Scherer
Institute of Construction Informatics, Dresden University of Technology, Germany
Herve.Pruvost@tu-dresden.de

Abstract: The purpose of the research presented in this paper is to establish connections between risk management and process management, based on the actual advances in both fields, and with the help of a new approach using reference modeling and multi-models. In this context, we demonstrate that risk management can take substantial advantage of the central position of process models in construction projects. The overall objective of this work is the implementation of an integrated system for dynamic process and risk management that will be part of collaborative construction project management software.

1. Introduction

For managing construction projects, traditional management techniques break down the project into manageable, self-contained subtasks within specific application fields. Based on a system engineering approach various separate application models of the delivered goods and services are used to support planning, coordination and control of the design and production processes.

However, no project ever goes totally as planned. Construction projects are exposed to numerous uncertainties and unexpected events that may result in changes to the initial financial, temporal and functional goals defined in the respective design and construction management plans. Hence, there is a variety of approaches to manage risks on construction projects. Most often they examine project risks either isolated or in the context of single engineering or management domains, such as constructability, cost or time management. Moreover, they focus on either design-related or construction-related risk. In addition, there is a tendency in the construction industry to leave probable risks and react to them when they have occurred, rather than dealing with them in advance (Loosemore et al. 2005).

This paper introduces a novel approach to risk management based on multi-models and reference modeling. Backbone of the approach are software technologies and collaborative methods developed in the German research project Mefisto (Scherer & Schapke, 2011). They enable combining various domain and application models from different AEC/FM disciplines and project phases into multi-models, thereby providing for process-centric integration and synchronization of relevant application models, such as schedule, cost, building or process models. In this context, risk models can be established as single application models that collects project risks from various project participants. On the basis of this general concept we develop a specific approach aiming at applying reference process models, which support automation and reuse of best practices in process management, for the purpose of risk management.

The paper is structured in 4 major sections. Following this introduction an overview on the state of the art in risk and process management in AEC/FM is given. Section 3 introduces the concept of multi-model-based risk management. Based on this general concept a specific approach for conducting risk management with support of reference modeling and construction process models is described in section 4.

2. Risk and Process Management in Construction Projects

2.1 Risk Management Principles

There exists a variety of concepts about *risk* in general. In some works, risks are associated with negative events and disadvantageous consequences only. For others it is defined as an error in a process. Risk can be defined and assessed in terms of fatalities and injuries, in terms of probability of reliability, in terms of sample of a population or in terms of the likely effects on a project. All these points of view are valid regarding the domain they reflect (Smith, Merna, & Jobling, 2006). The ISO 31000:2009 standard defines risk as the 'effect of uncertainty on objectives'. In this definition, uncertainties include events (which may happen or not) and uncertainties caused by ambiguity or a lack of information. It also includes both negative and positive impacts on objectives.

The standards and the common professional practice define four essential steps to be executed as part of the risk management procedure. These are: (1) risk identification, (2) risk analysis, (3) risk treatment planning and (4) risk monitoring. Risk identification involves an exhaustive listing of all possible threats that may affect the project. Risk analysis enables the evaluation and prioritization of risks with the help of existing methods such as different network analyses, like fault and event trees, or stochastic simulations. Risk treatment planning consists of determining preventive measures and reaction strategies to reduce threats to the project objectives and to enhance reactivity. Within the execution phase of the project, the risk monitoring and control tasks continuously re-evaluate the suitability of the planned treatment measures and support identifying new emerging risks.

2.2 Process Management in the Construction Sector

Construction process management is most often executed with the support of scheduling methods that describe the steps to be followed for the realization of a building through the different project phases. These methods give a good overview of the contractual deadlines and help to ensure respecting the budget. They are also useful for making project controlling that compares the real project state with the plans. In the last years, significant work has been done on the automated design of construction schedules using case-based reasoning (Tauscher et al. 2007) or relational algebra approaches (Huhnt et al. 2005). However, there are still little known efforts aiming at efficient knowledge reuse.

In contrast to the acceptance of scheduling tools and network analyses the AEC/FM industry makes little use of Business Process Management technologies. Process modeling and management tools are instead well developed and used in stationary production industries and static organizational structures. *Business process modeling* has demonstrated its supporting character for planning, controlling, optimization, simulation and execution of corporate activities. In the last decade, some process modeling standards like BPMN (*Business Process Model and Notation)* or EPC (*Event-driven Process Chain*) as well as respective data formats have been developed. They are used in numerous software applications for different sectors such as the software and the financial industries.

2.3 Researches on Process and Risk Management in AEC/FM

Currently business process management and risk management are handled separately. Risk management is still done mostly occasionally during a project as it should be accomplished continuously throughout all project phases. In order to bridge this gap, combining risk management and business process management has now become a topic of active research, and significant work has been already done in this area. A good overview of the scientific research efforts in the integration of risk into business process management is provided in (Jakoubi & Tjoa, 2009) where nine different research approaches are considered and categorized according to various criteria.

Most of the recent research works focused on enabling either process-oriented risk management or risk-oriented process management, as pointed out in (zur Muehlen & Rosemann, 2005). Functionally, process-oriented risk management supports a comprehensive identification of risks and their analysis among all the process units and chains, while risk-oriented process management is rather helpful for planning alternative processes as preventive or reactive measures to risks. Regarding this fact, (Sienou et al. 2008) identify a bidirectional relation between both process and risk management lifecycles. On one hand, the risk management process triggers the process management lifecycle in order to revise processes once the level of risk is over a predefined risk tolerance. On the other hand, the process management lifecycle triggers the risk management process in order to receive instructions for context analysis and risk cartography. To integrate this duality into a common notation, the authors merged both, a process model and a risk model, unifying them with semantic mapping. A similar approach is used in (zur Muehlen & Rosemann, 2005) where the authors extend process models based on EPC with risks, by mapping the latter to process-based errors. Sharmak (2011) also integrates risks in EPC, but introduces reference process modeling as a support for the instantiation of generic process alternatives in response to risks. On a more formal level, Lambert, Jennings, & Joshi, (2006) insert risks in the Integrated Definition for Function (IDEF) standard used as process modeling language. An approach that combines risk-aware business process management and ontologies is presented in (Goluch et al. 2008). In our work we decided not to merge models for handling processes and risks, but to use the multi-model approach that allows for integrating separate models by preserving their integrity.

3. Risk Management with Multi-Models (General Approach)

3.1 Multi-Model-Based Collaboration

The idea of a multi-model is to combine engineering and management models, so-called application models, in a single information resource. The main application models are, for example, the Building Information Model (BIM) describing the architectural and technical properties of the building to be erected, the Specifications Model (SPM) containing the bills of quantities and quantity take-offs, the Time Schedule Model (TSM) sequencing the activities in a timetable, the Cost Model (COM) allocating monetary values to product elements and processes, the Organization Model (ORM) inventorying the actors involved in the project, the Construction Site Model (CSM) comprising data about the production site as well as machineries and equipment, the Process Model (PCM) describing the activities to be executed, and the Risk Model (RIM) developed in our research. Within this single information resource, the application models are bound together by link models. The link models explicitly specify the interdependencies between items from different application models, referencing the interlinked elements by their identifiers (ID). The resulting compound model can be used to integrate and analyze heterogeneous project information as well as to exchange associated models among the project participants by a common multi-model container format. A multi-model container comprises an archive of several data files which includes, besides the meta-information about the container content, several application models as well as link models (Scherer & Schapke, 2011).

Multi-models provide for new ways of collaborative work on construction project. Instead of pursuing a single integrated project model or project data base it allows for the coupling of common engineering and management models traditionally separately handled in existing software application. Multi-models are created locally using specialized multi-model applications to combine existing application models or to create additional new ones. Throughout the last years several of these applications have been available as 5D application or model integrator. In the Mefisto project the two software systems GRANID (gibGreiner) and iTWO (RIB Software AG) as well as a Multi-Model Framework prototype (Fuchs, Katranushkov & Scherer 2010) are used to create, visualize and further process multi-models for the purpose of construction management.

3.2 Risk Identification and Analysis using Multi-Models

In the context of multi-models the identification and the analysis of project risks can be carried out as illustrated in the Figure 1. On a construction project a risk model is created and edited through a risk editor integrated in the multi-model framework mentioned above. This allows the user to insert his own risk information in order to create a consistent risk list. Through this editor a risk catalogue that has the same structure and format as the risk model can be imported. Generic risks from the catalogue can then be sorted by category, effect, criticality, etc., as well as filtered in order to select only relevant risks regarding the current project state.

As the multi-model framework integrates the other application models, and thanks to its models interlinking functionality, risks are associated by the user to all kind of affected project objects from other models, such as construction processes, building parts, organization units or resource items. In case the standard values from the catalogue are obsolete, risk attributes such as likelihood, time or cost effects can be modified in the editor to adapt the risk values to its associated items and to the project context. The associations are automatically stored in link models that distinguish themselves through the types of application model that they interlink. The application domain of a model determines with which categories of risk it will be preferably linked. For example, a resource risk will rather be associated with an item of the Specifications or Construction Site Model, an organizational risk with the Organization Model, and a climatic one with the Time Schedule Model. This principle allows for considering all types of risk in a common integrated system instead of having to deal with risk categories separately as it is often done with current risk management systems. Indeed, resource risks used for example in a cost analysis, and schedule risks used in a schedule analysis, are nowadays still handled in different applications.

Taking this modeling approach several multi-models can be assembled all along the project, each one related to a specific time, and stored in multi-model containers that comprise the information required for different types of risk analyses. From a multi-model resource and with the support of built-in filters the framework can provide specific data sets as input to different kinds of risk simulation applications accessible through a Web service. These data sets are built upon multi-model queries that extract relevant analysis information with support of the link models according to the simulation type (cost simulation, schedule simulation, network analyses etc…).

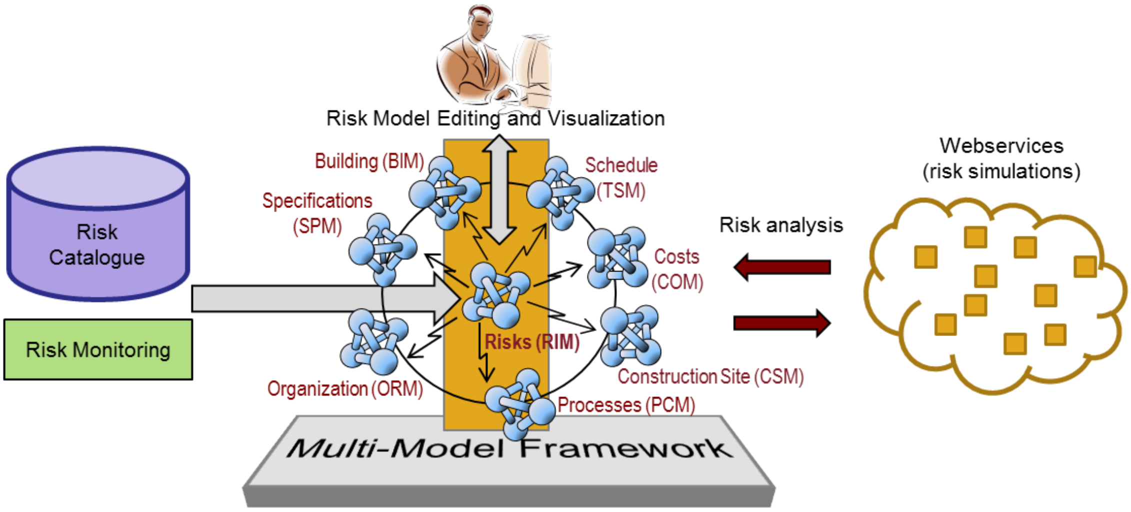

Figure 1: The Risk Model in the context of Multi-Models

3.3 Risk Model Structure as Basis for the Creation of Risk Catalogues and Risk Lists

The construction industry still suffers from poor formalized risk management procedures and models that support the retrieval and application of best-practice knowledge. A part of the problem resides in the lack of reusable risk documentation that classifies risks and remedial measures using common terms and descriptions. In each project, the relevant risks have to be newly identified and documented in varying forms, hindering the efficient build-up of risk models and their reuse in risk analysis applications.

We decided to develop a data structure for the risk model that allows for an exhaustive qualitative and quantitative description of every risk object. Semantically, a risk object can be defined as a probabilistic event that has certain or uncertain consequences. Correspondingly, our structure defines a risk mainly with the following information compiled from the risk management literature:

- Factors: other risks that condition the existence of a risk and influences its occurrence and impact.
- Occurrence: likelihood, occurrence time periods or context (negotiation phase, planning phase, execution phase, whole project…).
- Effects: effect types (cost, time, quality, safety), qualitative or quantitative effect assessment (low, medium, high, effect probability distribution…),
- Criticality: basically the product Likelihood x Effect,
- Category: resource, financial, legal, human, climatic, technological…
- Responsible actors: owner, general contractor, subcontractor…
- Treatment: measures, treatment date, treatment team…

This risk data structure is partially shown in the figure 2 and is used for the creation of risk catalogues as well as risk lists. For convenient use with multi-models, it was defined in a XML schema. Risk catalogues were implemented from which generic risks and measures can be selected for a particular project. A catalogue has similarities with the hierarchical risk-breakdown structure (HRBS) formalized in (Tah & Carr, 2001), that sorts risks in categories and sub-categories and that allows for describing the whole risks that could occur in a project. The categories are differentiated by the risk nature that can be defined as the domain in which the risk emerges or in which it has effect. For example, environmental, financial, contractual, organizational, management, resource, design, personal risks are some of the categories.

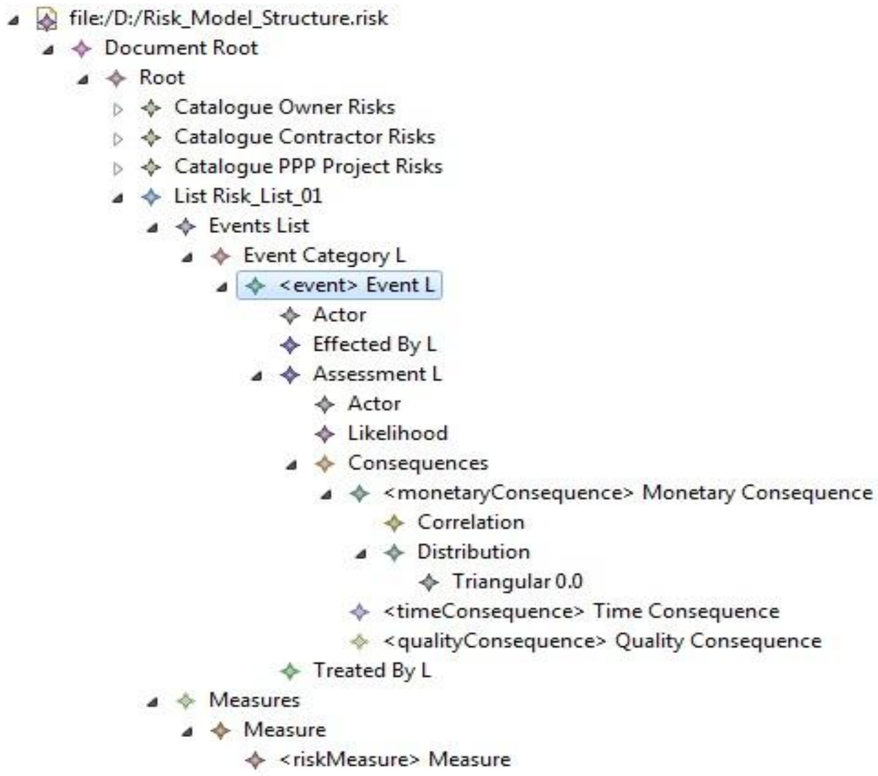

Figure 2: A Risk Model Instance viewed in an Eclipse-EMF Tree Editor

4. Process-Centric Risk Management (Particular Approach)

Using the general approach for multi-model based risk identification and analysis a specific approach has been developed to support risk management by using reference modeling and process models. Because processes represent the core of a construction project, process models have a central position in multi-models. They request information from other application models and are the enabler for their combination. From this principle process-centric and risk-loaded multi-models can be created and taken as basis for risk analyses. Reference process models bring a significant support to construct such multi-models by enabling to associate risks to process types that are applied several times in the project.

4.1 Construction Processes Based on Reference Models

To allow for efficient process modeling construction companies often strive towards the description of internal process knowledge in a project neutral and modular form. This can be done with the help of reference processes that can be used for fast and reliable process configuration. Reference processes represent modules that model certain types of process together with the resources and services required for their execution.

Backbone for process modeling in our research is a methodology for ontology-based reference process module definition and process configuration, partially built upon the concepts suggested in (Benevolenskiy et al., 2011). Two ontologies are used in the process configuration system. The Process Pattern Ontology stores process patterns that can be instantiated as needed in different projects. The process patterns contain information about the type of product that they produce as well as the type of resources and sub-processes that they use. The Process Instance Ontology is uniquely populated with instantiations of process patterns that are configured for a specific purpose within a concrete construction project.

The reason for using ontology and not a relational database for the modeling of processes is that a complex hierarchy of processes can be easily represented in the ontology by using its taxonomical concept inclusions. Moreover, an ontology enables to apply a reasoning mechanism defined by a set of rules in order to allow for automatic sequencing of processes according to specific construction constraints. Also, ontologies can deal with incomplete information and have a flexible structure that can be easily adapted and changed.

The process model describes a hierarchy of construction processes saved in the Process Instance Ontology that provides references to their related objects from other application models, like the building part to be produced and the required resources. The process model is created consequently in a process configuration procedure conducted in a software component called "Process Configurator". At first necessary patterns are imported from the Process Pattern Ontology according to the group of building elements to be built. They are then instantiated as concrete processes, and references to their related objects from the Building, Specification and Construction Site Models are created. After that, the instantiated processes are sequenced regarding specific configuration parameters with the help of rules. Finally, the processes can be scheduled in a Time Schedule Model with the support of a process simulation. A more detailed description about the ontology-based process configuration can be found in (Benevolenskiy et Al. 2012).

To allow for interoperability with the multi-model framework multi-model containers are used. At first, the Process Configurator imports a multi-model container that comprises the required application models. After the process configuration it exports an updated multi-model container that includes the configured process model with the corresponding link models. To do so the process instances as well as their related process patterns are exported from the ontologies into a specific multi-model compatible format based on a XML Schema.

4.2 Risk Identification and Analysis with Process-Centric Multi-Models

Initially the process patterns and their instantiated processes contain no information about the risks that can affect their expected function. However, the need to consider risks and uncertainties in processes encourage us to associate the process model with a risk model. This association can be done on three levels. On a first level, a risk can be linked to a process pattern, on a second level to a process instance, and on the third level to a referenced object from another application model. In each case a link is generated and stored in a *Process-Risk* link model. The Figure 3 below shows an example of a process indirectly associated with some risks through its related objects.

It can happen, for example, that a climatic condition forbids the execution of all processes of type "Wall_Concrete". In this case, as a risk is linked to a process pattern, all process instances of this type will be automatically linked to this risk. To ensure that, the multi-model framework, whose main functionality is to analyze and synchronize multi-models, generates new links between risks assigned to process patterns and the corresponding process instances. In case a risk is linked to a process-related object from any application model, a new "risk-process" link will be generated by transitivity using both links, i.e. "risk-object" and "object-process".

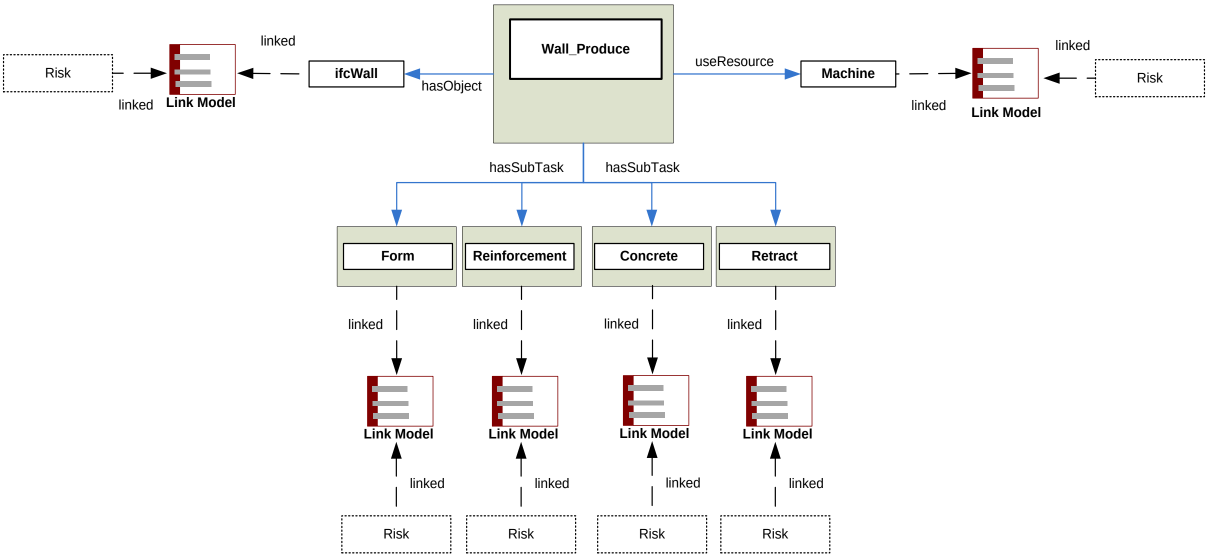

Figure 3: a Process associated with some Risks

The rich structure of the processes defined in multi-models allows for the consideration of many categories of risks from the risk catalogue as illustrated in the Figure 4 inspired from (Sienou et al. 2006). The multi-model structure can be recognized in the figure thanks to the labels of suggested application models containing the process-related objects.

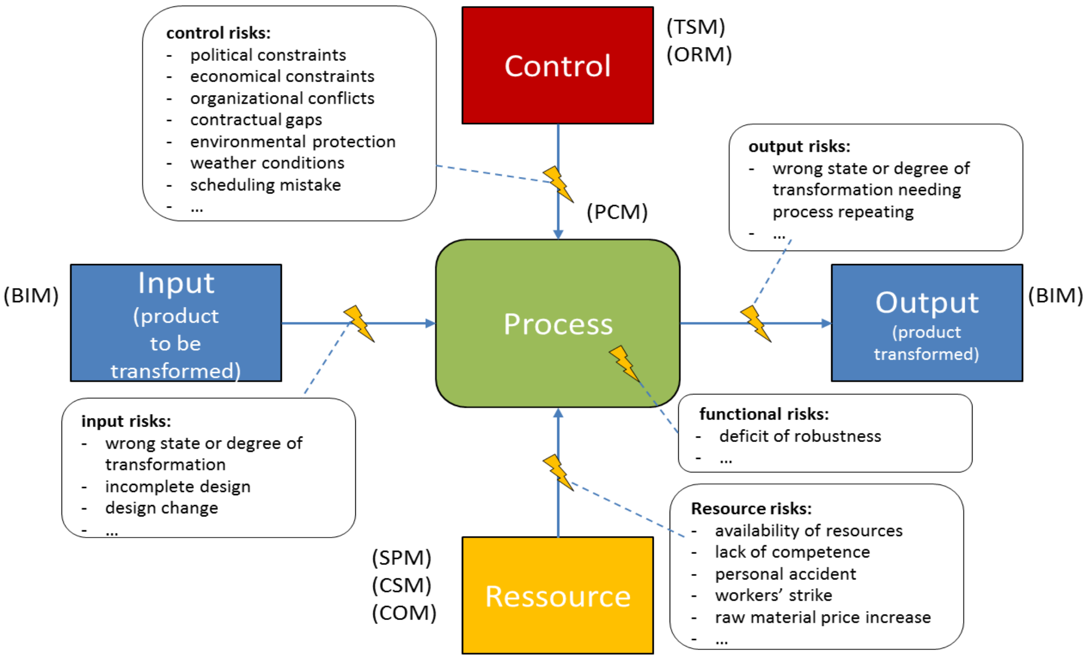

Figure 4: Process Basic Structure assorted with Risks

After completion of the process-centric and multi-model based risk identification, the resulting risk-loaded multi-model can be used to proceed with risk analyses. For this purpose a query engine that uses specific filters and that is integrated in the multi-model framework extracts from the multi-model the information needed for the analysis (Fuchs et al. 2010). In our approach we focused on a schedule Monte Carlo simulation. To provide the analysis information, the multi-model is queried in order to extract by every process all risks that possess a time effect. An analysis model is then generated on the basis of the extracted data and the Time Schedule Model, which include the necessary information for the simulation. The results of the risk analysis can later be appraised in order to prioritize risks and implement treatment strategies by reconfiguring processes, modifying the content of application models and consequently building new multi-models. The three steps of risk identification, analysis and treatment planning can be in this way continuously pursued all along the project.

5. Conclusion and Outlook

The concepts and approaches described in this paper aim at opening new perspectives in risk management of construction projects. The multi-model approach shows that risk management can be carried out in an integrated system like a multi-model framework or a nD application. Moreover the linking and synchronization functionalities of such systems make it possible to handle all categories of risks in a process-centric multi-model and then to perform comprehensive risk identifications and analyses. Applying the multi-model approach to couple risks and reference process modeling brings additional support to risk management. Indeed the main advantage of using reference modeling resides in the semi-automatic risk identification performed by assigning risks to process patterns, later instantiated in several processes.

Our prototype currently focuses on schedule risk analyses, but further implementations have to be done to allow for a wider range of analyses (cost simulation, fault and event trees, reliability analyses, etc…), and then confirm the effectiveness of this approach. An interesting aspect, not yet developed in this work, is that the nested structure afforded by link models can be of substantial help for performing risk chain analyses like Failure Modes, Effects and Criticality Analysis (FMECA), or like fault and event tree analyses.

In order to further complement the risk management cycle in the context of multi-models and reference process modeling, the step of risk treatment planning has to be further studied. For this purpose, applying reference processes as well as using ontology and rules for the configuration of alternative processes as responses to risk could be promising.

6. Acknowledgements

The research described in this paper was enabled by the financial support of the German Ministry of Education and Research, Department of ICT under Contract No. 01|A09001A, which is gratefully acknowledged. Moreover, the authors would like to point out that the presented work is developed in collaboration with industry and academic partners (www.mefisto-bau.de) of the Mefisto project.

References

Benevolenskiy A., Roos K., Katranuschkov P. & Scherer R. (2012). Construction processes configuration using process patterns. Submitted to Advanced Engineering Informatics Journal, Special Issues of the EG-ICE 11 Workshop, Elsevier.

Benevolenskiy A., Katranuschkov P. & Scherer R. (2011). Ontology-based configuration of construction processes using process patterns. Proceedings of the 2011 EG-IC Workshop, Enschede, The Netherlands.

Cope, E.W., Kuster, J.M., Etzweiler, D., Deleris, L.A. & Ray, B. (2010). Incorporating risks into business process models. IBM Journal of Research and Development, Vol. 54, Iss. 3, pp. 4:1-4:13.

Cuske, C., Dickopp, T. & Seedorf, S. (2005). JOntoRisk: An Ontology-Based Platform for Knowledge-Based Simulation Modeling in Financial Risk Management. European Simulation and Modelling Conference, ESM 2005 (pp. 79-86). Ostende, Belgium: EUROSIS.

Fuchs, S., Katranushkov, P. & Scherer, R.J. (2010) : “A framework for multi-model collaboration and visualisation”, In: Proceedings of the ECPPM 2010, Cork, Ireland.

Goluch, G., Ekelhart, A., Fenz, S., Jakoubi, S., Tjoa, S. & Muck, T. (2008). Integration of an Ontological Information Security Concept in Risk Aware Business Process Management. Proceedings of the 41st Annual Hawaii International Conference on System Sciences HICSS 2008. Waikoloa, Hawaii: IEEE.

Huhnt, W., Racky, P. & Holzer, S. M. (2005). Logic of Processes in Civil Engineering. In: Proc. of the 22nd CIB-W78 Int. Conf. on Information Technology in Construction.

Jakoubi, S. & Tjoa, S. (2009). A reference model for risk-aware business process management. Fourth International Conference on Risks and Security of Internet and Systems CRiSIS 2009; Vol. 7, Iss: 12 (pp. 82-89). Toulouse, France: IEEE.

Katranuschkov, P., Gehre, A. & Scherer, R.J. (2007). Reusable Process Patterns for Collaborative Work Environments in AEC. ICE 2007 - Proc. 13th Int. Conf. on Concurrent Enterprising. Sophia Antipolis, France.

Lambert, J., Jennings, R. & Joshi, N. (2006). Integration of risk identification with business process models. Journal Systems Engineering, Vol. 9, Iss. 3, pp. 187-198.

Lee, S., Pena-Mora, F. & Park, M. (2006). Web-enabled system dynamics model for error and change management on concurrent design and construction projects. Jounal of Computing in Civil Engineering, Vol. 20, No. 4.

Loosemore, M., Raftery, J., Reilly, C. & Higgon, D. (2005). Risk Management in Projects. Taylor & Francis Group, London.

Scherer, R.J. (2006). Integrated dynamic product and process modeling with the aim of construction project risk assessment (in german). Wenzel S. (ed.) Simulation in Produktion und Logistik 2006, 12. ASIM Fachtagung. Kassel, Germany. SCS Publishing House e.V., San Diego-Erlangen.

Scherer, R.J. & Schapke, S.-E. (2011). A distributed multi-model-based management information system for simulation and decision-making on construction projects. Advanced Engineering Informatics 25, Elsevier, pp. 582-599.

Sharmak, W. (2011). Dynamic Network Planning in Construction Projects using Configurable Reference Process Models (PhD). Faculty of civil Engineering, Dresden University of Technology.

Sienou, A., Karduck, A. & Pingaud, H. (2006). Towards a Framework for Integrating Risk and Business Process Management. Information Control Problems in Manufacturing - INCOM 2006, Elsevier, pp. 615-620.

Sienou, A., Lamine, A., Karduck, A. & Pingaud, H. (2007). Conceptual model of risk: Towards a risk modelling language. WISE 2007 Workshops, LNCS Vol. 4832/2007, pp. 118-129.

Sienou, A., Lamine, E., & Pingaud, H. (2008). A method for integrated management of process-risk. Proceedings of GRCIS 2008.

Smith, N., Merna, T. & Jobling, P. (2006). Managing risk in construction projects. Blackwell Publishing.

Tah, J. & Carr, V. (2000). Information Modelling for a Construction Project Risk Management System. Engineering, Construction and Architectural Management, Vol. 7, Iss. 2, pp. 107-119.

Tah, J. & Carr, V. (2001). Knowledge-Based Approach to Construction Project Risk Management. Jounal Of Computing in Civil Engineering.

Tauscher, E., Mikulakova, E., König, M. & Beucke, K.: Generating Construction Schedules with Case-Based Reasoning Support. In: Soibelman L., Akinci B. (Eds): American Society of Civil Engeneers (ASCE) Workshop 2007, Pittsburgh, July 2007.

Tjoa, S., Jakoubi, S., Goluch, G., Kitzler, G., Goluch, S. & Quirchmayr, G. (2011, April-June). A formal approach enabling risk-aware business process modeling and simulation. IEEE Transactions on Services Computing, Vol. 4, No. 2, pp. 153-166.

Tserng, H. P., Yin, S. Y., Dzeng, R., Wou, B., Tsai, M. & Chen, W. (2009). A study of ontology-based risk management framework of construction projects through project life cycle. Automation in Construction, Volume 18, Iss. 7, 994-1008.

zur Muehlen, M. & Rosemann, M. (2005). Integrating Risks in Business Process Models. 16th Australian Conference on Information Systems - ACIS 2005. Sydney, Australia.

zur Muehlen, M. & Ting-Yi Ho, D. (2006). Risk Management in the BPM Lifecycle . Lecture Notes in Computer Science, pp. 454-466.