TOWARDS ONTOLOGY-BASED MANAGEMENT OF DISTRIBUTED MULTI-MODEL PROJECT SPACES

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ABSTRACT

Collaboration between building owners and contractors is still poorly supported by today's information technologies. Project planning and management applications still focus on selected tasks selected tasks of project participants on either the owners or the constructors side. The software systems lack an interoperable view on the processes to provide adequate up-to-date information for the decision.

The paper presents the concept of a Management Information System, elaborated within the German research project Mefisto. A central challenge of system is the management of interdependent engineering and management models to support the retrieval, aggregation and combination of information from different organisations, disciplines, management levels, software systems and points in time. Backbone of the system is an open service platform and a layered ontology-based model framework to allow for sharing distributed, yet interrelated information in a multi-model space. Central to the multi-model space are process models that provide for inter-relating object models in regard to particular planning, production and controlling tasks. Both, the process and the object models shall be structured in coherent model hierarchies, to support interlinking of the models and information provision on different management levels.

The paper discusses (1) the main components of the platform providing for horizontal, vertical and longitudinal interlinking of information, (2) the ontology-based multi-model framework and principles for the hierarchic structuring of engineering and management models as well as (3) the development of dynamically process models to route and document the information model's logistics.

Keywords: multi-model management, conceptual modelling, ontologies, information logistics

1. INTRODUCTION

The heterogeneity of application models and the lack of an accepted business semantics for sharing of model-based information still hinder a close collaboration of building owners and contractors. In practice, project planning and management applications still focus on selected tasks of architects, engineers and managers on either the owners or the constructors side. Particularly in construction planning there is little support to efficiently reuse information from building design and ongoing construction execution to evaluate the consequences and risks of current planning decisions. Firstly, there are numerous interoperability problems remaining horizontally among the management and engineering disciplines involved in the project. Secondly, there is very little support for vertical model transitions: either top-down when detailing a general project plan to evaluate the estimated resource and set-out performance parameters or bottom-up when on-site progress information must be aggregated for higher level controlling decisions.

Given these shortcomings the German research project Mefisto is developing a Management Information System that integrates model-based information in a distributed multi-model space to support decision making in different disciplines as well as on different management levels (Scherer et al. 2010). Backbone of the envisaged system is a semantic service platform acting on a layered ontology-based model framework. The model framework defines the multi-model space representing core concepts of construction planning and management within most common application models as well as possible model interdependencies and combinations. Central to the framework is a process model that provides for inter-relating the engineering and management models in regard to planning, production and controlling tasks.

The paper discusses (1) the main components of the platform providing for horizontal, vertical and longitudinal interlinking of information, (2) the ontology-based multi-model framework and principles for the hierarchic structuring of engineering and management models as well as (3) the development of dynamically process models to route and document the information model's logistics.

2. A FRAMEWORK FOR MULTI-MODEL MANAGEMENT

The information backbone of the Mefisto platform is developed in anticipation of the fact that not all project data can be structured in an all-encompassing data schema and managed in an all-integrating information base. Hence, a distributed information space is envisaged that supports collaboration among project participants working on local task- and discipline-specific application models. To recognise the interdependencies among the different application models a selection of semantic model specifications, novel modelling tools and respective information management services shall provide for the interlinking, filtering, transformation, combination, aggregation and expansion of the model-based information. The following three sections provide an overview over the main components and describes the requirement analysis, that has been carried out for their design.

2.1 Semantic Resources

To allow for information sharing within a distributed multi-model space it is important to explicitly identify and denote the various application models and their interdependencies as well as to track, visualise and coordinate the development and reuse of the models throughout the project. On the Mefisto platform such multi-model management is realized by (1) a common exchange format, named the Mefisto Container, (2) a layered ontology-based model framework and (3) a set of Multi-Model Definitions:

- The *Mefisto Container* represents a logical envelop for handling distributed, yet inter-related application models in combination with corresponding link models as a single information resources. The XML-based container does not specify any standardised data format for the formalisation of the actual application models. However, it provides for describing the models and their content in more detail using the ontologies and model definitions described in the following.
- The *layered ontology-based model framework* defines a reference schema to classify elements of distributed multi-models in accordance to different application domains and levels of detail. It comprises a *Construction Core Ontology (CCO)* defining core concepts of selected construction planning and management domains and a *Project Collaboration Ontology (PCO)* representing the organisational actors and IT tools to process such model-based information. The construction core and the project collaboration ontology only represent selected aspects of the application models and the project collaboration of the Mefisto platform required to semantically annotate the content of multi-models and compare, analyse and verify them for further use.
- To formalise the application models used within the Mefisto Container a set of general model schemas such as the IFCs and the German GAEB standards is selected to cover the different modelling domains. These general schemas are merged in *Multi-Model Definitions* (MMDs) specifying more detailed exchange requirements for particular planning and controlling tasks as well as for respective software systems. A Multi-Model Definition typically comprises a set of *Elementary Model Definitions* (EMDs) specifying model subsets or even additional model constraints based on the general schemas. It may also include *Elementary Link Model Definitions* (LMDs) that define inter-model relations and integrity constraints that need to be fulfilled by the overall multi-model composite.

2.2 Software Services

The implementation of the Mefisto platform recognises the fact that the project model data is distributed among the participants in a construction project. The overall technical architecture of the platform features a hybrid SOA-based system integrating local legacy applications and various platform services via standard web service and .NET technology. In the scope of the Mefisto project these legacy applications comprise the 3D parametric CAD system SolidWorks, the novel project management system iTWO by RIB, the integrated monitoring and controlling system GRANID by gibGreiner and several complex simulation tools such as Plant Simulation and AnyLogic.

Complementing the legacy systems, the service platform provides dedicated information logistics and multi-model management services to realize the integration of the disjoint information on owner and contractor side. The information logistics services provide for the necessary user management and services registration based on the Project Collaboration Ontology. The *multi-model management services* are dedicated to different model analyses, annotation, retrieval and transformation tasks. Broadly, they can be divided into (1) basic single-model services to filter, check and transform single models and (2) advanced multi-model services to interlink elementary models and analyse respective model compounds. Planned developments of multi-model management services in Mefisto include:

- *Multi-Model Interoperability Services* supporting horizontal and vertical model transformations. Horizontal interoperability is needed when data from one or more models have to be restructured for use in another context by some other application, e.g. when using BIM data to exactly quantify and allocate work specification splits in a project management system. Vertical interoperability is needed for the synthesis of detailed data for decision making on higher level. This involves various structural and functional aggregation mechanisms to create performance indicators out of the available detailed data.
- *Multi-Model Toolboxes and Plug-ins* for the retrieval, annotation and visualisation of compound models. They represent reusable software components with basic functionality for the inspection, reuse and publication of multi-models and can be used in connection with different interoperability services and legacy systems.
- *Multi-Model Assistant Systems* for the development and the analysis of compound models. In contrast to the toolboxes and plug-ins, the assistant systems provide dedicated application logic and storage as well as a full-fledged user interface to support the development and utilisation of compound models by reusable model components and advanced analyses functionalities. This also includes model configurators for process and construction site modeling as well as a the development and management of simulation models.

2.3 Requirement Analysis for Software Realisation

The modelling domains and core concepts of the multi-models were identified based on an analysis of planning and controlling processes as well as on a review of general data schemas. Overall the requirement analyses and model definitions were carried out in a four step process that resembles the Process Matrix methodology (Scherer et al. 2004) and the Information Delivery Manuals (ISO 29481-1 2010).

Firstly, general application scenarios were conducted with the project partners for the project phases from project bidding to construction execution. Fundamental to the scenarios was the premise, that owner and constructor organizations would have unlimited access to integrated model-based information in the form of multi-models.

Secondly, the multi-models used in the general scenarios were examined in accordance to different modelling domains, data schemas and engineering applications. Based on this comparison ten modelling domains described in chapter three and three types of model-interdependencies were identified:

- *horizontal interdependencies*, between models of owners and constructors, with different application domains and/or model formalization,
- *vertical interdependencies*, between models representing different levels of abstraction supporting decision making on different management levels,
- *longitudinal interdependencies*, between model versions generated at different points in time.

Thirdly, the general application scenarios were further detailed in single use cases particularly identifying the basic components of the application models for each task as well as their inter-model relations. The detailed scenarios were documented in BPMN diagrams that illustrate the development and reuse of the model-based resources. Moreover, a corresponding Scenario Matrix was developed, illustrated by figure 1, that extends the Process Matrix to explicitly denote the exchanged models in accordance to the model type, the originator and the respective planning or controlling tasks as well as to capturing necessary model interrelations indicated by the arrows.

Task: Detailing of construction-site plans and specification of equipment and machinery							
	Building	Construction Site	Organisation	Specification	Cost	Time Schedule	Risk
Input	BW-AG_ANG-BWK building model for coordinating bid development	BS-AN_ANG-BOM construction site plan based on bidding documents → BW-AG_ ANG-BWK	BO-AG_ANG-POK anticipated project organization of planers and consultans → BW-AG_ ANG-BWK	BL-AG_ ANG -LVK building specifications based on the bidding documents → BW-AG_ ANG-BWK → BS-AN_ANG-BOM		BT-AG_ ANG-BSP overall Project schedule based on bidding documents → BL-AG_ ANG-LVK	
	Software: Construction Site Modeller				Actor: Site Manager		
Output		BS-AN_ANG-BST Detailliertes Baustellenmodell der Arbeitsvorbereitung, mit Baumethoden, → BW-AG_ ANG-BWK → BS-AG_ANG-CLK	BO-AN_ANG-BST anticipated project organization of construction site personnel → BL-AG_ ANG-LVB	BL-AG_ ANG-LVB building specifications based on the bidding documents, requirements for construction equipment and machinery revised → BW-AG_ ANG-BWK → BS-AN_ANG-BST			

Fig. 1: Module from the Scenario Matrix for the development of a Construction Site Model

Fourthly, the information exchange requirements for the Multi-Model Definitions were examined in detail. In addition to the identification of central concepts and properties the analysis included the *level of detailing* that the models of a MMD should typically reflect, the *presentation form* that most adequately illustrates the models of a MM, and the *model interdependencies* that the models have within one as well as among multiple MMD.

3. LAYERED ONTOLOGY-BASED MODEL FRAMEWORK

To handle application models of different engineering and management disciplines in different formalisations a layered ontology-based model framework is developed providing a general ordering schema, explicit inter-model relationships and a set of supporting information logistics and management functions. The model framework provides the general basis for the uniform annotation of multi-models generated by different software applications as well as for the verification, comparison and analytics of their content. Within the Mefisto containers the ontologies allow for annotating the model content on three levels:

- *Model element*: If necessary, particular model element specifications within a model can be complemented with additional annotations inside or outside that model.
- *Elementary application model:* The elementary application models are described on meta level in regard to the model domain, the core objects and the level of abstraction as well as the respective general schema and model definition.
- *Composite model*: Complementary to the descriptions of the elementary models the Model Container holds also meta information about the corresponding link model. Moreover, it can capture additional content and contextual information describing the focus and the possible visualisations of the composite model as well as the users and software application involved in its creation process.

The semantic annotations of the information resources shall support the retrieval, the re-use and the archival of multi-models on the Mefisto platform. Moreover, they may provide for the coordination and the documentation of the information processes in which the multi-models are created, transformed, altered and used by software services and users as described in chapter four.

3.1 Construction Core and Project Collaboration Ontology

Central to the model framework is the *Construction Core Ontology* as illustrated in figure 2. On four layers it reflects the core concepts of construction planning and management in accordance to selected standardized as well as non-standardized data schemas. Superordinate to the Construction Core Ontology the fifth layer defines the *Project* C*ollaboration Ontology*. On metadata level it provides for the semantic description of the contents, formalisations and views of the multi-models in the Mefisto container as well as it represents the organisational actors, software services and information tasks that describe the possible use of the respective models in construction planning and management.

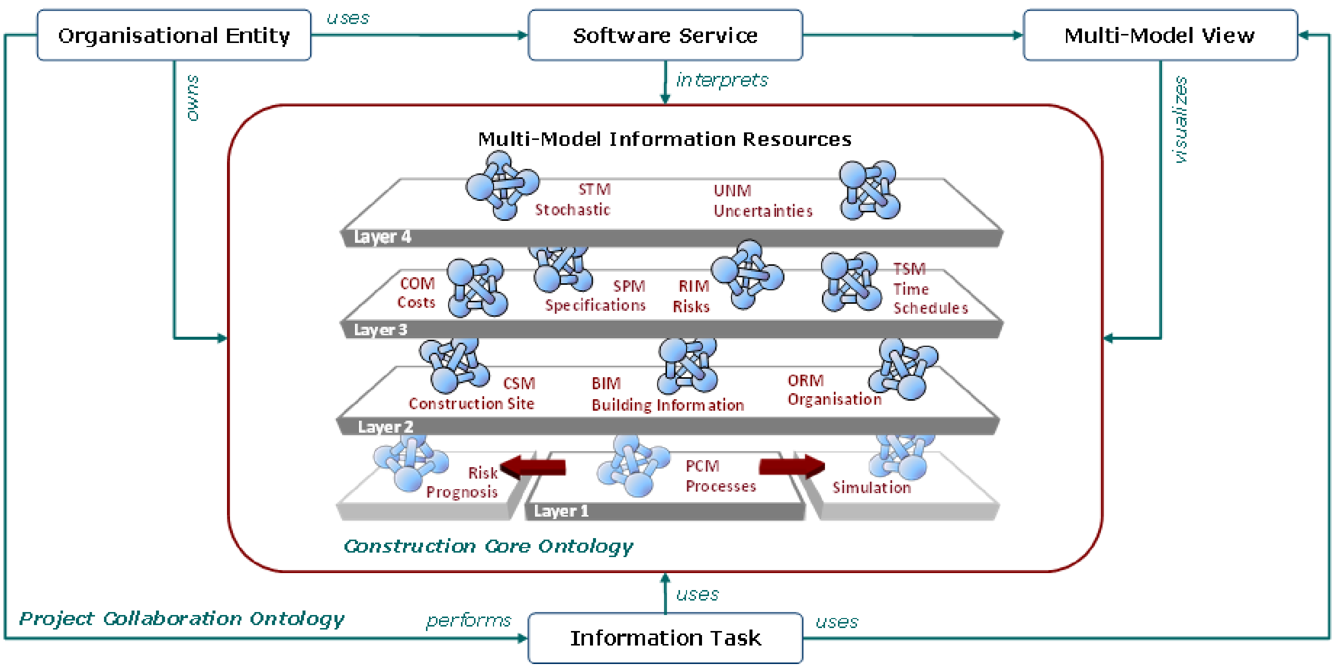

Fig. 2: Integrated information management based on the shared collaboration ontology of the ICT platform

The first layer of the Construction Core Ontology represents the construction processes to plan, execute and control a construction project. The construction process model takes a key-position within the model framework. In a process-centred approach it allows for interrelating model-based information from different engineering and management domains in integrated business process models as described in chapter four.

The second layer defines the core concepts that reference concrete construction products and resources. The concepts are organised in three modelling domains:

- The domain of *Building Information Models (BIM)* focuses on the functional, geometrical and topological description of the building elements and their composition. All data schemas for the building model EMDs are developed based on the IFC Model (Liebich et al. 2005).
- The domain of *Construction Site Models (CSM)* comprises the site infrastructure elements, the construction materials, the pre-fabricated building elements as well as construction machinery and equipment together with their basic geometrical, mechanical and economical properties. There was no formal models identified that satisfied the information requirements of construction site model EMDs, hence, a new data schema is developed in the Mefisto project that, among others, builds upon the Geometry Resources of the IFCs.

– The domain of *Organisation Models (ORM)* defines organisational actors and resources as well as their interrelations. Depending on the application area and the level of detail these concepts may be used to model supply networks or reporting structures of a project as well as the deployment of works on the construction site. For the exchange of organisational information a new data schema is developed that builds upon previous research in the German BauVOGrid project (Hilbert et al. 2010) and proprietary schemas of the software developers in the project consortium.

The third layer comprises concepts describing the qualities and risks of construction products in the building model and of construction processes in the construction process model. Here, concepts are organised in four modelling domains:

– The domain of *Specification Models* (SPM) subsumes formal and informal models describing qualitative properties of building products and processes, such as functional, material or regulatory requirements. In principle, specification models comprise functional building requirements, work specifications and building element catalogues. However, Mefisto project first of all focuses on work specifications of unit price contracts formalised according to the German standard GAEB DA XML (GAEB 2009).
– The domain of *Cost Models* (COM) comprises all models that allocate monetary values to building products and processes e.g. in estimating, calculating, contracting and construction controlling. Until today such cost information is handled separately by owners and contractors with regard to very different building and process elements. In Mefisto the interlinking of building and process elements with corresponding quality models now allows for the synchronisation of these cost models in selected application areas such as contracting, progress reporting and billing. The definition of respective EMDs are again based the GAEB DA XML specification (GAEB 2009).
– The domain of *Time Schedules* (TSM) represents the core concepts of common scheduling models including elements such as activities and sequential relations as well as resource loads and calendars. The EMDs for the Time Schedule Models are defined using a proprietary data schema developed in accordance to selected commercial scheduling application to provide for the preliminary design as well as for the reuse of construction process models in these applications.
– The domain of *Risk Models* (RIM) represents project risks that may severely affect the other specification, cost and time schedule models and shall thus be shared between the owner and the contractor.

The fourth layer contains analytical models that are used to evaluate design and management decisions reflected by the models on the lower levels. Here, *stochastic models* and *fuzzy models* are used to explicitly capture the uncertainties involved particularly in the estimates of product and process qualities such as costs and durations.

The fifth layer defines the concepts to support the overall multi-model logistics of the platform. Complementary to the Construction Core Ontology the *Project* C*ollaboration Ontology* allows for describing the life-cycle context of the multi-model resources specifying:

– the *information tasks* in which specific multi-models are created, transformed, changed or re-used
– the *software services* that can read, interpret and create certain multi-models
– the *organisational entities* that have access and user rights to certain multi-models
– the *multi-model views* that provide a most adequate visualisation of certain multi-models.

3.2 Hierarchical Organisation of Application Models

To support the interlinking of the application models the Construction Core Ontology shall not only represent selected elements of the general data schemas but also extend the semantic definitions of their elements as well as of the types of possible inter-model relationships.

Today's data schemas provide very little semantic support for the interlinking of application models. To allow for the formalisation of different management and engineering models on the owner as well as on the constructors side the general data schemas have to be kept most generic in nature. Hence, a certain type of element in an application model may represent very different concepts such as a single work task or the erection of the overall building structure as well as the a single wall segment or an overall stair case. While such generic schemas provide for a most flexible utilisation of data formats it requires a great amount of engineering knowledge to distinguish different elements types and identify their interdependencies.

In construction practice work breakdown structures are often used to structure the application models on a project in a more coherent way. However, these systems are usually limited to a few disciplines and model domains as well as they are only loosely connected to the applied data schemas. Moreover, within a given model domain owners and constrictors most often use different breakdown structures maintaining only a few synchronisation points such as the work specifications in unit price contracts. Given these shortcoming several design and contractor organisation have started to reengineer their modelling procedures to build more coherent application models and establish direct relations among selected model elements such as the pre-cast elements in building models and in production schedules. Research has paid quite some attention to extending the classification depth of the general data schemas focusing mainly on the application of semantic object libraries () or to some extend at construction classification systems (Kang et al. 2005). However, there exist only a few commonly accepted modelling techniques, nomenclatures and catalogues.

On the Mefisto platform the Construction Core Ontology is granted the role to establish a common ordering scheme for the different application models on a given project. Defining semantic concept hierarchies for central elements of the model domains in regard to the general data schemas shall allow for using common application models to define a project breakdown structure that can be represented by a set of interrelated reference model elements in each of the different model domains.

Starting point for the definition of the semantic concept hierarchies is the analysis of the model hierarchies in the scenario analysis as well as of the hierarchical structures already supported by general data schemas a. Figure 3 depicts the possible formalisation of the hierarchical building structures of four levels in IFC, namely (1) the spatial building structure, (2) the structure of arbitrary material or work related building element groups contain therein, (3) the elementary building elements as well as (4) the components of these elements.

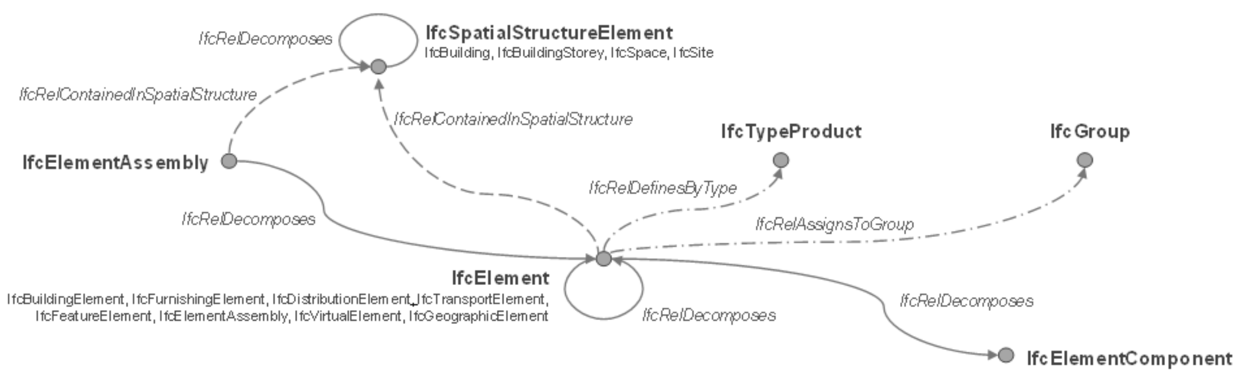

Figure 3: Representing Hierarchies of Building Models in IFC

4. PROCESS-CENTERED INTEGRATION OF MULTI-MODELS

An important instrument for the effective utilisation of model-based information on the Mefisto platform are the assistance systems for semi-automatic modelling of material as well as informational production processes. The large arrows in figure 4 below illustrate the two types of processes on different hierarchy levels of the project, i.e. the information processes to produce plans and controlling reports as well as the material construction processes to produce the actual physical building elements. In practice they are interrelated by supplementing coordination and reporting processes as indicate by the small arrows.

Within the multi-model framework the production processes represent the backbone for information integration as they provide for interrelating elements of diverse application models in a uniform way. Models of construction processes can interrelate elements of application models such as building models, construction site models or specifications and schedules that determine the necessary work tasks, the possible sequencing as well as the available equipment and staff. The information from such static application models, also simply referred to as object models, can be used to support the development, the animation and the simulation of the construction execution processes as described in (Scherer et al. 2010).

Correspondingly, the models of planning and controlling processes can interrelate model elements of object models that are themselves either indirectly required or directly altered by an information process. Indicating the actual editing status of related model elements, an information process provides for documenting the evolution of a management and engineering model as well as for identifying possible, subsequent model development tasks. The following two sections describe the approach to developing and using information process models on the Mefisto platform.

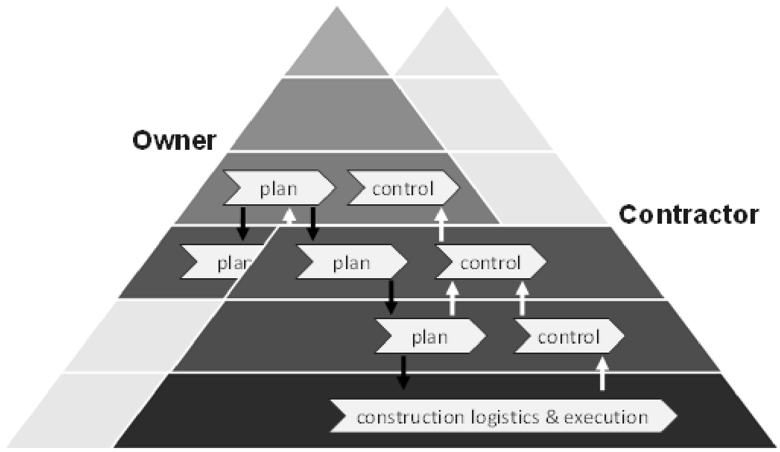

Figure 4: Hierarchical Organisation of Business Processes on Construction Projects

5. REFERENCE PROCESS MODELLING OF INFORMATION PROCESSES

For the semi-automatic modelling of production processes and the efficient utilisation of information from the multi-model space a modelling approach is suggested that combines methodologies of business process objects and reference process modelling.

A *Business Process Object* (*BPO*) is an extension to currently known Business Objects Specifications that allows for a better binding of real-world products and their descriptions in information models to the processes using this information (Katranuschkov et al. 2006). Hence, a Business Process Object interrelates object information to processes information as well as it specifies the related actors and software services involved in such a process. In the context of the Mefisto multi-model framework the Business Process Object reflects a set of model elements from the distributes multi-model space that is bound to a particular planning, controlling or construction execution process.

In turn, *Reference Modelling* provides a technique for the systematic reuse and customization of the BPOs. It organizes the tasks of information modelling in two cycles: The model development cycle includes problem definition, reference model construction as well as their subsequent evaluation and care. The subsequent model application cycle covers the retrieval, customization, integration and the application of reference models (Fettke & Loos 2004). Key modelling task to most reference modelling approaches is the customization of selected reference models, which may involve the two subtasks of reference model configuration and reference model composition that can be performed alternating.

For reference process modelling on the Mefisto platform a *Process Configurator* is implemented based on the Construction Core and the Project Collaboration Ontology to support the development of process models reusing predefined parametric business process objects called process modules. Informational *process modules* define recurring planning and controlling tasks in combination with their informational requirements and outcomes that can be used as building blocks to assemble planning and controlling processes interrelated with respective elements of static object models.

A key point for the effective reuse of the process modules and the interlinking of process and object models is the hierarchical structuring of the process models in coherence with the hierarchies of related management and engineering models as well as the hierarchy of the overall project organisation creating and using this information. In contrast to common workflow systems that link a set document or data files to a given workflow task, the hierarchical multi-model framework provides for referencing a particular set of model elements such as the elements of a building system in a particular story denoting an abstract, yet a semantically explicit tasks-specific description of the model-based information required or produced by a certain information process.

Figure 5 illustrates a possible sequence of modelling tasks for detailing the planning process “P-1: plan construction site infrastructure”. Input to the process are a high-level building model and a corresponding construction schedule as well as a first reference element for the construction site infrastructure. Output of the process is a detailed construction site infrastructure model comprising a construction site layout and facilities. In the superordinate process the input and output elements are connected to the process via status elements assigning the status “approved” to the building and schedule elements and the status “to plan” and “planed” to the superordinate infrastructure element. Given this process model the development of the subordinate process model may comprise five steps with the following results:

1. the formal definition of the anticipated process result, here the detailed models of the construction site layout and the construction site facilities,
2. the retrieval and selection of applicable modules from a library, here the modules P-1.1 and P-1.2,
3. the configuration of the modules and filtering of respective information from the multi-model space, here e.g. the request of information on the available construction equipment from the construction site model.
4. the composition of the modules, here the positioning of P-1.2 after P-1.2,
5. the application of developed process model, e.g. in a workflow system or a simple task list.

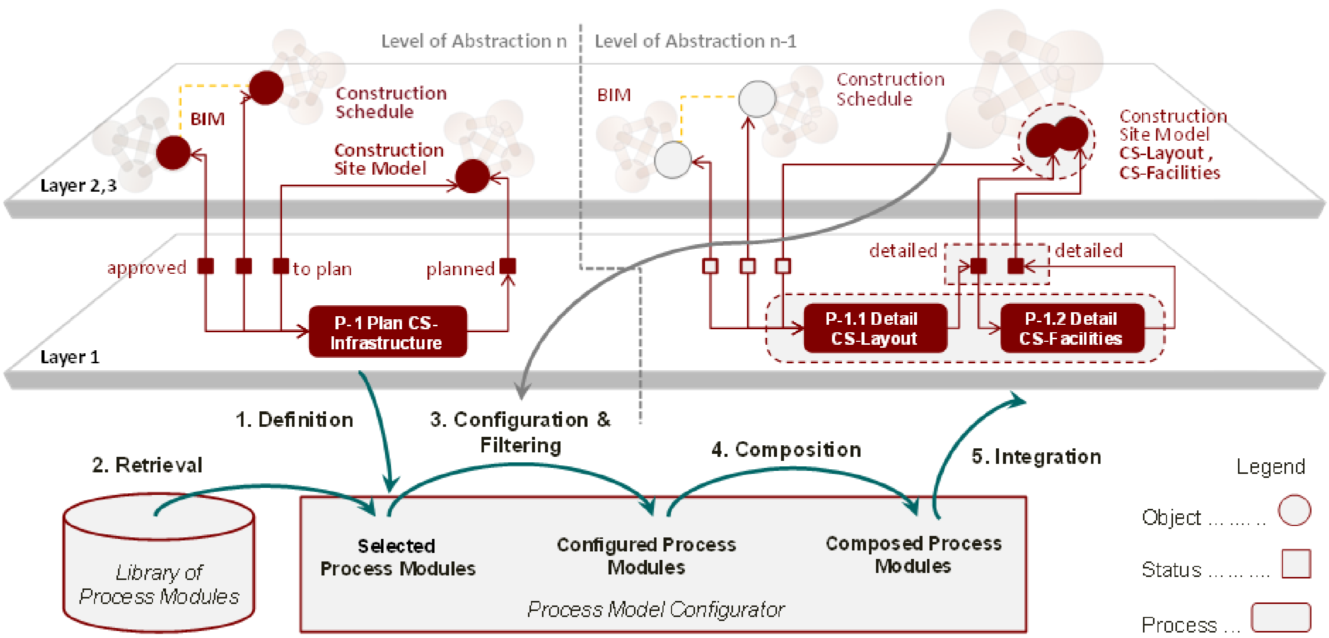

Figure 5: Exemplary Procedure to Reference Modelling of a Planning Process

The definition of a process module may comprise a set of sub-processes (functions) as well as respective status elements and configuration rules. To support their retrieval, configuration and composition these elements are specified based on a process ontology that formally defines the types of processes and their possible interdependencies with respective types of model elements in the Construction Core and the Project Collaboration Ontology. As described in Scherer et al. (2010) and Baling et al. (2010) the process ontology shall allow for encoding three types of knowledge extensions within the process module.

Firstly, the process modules are enhanced with functional process-related application and composition knowledge to supports the retrieval and customisation of process modules. The *application knowledge* constitutes meta-knowledge on the contextual requirements and results of a process module, which can be used to retrieve adequate modules and configure the process parameters e.g. specifying size and material of an element or available equipment and personnel. In turn, the c*omposition knowledge* captures information on the possible sequencing of process modules to semi-automatically generate and verify alternative process sequences.

Secondly, the process module shall incorporate *strategic knowledge* providing management heuristics and planning rules for detailing a process models on a subordinate level of abstraction. Such strategic knowledge shall be used e.g. to pre-select key parameters for the retrieval and the configuration of reference modules as well as to reduce the number of alternative module compositions.

Overall the utilisation of the application, composition and strategic knowledge underpins the role of the model framework for the process-centred harmonisation and interlinking of the distributed information resources on the building, the construction site facilities and equipments, the project organisations and the related construction management plans.

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