ACTIVE PROCESS REUSE MODEL FOR COLLABORATION

SUBMITTED: December 2005
REVISED: May 2006
PUBLISHED: July 2006 at http://www.itcon.org/2006/35/
EDITOR: P. Katranuschkov

Tomo Cerovsek, Dr. Ing.
University of Ljubljana, Faculty of Civil and Geodetic Engineering, Slovenia
email: Tomo.Cerovsek@ fgg.uni-lj.si, http://itc.fgg.uni-lj.si

Peter Katranuschkov, Dr.-Ing.
Institute of Construction Informatics, University of Technology Dresden, Germany
email: Peter.Katranuschkov@cib.bau.tu-dresden.de, http://cib.bau.tu-dresden.de

SUMMARY*: We discuss the reuse of process knowledge through conceptualized workflow patterns. Whilst knowledge reuse in the lifecycle of projects has been widely studied, most of the known solutions have been focusing on the reuse of communicated information – the process results – isolated from the processes themselves. Consequently, the focus on the immediate reuse of communicated project information (i.e. architectural and structural solutions, drawings, technical specifications and so on) intensified the research in the field of information retrieval and contextualization of the retrieved information. Actual processes, actors and tools that have led to the results of the work usually remain unrecorded, the latter was considered technically almost impossible. In contrast to the intuitive ad-hoc reuse of parts of existing results in a given context, ad-hoc reuse of parts of previously executed processes – together with processes' meta-descriptors – is not so straightforward. In this paper we identify the methods and media in which processes are modeled and executed as a major barrier for process reuse. Based on the analysis of process modeling techniques we suggest a novel methodological approach and a conceptual solution for a collaboration system supported by active process models – utilizing the idea of conceptualized reusable workflow patterns. We present an architecture supporting process reuse, and two early prototypes. At the end, we also outline issues for further research.*

KEYWORDS*: active process modeling, collaboration, process reuse, workflow patterns, business intelligence.*

1. INTRODUCTION

Empirical optimization of processes requires specific knowledge. From the process perspective we can divide this knowledge into two main categories: (1) *how,* knowledge about the processes, and (2) *what,* the process results as containers of knowledge. For example, whenever we do a task, we can either use procedures that work, or/and use existing results of similar process that were carried out in the past. The focus of this paper is on the *reuse of knowledge about processes in the context of collaborative activities* – affecting the decision making procedures during building projects. The goal is iterative process optimization based on empirical studies.

The reuse of knowledge in the lifecycle of building projects has been widely studied. However, most of the known solutions address only the reuse of process results. These results can be seen as *messages* produced during projects and communicated through different traditional and digital communication channels. Examples of communicated messages include architectural and structural solutions, drawings, technical specifications etc. Such messages are usually detached from the processes that produced them. The reuse of parts of a message (e.g. detail from a drawing) is often straightforward and intuitively correct, even without knowledge of the process. This fact intensified the research on information retrieval techniques and the contextualization of the retrieved information. The reuse of the processes that led to the results has not been deeply studied (in our example: the process that produced the drawing detail).

In current practice, reuse of process knowledge is largely limited to the representation methods describing processes, such as GANTT, PERT, IDEF0, UML and other process models (cf. Katranuschkov et al. 2002). Such models are passive and cannot be used in real-time. In contrast, effective project teams are proactive, dynamic, and must react in real-time.

1.1 Problem statement and hypothesis

Much higher efficiency of collaborative work could be achieved through the reuse of *all available knowledge*. The reuse of processes and not only process results, would enable more efficient and dynamical decision making (DDM) in project teams. Gonzales (2005) aggregates three definitions of DDM: (1) the need to make multiple and interdependent decisions in an environment that changes as a function of the decision maker's actions, in response to environmental events, or in both ways, (2) real-time decision making where time constraints become an important performance determinant, and (3) dynamical complexity, meaning time delays and decisions that positively or negatively influence one another in complicated ways over time.

The major research question is: *how to reuse processes in dynamic decision making?* In contrast to the intuitive ad-hoc reuse of parts of results of processes (i.e. text documents or technical drawings), ad-hoc reuse of parts of actual processes with meta-descriptors is not so straightforward. In collaborative activities it is very hard to track who does what and when, and intensive communication can "blur" important processes. We identify the methods and media in which processes are executed and modeled as the main problem and barrier to achieve process reuse. Actual real-world processes, actors and tools that lead to results – or have been used in communication – usually remain unrecorded. Consequently, empirical knowledge and DDM support in ad-hoc assembled AEC teams are insufficient. Our *hypothesis* is that the knowledge about processes can be enriched in the process reuse life-cycle as illustrated on FIG. 1. Monitoring of activities would provide the necessary empirical observation of process, which must be later measured and profiled in the process analysis used for the modeling of processes. Through capture, analysis and modeling of process activities we can learn about, execute and reuse processes.

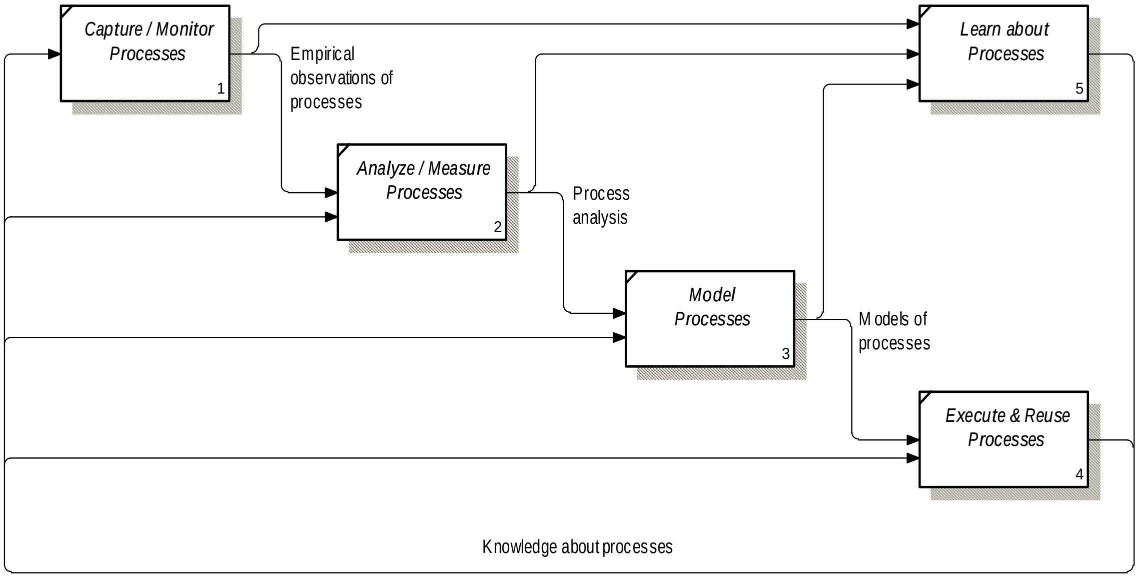


FIG. 1: Extending knowledge about processes in the process reuse life-cycle.

Active process models (APM) are process reuse models, where *active* means that processes are modeled and executed in a media which can actively in real-time influence process execution. An APM can connect actors, tools, services and models together in the process reuse life-cycle. Rapid progress in web-mediated collaboration can provide such a media – an APM supported collaboration platform for DDM. Such a platform should support process reuse in collaborative, as well as in individual activities. All activities on the platform can be captured, analyzed, modeled, and reused conceptually, or explicitly. An APM supported platform would enable generation of new knowledge about processes through constant learning. Where the granularity of captured activities is too dense, we also explore the reuse of captured process knowledge by means of *conceptualized workflow patterns*.

In order to improve collaboration and processes in DDM we must first classify them. Section 2 gives an overview of the taxonomies providing the necessary understanding of collaboration and process models. In section 3 we describe the needed meta-modeling aspects. Section 4 describes the suggested framework for real-time process reuse, including detailed description of APM and conceptualized workflow patterns and process-centered business intelligence. At the end, in section 5, we present prototype architecture and two prototype examples.

2. TAXONOMIES FOR ACTIVE PROCESS MODELS

Optimization of collaborative processes requires qualitative and quantitative views on categorization of causes. Taxonomies for active process models identify such views on qualitative and quantitative issues in collaboration and process modeling. Identified taxonomic views improve understanding of collaboration and process modeling in a given context. Different taxonomic views can be combined into measures that can be graphically representted. Described taxonomies have been also used for ontological analysis, for an AEC-focused review of process modeling, and have been used as important input to the developed framework for a real-time process reuse. The following understanding of the used concepts has been assumed:

- *Taxonomy – a* well-defined principle of classification. Principles are views that can be used at different levels of classifications. We have used taxonomic views to describe modeling principles.
- *Model* – a view that provides an abstraction or simplification enabling better understanding of the (real-world) subject being modeled.
- *Meta-model* – a representational model that describes other models, often addressing issues related to the modeling capabilities.
- *Collaboration* – work performed jointly with others, especially in an intellectual endeavor.
  It is important to note that we understand interaction of tools as *integration,* and involvement of people in the interaction as *collaboration*.
- *Process* – a business activity that can be divided into smaller parts, which can then be executed sequentially or in parallel under certain conditions.

2.1 Collaboration Taxonomy

Collaboration in AEC is noticeably different from joint intellectual endeavors in other industries. Kalay (2004) uses the term “multi-organizational teams” and mentions the following exceptionality of AEC teams: individuals representing often fundamentally different professions, perforce, hold different goals, objectives, and even belief system. Collaboration is by definition not possible without teamwork, and so are views for taxonomies (TABLE 1).

TABLE 1: Views for collaboration taxonomies (Cerovsek and Turk, 2004)

View	Qualitative	Quantitative
Location	Same, Different	Number of locations
Time	Synchronous & Asynchronous	Date & Time, Duration
Group	Type of group	Size (# of Members)
Teamwork	Forming, Storming, Performing	Frequency of interactions , # of teams
Process	Types of processes	Time, Money, Resources, etc.
Information	Types of information/knowledge	Quantity (# of records, Mb)
Communication Channel	Types of media/messages	# of channels , # of messages
Interaction	Communication, Coordination, Collaboration	Modality, Devices

By selecting any the two of the above listed views we can build a *two dimensional collaboration matrix* that depicts the interactions between the selected two views. As an example, let us consider the *‘Location’* view. It is related to physical locations as well as virtual locations (groupware environments) of the collaborators. Collaboration quality is completely different if the collaborating parties are at the same location or if they are at different locations. From quantitative perspective we can consider number of locations – geographical places or virtual environments. If we combine location and time we can produce a collaboration matrix with location and time on the x and y axes respectively. We can use qualitative measures for groups – what is the quality of group, teamwork – quality and stage of interaction, or process – type of processes they are conducted (e.g. feasibility study, design). Under communication channel we understand sender, receiver, medium, and message. Special importance is given to the medium in which processes are modeled and in which collaboration takes place.

We can also use views to quantitatively and qualitatively measure collaboration. For example, collaboration can be characterized by a *Collaboration Circumference,* where radial directions represent *task frequencies for specific roles,* observed for specific use case in the whole project life cycle. Such collaboration circumferences can also be drawn for *specific processes*, thereby providing a synthetic view of the collaboration requirements of the process. An example based on the Process Matrix approach is shown on FIG. 2 below.

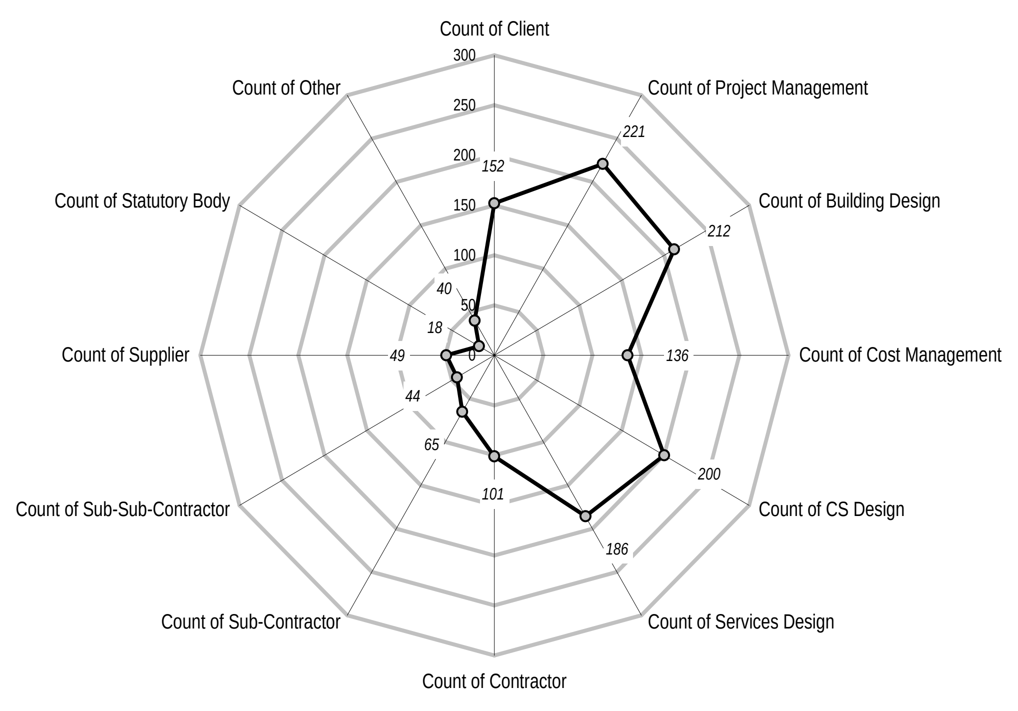


FIG. 2: Collaboration circumference: involvement of different roles in communication during project life cycle (data for the example taken from the EU project ICCI – cf. Katranuschkov et al. 2004).

2.2 Process Modeling Taxonomy

A process modeling taxonomy should address numerous interrelated issues, providing answers to the questions: why, what, who, for whom, where and how? Some of the corresponding views derived from observations of a large number of process models found in the literature are listed in TABLE 2. In relation to process modeling, the following basic concepts need to be introduced:

- *Actor* – a human being or a machine that can perform a task.
- *Role* – a logical abstraction of one or more physical actors, usually in terms of functionality.
- *Task – a* definite piece of work that participates in the formation of processes.
- *Task specification* – a descriptive abstraction of a task.
- *Process model* – an abstraction of (business) processes with emphasis on the coordination of tasks and their interdependences.
- *Organization – aggregation* of actors into groups which are structured in some hierarchical way.
- *Organizational model* – an abstraction of hierarchical organizations.
- *Workflow (instance) – a* process combined with an organization; it assigns the tasks in the process to actors in the organization together with other requirements and constraints for their execution.
- *Workflow model* – sequences of task that combine a process model, and an organizational model.

TABLE 2: Overview of process modeling technologies for collaboration (Cerovsek, 2003).

View	Qualitative	Quantitative
Purpose	Planning, Education, BPR …	Range of use, and ways
Basic types	Meta, Conceptual, Customized, Workflows	By type of quantities addressed in process model
Media	Active, Passive	Communication channel
Coverage	Ontological concepts	Number of concepts covered
Used by	Man, Machine	Single, Group, Network
Decision making	Recognition, identification, criteria, proposing, evaluating, making final choice	Number of problem parameters, Resources, Time, Criteria Taxonomy, etc.
Process groups	Initiating, Planning, Executing, Controlling	Time, Resources, Dependencies, Roles, etc.
Representation	Graph-based: Arrow Diagramming Methods, Conditional diagramming; Swim lanes; Matrix, Text-based	Single / Multiple representation methods, ability to represent different quantities and ontological concepts

In the past different process modeling techniques have been used to describe or prescribe the way processes were, or should be carried out. Each view is important for a specific perspective, and there is no universal view that corresponds to all possible aspects of process models (Cerovsek, 2003). We address below some combined views that are important in the context of this paper. More detailed explanation of views and corresponding qualitative and quantitative classifications is beyond the scope of this paper.

Although several research efforts have been focusing on modeling of processes with the purpose of process reuse, most conceptual process models were modeled on paper, or as digital files, without any dynamic and/or enactment power on actual processes. The strength of such passive process models is mainly in their descriptive nature and conceptuality – meta descriptions improving overview, control, understanding and communication about the processes themselves. On the other hand, several enactment enabled process models have been studied and prototyped, usually in the form of workflow models. Such models typically operate on concrete tasks, actors and times. They have two drawbacks: (1) workflow models neither provide conceptual descriptions, nor are flexible for real-time DDM, and (2) they do not rely on better human interpretation compared to programmed.

A suggested taxonomy for the classification of second generation process modeling languages for software engineering indicates five categories (Zamli & Le 2001): (1) Modeling support covering the ability to represent concurrency, artifacts, roles, tools, communication mechanisms, (2) Enactment support, (3) Evaluation support with “enactment data”, (4) Evolution support, and (5) Human dimension support, understandability.

FIG. 3 provides a concretization of process models with focus on process reuse, thereby ordering the observed *indeterminacy of process descriptions* into the following 5 distinct levels:

- *Descriptive level:* This is the first and only modeling independent level in the process description framework. It provides descriptive specifications of the collaboration processes using natural language only. It might have some basic structure, but has almost no specific modeling syntax or vocabulary. The process descriptions include basic abstractions of actors into roles, and tasks into task specifications. This level also indicates process as well as organizational dependencies.
- *Meta ontology level:* This level contains information on ontological constructs that can be used in the process modeling language. Depending on the subject process there must exist corresponding ontological constructs that enable modeling the process without redundancy or loss of information.
- *Meta level:* This level includes models of organizations, workflows and processes on various levels of concretizations. On this level we can find all developed process modeling schemas.
- *Concrete level:* Models on this level refer to concrete organization, workflow and process representations. It addresses specific material or information processes that appear in real life.
- *Instance level:* On this final level we define the captured process model of a real world process.

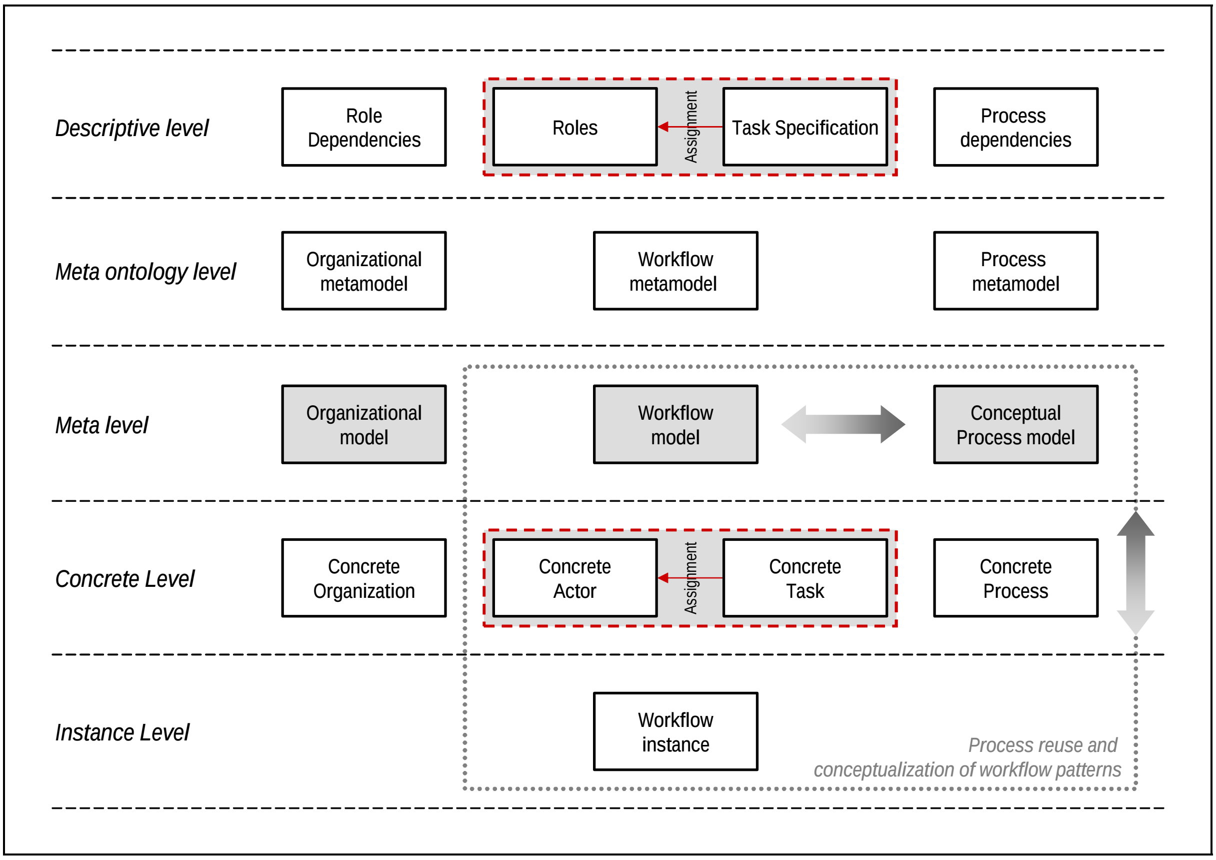


FIG. 3: Concretization of process models – focus is on process reuse and conceptualization of workflow patterns.

Note the difference between Meta-otology level (about modeling) – addressing modeling language capabilities for the formalization of modeling, and Meta-level (about modeled subject) – utilizing modeling capabilities.

In the following, section 3, we addresses the top two levels, i.e. the descriptive level and the meta ontology level, section 4 presents in detail the developed ideas for process reuse and conceptualization of workflow patterns to define a suggested framework for real-time applications. Finally, section 5 outlines major user and technological requirements, applicable use cases, and provides detailed description of possible practical implementation.

3. PROCESS MODELING FOR AEC COLLABORATION

Björk (1999) divides processes in general into material and information processes. The focus here is on the latter, i.e. information processes carried out in virtual environments. The main interest is in the analysis of process modeling support for process reuse in AEC collaboration. To achieve that, we study both collaboration activities in AEC, and how to model corresponding processes. As a starting point two developments are analyzed:

1. *The Process Matrix approach* (Katranuschkov et al. 2002, 2004) – used as a foundation for the study of AEC collaboration.
2. *The Bunge-Wand-Weber* (BWW) analysis of 12 different process modeling techniques with focus on ontological completeness (Rosenmann et al. 2005) – used for the selection of criteria for the description of process models.

The use of Bunge's theory is not new - it has been applied e.g. to define theoretical foundations for a conceptual framework for classification (Ekholm 1996). In this paper we apply Bunge's theory to the analysis of meta ontologies. This analysis served as valuable input to determine adequate criteria for the selection of process modeling techniques for use in effective APM environments.

3.1 Process Matrix

The approach termed 'process matrix' was developed in the frames of the EU ICCI project and further extended in the prodAEC project (cf. Katranuschkov et al. 2004). It provides the definition of a multidimensional matrix capturing the classification of roles, activities and communication in AEC processes, together with their interrelationships and the associated input/output information, services and tools. The matrix was designed in accordance with two main objectives: (1) to improve the capabilities for information capture so that various analyses can be easily performed and reported, as and whenever needed, and (2) to provide a suitable form for database management as well as web-based presentation and processing for the support of AEC collaboration.

From end user viewpoint the Process Matrix appears as a simple table that brings all stored information concerning a reference process together in one line. This approach has been adopted because experience has shown that industry end users are not particularly familiar with formal modeling notations. However, they are familiar with, like, understand and respond to the tabular approach of the Process Matrix. The basic structure of the matrix is shown in FIG. 4. This general structure can be expanded by inclusion of further tables enabling the representation of information, communication, standards requirements and more.

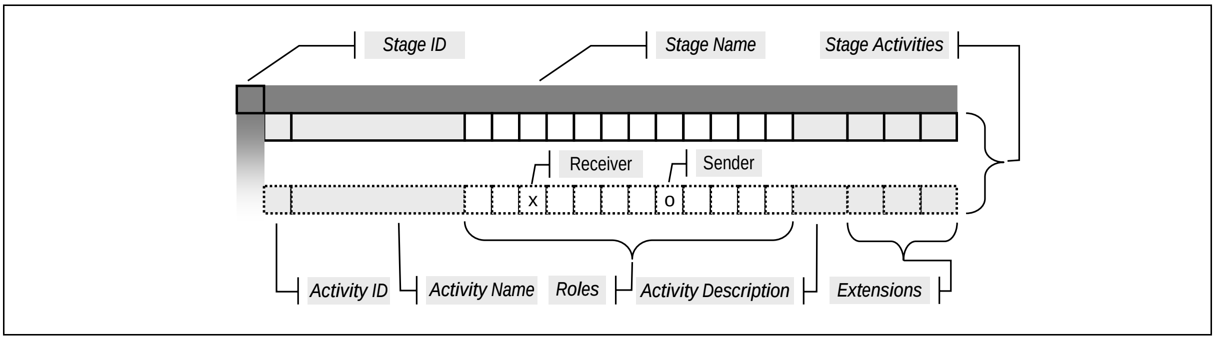


FIG. 4: Basic structure of the Process Matrix.

Actions and activities at all levels are termed *process*. The 'ActivityID' field asserts the identity of each process within the matrix. It is a number that serves also as primary key in a database implementation of the matrix. Each row in the matrix represents a single business process and the information communication shows the end result and who is supposed to use that result in subsequent processes. Each process may be broken down further into sub-processes or detailed by using a diagramming approach such as UML activity diagrams.

Processes are typically organised by project stage whereby the organisation of project stages set down in some standardised national specification such as the German HOAI can be used. This provides a framework for carrying out any construction project.

A process has a typical formalisation of communicated information indicated in the matrix, e.g. 3D model, 2D drawing, cost plan, schedule, list etc. This is covered by the attribute *basic information type*. Information in a process is received from one or more predecessors (as a prerequisite for executing the process), created and exchanged within the process, and passed over to subsequent processes. However, information requirements of processes have also many other aspects that need to be considered. In the basic table of the matrix shown on FIG. 4 two of these aspects are explicitly represented, namely the *generic information type* (related to some classification system) and the *specific information type* (enabling association of information items to secondary, more detailed classification items). The classification of information items is largely adopted from the IFC model which provides two different methods of classifying objects. The first uses a *classification reference*, where only a classification item is given by an identification string and eventually a reference to a classification system. The second involves a *classification notation* which provides a possibility for more comprehensive description by appropriate association to a respective classification facet or table (Wix et al. 2003).

Communication occurs between the participating actors. Predominantly, actors are identified by discipline in most current models. Within the Process Matrix, it is considered that communication occurs between actors fulfilling *roles*. That is, the same actual actor may fulfil multiple roles – communication at the role level is the aspect of interest.

To enable adequate capture of the data associated with an AEC process, three extensions of the basic matrix are provided: (1) *Information Requirements Extension* covering data model and data content, (2) *Communication Requirements Extension*, covering the technical aspects of communication described by communication model, communication method and exchange format, and (3) *Standards Extension*, covering formal or ad-hoc standards to be applied to a process such as building codes and regulations, use of a specific classification system for construction related information, exchange format, schema, network topology etc. This extended form of the Process Matrix is shown in FIG. 5. It was used for the development of the prototype presented in section 5.5.

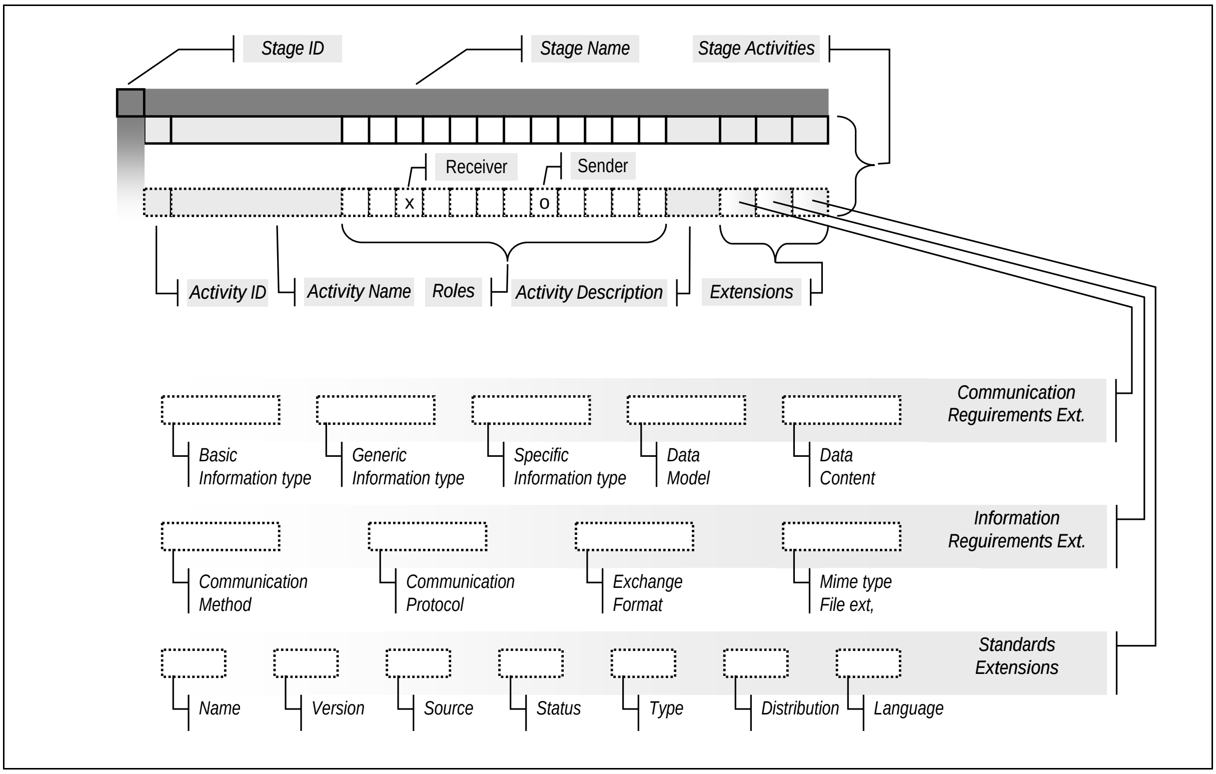


FIG. 5: Process Matrix with extensions. For each extension, a separate table is specified and linked to the basic matrix via the ActivityID and the respective Extension IDs.

3.2 Bunge-Wand-Weber (BWW)

BWW is a comparative meta ontology for Information Systems and System Analysis and Design. It consists of four elements that can be used to structure a framework for research: (1) conceptual modeling grammar – a set of constructs and their construction rules, (2) conceptual modeling method – a procedure by which the grammar can be used, (3) conceptual modeling script – the product of the conceptual modeling method, and (4) context – the setting in which the modeling occurs. FIG. 6 gives an overview of the expressiveness of different process modeling techniques.

The most important ontological constructs that were taken into account for detailed analysis are related to the concept *thing* including its *properties* and *types.*

- *Thing* – the elementary unit in the BWW ontological model. The real world is made up of things. Two or more things (composite or simple) can be associated into a composite thing.
- *Property* – attribute of a thing modeled via a function that maps the thing into some value.
- *Class* – a set of things that can be defined via their possessing class-specific properties.
- *Kind* – a set of things that can be defined only via their possessing two or more common properties.
- *System* – a set of things such that for any bi-partitioning of the set, couplings exist among things in the two subsets.

- *State* – the vector of values for all property functions of a thing.
- *Transformation* – a mapping from one state to another state.
- *History* – the chronologically ordered states that a thing traverses in time.

A chronological overview related to the scope of developments expressiveness and support of different process modeling techniques over time is presented on FIG. 6 below.

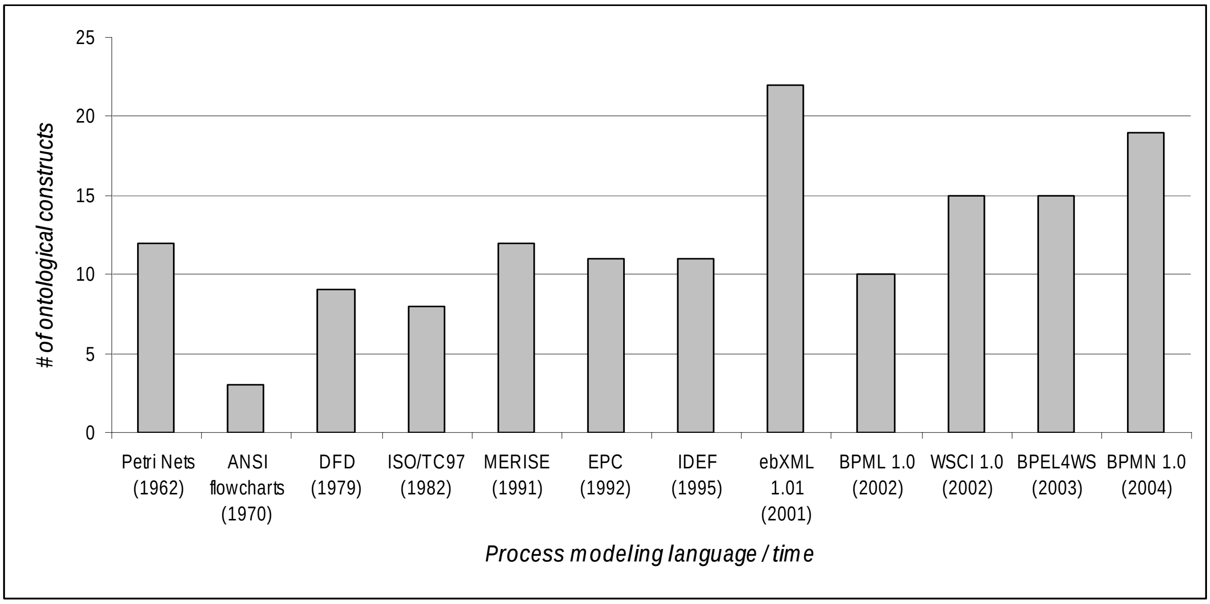


FIG. 6: Process modeling techniques and number of supported ontological constructs. Source: (Rosenmann et al. 2005).

The following definitions are related to states assumed by things:

- *Conceivable state space* – the set of all states that the thing might ever assume.
- *State law* – restricts the values of the properties of a thing to a subset that is deemed lawful because of natural laws or human laws.
- *Lawful state space* – the set of states of a thing that comply with the state laws of the thing.

The results shown in TABLE 3 provide an overview as to how process modeling techniques support various process-related concepts.

TABLE 3: Most and least supported ontological constructs in analyzed process modeling languages. Source: (Rosenmann et al. 2005).

Most supported ontological constructs	
Construct	Ratio [%]
Transformation	100%
Event	83 %
Lawful transformation	83 %
Internal event	75 %
Coupling	67 %
State	58 %
System	58%

Least supported ontological constructs	
Construct	Ratio [%]
History	8 %
Lawful event space	8 %
Conceivable event space	8 %
Conceivable state space	8 %
Kind	8 %
System	17 %
System environment	17 %

3.3 Assessment Criteria for Active Process Modeling Techniques

To enable improvement of process modeling for collaboration, a study of process modeling techniques should include analysis of process capture, modeling language, ad-hocness, and model reuse.

Collaboration process capture. Several modeling techniques have been used in order to support process capture, but not activities in real-time. Ontological analysis showed that this is one of the least supported concepts, covered in only 8% of all known techniques. Capturing should be enabled by communication channels used in collaboration, as e.g. suggested by the Process Matrix approach.

Comprehensiveness of modeling language. The comprehensiveness of a modeling language can be expressed through ontological analysis, since the plethora of process modeling languages (PML) currently in use for different purposes offers very diverse coverage of ontological concepts. The most comprehensive BWW analysis addressing expressiveness of PML is done in (Rosenmann et al. 2005). Here it is worth noting that from ontological perspective ebXML appears to be the most comprehensive process modeling language system.

Ad-hocness support. Several applicable examples exist in the field of scientific collaborative environments – scientific workflows characterized by ad-hocness and incompleteness, partial reuse, abandon/rewind and dynamic modification, tracing of individual processes, specification from case and so on. Other approaches have been used in practice-oriented Decision Support Systems (DSS). To facilitate teamwork, group oriented support systems (GSS) have been implemented e.g. for code inspection meetings. This is a broad field where much research is yet needed to achieve real-practice results.

Process model reuse and improvement. A rather basic, but representative example here are *Network Templates* – a well known concept used to expedite preparation of project network diagrams. Another important example are *low fidelity process models* which specify nominal order of tasks but leave actors free to carry out their activities as their expertise and the situation dictates. This approach is grounded on three main components: (1) process specification based on low fidelity process models, (2) a distribution process deployment and execution mechanism for enacting low fidelity process models, and (3) a virtual repository of artifacts providing access to distributed physical repositories related to the current work.

TABLE 4 below identifies candidate process modeling techniques that could be used to provide the required features of an APM supported collaboration platform. The rationale behind the selection of PML takes into account that transition between existing and targeted practices will be required. Therefore, in the case of capturing, ASME diagrams are found most adequate for the tracking of information exchange in paper-based offices, since they are proven as an effective technique for recording of tasks' time consumptions and value added. Other modeling techniques such as DFD, EPC and UML are widely acknowledged and have broad-scoped applicability. Criteria for comprehensiveness are predominantly selected on the basis of the BWW analysis method outlined above.

Thus, the selection here is based on the ontological constructs of PML where ebXML provides the broadest support. The criteria for the support of ad-hocness, comprehensiveness and visual readability are equally important. Here, ebXML, IDEF0 and BPEL4WS are considered the best candidates. Finally, for the reuse, and especially for the improvement of processes, it is very important to be able to model transitions (i.e. Matrix of Change), and to show the interaction among processes and actors (Process Matrix, GPP). More elaborate discussion on the selection of process modeling techniques is beyond the scope of this paper, and requires a dedicated publication.

TABLE 4: Preliminary selection of process modeling techniques for APM supported collaboration.

Feature	Candidate process modeling technique
Capturing	ASME diagram, ebXML, DFD, EPC, UML, Process Matrix, IDEF0/IDL
Comprehensiveness	ebXML, BPMN, UML, PetriNets
Ad-hocness	ebXML, IDEF0, BPEL4WS, BPMN , DFD, EPC
Reuse and improve	IDEF0, Petri Nets, ebXML, GPP, Process Matrix, Matrix of Change, DSM (Design Structure Matrix)

4. FRAMEWORK FOR REAL-TIME PROCESS REUSE

The real-time process reuse in virtual environments addresses collaboration as well as integration of systems, tools and services. The IDEF0 diagram on FIG. 7 below illustrates the overall process that could be supported by the suggested enabling framework for APM supported collaboration.

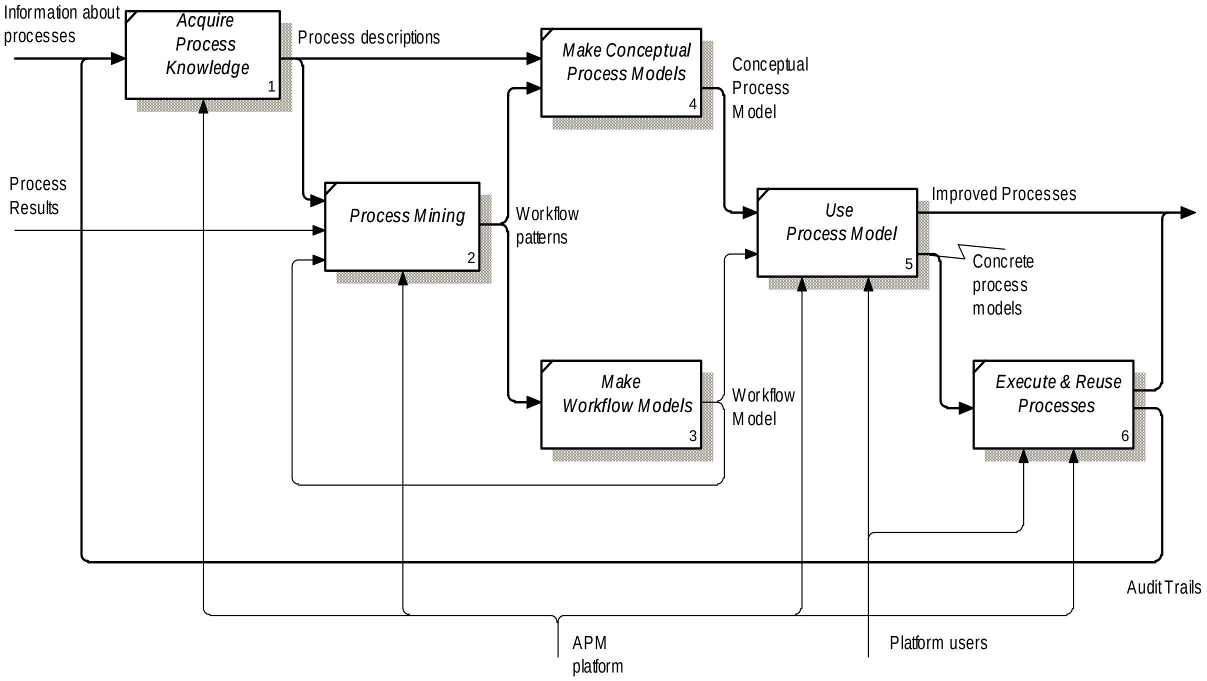


FIG. 7: Schematic presentation of the suggested framework for Active Process Model supported collaboration.

The top level ICOMs (Input-Control-Output-Mechanism) expose the following important characteristics of an APM: *inputs* (I) to the APM framework are provided by the knowledge about processes and process results, and the *outputs* (O) should be improved processes; this is achieved through *mechanisms* (M) supported by the APM platform and its users as well as various *controls* (C) that influence the process (not included in the diagram for the sake of clarity). The APM framework consists of five major activities (FIG. 7):

- *Acquire Process knowledge*: This activity concerns the acquisition of process knowledge that results in identified workflow patterns. The workflow patterns are then used in process mining procedures as well as for conceptualization of processes. Knowledge about processes is acquired dynamically through the APM platform by tracking the activities of the users. Information about processes may come from outside the system or as a feedback from the system.
- *Process Mining*. This activity takes into account already identified workflow patterns as well as raw process data captured by the APM platform, together with information about the process itself – process mining algorithms take into account process results. Process mining can detect workflows from the process data and/or from metadata in non-process data.
- *Make Conceptual Process and Workflow Models.* Worflow patterns can be used for conceptualization or for workflows. Conceptualization applies uses abstraction mechanisms that enable role-task assignments, and conceptualization of process with dependencies.
- *Use Process Model.* Conceptualized process models and workflows can be used in many ways: directly in the platform, as an enactment mechanism or traditional workflow application on top of document management systems, as a visual representation providing efficient learning material, or as part of a decision support system. The main outputs are audit trails and improved process specifications for later reuse.
- *Analyze Use of Process Models.* In this activity audit trails are used as input to provide feedback on the use of the APMs.

4.1 Active Process Modeling

In short, active process modeling (APM) is “the process modeling for real-time enterprise collaboration”. Snowdon (1995) was the first to make a distinction between the three principal types of process models: (1) passive models, (2) active models that are passive, and (3) active models. Warboys (1999) further defined an active model as the one constructed in a modeling medium which *allows the modeling relationship to be maintained, even though elements of the subject may change*. APM is characterized by:

- *Enactment* – the model actively affects the behavior of its subject system,
- *Adaptability* – the model actively changes in response to changes in its subject system,
- *Learnability* – the model has the ability to learn from the processes,
- *Predictability* – the model can predict activities based on the history of captured processes,
- *Interoperability* – the model and/or its parts are reusable and interoperable.

These features of active process models are the basis for development of real-time process-centered information management tools that would enable real-time capture, reuse, conceptualization, customization, later reuse, and improvement of processes through their process models.

Furthermore, active process models can provide a bridge between the two types of models using automated analysis of workflow patterns. This can be enabled by: (1) the media in which processes are modeled, (2) the workspaces in which processes are carried out, and (3) the real-time paradigm of collaboration used. Moreover, active process models can offer support in all stages of problem solving, and therefore enable:

- easy recognition of problems,
- identification of objectives,
- establishing criteria,
- gathering data,
- adequate provision of applicable workflow patterns,
- enactment of selected processes.

One of the most important aspects of active process model systems is the combination between conceptual models and concrete, enactable process models, i.e. workflows.

4.2 Conceptualized Workflow Patterns

According to the taxonomy outlined in section 2.2, we can use process models at different granularities – from workflow models to high-level conceptual process models. *Conceptualized workflow patterns* provide a mapping between different models through simplified views of processes represented for a specific purpose. Conceptualized workflow patterns are therefore defined by history and purpose. Different models can be used interchangeably – workflows, event–process chains, cause-effect, IDEF diagrams, etc. Diversity in representation granularity is among the main advantages of an APM framework as it provides both conceptual and dynamic, runtime modeling support. An example for the individualization of a generic process model is demonstrated in (Scott & Schachter 2005) but there are several more aspects needed to utilize conceptualization of workflow patterns efficiently. Basically, the following two major issues need to be addressed:

- *Horizontal and vertical abstraction mechanisms*. Abstraction mechanisms are provided through definition of canonical forms on different levels. They must embed rules that allow for m:1 mapping of assignments of concrete actors and concrete tasks, assignments of tasks to specific roles, and vertical mappings between organizational, process and workflow models as illustrated in FIG. 8.
- *Identification of context and content for the end user*. The main purpose of the conceptualized workflow patterns is not to automate the work, but to provide conceptual descriptions of actual workflow instances that embed a specific organizational model. These conceptualized models can be used by man or machine and may be effectively applied in known contexts and contents.

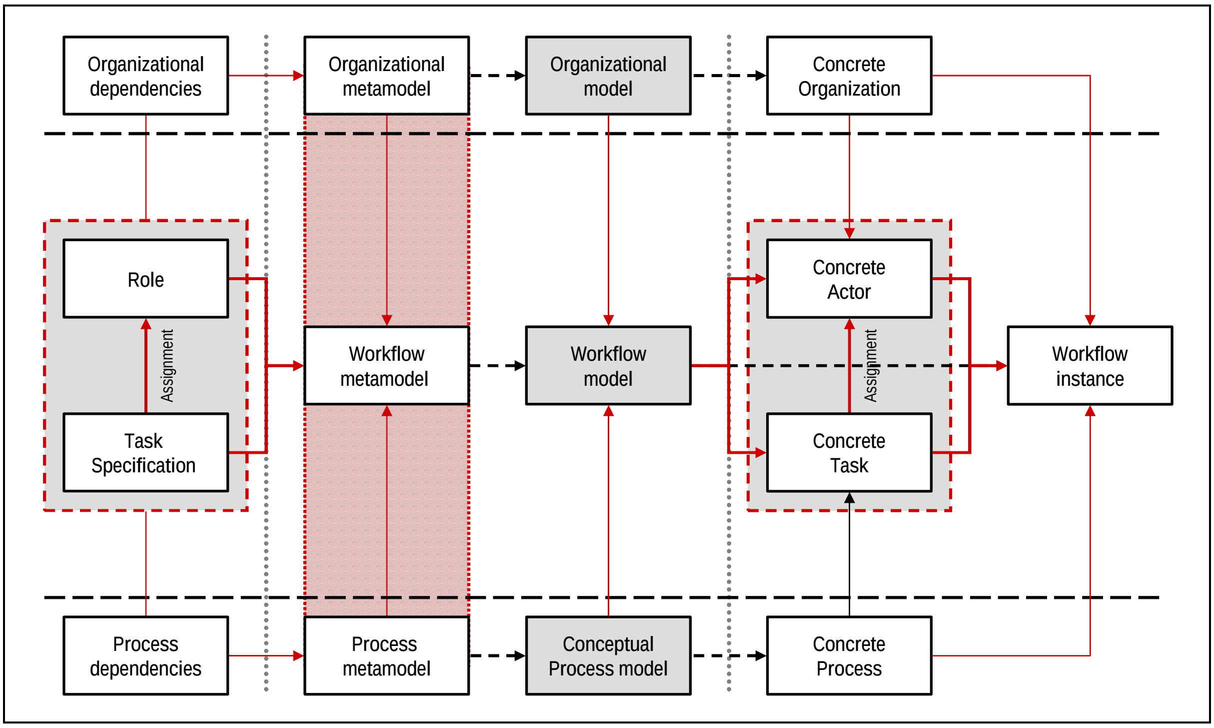


FIG. 8: Relationship between conceptual models and workflow models (adapted from Lei & Singh 1997).

4.3 Process Conceptualization via a Process Centered Business Intelligence Approach

Process Centered Business Intelligence (PCBI) is a new framework that enables conceptualization of the HOW and WHAT. It refers to the web-mediated approach integrating three interrelated components for effective dynamic collaborative problem solving in virtual environments:

1. business intelligence with data mining,
2. process mining techniques, and
3. real-time decision support systems (DSS).

PCBI extends this traditional approach through *process-oriented analysis*. Whilst the methods and algorithms that can be used for the analysis of process and data can often be the same (i.e. distances, clustering mechanism, frequency-based analysis such as shopping basket analysis, etc.), it is essential that they are supported by analyses of product models. The envisaged features of PCBI are illustrated on FIG. 9 below through definition of components and exemplary applications. These features are shortly discussed in the following subsections.

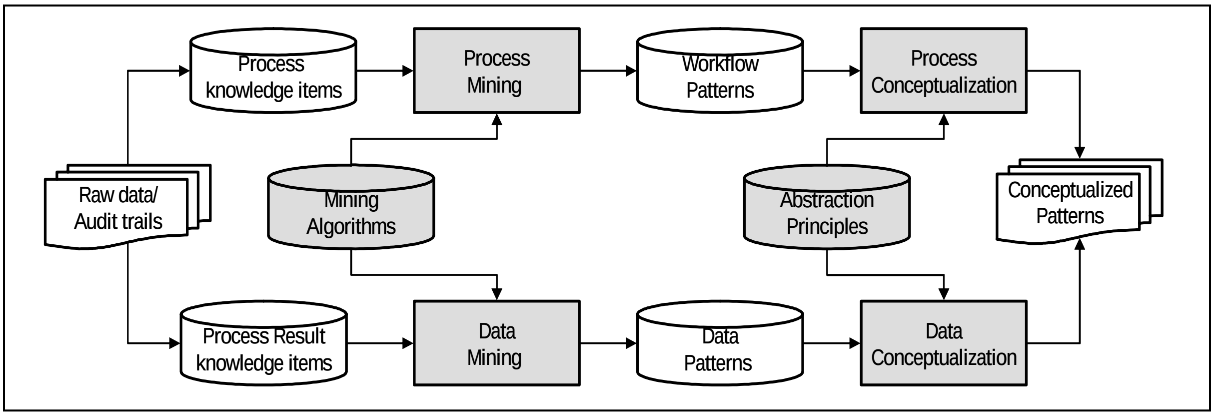


FIG. 9: Major components of Process Centered Business Intelligence.

Business intelligence (BI) generally refers to the process of transforming the raw data companies collect from various operations into usable information (Quinn, 2003). Since data in its raw form is of fairly limited use, companies are increasingly electing to use business intelligence software to realize their data's full potential. BI software comprises specialized computer programs that allow an enterprise to easily aggregate, manipulate, and display data as actionable information, or information that can be acted upon in making informed decisions. BI is a broad category of applications and technologies for gathering, storing, analyzing, and providing access to data to help enterprise users make better business decisions. BI applications include the activities of decision support systems, query and reporting, online analytical processing (OLAP), statistical analysis, forecasting, and data mining. However, the information that is candidate for mining processes in the context of construction projects is very diverse: from CAD data to schedules, diaries and technical specifications. Thus, the traditional understanding of BI was limited mostly on knowledge produced as process results and not on the processes themselves.

Newer developments as e.g. in the EU projects InteliGrid and VIVACE (Katranuschkov & Gehre 2006, Lindahl 2005) or the IDM project in the IAI BuildingSMART initiative (Wix 2005) put forth the concept of *business objects* to enable more efficient support of the business process than traditional workflow approaches. InteliGrid emphasizes the use of shared ontological representations, VIVACE focuses more on the information resources and their inter-relationships in the business process, and IDM is mainly interested in the relationship between process and Building Information Model (BIM), especially with regard to the definition of process-related IFC views. However, whilst definitions, terminology and methods vary, common to all these efforts is the idea of process-centric information and services integration. According to that, the process – represented as an object with associated meta descriptors – binds together into a uniform ontological representation the information resources used and created in the process, the involved actors, the tools and services used, and the deliverables produced. This can potentially enable: (1) reasoning about the process and its resources, (2) definition of formalized process templates that can be used for specific workflow instantiations, (3) integration of various services like data and process mining, statistical analyses etc. within a uniform approach, and (4) use of business objects as quasi "off-the-shelf" building blocks in component-based inter-organizational decision support systems.

Process Mining (PM) refers to techniques and algorithms used for discovery of raw process data, such as workflows and audit trails as well as conceptual models. Typical examples include pattern recognition by Dependency / Frequency Tables (DFT) containing frequencies of different tasks individually in relation with their predecessors, successors and causality (Weijters & Aalst 2001). A DFT table can be successfully applied for semi-automatic generation of process models, but not for conceptualization. Process mining techniques are also used in the field of bioinformatics – for discovery of structured multidisciplinary care plans. Lin et al. (2000) have developed a process mining technique for mining time dependency patterns for discovery of clinical pathways. The solution to these problems can also be applied to the problem of providing support for DDM in the context of AEC. The uniqueness of the solution is in particular in the algorithm for the analysis of directed acyclic graphs where vertexes represent time and nodes transition between times, and not events, as most frequently used.

It is important to note that process mining consists of several steps, where most important for APM are the preprocessing of raw process data with feature extraction, process data analysis, and process visualization. For the purposes of process mining standard data mining algorithms can be readily applied, such as clustering algorithms including hierarchical and k-means clustering, algorithms for finding association rules, and other learning algorithms. These algorithms are easily accessible via open source packages like WEKA (Witten & Frank 2005), where one can find a plethora of available algorithms including the above mentioned and several others useful for APM (classification tasks through Bayesian Networks, decision trees ID3, regression instance-based learning schemes, etc.). Solving the visualization task is less obvious as it goes far beyond existing visualization techniques. It requires to take into account the subject of mining processes, namely the process model itself. Thus, successful mining of workflows would result in a conceptual process model, but how to visualize that result is not at all trivial. Here much more work needs yet to be done.

Decision support systems (DSS) are another important part of PCBI. They combine both BI and PM as well as other methods. DSS for single use are well established, in contrast to group (or intra-organizational) and inter-organizational DSS which are not very widespread. An interesting example of inter-organizational DSS is the emergency collaboration platform ENSEMBLE developed at ISPRA (Bianconi et al. 2004). It combines the following three features: (1) simulation through forecasting using different models, (2) spectrum of different scenarios that affect the decision making process, and (3) multinational and multi-institute collaboration. ENSEMBLE provides an efficient, web-based solution of multi-institute collaboration for long range transport and dispersion forecasts in the event of release of radioactive material. The principles of the developed system could serve for any type of problems that require real-time consultation of large amounts of information produced by a number of remote sources and tools since it provides accessibility to several model results and real-time verification of the models' quantitative and qualitative predictions.

Recent innovative techniques in real-time support systems for AEC come from the area of transport management (Zografos et al. 2002, Tavana 2004). Hernandez & Serrano (2000) suggest a framework for application to real-time traffic management – an intelligent system based on a reflective knowledge model for human-computer interaction with three classes of questions that are especially relevant for decision support of effective systems, i.e.: (1) "What is happening?" (2) "What may happen?", and (3) "What should be done?". The core of the system is based on a reflective architecture where a meta-level layer dynamically configures reasoning strategies.

Developed DSS can be measured by their *effectiveness* (output of the DSS) and *efficiency* (best possible use of resources). They can vary considerably in complexity. An evaluation method according to steps of decision making is described in (Phillips-Wren et al. 2004), and a methodology for defining, modeling and measuring complexity is described in (Coskun & Grabowski 2001). The latter address *Embedded Intelligent Real-time Systems* (EIRTS) which are introduced into safety-critical large scale systems to improve the system's reliability and safety, and to reduce the risk of accidents or mishaps. EIRTS are interesting since they exhibit characteristics of embedded systems, intelligent systems and real-time systems, show how to communicate with larger systems, process data and produce results based on intelligence, and complete their work in real-time. The developed metrics includes: (1) Architectural / Structural Complexity, (2) Data Processing / Reasoning / Functionality Complexity, and (3) User Interface and Decision support / Explanation complexity.

5. PROTOTYPE APM PLATFORM

This section outlines a suggested APM platform based on the above considerations, the anticipated user needs, the goals to be achieved, and the related technological and technical requirements. It presents a generalized ICT architecture and provides two early prototype examples that are primarily intended to illustrate the developed concepts in more practical terms. Implementation work is at the very beginning and there is yet a long list of related issues that require further research and development efforts to achieve a real production environment.

5.1 User Needs and Goals

With regard to the user needs and goals the envisaged APM platform should provide:

- infrastructure enabling rapid establishing of interdisciplinary ad-hoc teams, aligning different stakeholders and tools to pull required discipline and project knowledge,
- instant team-focused communication infrastructure enabling real-time communication and collaboration,
- easy combination of projects' internal and external roles through collaboration and interoperability among the stakeholders, as well as their enterprise networks,
- pervasive information availability, i.e. team-specific access and retrieval of relevant information from all lifecycle phases and all related enterprise networks,
- capabilities for mobile teamwork, particularly considering requirements of safety at work and life-cycle management tasks such as monitoring, maintenance, redesign, etc.,
- capabilities for process reuse including advanced features like finding similar processes by given output information type of the process, type of stakeholders, used resources, or other process parameters,
- user-friendly profile-based access to the information.

5.2 Use Case Summary

Use case modeling for the APM platform includes the following actors, principal uses cases, and their triggers:

- *Actors.* The actor roles that are defined in the process matrix approach are adopted as actors in the identified APM specific use cases. However, additional actors may also be considered if a need arises.
- *Use cases.* The main use cases that give identity to the APM platform are as follows:
  - Multimodal ad-hoc project communication: Audio-visual communication with document sharing and other project data (i.e. tasks, calendar, finance) should be enabled
  - Customize working space: Context is based on created profile and personalization features
  - Enact – Capture – Monitor process: Project collaboration activities are dynamically captured and monitored
  - Conceptualize process: Processes that are captured can be conceptualized.
  - Use existing process templates: Existing processes are (re-)structured in the form of configurable templates and stored for future reference and reuse.
- *Triggers.* These are events that would trigger execution of a respective use case on the APM platform on the basis of constant observations of the communicated data, typically using an agent-based approach. Such events may be triggered automatically, in the case of some possible failure, or manually, in account of specific project needs or external influences.

Thus, whilst use cases basically correspond to the main activities in the APM framework shown in FIG. 7, their enactment is dynamic, depending on the specific project situation and/or team needs.

5.3 Technological and Technical Requirements

Several technological and technical requirements that need to be considered in the development process can be derived by analysis of the user needs and the principal use cases for the APM platform.

Technological requirements include:

- Consideration of hybrid decentralized environments – since different collaborative environments require different modality, it is essential that different collaboration environments are supported; important sub-issues here are:
  - balanced use of Push and Pull Technology,
  - platform independence with open API.
- Provision of a software infrastructure that:
  - is highly generic and reusable in any context of one-of-a-kind industries and services,
  - is ontology-based, to enable the semantic interoperability of the involved business services,
  - can wrap up heterogeneous information sources including external legacy applications,
  - supports dynamic on-demand creation, management, and control of sustainable teams of different stakeholders,
  - provides fast, ad-hoc creation of workflows focusing on the specific team-oriented tasks on the basis of project wide knowledge, local context and predefined process templates.

Technical requirements include:

- Federated identity management: techniques allowing users to utilize personal(ized) information across systems.
- Security services: all basic security services must be endorsed, with special attention to confidentiality.
- Process information retrieval: provision of mechanisms that enable information retrieval techniques to be used in the framework of processes.
- Traceability of interconnected processes.
- Information characterization by type of process.
- Extended presence awareness with activity awareness.

5.4 High-Level Conceptual Architecture

The suggested high-level architecture of the system is divided into four main, dynamically linked layers (FIG. 10):

- *Knowledge layer* with two sub-layers representing a) knowledge about processes, and b) process results as containers of knowledge.
- *Tools and services layer*, providing utilization of specific user needs during collaborative activities and personal work.
- *Organizational layer*, containing different intra-organizational schemes matching the project specific organizational scheme.
- *Project layer*, providing project-related linkage between the components influencing the completion of the project.

These components are combined through different communication channels and supported by APM features.

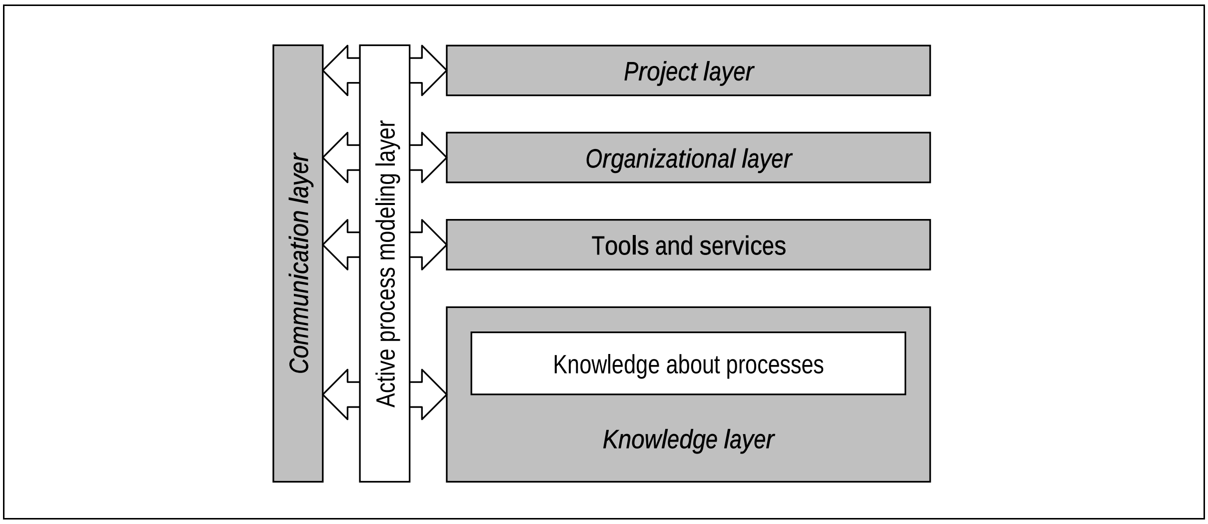


FIG. 10: High-level APM conceptual architecture.

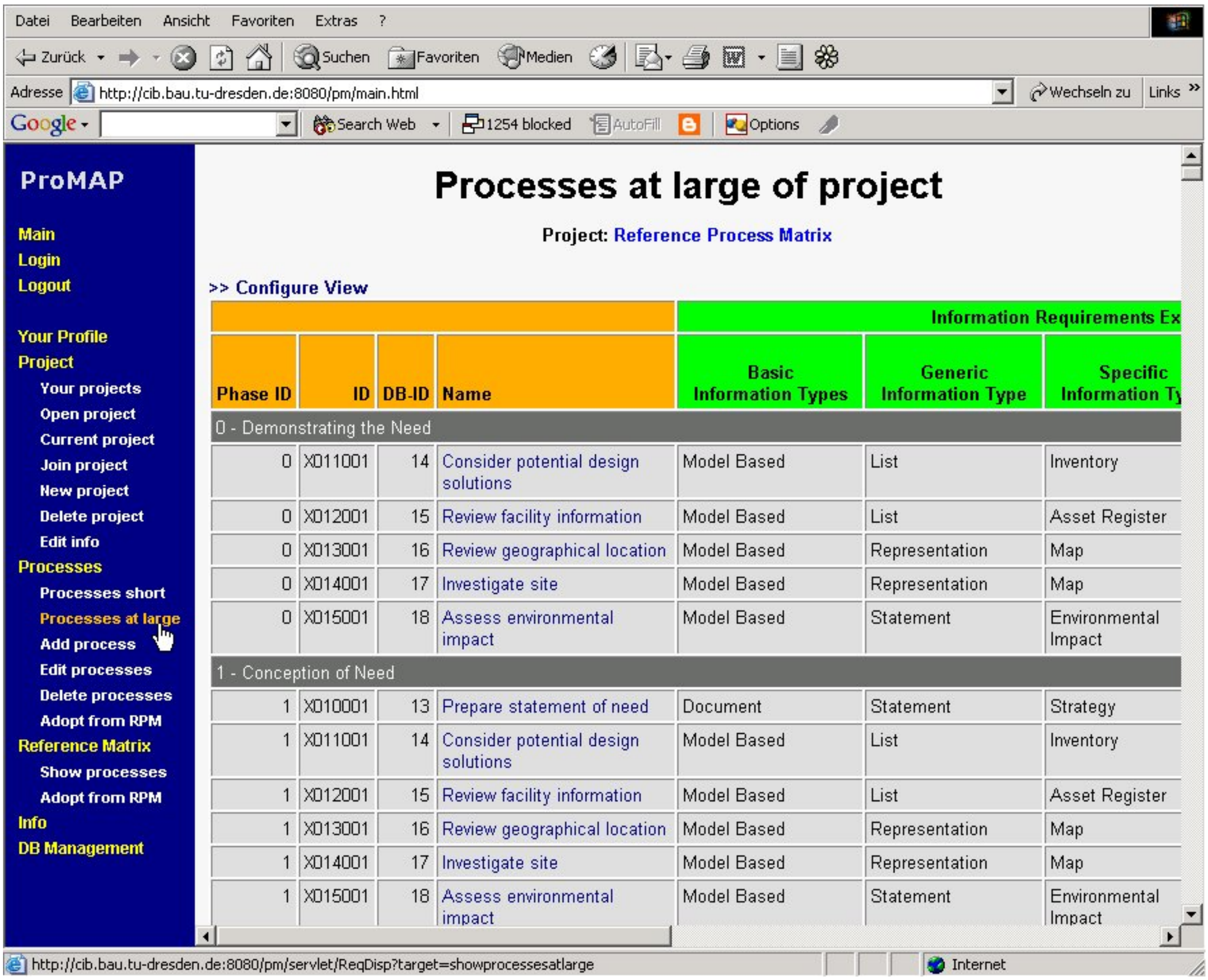
The vertical *communication layer* with multimodal communication is connected to the four horizontal layers via an *active process modeling layer*. Such conceptual architecture, based on the understanding of project collaboration processes – and how this processes are modeled – can support capturing, analysis and reuse of processes, and process knowledge generated in teams, or individually using different tools and services available through the platform. An important role is given to organizational issues supporting the project. Any type of communication in collaboration and

5.5 Discussion on Early Prototypes

For the early assessment of the developed concepts, two rapid prototypes have been realized:

1. Web-based prototype based on the process matrix approach, and
2. APM prototype P2P collaboration platform, matching architectural foundations and requirements.

Process Matrix Prototype. Within the EU project ICCI a prototype implementation of the Process Matrix, named ProMAP, has been realized mainly for the purposes of user requirements capture in distributed Web-based environments (see FIG. 11). It supports process and requirements capture in two ways. On the one hand, a new process can be created by entering a fresh set of mandatory data (process name, actors, basic information purpose etc.) and then storing the new process into the ProMAP database. On the other hand, processes can also be adopted from a pre-defined reference process matrix which offers a shopping list of reusable process templates. This provides for a light-weight implementation of the conceptualized workflow patterns described in section 4.2.



Processes at large of project

Project: Reference Process Matrix

>> Configure View

				Information Requirements Ex		
Phase ID	**ID**	**DB-ID**	**Name**	**Basic Information Types**	**Generic Information Type**	**Specific Information Ty**
0 - Demonstrating the Need						
0	X011001	14	Consider potential design solutions	Model Based	List	Inventory
0	X012001	15	Review facility information	Model Based	List	Asset Register
0	X013001	16	Review geographical location	Model Based	Representation	Map
0	X014001	17	Investigate site	Model Based	Representation	Map
0	X015001	18	Assess environmental impact	Model Based	Statement	Environmental Impact
1 - Conception of Need						
1	X010001	13	Prepare statement of need	Document	Statement	Strategy
1	X011001	14	Consider potential design solutions	Model Based	List	Inventory
1	X012001	15	Review facility information	Model Based	List	Asset Register
1	X013001	16	Review geographical location	Model Based	Representation	Map
1	X014001	17	Investigate site	Model Based	Representation	Map
1	X015001	18	Assess environmental impact	Model Based	Statement	Environmental Impact

FIG. 11: Screenshot of ProMAP showing a part of the pre-defined reference matrix, including reusable processes.

This prototype implementation of the Process Matrix approach clearly showed that there are many more opportunities to inter-link the various entities in the overall AEC process. Wix (2005) emphasizes that the effective use of Building Information Modeling (BIM) requires the improvement of communication between the different participants in the construction process. For this to happen, there must be a common understanding of building processes, as well as understanding of the input and output information of those processes. He then concludes that “the case for a comprehensive reference to processes in building construction is clear and compelling. By integrating information with the process, the value of such a reference is greatly enhanced and it becomes a key tool in really delivering the benefits of BIM”. The Process Matrix provides a first step and a baseline to achieve such goals.

APM P2P platform. As a platform for rapid prototyping of the APM framework we have used the peer-to-peer collaboration software *Groove* (www.groove.net). It offers several of the required functionalities: real-time communication with presence indicators, instant messaging, customizable shared space which enables users to select and adjust tools according to the specific needs of the project. Groove also embeds *Groove Web Services* that enable Groove Workspace components to be Web service providers. Another important characteristic of Groove is its decentralized architecture which allows seamless integration of the peer-to-peer and client-server paradigms. The screenshot of the prototype in FIG. 12 illustrates the use of conceptual process models which are represented in the form of *hypertext*. These process models could be located anywhere on the Web and could be generated dynamically. The gathered experience showed that it is very effective to organize processes through such web services and tools. Therefore, the Groove framework can be considered as a good basis for creating a first working prototype of an APM platform.

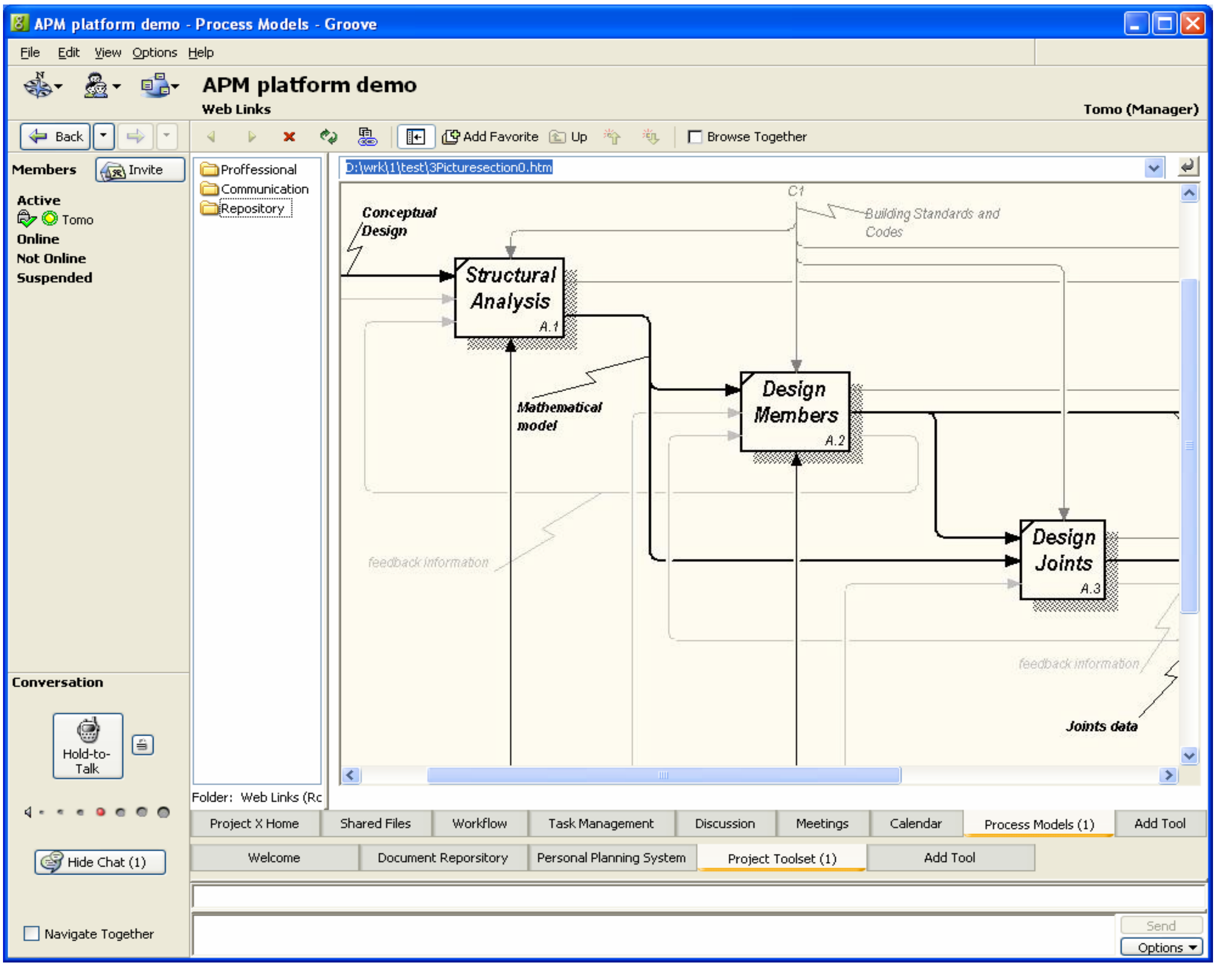


FIG. 12: The use of conceptual process model together with project toolset in APM supported platform. The prototype was implemented in the Groove P2P collaboration platform. Activities of a conceptual process model can be hyperlinked to tools or workflows that enable execution of specific activities.

One important aspect of the early APM platform prototype is the concept of a *virtual project workspace*. A virtual workspace has a Tool Container (Project Toolset), which can be customized and referenced within the platform. FIG. 12 shows the use of a conceptual process model as presented to the end user. The process model is a hypertext representation of conceptual IDEF0 diagram through which s/he can conceptual view sub-processes. In such a way user is able to learn about the processes and its task he or she has to complete. The conceptual model can be hierarchically decomposed into sub-processes, or can be linked to concrete workflows, or software programs that will enable user to complete the tasks. The best tool, or workflow for a specific task must be available in the Tool Container. Since activities, performed on the APM platform, can be captured, the platform would also be able also to suggest a tool or workflow that was used in the past.

This feature also enables use of the platform as a learning environment. Another major advantage of the Groove-based APM platform is the inclusion of complete audiovisual communication facilities; it can easily embed more communication channels, warranting reasonable access rights and security management. Thus, alongside the Groove client, a thin SOAP server runs in the background taking care to any external communication with other clients or third party applications. A SOAP port is provided to all main tools including projects, calendars, meetings, discussions, etc. In this way it is easy to integrate other services and publish/pull data to/from other resources on the Web. The published WSDL specifications grant all needed information to the developer. This Web Services approach provides an interesting possibility to combine a P2P environment with external web services through a single client. For example, an external web service that monitors progress on the project used only by one platform user would enable all peers in the project workspace to be automatically informed.

A first assessment of the prototype shows that a Groove collaboration platform with web services can meet many of the stated technical requirements (related to ad-hoc-ness, reusability, multimodal communication etc.), and is inline with the envisaged conceptual architecture. A major disadvantage is the operating system dependency – Groove Virtual Office runs only in a Windows environment. Consequently, a Groove solution is not open, and it is very difficult to include other non-Windows tools into the platform. Even though a GDK (Groove Development Toolkit) is provided, it is hard to develop complete tools with appropriate GUI suiting the full needs of an APM platform.

6. CONCLUSIONS AND FUTURE WORK

Support for the improvement of ad-hoc problem solving in AEC collaborative environments is not yet well established. This could be improved through ad-hoc reuse of parts of processes, i.e. knowledge about prior processes. In the paper we gave an overview of relevant techniques and suggested a framework for further developments. The suggested approach has two major innovative aspects:

1. Active process model supported platform that is characterized by:
    - combined real-time use of two paradigms: a) data centered, and b) process centered,
    - flexible, variable modeling media in which processes are modeled and in which models are used, thereby leading to a hypermedia active process model,
    - infrastructure supporting the real-time paradigm.
2. Enabled diversity of process models through concurrent use of several process modeling techniques, thereby providing for:
    - coexistence of process models of different granularity – from event process chains and workflow models to conceptual process models,
    - coherent use of conceptualized workflow patterns – repeating patterns can be used to generate conceptual process models,
    - customized process models – conceptualized process models can be customized for specific purposes using specific representation formats.

Techniques supporting such kind of platforms need to include different PCBI related components, such as data mining, process mining, and adequate real-time decision support. However, whilst the first two are highly generic and therefore readily reusable, the latter is tied to the targeted business domain.

Finally, it is important to emphasize two further aspects: (1) *Learning*, and (2) *Business Process Reengineering*. It is essential to be aware of the potential of APM platforms for the improvement of organizational learning. Considering that each recognizable process should be considered as learning process, the two most important facilitating factors for adoption of APM supported collaboration are identified as follows:

1. *The platform should support organizational learning.* This means that it should evolve towards a knowledge platform providing information on knowing what, knowing why, knowing how, and knowing who. The APM platform can be very effective in providing information about knowing how – since process models directly address that kind of knowledge.
2. *Conceptual process models facilitating learning.* Generic processes that are automatically conceptualized workflow patterns or ad-hoc conceptual process models can be very strong teaching tools.

The presented research is ongoing work that is still in an early stage. Planned future developments can be subdivided into three directions:

1. *Process centered business intelligence*. Provision of business intelligence for product models covering the development of algorithms as well as other relevant technical data using OLAP and data mining techniques. Here especially methods for defining process similarity are of interest. Hence, canonical forms should be more developed.
2. *Human-computer interaction*. Study of suitability of different process modeling techniques and their representation for use in digital media for different purposes.
3. *Study of adoption factors*. Adoptability of new ways of working is another aspect that requires more consideration – facilitating factors and critical success factors need yet to be established.

7. ACKNOWLEDGEMENTS

An earlier shorter version of this paper was presented at the CIB W78 22nd International Conference on Information Technology in Construction, held in Dresden, Germany, in July 2005 (cf. Cerovsek & Katranuschkov 2005).
Part of the presented work has been enabled through the support of the European Commission in the EU Projects ICCI (IST-2001-33022) and InteliGrid (IST-2004-004664). This support is gratefully acknowledged. The authors wish also to thank the reviewers for their useful comments, which helped them to improve the quality of the paper.

8. REFERENCES

Bianconi, R., Galmarini, S. & Bellasio, R. 2004. Web-based system for decision support in case of emergency: ensemble modelling of long range atmospheric dispersion of radionucleides, *Environmental Modelling & Software* 19(4), April 2004, pp. 401-411.

Björk, B.-C. 1999. Information technology in construction: domain definition and research issues. In: C. J. Anumba, (ed.), *Computer Integrated Design in Construction*, vol. 1, SETO, London, UK, pp. 3-16.

Cerovsek, T. 2003. *Distributed Computer Integrated Construction* (in Slovene). Doctoral Thesis, University of Ljubljana Ljubljana, 308 p.

Cerovsek, T. & Katranuschkov, P. 2005. Active process model supported collaboration. In: Scherer, R. J., Katranuschkov, P. & Schapke, S.-E. (eds.) *Proc. 22nd CIB-W78 Conf. "Information Technology in Construction"*, Dresden, 19-21 July, publ. by Insitute for Construction Informatics, TU Dresden, Germany, ISBN 3-86005-478-3, CIB Publ. No. 304, pp. 97-104.

Cerovsek, T. & Turk, Ž. 2004. Working together: ICT Infrastructures to support collaboration. In: Beucke, K. et al. (eds.) *Proc. Xth Int. Conf. on Computing in Civil and Building Engineering (ICCCBE-X)*, Weimar, Germany, June 02-04, ISBN 3-86068-213-X, 12 p. (available on CD-ROM).

Coskun, E. & Grabowski, M. 2001. An interdisciplinary model of complexity in embedded intelligent real-time systems, *Information and Software Technology* 43(9), pp. 527-537.

Ekholm, A. 1996. A Conceptual Framework for Classification of Construction Works , *ITcon*, Vol. 1, pp. 25-50, http://www.itcon.org/1996/2

Gonzalez, C. 2005. Decision support for real-time, dynamic, decision making tasks. *Organizational Behavior and Human Decision Processes* 96(2), March 2005, pp. 142-154.

Hernández, J. Z. & Serrano, J. M. 2000. Reflective knowledge models to support an advanced HCI for decision management, *Expert Systems with Applications* 19(4), Nov. 2000, pp. 289-304.

Kalay 2004. *Architectures New Media*. MIT press, Cambridge, USA, 536 p.

Katranuschkov, P. & Gehre, A. 2006. *InteliGrid Business Process Ontology – Overview and Approach.* InteliGrid PowerPoint Presentation, Kranjska Gora, 24 Jan 2006, © InteliGrid Project, 30 slides.

Katranuschkov, P., Gehre, A., Scherer, R. J., Wix, J. & Liebich, T. 2004. User requirements capture in distributed project environments: a process-centred approach. In: Beucke, K. et al. (eds.) *Proc. Xth Int. Conf. on Computing in Civil and Building Engineering (ICCCBE-X)*, Weimar, Germany, June 02-04, ISBN 3-86068-213-X, 12 p. (available on CD-ROM).

Katranuschkov, P., Wix J., Liebich, T. & Gehre, A. 2002. *Collected End User Requirements and Common Structure, Part I – Description of Methodology and Requirements Synthesis.* Deliverable D121, EU Project IST-2001-33022 (ICCI), 68 p.

Lei Y. and M.P. Singh. 1997. A comparison of workflow metamodels. In *Proceedings of the ER97 Workshop on Behavioral Modeling*, Proceedings of the ER'97 Workshop on Behavioral Models and Design Transformations: Issues and Opportunities in Conceptual Modeling 6 - 7 November 1997, UCLA, Los Angeles, California, USA.

Lin, F., Chou, S., Pan, S. & Chen, Y. 2000. Time dependency patterns in clinical pathways. In *Proc. 33rd Hawaii International Conference on System Sciences*, Hawaii, USA.

Lindahl S. (ed.) 2005. *Virtual Enterprise Collaboration Hub – Services Description*. Deliverable D3.6.2_1, EU Integrated Project VIVACE, Doc. Number: VIVACE-3.6-2-ECS-T-05007 v1.04, © VIVACE Consortium Members, 49 p.

Phillips-Wren, G. E., Hahn, E. D. & Forgionne, G. A. 2004. A multiple criteria framework for evaluation of decision support systems. *Omega* 32(4), August 2004, pp. 323-332.

Quinn, K. R. 2003. *Establishing a culture of measurement. A practical guide to BI.* © 2003 Information Builders Inc. 23 p.

Rosenmann, M., Recker, J., Indulska, M. & Green, P. 2005. *Process Modeling – A Maturing Discipline?* Tech. Report, Centre for IT, Queensland University of Technology, 46 p.

Scherer R. J., Katranuschkov, P. & Wix, J. 2004. A Method to Meet Business and User Requirements with ICT Standards for eBusiness and eWork. In: Thoben, K.-D., Pawar, K. S. & Weber, F. (eds.) *Proceedings of the 10th Int. Conf. on Concurrent Enterprising (ICE 2004),* 14-16 June, Seville, Spain, published by Centre for Concurrent Enterprising, University of Nottingham, UK, ISBN 0-85358-128-2, pp. 345-356.

Scott, G. C. & Shachter, R. D. 2005. Individualizing generic decision models using assessments as evidence. *J. of Biomedical Informatics,* available online 2 Feb. 2005, 12 p.

Snowdon, R. A. 1995. *Overview of process modeling.* ICL Processwise Portfolio Centre, Kidsgrove, UK & Informatics Process Group, Manchester University, UK.

Tavana, M. 2004. Intelligent flight support system (IFSS): a real-time intelligent decision support system for future manned spaceflight operations at Mission Control Center. *Advances in Engineering Software* 35(5), pp. 301-313.

Warboys, B. 1999. *Business information systems: a process approach*. McGraw-Hill, 262 p.

Weijters, A. J. M. M. & van der Aalst, W. M. P. 2001. Process mining: discovering workflow models from eventbased data. In: Kröse, B., De Rijke, M., Schreiber, G, & van Someren, M. (Eds.) *Proc. 13th Belgium-Netherlands Conf. on Artificial Intelligence (BNAIC 2001).* Maastricht, NL, pp. 283-290.

Wix, J., Liebich, T., Katranuschkov, P. & Gehre A. 2003. A Process-Centred Approach to Product Model Development. In: Cha, J., Jardim-Goncalves, R. & Steiger-Garcao, A. (eds.) *Concurrent Engineering: The Vision for the Future in Research and Applications,* Proc. of the 10th ISPE Int. Conf. on Concurrent Engineering: Research and Applications, 26-30 July 2003, Vol. 1: Advanced Design, Production and Management Systems, ISBN 90-5809-524-6, Balkema Publ., Netherlands, pp. 687-698.

Wix, J. 2005. *Information Delivery Manual – Using IFC to Build SMART.*
Available from: http://www.iai.no/idm/learningpackage/idm_index.htm

Witten, I.H. and Frank, E. 2005. "Data Mining: Practical machine learning tools and techniques", 2nd Edition, Morgan Kaufmann, San Francisco, USA.

Zamli, K. Z. & Le, P. A. 2001. Taxonomy of process modeling languages. *ACS/IEEE International Conference on Computer Systems and Applications (AICCSA'01),* Beirut, Lebanon, 13 p.

Zografos, K.G., Androutsopoulos, K.N. & Vasilakis, G.M. 2002. A real-time decision support system for roadway network incident response logistics. *Transportation Research Part C: Emerging Technologies,* Vol. 10, Issue 1, Feb. 2002, pp. 118.-130.