SUPPORT OF COLLABORATIVE BUSINESS PROCESS NETWORKS IN AEC

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SUMMARY: *Projects in the building industry are extremely dynamic, driven by external conditions, modified user requirements and frequently changing business partners. Therefore, common principles should be established throughout the construction industry, which flexibly support the management of construction project information and processes. New members should be supported to easily join and leave the project consortium while still using their own ICT-applications. The need to rapidly set up such organizational structures and effectively manage these collaborative networks places high demands on the methods and models that are used to establish a common, homogeneous project structure. Therefore, this article presents an architecture for dynamic cross-enterprise processes' planning, execution and controlling on a conceptual and application level. It is based on a Collaborative Business Process Management Lifecycle for virtual enterprises. For the adaptation of the architecture to the specific requirements of the AEC&FM-domain, a feasible Construction Network Scheme for the representation of strategic inter-organizational construction project information is introduced. Within this architecture, collaborative business process modeling will be achieved by the use of pre-defined process modules. Finally, the realization of the proposed models and methods are demonstrated in an example.*

KEYWORDS: *collaborative business processes, process modules, collaboration architecture, virtual enterprises.*

1. INTRODUCTION

The realization of a construction project is a highly complex task. General conditions have become even more complicated by shortened construction times and limited budgets. However, clients in the construction market expect improved and extended offers for services around the building. Consequently, the economic situation in the construction market in Germany has become characterized by stagnating turnovers and increasing general costs. Furthermore, construction market competition has increased due to globalization and the extended European market, leading to the repression of ineffective companies.

These new market demands trigger intensive changes in working and economic conditions as well as those in social life. Adaptable and rapidly changing information and communication technologies support new patterns of work, focusing on cross-disciplinary, collaborative work. The opening up of organizational borders is no longer regarded as a necessary evil, but rather as an opportunity of strategic importance. Recently, new terms for contracts for AEC-projects have been discussed which should better support team-oriented cooperation amongst all participants in construction projects. The vision of this approach is *collaboration instead of confrontation*.

Consequently, the established methods for business process modeling and the existing information and communication systems need to be appropriately adjusted and extended with the objective of closed interlocking of the information and process management in between the organizations. This would better address the various changes of work-processes and value chains. But still, the integration of different IT-infrastructures from different partners is frequently hampered by incompatible or proprietary interfaces of their local (internal) information and communication systems. Thus, seamless information processing can rarely be accomplished at present.

The need to rapidly establish new organizational structures and effectively manage these virtual enterprises places high demands on the methods and models that are used for the coordination of project activities. Therefore, common principles should be established throughout the construction industry, allowing flexibility to specify and combine construction process information for inter-organizational collaboration. New members should be supported to join or leave the project consortium by providing them with all relevant project and process information in order to align their local processes and IT-systems to the global requirements and restrictions of the project. Thus, a common strategy needs to be established for the inter-organizational management of processes, data and IT-infrastructure of construction projects.

This article presents an architecture for dynamic cross-enterprise processes' planning, execution and controlling on a conceptual and application level. After distinguishing between local and global knowledge for the purposes of establishing a business process management lifecycle, an approach towards a common meta-model for the definition of strategic construction project constraints is presented. This will be followed by the design of an integrative architecture, which enhances adequate concepts of information and business process management to enable collaborative business integration on multiple levels. Finally, the applicability of the proposed methods and models will be illustrated by the example of errors and omissions management processes.

2. APPROACH

2.1 Views on Business Process Models

A requirement within collaborations is to keep business secrets of individual collaboration partners. The Architecture for Integrated Information Systems (ARIS) (Scheer, 1999) enables different views into business process models and allows a distinction of global process knowledge from local process knowledge (cf. Fig. 1). The vertical axis includes the organization view and the output view, which are necessary to establish a goal-oriented collaboration. It represents all collaboration partners' global knowledge (available for all network participants), while the horizontal axis represents single participants' local knowledge (available for two cooperating partners). Local knowledge is shared bilaterally between partners, i.e. additional information, like data structures and semantics, is exchanged. The information is stored in interface descriptions between process modules of the partners.

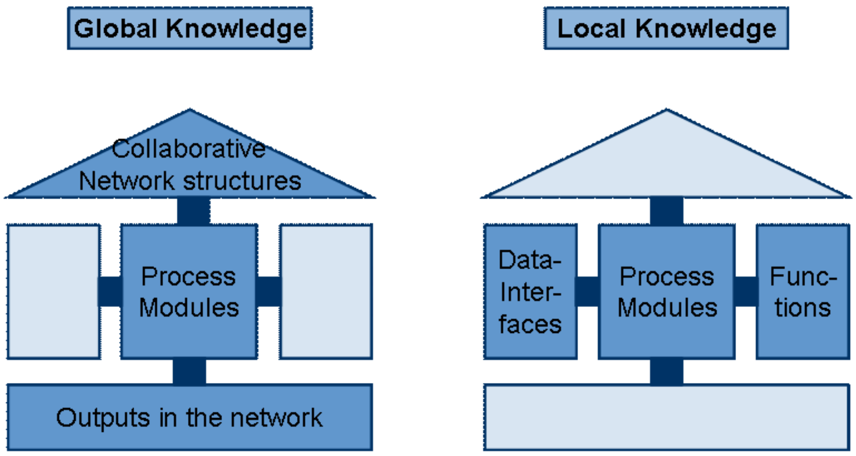

FIG. 1: Global and local knowledge in collaborations

Updates of local knowledge do not necessarily influence global knowledge. Nevertheless, changes in global knowledge have to be accessible to all partners immediately; for example, if a company leaves the network or if a product or service is no longer available within the network. Enterprise spanning business processes are not planned in detail at the strategic level, but are designed as concentrated, high-level process modules. Thus, they combine public knowledge about the collaborative processes shared by all participants. (Zang et al., 2004)

2.2 Collaborative Business Process Management Lifecycle

The lifecycle model serves as a manual for the process-oriented set-up and operation of collaborative networks. The usage of a consistent phase model and standardized modeling methods increases transparency and improves structuring of collaborations. It creates a basis for communication between participants, including management that lays down strategies, process-owners in the departments and IT-experts who integrate the different application systems. The model merges classic phase models with lifecycle models developed for virtual enterprises. Following the view concept presented before, the lifecycle alternates between phases that focus on global and local issues in order to reach a coherent solution (cf. Fig. 2).

In the first phase, *Cooperation Strategy* or formation phase, the collaboration partners are determined by the shared goals of the collaboration. To facilitate the collaborative output, graphical methods like product models (e.g. IFC) substantiate the collaboration's objectives. In addition to the characteristic features of a service or a product over its entire lifecycle, product models depict the organizational units participating in the production. By means of product trees, enterprises can conceal detailed service descriptions in an internal view that puts special focus on the organizational aspects of the product offered by the partners. In an external view, they simply provide the information required for the configuration of the common service bundle in the form of product bundle models. To support the *Cooperation Strategy*, a feasible model for the representation of strategic construction project information will be discussed in the following chapter.

Having completed the strategy finding, an existing or a new local as-is model and the *Global To-Be-Concepts* are compared in the second phase, *Local To-Be-Concept*. According to predefined conditions about collective product creation, intra-organizational business processes can be derived. Each partner considers his part in the inter-enterprise process. Starting with process modeling and optimization of process controlling up to implementation, the processes involved are aligned with the requirements of the collaborative scenario agreed upon in the former phase.

In the third phase, *Global To-Be-Concept*, coordinated public parts are allocated over the network, establishing a collective to-be concept. Each partner is able to connect his own private model with every other public process model. Each partner gains his partial view of the collaborative process, so that a virtual process chain of the whole collaboration is designed (cf. chapter 4.3). Global knowledge is described in a public interface, which can be provided by a BPMN representation. The semantic combination of the partners' models is necessary. As long as ontology-based approaches do not achieve a productive state, this combination process is an intellectual action.

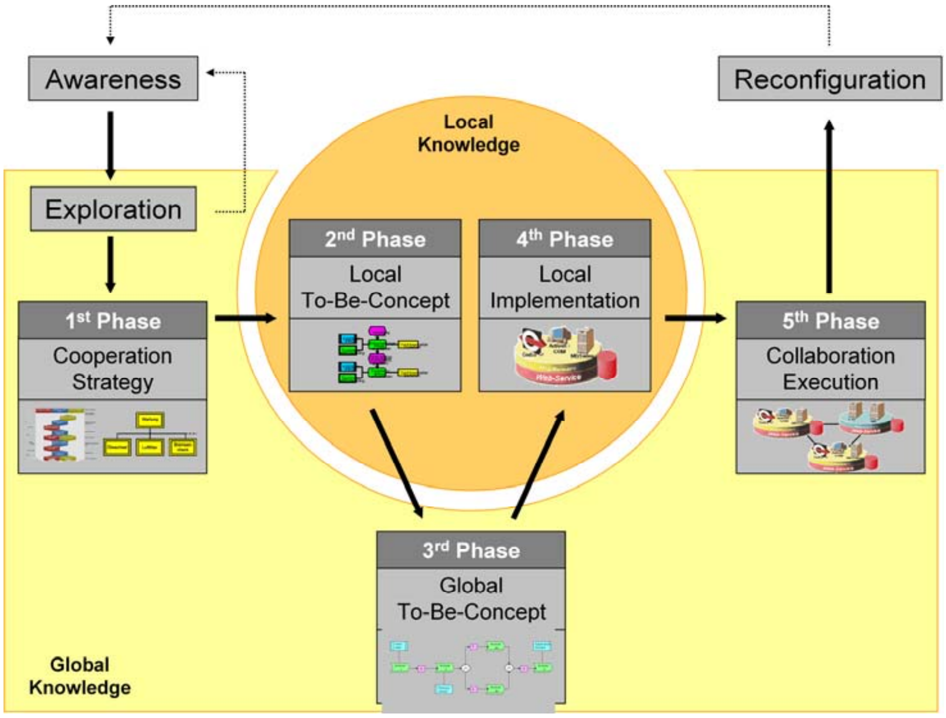

FIG. 2: Collaborative Business Process Management Lifecycle

The integrated collaborative business process model enables all partners to configure their application systems locally, in a fourth phase called *Local Implementation*. Reference systems for interfaces are provided by interface definitions of the collective to-be concept.

Now every partner is prepared for the execution of interactions within the collaborative framework (fifth phase *Collaboration Execution*). Based on bilateral bases, interacting information systems are able to communicate by using the standardized protocols and interfaces. The transactions are arranged and executed. The aim of this phase is to support collaboration through the appropriate use of information technology. Interfaces have to be configured, and inter-organizational workflows need to be implemented. At the same time, monitoring and adaptation of the collaboration have to be assured (Zang et al., 2004).

3. STRATEGIC CONSTRUCTION PROJECT INFORMATION MODEL

According to the developed *Collaborative Business Process Management Lifecycle Model*, it is essential to define the information that influences inter-organizational collaboration in the beginning of a new construction project. On this strategic level, information can basically be divided into global cooperation information and global process information (cf. Fig. 2). Thus, new partners have to be provided with all information required for the performance of their local tasks when joining a *Construction Network*. By means of this, information partners are able to define and adjust their local activities and IT-systems to the project's context.

For the representation of global cooperation information, a *Construction Network Schema* has to be developed. Such a schema should be qualified to describe and manage the global project information that influences inter-organizational collaboration. Therefore, it is firstly essential to define all constraints that influence the performance of construction networks. Thereafter, this information has to be transformed into an integrated model.

3.1 Identification of Construction Network Constraints

Construction projects are defined as complex, one-of-a-kind projects. Thus, to derive a common model for collaborative construction project management, its complexity has to be reduced by subdividing it into integral/coherent sub-projects or project views. Therefore, the entire project has to be decomposed into its controlling elements and structured in a reasonable manner.

Based on various sources, interviews and project analyses, four key dimensions that control the global project's performance have been identified: *Project Organization*, *Project Structure*, *Project Information* and *Project Phase*. The first three dimensions can be subdivided again into two categories. The dimensions and belonging categories are represented in Fig. 3.

By the dimension, *Project Organization*, the *Organizational Structures* within a project (e.g. 'general contractor' or 'joint venture') and the *Roles* (e.g. 'project manager' or 'planner') necessary for the accomplishment of the project are defined. The decomposition of the project into technical and functional aspects is realized by means of the dimension, *Project Structure*. The high-level tasks necessary for the completion of a project are defined by the category, *Function*. The category, *Building Object*, on the other hand, structures the project into spatial and/or physical sections. The dimension, *Project Information*, defines the *IT-Infrastructure* and systems for inter-enterprise information exchange, and specifies the *Information Content* that is exchanged in-between the partners.

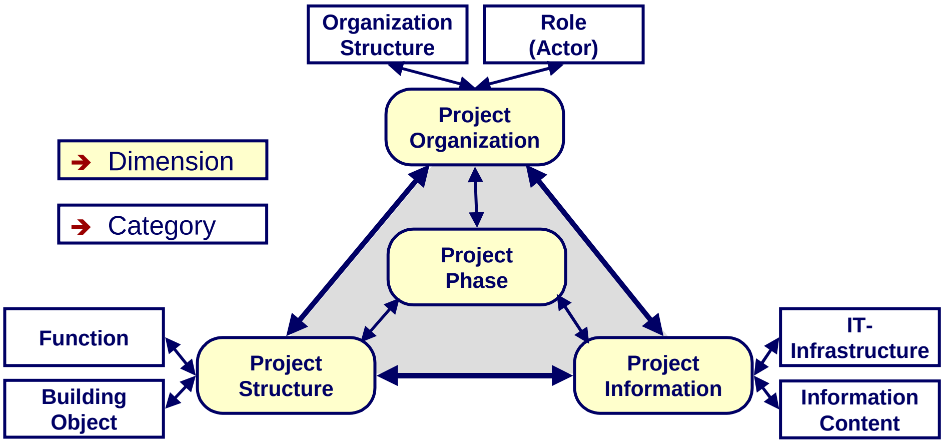

FIG. 3: Dimensions and categories to structure construction project constraints

The dimension *Project Phase* divides the project into distinct, closed periods (e.g. 'planning phase' or 'construction phase'). This dimension is of major importance in the *Construction Network*, since construction projects are strongly divided into distinct phases. The transition between phases requires an intensive re-arrangement of the overall project structure. New partners might enter the project, leading to new organizational patterns, different responsibilities and heavily modified IT-infrastructure.

For each of these categories, separated partial models have been developed or adopted from existing models like IFC or STEP AP 225. Furthermore, feasible content has been identified based on several construction projects' analysis and common building data standards. Technical regulations were also evaluated for their applicability to describe construction project constraints. This information can to be used as reference information to support the instantiation of a new project (cf. chapter 4.2). A more detailed description of the categories, their relations and content for the *Construction Network Schema* is explained in Keller et al. (2004&2005).

3.2 Design of a Construction Network Schema

The partial models of the categories identified in Fig. 3 have to be integrated into an overall/macro model, *The Construction Network Schema*, leading to a comprehensive specification of the strategic constraints of construction projects. By means of this model, the required information for collaborative project management is instantiated for a particular project; and semantic inter-operability between the categories is realized.

The general structure of the proposed model is depicted in Fig. 4. In this model, an interrelationship between the categories has been established according to the requirements identified in the project's analysis. The categories are represented by *Unified Modeling Language* (UML) package diagrams to indicate that each package can be described in more detail.

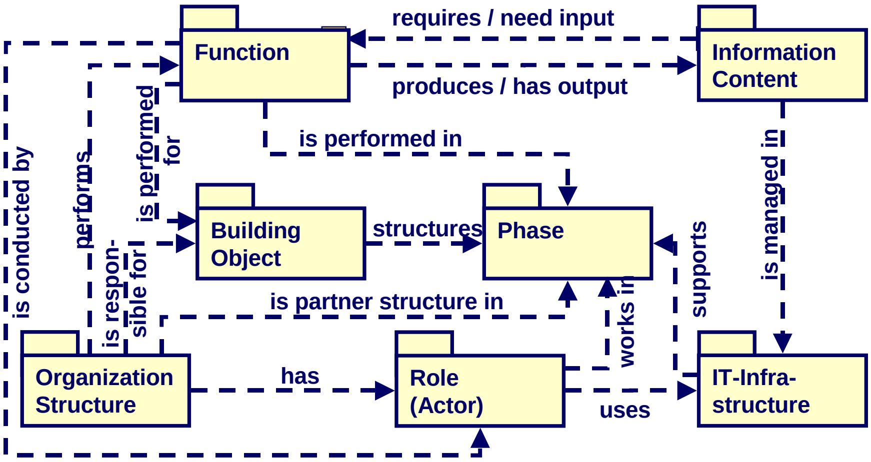

FIG. 4: Construction Network Schema

3.3 Instantiation of a Construction Network Meta-Model

In order to realize a *Construction Network* for a specific project, the classes and properties defined in the partial models have to be instantiated and their associations identified. The instantiation process is not performed randomly, but will obey certain legal, technical or organizational restrictions. Thus, the initialization of a *Construction Network Instance* for a specific project can be controlled and supported by the employment of a sequence model. Such a model assists the project partners to specify the content and relations of the different categories of the model in a structured manner. For construction projects, the sequence model should support iterations (loops), concurrency (AND-junctions) and decisions (OR-junction). Fig. 5 presents an extraction of a feasible sequence model on high level. This model is based on the UML sequence diagram notation. A more detailed description of the employment of the sequence model is given in Keller et al. (2005).

By means of the example in Fig. 5, the instantiation of a *Construction Network* might be executed as follows (simplified): After the definition of the project idea, global project goals will be specified. Next, the project will be divided into its major phases. For each phase, the organization structure and the functions, including its belonging roles and the input/output information, are defined. Following the definition of the building objects for a phase, they can be linked to a specific function.

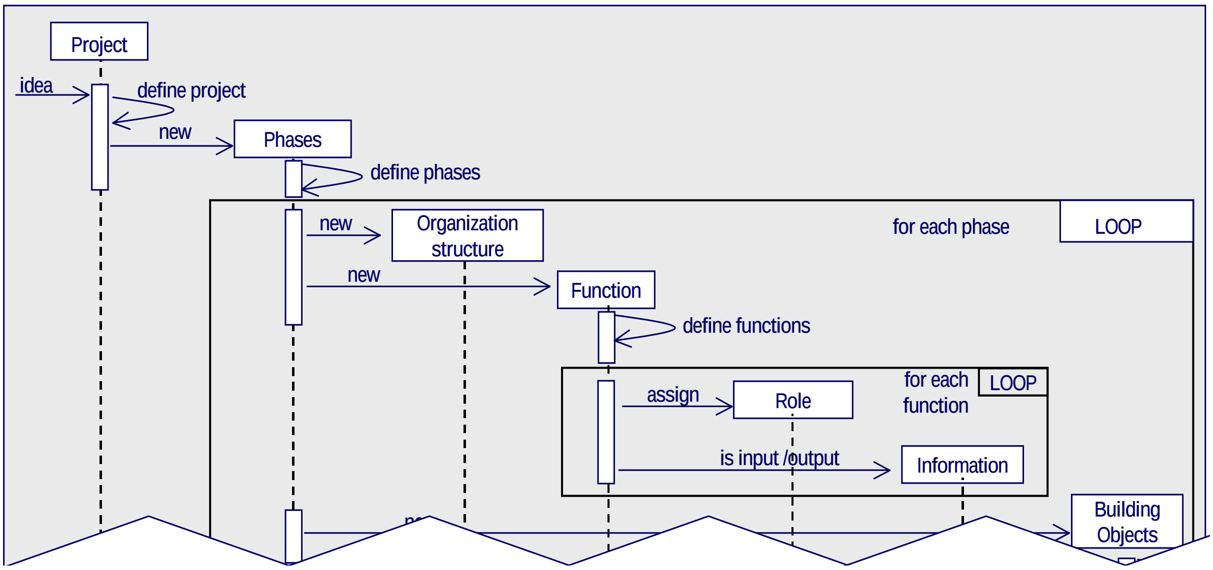

FIG. 5: Sequence model for Construction Network instantiation (extraction)

4. ARCHITECTURE FOR MANAGING COLLABORATIVE BUSINESSES

4.1 Architecture's Concept

Regarding the above-mentioned approach and the strategic construction project information model, an integrating concept for collaborative business process management has been established. It is depicted in Fig. 6.

The developed architecture considers organizational aspects and integrates existing concepts for workflow and business process management. Basic information for process execution is visualized in business process models, output models and organization models. These are created by modeling tools and stored in a distributed repository. Depending on business process models and organization models, the virtual service platform executes processes and integrates different operational systems of collaboration partners. The following sections describe components and characteristics of this architecture.

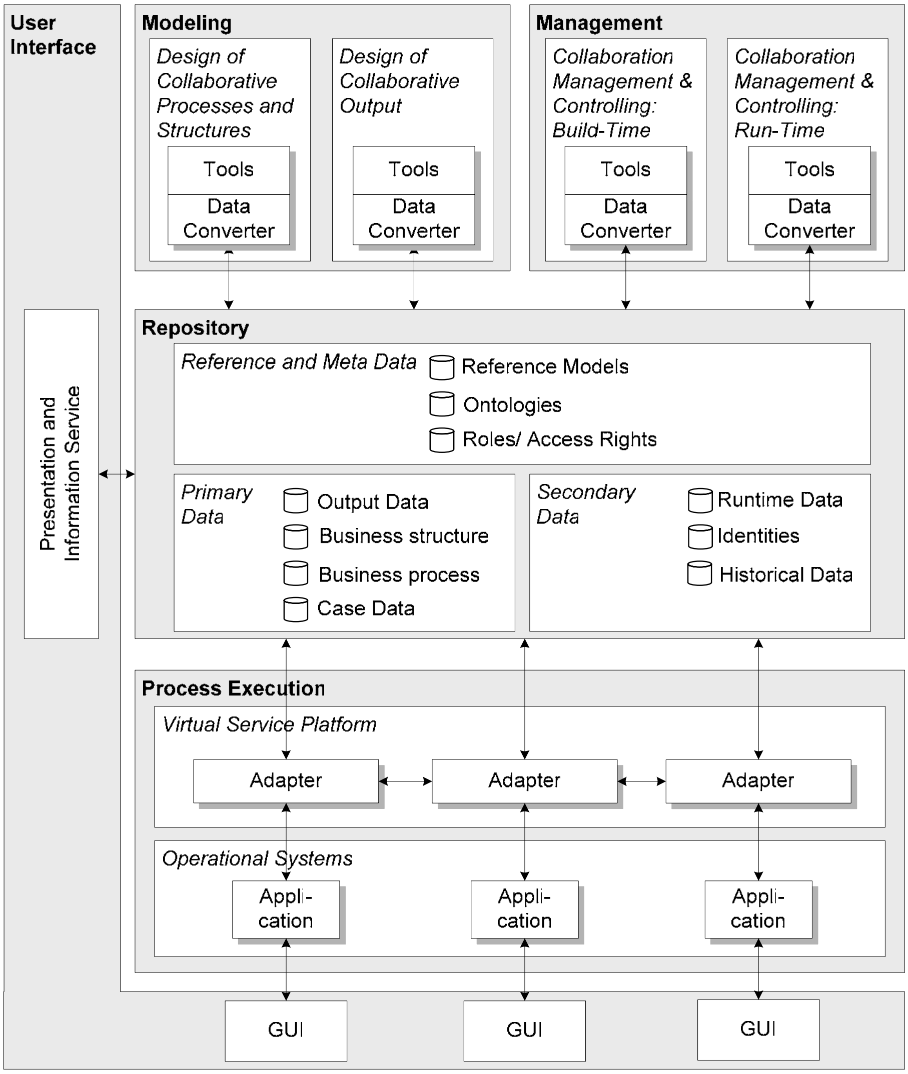

FIG. 6: Architecture for Collaborative Scenarios

4.2 Repository

An essential part of the architecture is a distributed repository. It enables business process management, common work on the models and cross-enterprise process execution. Local knowledge of each partner is stored within distributed parts of the repository, whereas global knowledge is represented by a logical centralization of the repository. The repository consists of the following conceptual components:

Reference and meta-data provide a basis for the design of *Construction Networks* and process models. *Reference models* are idealized models which are used as templates for concrete collaborations. They support the construction of individual business processes (see chapter 4.3.2), output and organizational models (Fettke and Loos, 2003; Mertins and Bernus, 1998). *Ontologies* are able to unify differing vocabulary of concepts and meanings regarding the contents and semantics of models (Gamper et al., 1999; Kishore et al., 2004). They establish a common conceptual understanding of modeled issues. Ontologies are formal conceptual systems of a domain, which obtain a knowledge transfer between applications and users. Within the architecture, ontologies enable e. g. the integration of different language formats between used applications. *Roles*, as a part of the security concept, define templates for the description of business requirements of persons within the collaboration. A role bundles access rights to architecture's resources and can be assigned to particular persons e. g. due to the enterprise affiliation or the workplace function (Edwards, 1996).

Following the distinction of primary and secondary business functions in a value chain (Porter, 1985), data used in the architecture can also be distinguished into primary and secondary data. *Primary data* support the operational realization of business processes and the primary purpose of the architecture: *Output data* provide descriptions of the outputs as results of executing collaborative business processes (Scheer, 1999). *Business process data* obtain process models of the collaboration, which can be distinguished into local and global processes (see above). *Business structure data* contain the organizational model of the collaboration. Global organizational models show the relationships of enterprises in the collaboration, whereas local models represent the intra-organizational structures. The data formats of both business process models and organizational models have to fulfill several requirements: on the one hand, different modeling tools with different modeling languages can be used, and on the other hand, global and local models may use different modeling languages. Therefore, we propose a BPMN-conform XML-notation (BPMN-XML) of these models in order to enable inter-operability (Theling et al., 2005). *Case data* are task-oriented resource data of the collaboration which pass through the processes and will be processed to a stand-alone product (Hollingsworth, 1995), e. g. documents or technical drawings. They also describe the task and the collaboration itself. Examples include data about partner enterprises and their collaborations.

Secondary data are orthogonal to business process management and embrace recording data or phase-overlapping data for supporting the process management: *Historical data* and *runtime data* are recorded data which contain specific execution data and possible exceptions due to disturbance of process execution. *Historical data* store information about executed or former processes, whereas *runtime data* record information about the current running processes of the collaboration. Both the historical data and the runtime data serve primarily the Collaboration Management and Controlling (CMC). In addition to the aforementioned roles, *identities* are basic elements for access control on data of the repository.

4.3 Modeling

Business processes and organizational models are designed by business analysts of the enterprises. They use appropriate tools, which are available in each company. The created models are stored in the *Repository*. Modeling includes the design of global and local models, whereas business secrets have to be kept by assigning corresponding roles and access rights. Reference models can be loaded from the *Repository* and used as templates. By using converters, different modeling software can be integrated; although they do not support the proposed BPMN-XML format.

Collaborative business process modeling is conducted on different levels of abstraction and detail. On a global level, abstract and less detailed information have to be spread throughout an entire collaborative value chain while detailed information with a low granularity is only considered on a local level between direct business partners. Locally, a certain degree of trust and willingness to reveal information are assumed. Thus, different description and representation mechanisms are required in order to describe information on a global and local dimension (Adam et al., 2004). Moreover, both description dimensions have to be linked consistently and transparently. In the following a methodology for modeling global and local processes is introduced.

4.3.1 Collaborative Business Process Modeling

Global process knowledge is expressed by a *Process Module Chain* (PMC) (Adam et al., 2004) while local process data is kept within such models described as *Event-driven Process Chains* (EPC) (Scheer et al., 2005) or other process modeling languages, such as *Business Process Modeling Notation* (BPMN) (White, 2004) or UML (Object Management Group). Local business processes have to be mapped onto global process descriptions and vice versa. In a collaborative business process, this is achieved by an encapsulation of information on detailed processes, organizational units and global process interfaces.

The PMC is based on the vertical axis of the ARIS-house (cf. chapter 2.1). It connects different organizations as entire partners of a collaboration project. Due to common strategies and goals, organizations have to link their internal activities through a mesh of data, products and services. Organizational as well as output-oriented relationships between network partners are described through a connection of process fragments modeled on a high level of abstraction. Primarily, this enables a provision of highly aggregated data for managerial purposes. Protecting critical information from network partners is considered as information hiding and information selection. Hence, on a process-driven level organizations publish abstract process modules as main parts of a PMC only. These modules represent the internal processes of a collaborative business process from a service-oriented point of view (Kahl et al., 2005). The granularity of a process module and the description range of internal processes are defined in detail by a collaboration partner itself. Organizations cluster those internal processes which add value to an entire global process. In an organizational dimension, collaboration partners are represented as value-adding network units within a PMC. These units are the owners of process modules and responsible for the execution of internal processes. Moreover, an interdependency connection between those network units is required. These connections are expressed through *interfaces* between process modules. A service-oriented description of products and services builds the connection between partner organizations from a managerial point of view. However, details about preliminary supplier inputs of single network participants are not of paramount importance for a global process description. Due to the fact that every partner is urged to conduct his/her own supplier management, only those inputs and outputs that are directly adding value to the overall network targets are important for a special collaboration project. To obtain such a connection, products and services as well as additional information like order documents are added to the interfaces descriptions. This information fills the gap between process information (process modules) and organizational responsibilities (value-adding network units). A consistent connection of process modules within a collaborative business process is established. Process modules and process interfaces are connected by an abstract control flow. Beyond sequencing, AND and XOR connectors allow splitting and joining. Fig. 7 depicts a typical PMC.

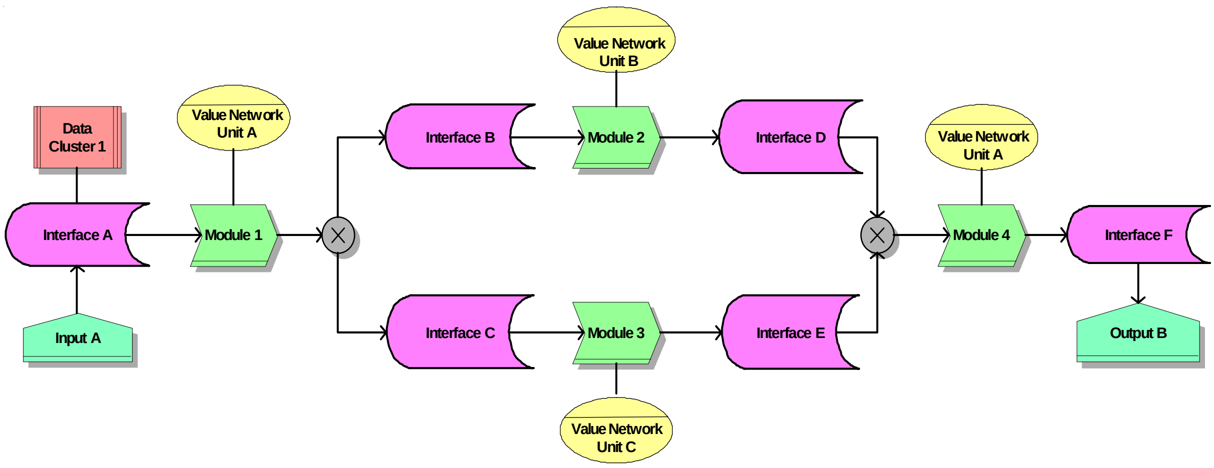

FIG. 7: Process Module Chain: collaborative business process on a global description level

Collaborative process models expressed by PMCs help to describe collaboration projects from a process-oriented point of view. PMC models are necessary for an integrated design and the execution of projects with multiple partners involved. Interdependencies are expressed explicitly. Moreover, with the PMC, an instrument to ease cross-organizational coordination is provided.

4.3.2 Local Business Process Modules Design

Since the *Process Module Chain* is composed of local process modules, each company has to redesign their processes in accordance to the constraints of the different projects. Thus, to preserve and reuse the generated knowledge the modeled processes should be stored in a reusable and coherent manner. Therefore, the process models should not only be developed for one specific application context, but also for general validity. The aim is to increase the economy of the information models by making the initial solutions available and adaptable. Thus, they serve for the transfer of business knowledge.

Process modules are generally predefined for the performance of a certain bundle of activities and are adaptable to different project contexts. Each process module represents a logical element with distinct interfaces (Menzel, 2003). These process interfaces are developed for a seamless integration of instantiated process modules into the existing *Process Module Chain*, defining all relevant input and output parameters.

In order to improve access to the knowledge contained in the reference processes, methods have to be developed that support the adaptation of reference models for a specific application context (Becker et al., 2002). The application context is represented by enterprise or project specific characteristics. The selection of the models' versions will be conducted by means of these parameters. By means of the *Construction Network Schema* introduced in chapter 3, a standardized description for the project contexts has been achieved.

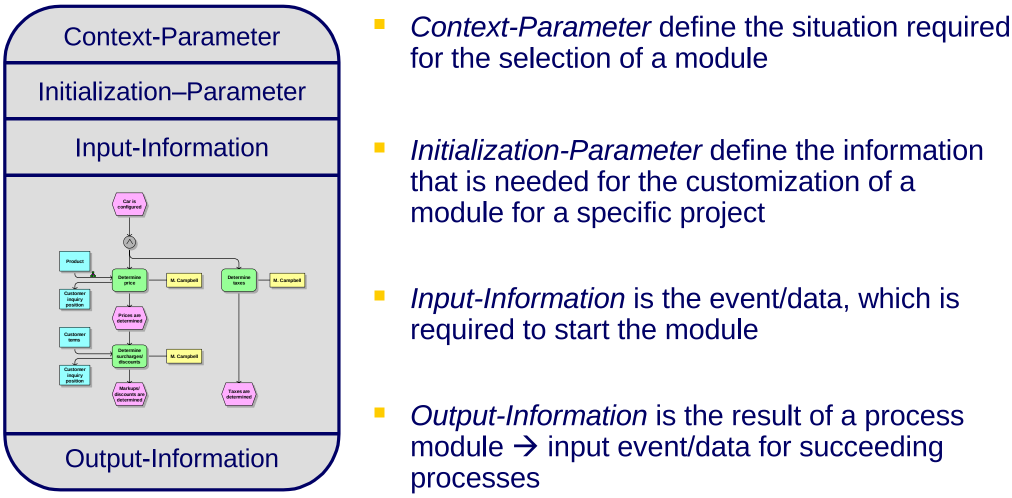

FIG. 8: Process module design

Each process module will be identified by certain meta-information that describes the parameters needed for its selection, initialization and integration (e.g. *Project Phase*, *Organization Structure* and *Information Content*). A schematic representation of a process module for construction processes is given in Fig. 8. The generic processes (modeled as an *Event-driven Process Chain*) will be identified by *Context* and *Initialization Parameters* as well as *Input* und *Output Information*.

4.4 Collaboration Management & Controlling

Collaboration Management & Controlling (CMC) is distinguished into build-time-CMC and run-time-CMC. Build-time-CMC includes early phases of the *Collaborative Business Process Management Lifecycle* (*Cooperation Strategy*, *Local To-Be-Concept*, *Global To-Be-Concept* and *Local Implementation*), while run-time-CMC encompasses the phase, *Collaboration Execution*, and the reconfiguration of collaborations. Following the distinction into a processual and an organizational view of collaborations, the methods of CMC are divided into process-oriented and organization-oriented tasks.

For a pre-evaluation of the processual and organizational behaviour of the collaboration, we suggest a Petri net-based simulation (van der Aalst, 1994). Business process models and organizational models are transferred into PNML-noted Object Petri nets in order to be validated and verified (Sarshar et al., 2006). The simulation can estimate lead-times, costs and capacity utilizations by delivering useful data for optimizing the business processes and organizational structures a priori.

4.5 Process Execution and User Interface

The Virtual Service Platform enables process execution and integrates operational applications of collaboration partners while process data and organizational data from the repository are used. Workflow functionalities (Hollingsworth, 1995) realize process execution, while EAI-functionalities (Linthicum, 2003) ensure data and process integration. By using *Adapters*, operational systems can interact with each other without implementing a central coordination instance. As a technical realization of the adapters, web service technologies are suitable (Werth et al., 2004). Web services interact with Simple Object Access Protocol (SOAP), based on internet protocols like Hypertext Transfer Protocol (HTTP) (Blake, 2000).

A further part used for the process execution is the *User Interface*. A user in this case is a person or an organizational unit which fulfils functions and processes within the collaboration. Two different types of users can be distinguished. On the one hand, they use presentation services as well as information services to get access to the repository (e. g. technical drawings, process definitions or visualizations of other data). On the other hand, they use the “traditional” user interfaces of the operational systems in the companies to fulfill their tasks.

5. SHOWCASE

For the verification of the proposed approach, “errors and omission management processes” (E&O) in the building industry have been analyzed. The E&O management involves numerous organizations of different size and varying roles. It also comprises primary as well as supporting functions. Furthermore, a precise specification of the structure of the building is required for E&O management.

Currently, E&O management, in particular E&O documentation and inspection on the site, is little supported by software applications. Additionally, different inhomogeneous IT-formats are common practice. Therefore, it was decided to prototypically develop and implement an E&O management system, running on mobile wireless devices (such as PDA). The system architecture should support easy integration into already existing desktop-based IT environments.

The development of the showcase started with a project analysis, which led to a general specification of typical constraints and requirements for E&O management. Therefore, building sites of heterogeneous structure but different organizational types were examined.

5.1 Collaborative Network Information to support E&O Management

One major task of the showcase was to demonstrate that seamless information exchange between different project participants can be organized more efficiently. This means that the existing global and local knowledge should be used as part of the mobile application. According to numerous analyses of construction projects, the required global knowledge for E&O management is in general characterized as follows (cf. Fig. 9):

E&O management processes belong to the "*Construction-Phase”* of a building project. A common *Organizational Structure* in this phase is the “General Contractor” model. This model is composed of three major partners: a) the client, b) the general contractor and c) subcontractors. The client contracts the general contractor for the installation of the complete building or major parts of it. The general contractor might be either one single company or a consortium of two or more companies. In each case, the general contractor usually assigns several subcontractors to distinct tasks. Each of these organizations has its own internal structure. However, for E&O-management, all companies have to establish the *Role* “*Quality Manager*”.

Each project is characterized by its individual *Building Objects* as output of the network. The availability and accessibility of that information is required if a so called “context-sensitive” application is to be configured. In our showcase, additional SOAP-services were implemented supporting the information transfer from desktop-based project management applications to the mobile E&O management system. In this way, the existing global knowledge of the project can easily become an integrated part of the mobile E&O-system. The global project workflow was modeled by using the *Process Module Chain* approach which is part of the ARIS-methodology.

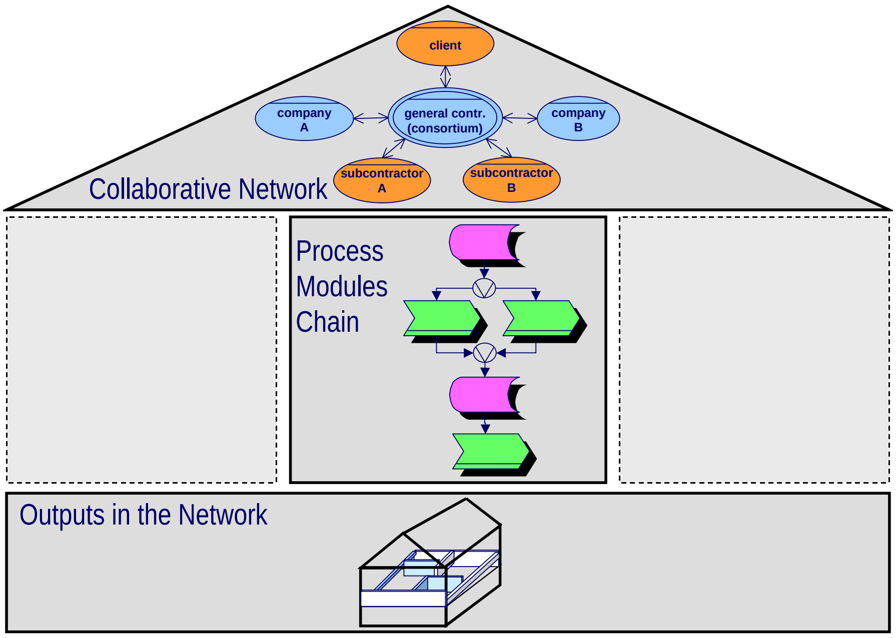

FIG. 9: Global knowledge of E&O management

However, additional local knowledge must complement the global knowledge, describing the individual steps how to fix detected errors and omissions appropriately. Therefore, the *Project Information* Structure indicated in the left of Fig. 10 has been developed and implemented. The developed service oriented architecture allows mobile and office applications to access two servers, one storing the E&O documentation and another one managing all project-related information, such as *roles*, *participants*, *building product specifications*, etc. The communication between the various applications and the different servers is realized by web services. Information exchange is handled by XML based SOAP messages. The data structure for the exchange of E&O information and E&O categories was developed and is exchanged by WSDL-specifications. The usage of such an open, transparent service-oriented architecture supports the integration of existing applications. Thus, each partner can participate in the E&O management processes by using his/her own application(s) complemented by the mobile application.

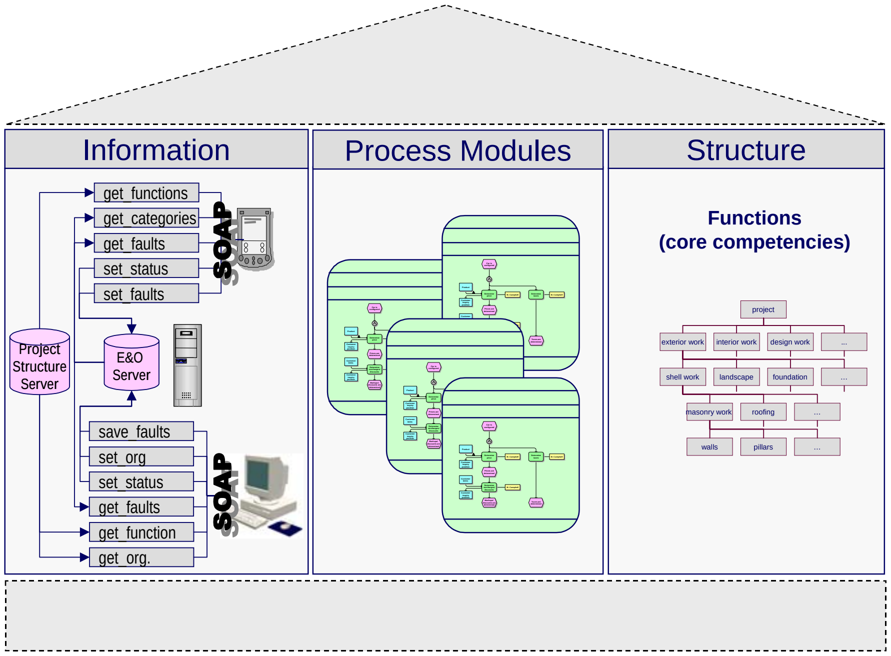

FIG. 10: Local knowledge for E&O management

This approach simultaneously protects the consistency of global collaborative network information and ensures the extension of the project specific knowledge space by homogeneously adding local knowledge.

5.2 Reference process models to support E&O management

At present, no standardized model for E&O management processes has been realized. Regulations are dealt with in project-specific ways. Thus, various E&O management processes have been analyzed and combined into a general process model. Subsequently, the general process has been decomposed into coherent process modules based on the modeling methods introduced in chapter 4.3. Developed process modules can be applied for different project types. The various process modules are stored in the *Repository* of the *Architecture for Collaborative Scenarios* (cf. next chapter).

For the identified process modules, the meta-information described in chapter 4.3.2 has been specified. An example of the “E&O Recording” process module is given in Fig. 11. This module can be applied by the quality manager of the general contractor and is applicable for all major types of building objects. For the initialization of the process module, a server for E&O data management has to be established in the project. Input-data is not required to start the process module. At the end of the process, a “fault notification” will be send to the responsible partner.

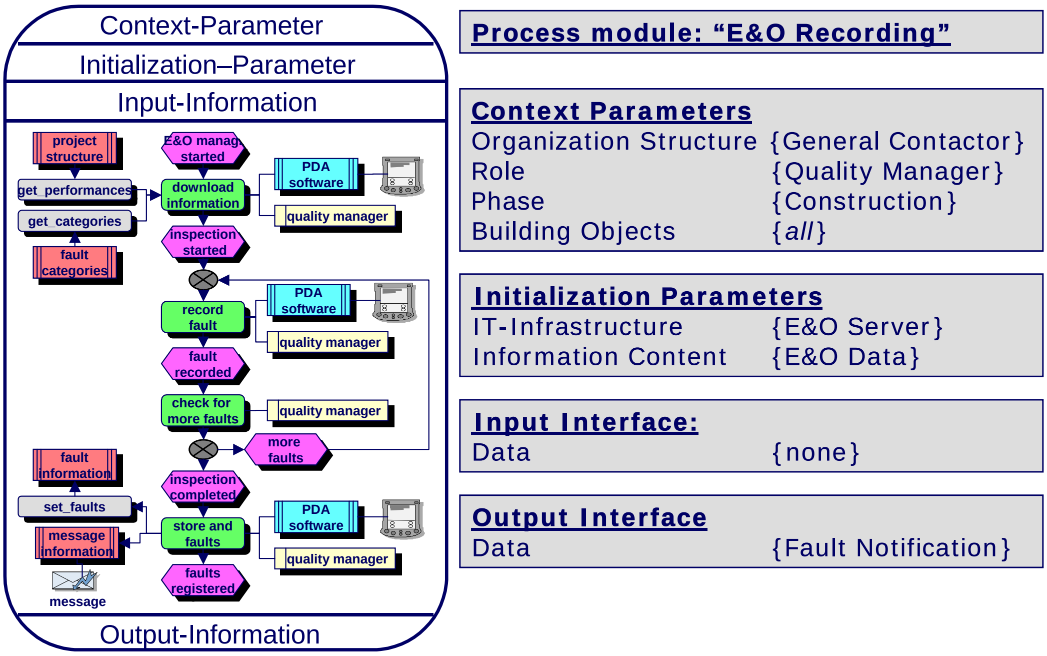

FIG. 11: Process module “E&O Recording” (Event-driven Process Chain)

5.3 Applying the Architecture

The general system architecture model as described in chapter 4.1 was adjusted to our showcase depicted in Fig. 12. Firstly, a set of E&O reference processes was developed by using the ARIS-toolset and the extensions developed (see topics 2.2. and 4.3) which support the modeling of cross-company collaborative networks.

Secondly, complementary project-specific process descriptions were made accessible by using the SOAP-services described above. The E&O-process modules and the project specific functions are both part of the process-data-pool.

Thirdly, diverse AEC-modeling tools, such as CAD-tools and their inherent standards (e.g. IFC, STEP AP 225), can be used to produce a complete model of the built artifact. The technical and structural information of the building are both combined in the project-data-pool. In addition, project documents can be attached to the process and project data by document management applications.

Existing E&O-protocols were also analyzed in depth in order to define a comprehensive but general catalogue of E&O descriptions. These descriptions were categorized, leading to a complete E&O classification.

The process-data-pool, the project-data-pool and the E&O classification are part of the global E&O-knowledge base, supporting a specific collaborative E&O-network. This knowledge-base delivers the input data for the mobile E&O system component. The accessibility of these knowledge components reduces data-acquisition efforts, contributes to consistent data management and supports an effective, holistic project management for all participants of the E&O collaborative network.

The developed E&O system architecture also contains two management components. During build-time, nine different states were defined, describing the "life-cycle" of an error or omission. The precise definition of the different states allows at each time of the project the evaluation and analysis of the work progress with regard to E&O-management. The following states were defined: (1) E&O registered, (2) in progress by general contractor, (3) in progress by subcontractor, (4) rejected by subcontractor, (5) under negotiation with subcontractor, (6) completed by subcontractor, (7) completed by general contractor, (8) rejected by general contractor, (9) completed, (10) under negotiation with client.

Finally, a time-stamp is generated for each error or omission. Additionally, the user can define a priority and deadline for each detected error or omission. This data is generated during "build-time" and allows exact controlling of E&O management processes.

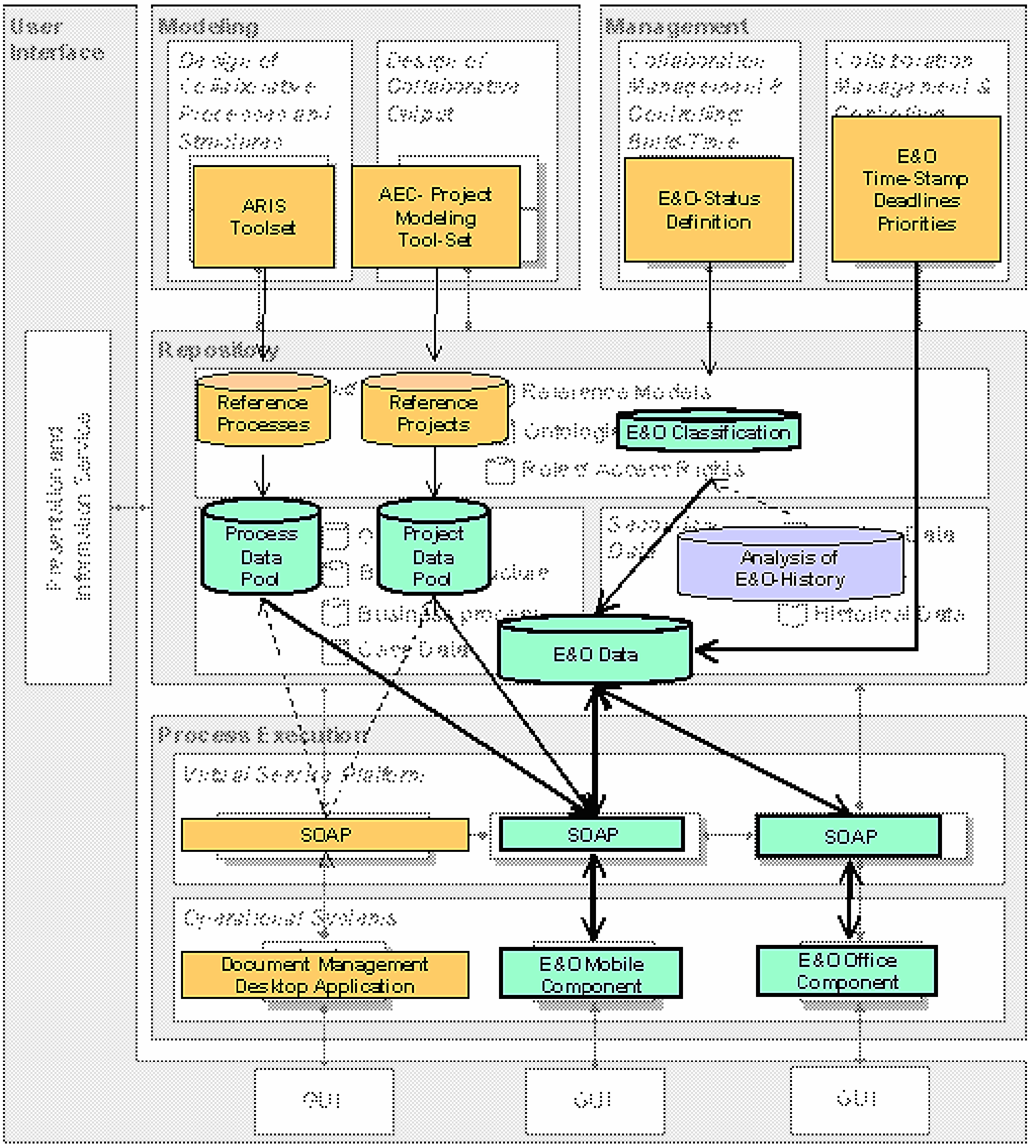

FIG. 12: System Architecture to support „Errors and Omissions Management"

5.3.1 Process Execution Applications

The mobile E&O-system component consists of three parts: (1) data acquisition, (2) data analysis, and (3) synchronization. Within this section, the first two parts are described in more detail.

The GUIs depicted in Fig. 13 illustrate the data acquisition sequence supported by the mobile system component. On the first screen, the user must localize the error. Most of the information is delivered from the project-data-pool (e.g. building, floor, room). The user only selects this information instead of needing to acquire this information redundantly.

The second screen supports the error or omission specification. Again, the necessary information specifying the profession and building part is delivered by the process-data-pool. The error category as well as a pre-defined error description is selected from the error catalogue.

Finally, the application automatically adds the current date and deadline. The user might wish to specify the cost necessary to fix the error in addition to specifying the original company responsible for fixing the error. The information of the responsible company (subcontractor) is already specified in the project-data-pool and can be selected according to the specified profession (e.g. electrician, plumber, painter, etc.).

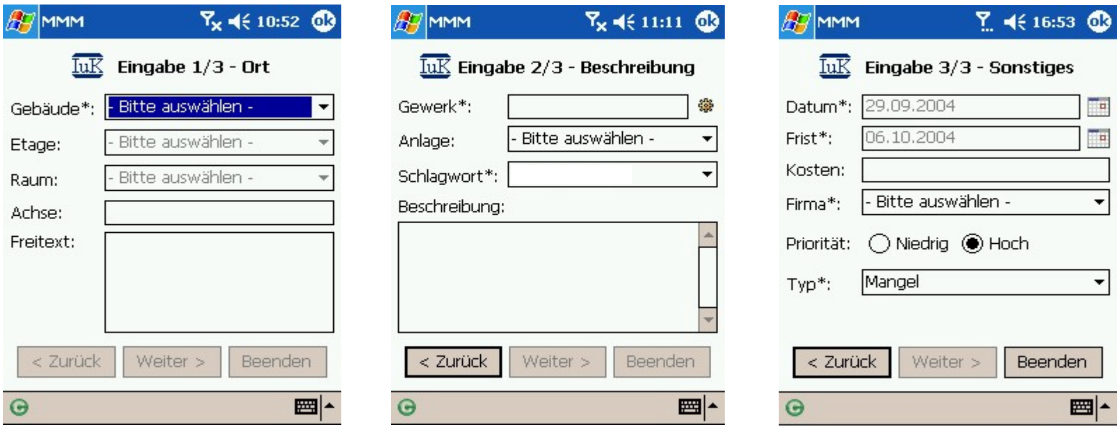

FIG. 13: Screen-shot Mobile Application for Error and Omission Management (German version)

The detailed and precise error & omission specifications are stored temporarily in a local database on the mobile device. The status of all new acquired errors is “1=registered”. The local and main “E&O-database” are synchronized by analyzing the E&O-states and using SOAP-services, as described above.

All errors and omissions will be propagated without delay to the responsible partners of the collaborative network. The partners can act quickly and immediately to start fixing an error or omission. Short response times contribute to decreased costs of errors & omissions management and to a higher quality of the built artifact. Finally, the client is served in a better way, and the overall costs for delivering the built artifact are decreased.

6. CONCLUSION

This paper discusses novel methods and tools to support inter-organizational collaborations within the AEC industry more efficiently. Firstly, the concept of local and global knowledge in construction projects was developed in order to support all phases of the *Collaborative Business Process Management Lifecycle*.

Secondly, a potential model for the description of inter-organizational construction project management information, *The Construction Network Schema*, was introduced. This model provides a schema for the definition of construction project-specific constraints. It employs various sources of reference data for the instantiation of a project-specific *Construction Network Instance*.

These *Construction Network Instances* can be used for the selection and initialization of pre-defined process modules. Process modules generally define the local (in-house) activities necessary for the performance of a set of functions. Specific parameters have been identified to adapt the process modules to the context of a certain project. The newly developed *Process Module Chain* modeling approach supports the integration of the local process modules into a virtual, project-centered process chain, representing a complete collaboration network.

Additionally, the concept of an integrated architecture for the management and controlling of collaborative business processes was developed. The architecture's tasks are (1) to support modeling of business processes and collaboration structures, (2) to integrate these models into a common repository, (3) to enable a collaborative management & controlling based on these models, and (4) to use detailed models for automated process execution.

Finally, a showcase, based on the example of errors and omissions management in AEC, was developed and implemented. The required global and local knowledge was identified, and a general business process model was developed and decomposed into coherent process modules. Additionally, a mobile application was implemented to demonstrate the basic functionalities of the proposed system architecture. The applications were successfully tested in demonstration projects of various sizes (from 5 €M to 50 €M.).

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