IFC BASED COMPUTER-INTEGRATED CONSTRUCTION PROJECT MANAGEMENT MODEL

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ABSTRACT: In this paper, we present a conceptual framework enabling to manage broad set of activities supported by multi-module software application for construction project management. In order to maintain an integrated generic structure to enable interoperable use of standardized data in a general CPM model, we proposed an IT environment which is based on a formal process methodology, standardized product and process model (IFC), and overall architecture integrating technical (design) work, construction process planning and project management in an open and modular manner. In this context, we developed Construction Management Phases for Software Interoperability, Organizational and IT Management Processes with using of ARIS methodology in order to implement IFC views. Based on this, we outline a web-based environment enabling to plug in all component tools via a common client, providing a coherent GUI.

KEYWORDS: integrated project management, product and process modeling, web services, IFC, ISO.

1 INTRODUCTION

The systems and methodologies for building descriptions have improved over many years ranging from simple sketching to complex nD models and databases. Today, due to the increased interactions and interrelations among the actors and organizations participating in a construction project, there is a well understood need for computer-supported conceptual models that can define precisely the complex communications between all stakeholders so that more efficient concurrent development of the construction facilities can be reached.

Although important implementations have been achieved in the last years, the effects on the practical side have not yet reached to expected level. Information is produced in an effective way, but the information management is still the same as is in the past decades. This can be explained by lack of generality in terms of data and process interoperability and the insufficiency of applications utilizing each other's data directly in digital format. This significantly decreases flexibility, information exchange between the component systems and last but not least, inter-enterprise cooperation and knowledge transfer.

To improve a solution to these complex problems considerable achievements were determined in the conceptual specification and the development of integration models. Following early suggestions such as the IRMA model (Luiten et al. 1993), many national and international projects as; VEGA (Zarli et. al., 1997), ToCEE (Scherer 2000), OSMOS (Rezgui & Wilson, 2002) etc. have developed models of increasing complexity, targeting various aspects of interoperability. Supported through these efforts, the industry-driven IFC (industry foundation classes) model was born in the 90s. This model is continuously improving and maturing towards a true standard for cooperative model-based working processes in AEC/FM (Liebich et al. 2006).

However in spite of all achievements for managing the process, product, documentation and communication, the organizational and information infrastructure in the AEC sector is still highly fragmented.

In order to maintain an integrated structure to enable interoperable use of standard data in a generic CPM model in this research, we proposed an IT environment which is based on a formal process methodology, standardized product and process model (IFC), and overall architecture integrating technical (design) work, construction process planning and project management in a web-based configuration, enabling to plug in all component tools via a common client providing a coherent GUI.

2 OBJECTIVES

To achieve interoperability in the area of construction project management (CPM) it is necessary to describe the building products, their parts and the related processes with multiple inter-related features. This requires to take into consideration (1) the economic and technical aspects, that can affect the products and processes during their lifecycle, and (2) the different involved discipline domains.

In this context, based on the experience gained from studying state-of-the art systems and best practice examples, the operational objectives for the development of an efficient IT-supported CPM solution can be defined as follows:

1. Generalize and formally describe CPM processes to facilitate interoperability over a broad spectrum of applications
2. Develop a common formalized information model for CPM based on the schemas of the IFC standard (ISO PAS 16739), to provide for the integration of product, process, cost and management data
3. Develop methods to integrate existing legacy systems.
4. Develop a CPM assistance tool to interactively prove context relevant data completeness.

3 APPROACH

The specific requirements, the highly distributed nature of the construction industry, and the independently used systems for management processes provide the rationale for setting up the basic principles of the proposed systems.

In this research, a feasible methodology for interoperability was developed according to: (1) The IFC model of the IAI for a hierarchically structured product model, (2) The ISO Quality Management System (ISO 9001:2000) for the existing real-world process specification for managing CPM requirements of outcome and (3) Web-based integrated methods for encompassing the product and process information exchange within the CAD, ERP and Scheduling Systems that support IFCs.

In order to constitute an integrated CPM Model, the Construction Management Phases for Software Interoperability (CMPSI) was formalized with using of IDEF0 modeling methodology according to implied requirements. ISO9001:2000 Quality Management System Procedures were established subsequently, to support organizational management structure and to establish a control mechanism. In order to narrow the scope and to better define the CPM aspects, the Bidding Preparation Phase (BPP) of CMPSI was chosen and the overall BPP processes were formalized in two interrelated subsystems using ARIS methodology (1996): (1) Organizational Management Process (OMP) and (2) IT Management processes (ITMP). To provide completeness between these interrelated systems a mapping structure between CMPSI, OMP and ITMP was also obtained. The OMP provides the core process structure from which ITMP are referenced and coordinated. It was developed based on an implemented Process Lifecycle Model which was formalized according to CMPSI, ISO 9001:2000 Quality Management System Procedures, Procurement Systems, and Software Integration Requirements. The respective technical and support processes were then improved with using of ARIS, eEPC (ARIS, extended Event-driven Process Chain) Model, in order to provide a core/complete CPM model. The ITMP obtain the guiding process structure, related to interoperability of CAD, ERP and Scheduling systems which are used for CPM purposes. Using a process-centric approach (based on the eEPC), the related services and data resources for each task were identified. Referencing IFC Model data is provided via formally defined IFC views in the context of the respective tasks. This was achieved with the help of a formal specification using the Generalized Subset Definition Schema (GMSD) (Weise et al. 2003) developed at the TU-Dresden, rules for dynamic run-time filtering, and a dedicated service performing the actual view extraction for the specifically referenced CAD, ERP and Scheduling Systems. IFC core schema objects were used as much as possible, with some needed extensions for CPM purposes. However, as the objective is to propose an integrated framework and show how IFC fits into it rather than develop a specific IFC extension model for CPM, this has been done only for selected examples. Based on the envisaged configurations, an operational framework for CPM will be developed as an integrated client-server environment, enabling to plug in all component tools.

4 INTEGRATED CPM MODEL

Development of an integrated CPM Model requires a holistic approach, taking into consideration management items, software applications, product data descriptions and a web-based system infrastructure.

4.1 Construction management phases for software interoperability

In order to formalize an integration methodology, encompassing the product and process information exchange within the CAD, ERP and Scheduling Systems which supports IFCs, the phase formalization principles: (1) General Project View, (2) Process Consistency, (3) Phase and Process Reviews etc. were developed. This approach provides the basis for the envisaged structure.

Furthermore, the Construction Management Phases for Software Interoperability which composed of five basic phases as: (1) Design, (2) Bidding Preparation, (3) Planning & Construction, (4) Realization, and (5) Evaluation of Outcome and Feedback was improved with using of IDEF0 modeling methodology. In all phases specific databases and algorithms were used to provide suitable data structures which keep the information about function and content. These obtain re-use of requested information whenever needed. Bidding Preparation Phase of CMPSI was chosen to narrow the scope and to formalize a precise structure in this context.

4.2 ISO9001:2000 quality management system CPM procedures

To establish a concurrent management and control system in terms of monitoring ongoing activities, there is a need for a generic procedural model. This should include assessment of current work activities which relies on performance standards, rules and regulations for guiding employee tasks and behaviors.

In order to support required aspects and to obtain a generic procedural model, ISO9001:2000 Quality Management System (ISO-QMS) was examined in detail for

CPM purposes. To constitute a conceptual framework, the envisaged CPM structure was basically modeled according to interconnected procedures referencing ISO requirements. Moreover, four main procedures as; (1) General System, (2) Human Resource and Administrative, (3) Customer Relations, and (4) Project Management procedures were formalized. Based on these, the sub-procedures were developed to constitute supporting processes subsequently.

4.3 *Integrated CPM processes*

To represent all diverse parties interested in a process, the flexibility and clarity of which allows generic activities to be represented in a framework and which encompasses standardization, there is a need for a conceptual structure. Based on the implemented acquiescence in this research, two inter-related process formalizations as (1) Organizational Management Process (OMP) and (2) IT Management Processes (ITMP) were structured in ARIS-eEPC model which helps greatly to design an interoperable solution for the actual procurement system used.

4.3.1 Process life cycle model for OMP

To complete identified aspects, to develop integrated CPM process patterns and to define a process formalization structure, a Process Life Cycle Model was implemented for OMP formalization purposes. CMPSI requirements, ISO, Procurement Systems and Services were brought together in this structure, thereby exposing an integrated model which meets the envisaged interoperability. The Figure 1 below illustrates the main idea.

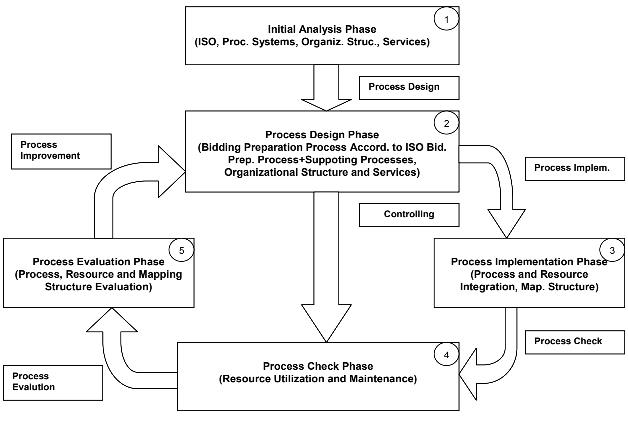

Figure 1. Process Life Cycle Model for OMP.

4.3.2 Organizational management process

The Organizational Management Process composed of interconnected processes (formalized in ARIS-eEPC model), based on a developed Process Life Cycle Model, was constructed to control whole process sequence.

According to Process Life Cycle Model, (1) initial analysis of bidding preparation phase of CMPSI, related to ISO-QMS procedures, organizational structures, procurement systems, and required services were possessed. This phase is fallowed by (2) a process design phase, during which the overall process structure is engineered, the resulting process model is designed, the resources examined and the mapping methodology is decided. This includes the modeling of organizational structures and services integrations. In the third phase (3) the designed processes were implemented. In our case ARIS-eEPC model which enables holistic consideration of processes, events, resources and organizational structures in their interrelationship, was used to formalize process sequence. The main process was defined according to ISO Quality Management System's bidding preparation process which is identified under customer relations main procedure. The supporting processes (six interrelated process) such as job development, design coordination processes etc. under project management main procedure were also defined and used within bidding preparation structure. With bringing together of procurement systems and integration requirements for CAD, ERP and Scheduling Systems, OMP was obtained. After implementation of work flow (4) established processes were checked whether that they are supporting generic integration comprising seamless information flow by using IT systems. The formalized resources consistencies were controlled and the mapping structure was scrutinized in this regard. The processes, resources and mapping structure were (5) evaluated in the next phase. The required improvements were suggested and they were designed and implemented again according to these suggestions. The OMP schema based on eEPC is given below in Figure 2.

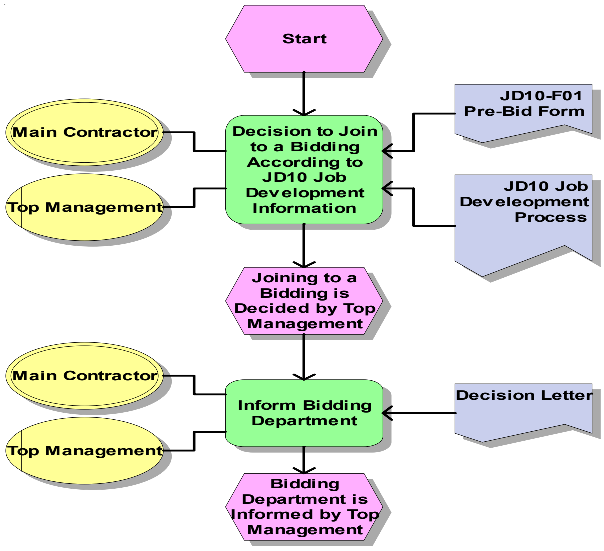

Figure 2. Organizational Management Process Partial Schema

4.3.3 IT management processes

IT Management Processes (ITMP) are defined (using of ARIS-eEPC model) in accordance with the CAD-ERP-Scheduling Systems interoperability needs and derived based on OMP. This includes the application sequence of the involved IT tools, their relations to processes, performing actors, input output and control information, and their general systemic interrelations in the IT environment. To show different level of system integration, Bidding Preparation Phase was organized in three subsequent structures as; (1) IT Mng. Design Process, (2) IT Mng. BOQ Process, (3) IT Mng. Scheduling Process.

4.4 *Process mappings*

In order to provide a generic concept which identifies workflow participants, in terms of resources that can be addressed by CPM processes, we identified a mapping structure between CMPSI, OMP and ITMP. This helps us to examine IFC views which are used to implement IFC based management approach. The mappings between three structures provide 1-1 mapping (pairing) formalization. The CMPSI phase processes are used as main processes which are referenced by OMP processes as sub-processes. Also CMPSI resources are referenced by OMP resources as sub-resources. The same approach is used within OMP and ITMP mappings, in this context.

5 IFC DATA EXCHANGE REQUIREMENTS

The IFC Object Model (IAI 2005) is essentially a project data model addressing the major data exchange requirements in the highly fragmented construction industry. It encompasses a large set of object definitions that individual end-user applications always implement only a subset of the IFC totality. In order to support practical data exchanges, applications need to develop the same or (at least overlapping) IFC subsets in order to obtain meaningful product data exchange in AEC/FM environment. Such subsets are called IFC Views or, more generally, Data Exchange Use Cases. For practical use various such subsets are currently being defined applying more or less formal approaches (cf. ProIT 2004).

IFC mainly describes the outcome of engineering processes performed with the help of CAD and other specialized tools. This is essential input for CPM but it cannot be readily integrated in the ARIS-eEPC model since IFC data are defined in STEP/EXPRESS (ISO 10303) or as instances of an XML Schema representation (cf. IAI 2005) which are both incompatible to ARIS. Therefore, to enable interoperable use of IFC data in the General CPM Model and the related CAD and CPM applications the following procedure is applied: (1) The CPM processes defined in ARIS are examined with regard to IFC Data Exchange Use Cases that should be related to them. An example for such a use case is the data exchange from Architecture to Quantity Take-Off. (2) For each identified use case the relevant IFC objects and their relevant relationships are determined. They are then associated to, the relevant organizational entities, and the relevant resource entities in the ARIS-eEPC model. In the first case these will always be instances of IFC object classes, but in the second case these can be individual objects, property sets or whole model subsets. (3) Whenever model subsets need to be applied, the IFC Views were defined with using of General Model Subset Definition Schema (GMSD) developed at the TU Dresden which is used for the formal specification of the subset content on class level. (4) Run-time use of the IFC data is then provided via a specialized GMSD client which enables proper extraction of the specifically needed IFC instances in each particular situation. This is done interactively, whereas in the CPM model we provide only some requirements and hints to the user.

5.1 IFC data exchange use cases

In order to examine IFC Data Exchange Use Cases, IT Management Processes were established in 3 sub-structures form as (1) IT Management Design Process (ITMDP), (2) IT Management BOQ Process (ITMBP) and (3) IT Management Scheduling Process (ITMSP) as it was envisaged. Each phase definition is mapping with software compatibility. For example, ITMDP reflects CAD-ERP information exchange for design and product data integration, ITMBP supports information exchange within CAD-ERP systems and exchange of BOQ information within ERP Systems, and ITMSP obtains BOQ and product data exchange within ERP-Scheduling Systems. Based on these formalizations, we constructed three data exchange use cases as: (1) Data Exchange Use Case for Product Catalogs, (2) Data exchange Use Case for Architectural Design and (3) Data Exchange Use Case for Exchange of BOQ. The Figure 3 below illustrates the basic concept.

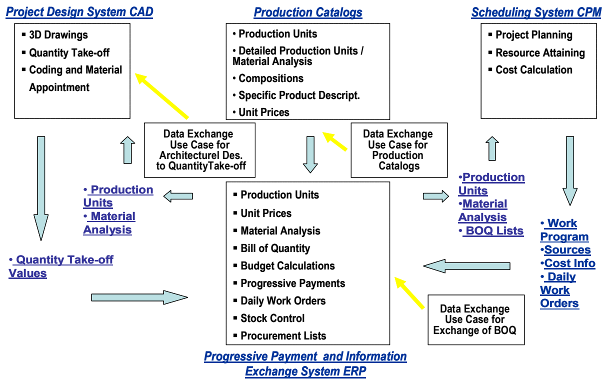

Figure 3. IFC Data Exchange Use Cases.

According to implied model, common items which are used for CAD-ERP and Scheduling Systems are based on reliable external sources in terms of production units and project material analysis. Generally bidding departments can form these items from different sources such as firm databank, production catalogs etc. Because of supporting information exchange within different CPM phases, Product Catalog information can be accepted as the milestone of the envisaged model. To obtain reliable forms also for architectural design and BOQ information exchange, the first data exchange use case was formalized based on the exchange of Product Catalog information with identifying a new type of ID formalization which can be also used for cost data integration for IFC based data exchange purposes.

Subsequently, quantity take-off data for cost calculations were taken into consideration. In order to formalize data exchanges between design to quantity take-off, Architectural Design to Quantity Take-off Data exchange use case was constituted.

Building product model which was produced by architectural design that can be used for cost estimations are the major inputs of the BOQ structure. According to information derived from CAD and Product Catalogs in this phase, BOQ can be structured within ERP systems. Although BOQ information can be implemented according to envisaged inputs, there is a need for to identify the relevant items, in order to specify general level exchange of BOQ information. In this case data exchange use case for BOQ information was formalized. The envisaged structure was designed to be also used for planning and controlling activities.

5.1.1 IFC objects

In order to identify the basic contents of the IFC product model, the minimum components have to be clarified precisely. The minimum product model should contain the product objects and its attribute values. To support minimum requirements, all the needed attribute values and possible relationships have to be modeled.

In this context, Product Catalog, Architectural Design and BOQ information which can be compatible with IFC model were searched. In order to formalize IFC objects, the central information elements were structured within Data Exchange Use Cases. This approach was developed based on the requirement analysis, and the process resources which were determined within IT Management Process structures (based on ARIS-eEPC Model). Figure 4 below illustrates the principal idea.

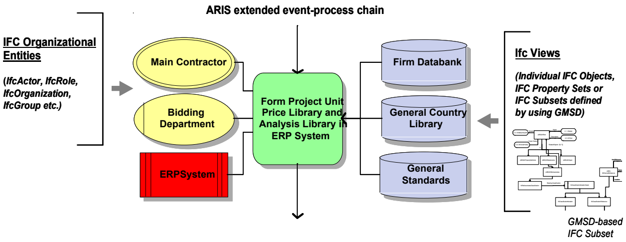

Figure 4. Schematic presentation of the association of IFC data to the CPM Model.

The mappings between the central information elements and IFC Classes were then structured subsequently. The Table 1 below shows mappings for Product Catalog's central information elements and IFC classes.

Table1. The Mapping for Product Catalog Cent. Info. Elem. into IFC Classes (Partial Sch.).

Product Catalog Central Information Elements	IFC Class
Product/Elements * Production Units	* IfcBuildingElementType/.... * IfcDistributionElementType/... * IfcElementComponentType/... * IfcFurnishingElementType/...
Assembled Products * Production Units * Material Analyses	* IfcBuildingElement * IfcDistributionElement * IfcElementComponent * IfcFurnishingElement * IfcRelAggregates

5.1.2 IFC views

We used different parts of the IFC product data model as IFC Views. An IFC View is grouping of an IFC product data model subset so that one IFC View describes object's such as building element' s objects, certain specific characteristics or bundled properties (ProIT 2005). The IFC Views which are needed for the implementation of the Data Exchange Use Cases were structured with using of GMSD for the formal specification of the subset content on class level. Runtime use of the IFC data was then provided via a specialized GMSD client which enables proper extraction of the specifically needed IFC instances in each particular situation.

Although there are initiatives can be seen to formalize IFC Views in this case, the formalizations which support cost information exchange based on IFC were not constituted up to now. In our structure with the new definition of Production Units and related IDs will be an answer to this gap. The Table 2 below illustrates Production Catalog information elements which are used for IFC Views.

Table 2. The IFC Views for Product Catalogs.

Information Element	IFC Aspect
Product Catalog Information: * Identification (IDs) * Production Units * Material Analysis * Classification * Grouping * Properties * Cost items (Unit Prices)	Product Catalog

6 SUGGESTED OPERATIONAL FRAMEWORK

From the operational point of view, interoperability means the ability of the system components to work together in a coherent way for the solution of complex tasks. In this sense, the operational framework has to be structured and established according to a coherent process and information exchange paradigm as shown in Figure 5 below. It is comprised of 4 clearly defined layers: (1) Application Layer, (2) TSD Layer, (3) Management Process Layer, and (4) WPA Layer.

6.1 Application layer

The purpose of this layer is to support different types of project activities, performed with the help of CAD, ERP and CPM programs. The main target is to combine the construction site and project partners' databases, thereby allowing improved project/cost control, increased work efficiency and fast response to changes within the construction environment. The layer is structured and established in accordance with the interoperable CAD-ERP-CPM environment.

6.2 TSD layer

This layer consists of Transfer Module, System Database and Data Exchange Module. The information that can be obtained from the application layer is stored in the System Database. This information should cover the identified needed outcomes of the CAD, ERP and CPM programs. The Transfer Module supports the data exchange between the Application Layer and the System Database. Assuming that IFC data can be exported by the involved applications, this can be done with the help of a general-purpose API in a convenient format (using ISO 10303-21 files and/or ifcXML). Information is transferred to the Data Exchange Module which is the coordination module for the below layers, ensuring synchronous and asynchronous information flows in a standardized, regular way.

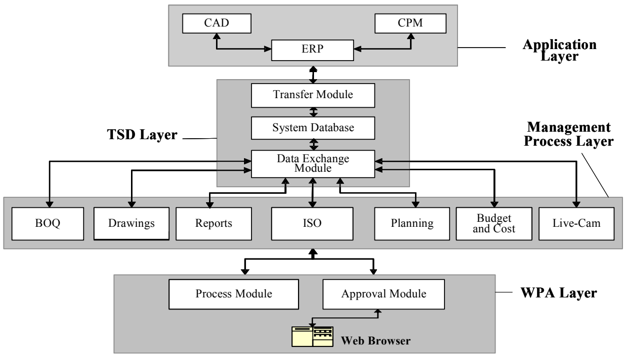

Figure 5. Web-based integrated CPM solution.

6.3 Management process layer

The Management Process Layer consists of 7 different modules that can perform and be managed separately. Five of them, namely the Measurement/BOQ Analysis Module, the Drawing Module, the Report Module, the CPM Planning Module, and the Budget and Cost Module include and further process the data obtained from the TSD layer. Additionally, a Live-Cam Module can be provided to track the execution on the jobsite, and an ISO Module can be included for process support in accordance to ISO Quality Management procedures. This module would also allow to observe the approval process within the partner organizations and within the applications.

6.4 WPA layer

The WPA Layer provides the facilities for (1) execution of the management processes and the related applications via the Internet, and (2) presentation of the obtained results to all stakeholders via a common Web Browser. The process workflows can be carried out using a standard based schema and on every step the information can be checked and approved by the responsible persons who are attained by the project organization.

7 CONCLUSIONS

In this paper, we outlined a novel CPM model based on a logical conceptual schema starting with the specification of management along a number of well-defined steps towards the creation of an operational framework.

The major goals of the suggested approach are to enable handling of various types of information coherently, including product, process, and management data, and to provide seamless information exchange between the actors and tools in the process. To reach these goals we have brought together state-of-the-art CAD-ERP-Scheduling Systems interoperability concepts, a novel formalization and integration approach for ISO9001 quality management procedures, advanced IFC-based integration issues, and an acknowledged holistic business process modeling methodology (ARIS). Some clear benefits of the integral treatment of all CPM aspects on the basis of ARIS, ISO9001 and IFC were identified, especially with regard to IFC penetration in practice. Currently IFC use is still modest, mostly for CAD-based data exchange. With the developed CPM model a contribution towards its much broader use in ERP and Scheduling applications in all life cycle phases of the virtual enterprise of a CPM can be accomplished.

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