IFC VIEW FOR BILL OF QUANTITIES FOR SOFTWARE INTEROPERABILITY

Kamil Umut Gökçe, Assist. Professor, umut.gokce@eos-ses.de
Hasan Ufuk Gökçe, Assist. Professor, ufuk.gokce@eos-ses.de
EOS Sustainable Energy Solutions GmbH, Vahrenwalder Str. 7 30165, Hannover, Germany

ABSTRACT

Building Information Modeling is a new work paradigm that denotes the broad set of activities supported by software applications targeting improved software interoperability and better coordination of AEC (Architecture, Engineering and Construction) processes. The Industry Foundation Classes (IFC) data model standard provides a core reference model for software interoperability along with a growing number of extensions for domain applications. In principle, the amount of necessary data can range from individual attributes to full models, but for domain applications the main focus is on partial, domain specific model views. This paper proposes a new IFC Model View for the exchange of Bill of Quantities (BoQ), addressing the Bidding Preparation phase of the American Institute of Architects' (AIA) construction general life-cycle model. Information resources required by the application systems used in the bidding preparation phase are defined and represented in a new process model namely the IT Management BoQ Process (ITMBP) which provides all required entities and relationships in the IFC partial model. In order to provide a standard approach, a new modeling method, "ceEPC" is proposed to develop ITMBP. The IFC View for BoQ is determined based on the ITMBP considering the requirements of three contract types: (1) Unit Price, (2) Design & Build, and (3) Lump-sum. The buildingSMART initiative's Model View Definition (MVD) format is used to obtain this new model view's formal specification. The Generalized Model Subset Definition Schema (GMSD) is utilized for the subset content's formal representation. The selected building model and the developed models (based on the IFC View for BoQ) are compared using ViewEdit and DDS Viewer for validation. The expected results are obtained by filtering the required data. The initial concept of the proposed concept has been tested in a demonstration test bed "America House Business Center" in Bucharest – Romania.

Keywords: building information modeling, industry foundation classes, bill of quantities, bidding preparation phase, IFC view for BOQ

1. INTRODUCTION

Construction projects are one-of-a-kind ventures with respect to the design of a facility as well as to the project organization, the production facility and to the production resources (Scherer et al. 2012). They are characterized by numerous heterogenic stakeholders, which have traditionally hampered the establishment of integrated information systems requesting distributed information management. Therefore in the last years several IT systems integrating various application domains have been developed to obtain networked-based environments for effective inter-organizational project collaboration. Such systems typically combine construction site and company databases thereby allowing participants to improve project control, reduce operation costs, increase work efficiency, and quickly respond to changes in the construction environment and market conditions (Gökçe et. al 2012). However, developed solutions largely lack generality in terms of data and process interoperability. In order to address integration in AEC, the IFC object model as a product data model which has a quite large scope is developed as a standard approach (ISO-PAS 16739) to identify the specifications and enabling the interoperability between AEC applications (Gökçe et al. 2011).

At present the majority of AEC software developers have IFC APIs (Application Protocols) that are capable of importing and exporting IFC/STEP files, however it is not possible to make full use of the IFC model and abandon the file based exchange scenario (Nour 2007). In this context, several solutions have been proposed such as IFC-compliant integrated AEC systems using smart objects (Halwafy et al. 2005), process oriented information modeling methodology for IFC model development (Chen 2004) and project ProIT, which addresses the development of product model based process modeling its data exchange, compiling design guidelines necessary for product modeling and establishes model structures for the re-use of product libraries (cf. ProIT 2004). However the goal of lossless, incremental data flow through different application systems used in the construction management domain based on IFC partial models has not been articulated.

This paper proposes a new partial model namely "IFC View for BoQ", encompassing the required (partial) product and process information exchange within application systems in the bidding preparation phase of the AIA (American Institute of Architects), in order to: a) determine standard approaches to the general construction lifecycle; b) identify a solution for seamless data flow between IT domains based on IFC; c) provide a process oriented information modeling methodology comply with contract types used in the construction management domain. The initial concept of the proposed view has been tested in a demonstration test bed "America House Business Center" in Bucharest – Romania. Moreover, this development approach has been utilized in the lead German project "Mefisto" to generate BIM-based Multi-Model Views (Scherer 2009-2012).

2. PROPOSED APPROACH

The introduced IFC View for BoQ is defined based on the state-of-the-art analysis of American Institute of Architects' (AIA) construction phases, contract types and IT domains used in the construction management domain. The AIA defines the construction lifecycle in six phases namely: (1) Feasibility, (2) Design, (3) Bidding Preparations, (4) Construction, (5) Contract Close-out, and (6) Operation & Management (cf. AIA 2012).
In this research, the Bidding Preparation Phase is considered. Generically in the Bidding Preparation Phase, cost estimations can be calculated after the quantity surveying is completed. Cost estimation is typically prepared on the basis of construction diagrams and technical specifications. In this context, the bid should be prepared based on a cost estimation which conforms to the owners' requirements. Quantity take-offs should be checked, recalculated, and classified. Based on the production analysis, production unit prices are calculated, and market values are formed. At the same time, the effect of inflation, and the budget and cash flows have to be considered with regard to a pre-work schedule. This process requires integrated work throughout the company. One group performs the quantity surveying and creates the quantity take-off database, another group undertakes market research and creates the production unit price database, a third group performs the construction cost analysis with respect to company standards, and a fourth group prepares the work schedule and creates budget and cash flow tables. These databases must be inter-related. Data produced in one group is used by another group (i.e. highly cooperative work is required). Hence, this approach requires integrated construction management tools which support bi-directional information exchange between IT domains.

Moreover, in the last decades, contract types such as: Design& Build, Unit Price, Lump Sum, Turn-key, BOT (Build Operate, Transfer) complying with the AEC procurement strategies, have been developed (for details see Gökçe 2008). For different contract types, different procurement strategies are necessary, which makes the bidding preparation phase even more complicated. However, in order to represent a standard approach integrating various application domains to obtain networked-based environments for effective inter-organizational project collaboration, various contract types should be considered (Gökçe 2012). In this research, the most general contract types; Unit Price, Design and Build, and Lump-sum, representing heterogeneous information resources are addressed. In the Design-Build contract type, all necessary design and construction expertise resides within one firm. The contractor has both design and construction departments and staff. In this contract type, integrated team work is required to finalize the bid in expected quality. In some cases, in what we may call the integrated design-build approach, the contractor is prepared to buy in design expertise when necessary. Also the design team may be an external organization, which has long-term relationships with the main contractor. As the demand in the construction sector is fluctuating, this is also a widely used approach. In the Lump-sum Contract Type the contractor submits a lump-sum amount to perform the work required in the documents. The owner or client, in this case, must have a complete design before soliciting bids. The extent of the work must be well defined in the plans and specifications. The lump sum offered by the contractor is not supposed to change. Changes and extra work orders signed after the contract are expensive and lead to disputes. To ease the risk of certain unexpected cost factors, lump sum contracts may contain escalation clauses for rising material and labor rates. In the Unit Price Contract Type the work to be performed by the contractor is measured and priced at the rates fixed by the ministry of public works in schedules of approximate quantities. In the private sector, the market rates may be used. The actual price paid, however, is determined by measuring the actual amounts of work done and paying these at bill rates. Variations are also paid for at bill rates. The benefit of the system is that, the calculation of the approximate and the actual cost is relatively easy. The unit price system is also advantageous when the volume of work cannot be exactly determined in advance. The approximate cost of the building is calculated by listing the unit prices for a list of items of work which are shown in the plans and drawings and described in the specifications and then multiplying these prices by the corresponding quantities. When the approximate cost of a building is calculated on the basis of drawings, then bids are solicited and the contractors must quote up or down (the usual practice is down quoting) on these rates.

BoQ have been one of the key control documents, in the construction management domain, for over decades. The use of BoQ increases the efficiency in obtaining competitive tenders, as well as being the key document when calculating monthly payments and valuing variations (Seeley 2001). BoQ are prepared for quantity surveyors and building estimators, and “Indeed the bill of quantities was the raison d’etre for the development of quantity surveying as a separate profession” (Potts 2004). BoQ compounds labor and material costs. They are combined into a single rate for the construction work entities and then adjusted in regards to quantities. The cost estimates are defined generally based on the square area in meters of walls and roofs, cubic meter of concrete, square area in the meters of painted building elements, the numbers of doors and windows, and systems as heating, plumbing and electrics, and many more items used in a construction project.

In this research, the information resources required by the application systems in the bidding preparation phase, and the contract types (given above) are defined and represented in a new process model namely IT Management BoQ Process (ITMBP). In this context a new process modeling method “complemented-eEPC” is proposed to develop ITMBP. The Information Delivery Manual, IDM (Wix 2006) and BPMN (Building Process Modeling Notation) (OMG 2006) are considered as baselines. The BoQ structures used in the Bidding Preparation Phase of the AIA have been analyzed complying with the IFC data schema. For example, although the BoQ can be implemented according to inputs, such as: (1) production resources, (2) material analysis, and (3) quantity take-offs, there is a need to identify relevant items such as: (1) space, (2) building zones, and (3) building elements in order to specify bill of quantities’ exchange based on IFC. The determined information resources in these structures used to obtain the IFC partial models. In order to provide IFC Views, IFC Concepts and IFC Instance Diagrams are developed based on the IFC Model View Definition Format (MVD). The MVD translates user-defined exchange requirements into a specification for a given exchange format (cf. buildingSMART 2012).

In this research, in order to enable interoperable use of IFC data in the general construction management model and within the related application systems the following procedure is applied: (1) The information resources based on the bill of quantities’ structures used in the Bidding Preparation Phase of the AIA which are defined in the “ceEPC” model are examined with regard to the IFC partial model views that can or should be related to them. (2) For each identified information resource the relevant IFC classes and their relevant relationships are researched. (3) The related IFC Concepts are defined. The IFC Model View consists of IFC Concepts, which define the complete set of IFC Classes. (4) Partial IFC Views are classified according to their application for exchanging information from one in another domain. (5) General Model Subset Definition Schema (GMSD) is used for the formal specification of the subset content on the class level. (5) “Viewedit”, a GMSD client is used for the runtime use of the IFC data. It enables proper extraction of the specifically needed IFC instances in each particular situation. (5) The validation is made with Viewedit and DDS Viewer, based on an alphanumerical comparison of the STEP physical file (SPF) on the numerical basis and building models based on three contract types. The expected results are observed, the size of the SPF is considerably reduced in order of about 9. The IT Management BoQ Process (ITMBP) supports exchange of bill of quantities (BoQ) information in ERP System and information exchange between ERP and scheduling systems as illustrated in Figure 1 (see Gökçe 2008).

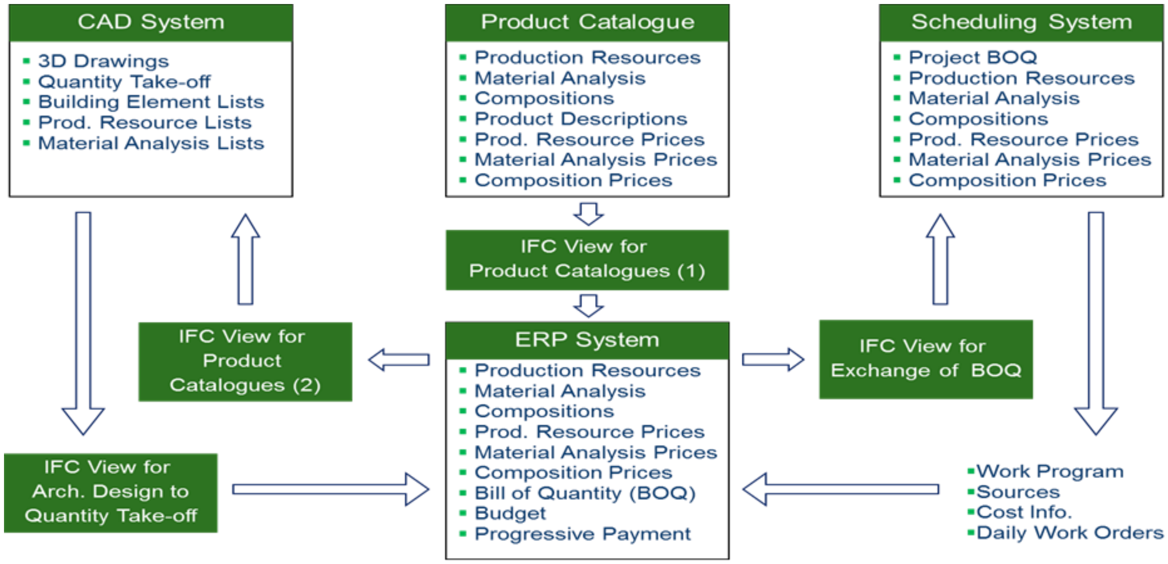

Figure 1: CAD, ERP and Scheduling Systems Information Structure and Related IFC Views Representation

In this context, the IT Management BoQ Process is utilized based on the building product model which is produced in CAD tools, and the product catalogue information which are used for cost estimations. According to information derived from the CAD and Product Catalogues, the BoQ can be realized within the Enterprise Resource Planning (ERP) systems. ERP originated in the manufacturing industry (Shi and Halpin 2003). Its primary functions are to integrate the inter-departmental operation procedures and Management Information System (MIS) modules, and to reallocate the resources of a company (Jyh-Bin et. al 20079). Despite that a number of initiatives recommend the use of ERP systems in construction projects for different purposes, IFC based applications have not been considered (Gökçe et. al 2012).

3. PROCESS MODELING CONCEPT

Hence, to provide a process oriented integration methodology in this research comply with the IFC object model, the overall modeling framework is established on the basis of ARIS-EPC modeling method which utilizes holistic modeling of processes, resources and organizational structures in their interrelationship. ARIS Architecture of Integrated Information Systems has been developed by IDS Prof. Scheer GmbH as a business process engineering tool in the 90s'. ARIS concept creates a guideline for developing, optimizing and implementing integrated application systems. The ARIS concept divides complex business process into separate views such as: (1) Function, (2) Organization, (3) Data, (4) Output, and (5) Control, and integrates these views to realize the whole process structure via Event-Process Chain EPC (for details see Scheer 2000). An EPC is an ordered and sequential graph of events and functions. The EPC links functions, organization and data. It unites the design results under Control View, which are developed separately in process views for reasons of simplification. Thereby, with EPC, the functions, events, information resources, and organization units are connected in a common format. However in order to define ITMBP for the actual contract types and to provide an effective detailing of system activities, in order to represent all associated resources, actors and attributes, a combination of these items within IFC definitions in a common format requires a new model. In this context, the ARIS-complemented eEPC (ceEPC) model is realized. In this case, the established process sequence is used to identify required information resources. Thereby it can reflect the existence of relationships and clarify types of relationships. This greatly helps to obtain mapping structure between interrelated data and functional definitions (for details see Gökçe 2008, 2012). In doing this, a new model "ARIS-ceEPC" is considered and adapted appropriate ideas from a number of developments including BPMN, BPML, UML Activity Diagram, IDEF. This new model describes processes by creating a chronological sequence of functions, events and their logical inter-dependencies using logical connectors, and related performing actors and services, in terms of information resources by applying a notation structure (Gökçe et al. 2011). The information resource defined in the process model with a specific ID is used for information requirement analysis which supports IFC model development and helps to provide definitions for the IFC Concept formalizations (for details see Gökçe et al. 2011). In Figure 2, a cut-off example of ITMBP is shown representing a main function and the information resources.

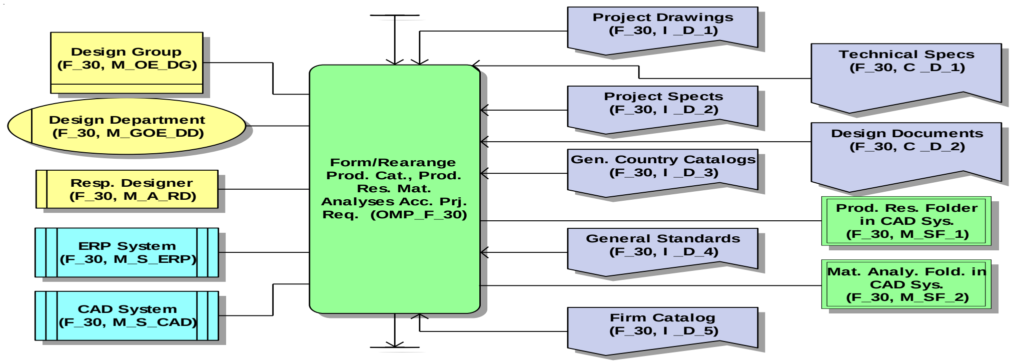

Figure 2: ceEPC Model Structure (A cut-off example)

4. IT MANAGEMENT BOQ PROCESS

The IT Management BOQ Process (ITMBP) represents the development steps of Bill of Quantities (BoQ) in the construction management domain targeting software interoperability. The information required for this process is produced during the design phase. Thus the detailed estimates can be carried out prior to drawings and contract specifications. To derive the project's BoQ, all possible systems are considered and an integrated structure is formed in the ceEPC Model. To provide seamless integration based on the IFC, a new type of product catalogue structure is considered which was suggested by Gökçe (2008, 2012). This new structure complies with the data schema of the IFC standard to provide coherent integration of product and cost information. The essence of the developed approach in this research is in the consistent definition and use of a new IFC View for BoQ that pulls together the needed product, cost and management data to provide for seamless information flow between different application domains through standardized product information. The initial concept has been utilized for the bidding preparation of a real project, namely the "America House Business Center" in Bucharest – Romania (2004 – 2006), as illustrated in Picture 1.

America House Business Center - Bucharest / Romania

Project Duration	2004 – 2006
Client	GTC MULTIFUNCTIONAL
Consultant	WEST FOURT ARHITECTURE
Type of Construction	Reinforced Concrete
Total Construction Area	47.204 m2
Total Closed Area	46.875.58 m2

Ficture 3: America House Business Center – Bucharest Romania

The proposal was developed based on the Lump-sum contract type. For this purpose, a specific ERP system has been developed and integrated with Autodesk and Primavera systems used in the Özer Construction Co., Inc.

based in Istanbul – Turkey. In the proposed (current) version of the ITMBP, the initial application and integration of CAD-ERP-Scheduling systems have been extended based on the IFC data standard.

According to ITMBP, two parties can be identified as the architect of the design department (based on the Design & Build contract type), or quantity surveyor of the bidding department (based on the Lump-sum or Unit Price contract types) who produces the quantity take-off information, and the bidding engineer of the bidding department who is the responsible person for the BoQ preparation, based on the quantity take-offs and production resources' costs. In this case, the building elements' specific quantity information which are composed of production resources and material analysis are exchanged within the CAD and ERP systems. Later these quantity take-offs are re-arranged within the ERP system and transferred to the BoQ folder. In order to form the BoQ lists production resource1 and material analysis1 (which are rearranged according to market prices) are sent to the BoQ folder and used for the bid preparations. ITMBP composed of two organizational entities namely the main contractor, and design office; two group of organizational entities, the design department, and bidding department; three actors as design architect, quantity surveyor, and bidding engineer; and 24 sequenced functions and events, 22 documents and two application systems (for detailed descriptions in ceEPC see Gökçe 2008, 2012).

5. IFC VIEW FOR BOQ

The domain of Building Information Models (BIM) describes the functional, geometrical and topological information of the building elements and their composition. The Industry Foundation Classes are used to facilitate the exchange of information on the physical building elements and their topology as well as e.g. the corresponding spatial and structural systems (Scherer et al. 2012). However, until today the BIM applications has mainly focused on the CAD data exchange and does not support construction management.

In this research, in order to combine the knowledge of model instances defined in the ITMBP via information resources addressing semantic interoperability, to provide seamless information exchange between different domain applications, a partial product model for the exchange of BoQ comply with the IFC schema namely "IFC View for BoQ" is proposed. The main goal for this formalization is to maintain lossless, meaningful, incremental product data exchange between domain applications used in the construction management domain. The main goal is to form the BoQ information to utilize quantity and cost information for the cost estimation, as well as for planning purposes. This is done by exchanging building elements related quantity and cost information. This information is used not only for the Bidding Preparation phase and also for the Planning & Construction, the Evaluation and the Feedback phases of the construction general life cycle model (for details see Gökçe 2008, 2012). In this IFC View the contractual responsibility issues concerning the data exchange are not defined. In order to illustrate the contractual responsibility issues, the IT Management BoQ process (ITMBP) is formalized using the ceEPC model. According to proposed data exchange in this research, the main requirements and statements are formalized as: (1) In order to implement the exchange of BoQ information, reliable tools such as CAD systems should produce quantity information for the building elements and spaces. (2) The envisaged software applications such as the Product Catalogues, CAD and ERP systems should use common formats such as Production ID's for the BoQ information exchange. (3) The CAD, ERP and Scheduling systems should have an ability to write out the BoQ information into data exchange representation form and exchange format using the Production ID's and also have an ability to post-process the BoQ information from this representation form into its representation structures. Based on ITMBP there are two items, which should be considered in this context: (1) The individual items for the BoQ information exchange such as individual building elements, and (2) The sum of individual items such as building elements' types, and space types according to intended classification's use.

Moreover, to formalize BoQ information, there is also a necessity to organize BoQ objects into groups. These objects are organized based on the different aspects such as: (1) the building elements, (2) the location of the quantity information based on the building sections, and (3) the price (cost) of the production resources and the material analysis as emphasized in the ITMBP. All the building elements have dimensional structures which are shown as length, area, volumes which are used for quantity take-offs. In order to define these dimensional entities, these items should be defined via quantity units. In order to use BoQ information, the additional dimensions such as cost information should be added to building elements which are composed of production resources and material analysis. The production resources and material analysis should be classified and grouped in order to obtain the exact building elements' cost as provided in the ITMBP. When the BoQ are examined different type of quantities which refer to same building elements can be observed. This is mostly related with the location of the production on jobsite. These locations are generally determined as building storey, the building sections and spaces. Depending on the envisaged interoperability structure, there is a need to attach the characteristic property information such as production resources and material analysis to individual quantity and cost information units.

In order to attach production resources and material analysis to these units under compositions, a new catalogue structure which was proposed by Gökçe is used in this context (for details see Gökçe 2008, 2012). On that basis, the main elements required for the exchange of BoQ information based on the ITMBP are defined as: (1) Project Information (e.g. Project ID, Project Name, Project Site, Project Building, Building Storeys and Spaces and Project Containment Structure), (2) The Building Elements, (3) The Building Element Types, (4) The Building Element Classifications, (5) The Product IDs, (6) The Identity of the BoQ objects (e.g. the production resources, material analysis, and compositions), (7) The classification of the BoQ objects, and the BoQ object's cost information, (8) The grouping of BoQ objects, and the BoQ object's cost information, (9) The logical location of BoQ objects (based on building elements), (10) The special properties of BoQ objects, (11) The quantities and the quantity units of the BoQ objects, (12) The measurement units of BoQ objects, (13) Cost information of the BoQ objects (material analysis and composition prices).

6. DEVELOPING AN IFC VIEW DEFINITION

In order to identify the basic content of an IFC-based model view, all necessary entities have to be clarified precisely i.e. all needed attribute values and possible relationships of objects have to be provided properly to support identified requirements. Figure 3 shows on high level, the necessary requirements - information (process) resources' mapping defined in the ITMBP to IFC classes, in order to develop IFC Views. The primary keys consist of single attribute or multiple attributes in combination. The foreign key identifies a column or a set of columns in one (referencing) table that refers to a set of columns in another (referenced) table. The columns in the referencing table must be the primary key in the referenced table. The values in one row of the referencing columns must occur in a single row in the referenced table.

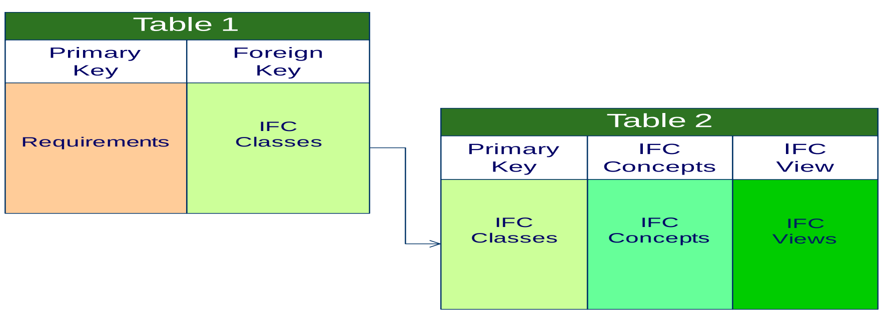

Figure 4: Table formalization from ITMBP functions to IFC View Formalization

In Table 1, the ITMBP related information resources are represented. The ITMBP information resources for the exchange of BoQ information which are structured in Table 1 are used to formulate related IFC classes. Each ITMBP information resource is using 1 or many (1:n) IFC classes. In order to develop an IFC View for BoQ Information, the collected IFC Classes referenced from ITMBP information resources in Table 1 are used to form the IFC concepts which are listed in Table 2. In this context, IFC Concepts are developed based on the proposed IFC Model View Definition format (Hietanen 2006) of the buildingSMART initiative. Each IFC Concept uses one (1:1) or many (1:n) IFC classes in its composition. On the other hand IFC classes can be represented in one (1:1) or many (1:m) concepts to support different demands. For example in IfcClassification, arrangement of objects into classes and assignment of classification notation to objects have to be represented separately.

Table 2: IFC Concepts for the Exchange of BOQ Information View

IFC Classes Referenced by the ITMBP Information Resources	IFC Concepts for the exchange of BoQ Information	IFC View for BoQ
* IfcRoot	* Identification	IFC View for BoQ is the Sum of 17 Concepts
* IfcSpatialStructureElement	* Spatial Element	
* IfcSpatialStructureElement, IfcSite		
* IfcSpatialStructureElement, IfcBuilding		
* IfcSpatialStructureElement, IfcStorey		
* IfcSpatialStructureElement, IfcSpace		
* IfcRelContainedInSpatialStructure		
* IfcBuildingElement	* Building Element	
* IfcDistributionElement	* Distribution Element	
* IfcComponentElement	* Component Element	
* IfcTransportElement	* Transport Element	
* IfcFurnishingElement	* Furnishing Element	
* IfcBuildingElementType, IfcDistrubutionElementType, * IfcComponentElementType, IfcTransportElementType, * IfcFurnishingElementType	* Type Object Concept	
* IfcClassification	* Classification	
	* Construction Type Classification	
* IfcMaterial,	* Material Concept	
* IfcConstructionResource	* Construction Resource Extension	
* IfcElementQuantity		
* IfcPhysicalQuantity		
* IfcSimplePhysicalQuantity		
* IfcGroup	* Group	
* IfcPropertySet, IfcProperty	* Properties	
* IfcCostValue	* Cost	
* IfcCostSchedule	* Cost Schedule	
* IfcCostItem	* Cost Item	

7. IFC VIEW REALIZATION

In order to formalize IFC Model View Definitions, the information resources which address IFC objects should come from the exchange requirements. In order to develop the formal view definitions with General Model Subset Definition (GMSD), the semi-formal IFC Model View Definition (MVD) Format proposed by Hietanen (2006) is used as baseline. The IFC Model View Definition format is divided into two main parts namely: (1) IFC release independent, and (2) IFC release specific. According to the MVD, the first detailed definition should be the IFC release independent part comprising the needed high level concepts and relationships. When that generic definition is done, the next step is to define the binding to a specific IFC release. In this stage, re-suing existing concepts and patterns is very important. Finally, when the IFC binding is done, the developed definitions can be implemented in software. In our work, the exchange requirements are formalized based on the information required in the BoQ. In order to formalize the transition from exchange requirements to an IFC Model View Definition, the information defined for BoQ is examined with regard to the IFC model data, to find out the commonalities between the identified concepts. An established requirement can define one or several partial IFC Classes. These classes represented in a network of mutual inter-dependencies that collectively define IFC Concepts, specified as standard one page description of the new IFC Model View Definition. An IFC View comprises several IFC Concepts which define the complete set of needed classes. GMSD is used to formalize the proposed view and explicate the respective IFC subset content with “ViewEdit”. The outcome of the defined subset can be presented using an appropriate IFC Viewer. The aim in forming each IFC Concept is to provide a clear definition and reuse ideas and software code. The main idea is to define on high level how the needed object instances should be selected and filtered from the actual model data using prescriptive generic view definitions. The selection of object instances is done using a set theoretical approach whereby a large set of functions is provided for the selection of object instances by value, class type and references. In this case, a specific GMSD

View Definition is realized with the help of the ViewEdit tool developed by Weise et al. (2003) to interactively define formal IFC model views. Using the outlined approach, the IFC View for BoQ is realized, based on the concepts shown in table 2. ViewEdit is used to define formally the developed concepts in GMSD, and the DDS IFC Viewer (cf. DDS 2012), which allows viewing of IFC data in 2D and 3D and for inspection of their detailed properties, is used to validate the developed view. Validation of the formalized concepts is done on example IFC model data taken from the BuildingSMART web site (cf. BuildingSMART 2012). The outcome of the GMSD definition generated with the help of ViewEdit is validated with the help of a Client-Server application enabling the actual extraction of the required view model data from the full IFC model.

8. OBSERVED RESULTS

Using a sample building model which contains all building information in IFC format from buildingSMART initiative (cf. 2011) the formalized concepts for the IFC View for BoQ addressing the Unit Price, Design & Build, and Lump-sum contract types (including the Construction Resource Extension Concept) are validated. Thereby the correctness of the proposed classes is controlled. In this case the following steps are applied: (1) The outcome of the IFC View for BoQ in ViewEdit is embedded in a sample building model via Client-Server in DDS Viewer. (2) In order to control/check whether all required elements are represented within the DDS Viewer based on the BoQ, the outcome of concepts in ViewEdit which represents related IFC classes and object relations are compared with the outcome of DDS IFC Viewer for the sample building model by eye inspection. The IFC View for Product Classes which are provided in GMSD and the outcome of the DDS Viewer overlapped in this context. (3) The selected original file of the sample building model which includes all building information in IFC format including IFC Classes has 8892 Kb. (4) The derived IFC View for BoQ addressing Unit Price contract type (excluding Construction Resource Extension) is 878 kb. (5) The derived IFC View for BoQ addressing Design & Build and Lump-sum contract types (including Construction Resource Extension) to provide only Product Catalogue data has only 1237 Kb. In this context the subset of the sample building model is provided. The result is determined as 'Positive'. As a result, by defining the IFC View for BoQ, we excluded unnecessary objects to create a more meaningful subset of the targeted domain. In this case the selected sample building model with all building information is composed of 8892 Kb. Our main aim is reduce information size via applying partial models to extract required data. After the application of the proposed partial IFC Model, in the first case, without adding construction resource concept, the output is reduced to 878 Kb for Unit Price Contract Type, and in the second case with adding construction resource concept the output is reduced to 1237 Kb for Design & Build and Lump-sum contract types which is desired result. In this research the validation addresses only a small building unit. The proposed partial IFC view for BoQ can also be applied to complex projects like University Campuses or Hospitals which may include huge amount of building details and data sets associated with production resources, material analysis and compositions in the size of thousand MBs (megabytes) which can cause enormous problems for software interoperability. Therefore the reduction of data transfer between different application domains via applying partial models is must in the current AEC environment for efficient construction management. With applying partial models to current domain applications, it is evitable to improve efficiency in construction tasks.

9. CONCLUSIONS

The IFC View for BoQ based on the requirements of IT Management Bill of Quantities (ITMBP) is outlined in this research. The ITMBP is developed based on the bidding preparation phase of American Institute of Architects construction general lifecycle model and contract types used in the construction management domain. The main aim in formalizing this view is to develop a process oriented information modeling methodology and to enable handling of various types of information in a standardized way. To provide this, ITMBP defined in the ceEPC model is used as baseline, and defined information resources which are relevant to IFC Views are examined. Subsequently mappings between the information resources and IFC objects are obtained. Whenever model subsets need to be applied, IFC Concepts and IFC Instance Diagrams are defined based on the buildingSMART initiative's IFC View Definition Format (MVD). The mapping between process information resources and IFC classes are provided in order to develop a partial IFC View which contain several IFC Classes. Later these classes are brought together in a network of classes namely IFC Concepts. Therefore the defined information resources' (within ITMBP) mapping to IFC objects/classes are provided. This approach leads to the development of an integration methodology to existing domain applications. In order to realize the integration methodology between the IT domains, the related IFC Concepts and IFC Instance Diagrams are developed according to the MVD format with some modifications. In order to provide IFC views, GMSD is used. The GMSD method allows a neutral definition format for the different type of data exchange and has a capability to specify generic views. Due to the requirements of the GMSD method, the IFC Views are represented in EXPRESS-G format. Two validation scenarios applied based on contract types includes: 1) Unit Price and, 2) Design & Build and Lump-sum contract types. Moreover to provide exchange of cost information in our approach comply with Design & Build and Lump-sum contract types, an extension to IFC is suggested. The new classes and relations are represented in "Construction Resource Extension" concept. Developed concepts are possessed to form the IFC View for BoQ in GMSD. This is realized with ViewEdit and DDS Viewer. The validation has been made for two scenarios based on an alphanumerical comparison of the STEP physical file SPF on the alphanumerical basis. The expected results are observed in the first scenario for Unit Price contract type. For Design & Build and Lump-sum contract types, the IFC model is extended with new classes and relations in a new concept "Construction Resource Extension". In both cases, the size of the SPF is considerably reduced.

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