

IT Supported Construction Project Management
Methodology Based on
Process and Product Model and Quality Management

Eine Methodologie für das IT-unterstützte
Bauprojektmanagement auf der Grundlage von
Prozess - und Produktmodellen und Qualitätsmanagement

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Abstract

Computer Integrated Construction Project Management (CPM) supported by product and process models can be seen as a future type of integration structure facilitating the solution of various management problems in the fragmented Construction Industry. The key to success is directly correlated with the comprehensive integration of currently isolated IT applications. However, despite that a number of initiatives have been developed, no fully generic models have yet to be formally standardized. This topic has been the subject of intensive research during the last decades.

In this thesis a Computer Integrated CPM approach, which is supported by IFC (Industry Foundation Classes) and ISO9001:2000 Quality Management System, is proposed. The main aim is to provide integration of product, process and organizational information to help achieve the interoperability of the involved actors and tools in a concurrent environment.

According to implied requirements which are represented in the 'state of the art' section, the fundamental concepts are presented in two parts as: (1) realization of CPM in an IT concept and (2) formalization of IFC Views for software interoperability on the example of Bidding Preparation Phase.

In order to realize a generic framework using a high-level process core model named Organizational Management Process (OMP) model, different aspects have been brought together into a consistent life cycle structure. These are: (1) a set of layered processes based on ISO procedural definitions, (2) software integration requirements based on Construction Management Phases, (3) application methods of the Procurement System and (4) Organizational data. This provides for synchronizing technical products, processes, documents, and actors in their inter-relationship. The framework is hierarchically structured in three layers Phases – Processes - Product data. The developed IT Management Processes (ITMP) which are used as a baseline for the IFC Views implementation are derived from the OMP. Moreover, in order to support completeness, a mapping structure between processes and scenarios based on the Procurement Systems was constituted. The representation of OMP and ITMP is provided by using the ARIS eEPC (extended event-driven process chain) modeling method.

On the basis of a generalized representation of product data, a system-wide integration model for heterogeneous client applications which supports different CPM areas can be achieved. IFC Product Data Model integrates different domains thereby enabling coordination of bidding preparations. However, there is a need to realize individual model subsets. i.e. views of the product model. In this context, adaptable views were developed based on ITMP. The defined resources' relevancies to IFC Objects are examined by realizing central information elements. These provide a mapping structure between process resources and IFC Classes. On that basis integration of process and product models can be accomplished. In order to realize IFC Views, IFC Concepts and IFC Instance Diagrams were developed based on IFC View Definition Format. The grouping of IFC Concepts enables the implementation of the adaptable IFC Views that are required for standardized system integration. This is achieved with the help of formal specification using the Generalized Subset Definition Schema.

The validation has been made based on an alphanumerical comparison. The selected 3D full-model and the developed IFC View for Product Catalog models are compared in this context. There are two consequences observed. In the first case, which also addresses Unit Price Procurement systems, the desired results were obtained by filtering the required data. However, when the results were compared for Design & Build and Lump-sum Procurement Systems (contracts), an extension need was observed in the IFC Model. The solution is provided via formalization of cost data and material analysis information by an extension of IFC Concept namely 'IfcConstructionResource' with new classes and with new relations. Thereby a common information model based on the data schema of the IFC standard is constituted.

Kurzfassung

Das von Produkt- und Prozessmodellen unterstützte computerintegrierte Bauprojektmanagement (CPM) kann als der zukünftige Typ der Integrationsstruktur angesehen werden, der die Lösung verschiedener Baumanagementprobleme in der fragmentierten Bauindustrie erleichtern kann. Der Schlüssel zum Erfolg steht in direkter Beziehung zu einer umfassenden Integration derzeit getrennter IT-Anwendungen. Trotz zahlreich entwickelter Ansätze, die zur Verfügung gestellt wurden, sind bisher noch keine vollständig generischen Modelle formell standardisiert worden, obwohl dies in den letzten Jahrzehnten ein Thema intensiver Forschung war.

In dieser Promotionsschrift wird eine computerintegrierte CPM-Methode, die auf Basis der IFC (Industry Foundation Classes) und dem Qualitätsmanagement ISO 9001:2000 aufbaut, vorgeschlagen. Das Hauptziel besteht in der Schaffung der Integration von Produkt-, Prozess- und Organisationsinformationen, um die Interoperabilität der beteiligten Akteure und Tools in einer parallelen Umgebung erreichen zu können.

Entsprechend den Anforderungen, die im Abschnitt „Stand der Technik“ aufgeführt sind, werden die vorgeschlagenen, grundlegenden Konzepte in zwei Bereiche aufgeteilt: (1) Umsetzung der CPM-Prozesse in ein IT-Konzept und (2) Formalisierung der IFC-Sichten für die Interoperabilität von Software, beispielhaft ausgeführt für die Ausschreibungsphase.

Um einen generischen Rahmen unter Verwendung eines hochrangigen Prozesskernmodells, das als organisatorischer Managementprozess (OMP) bezeichnet wird, zu realisieren, werden zuerst die verschiedenen Aspekte in einer konsistenten Lebenszyklenstruktur zusammengefügt. Diese sind: (1) eine Menge hierarchisch geschichteter Prozesse, erstellt auf der Grundlage der Verfahrensdefinitionen von ISO 9001, (2) die Softwareintegrationsanforderungen auf der Grundlage der Baumanagementphasen, (3) die Anwendungsmethoden des Beschaffungssystems und (4) die Organisationsdaten. Dadurch wird die Synchronisation der in Wechselbeziehung stehenden technischen Produkte, Prozesse, Dokumente und Akteure geschaffen. Das gesamte System ist hierarchisch in die drei Ebenen Phasen – Prozesse – Produktdaten strukturiert. Die entwickelten IT-Managementprozesse (ITMP), die als Grundlage für die IFC-Implementierungssichten dienen, werden aus dem OMP hergeleitet. Der Vollständigkeit halber, wird eine Abbildungsstruktur zwischen den Prozessen und den Szenarien, die die Beschaffungssysteme beschreiben, entwickelt. Die Darstellung der OMP und ITMP erfolgt unter Verwendung der erweiterten ereignisgesteuerten Prozessketten (eEPK) nach der ARIS-Modellierungsmethode.

Auf der Grundlage einer verallgemeinerten Darstellung der Prozessdaten kann das systemweite Integrationsmodell für heterogene Client-Anwendungen, das verschiedene CPM-Bereiche unterstützt, erreicht werden. Das IFC-Produktdatenmodell integriert verschiedene Domänen und ermöglicht somit die Koordinierung der hier beispielhaft gewählten Ausschreibungsbearbeitungen. Hierzu ist es notwendig, Teilmodelle, d. h. Sichten des Produktmodells zu erzeugen. Entsprechend wurden anpassbare Sichten auf der Grundlage von ITMP entwickelt. Die Bedeutung der in diesem Zusammenhang identifizierten Informationsprozessressourcen in Bezug auf die IFC-Objekte wurde durch die Einführung zentraler Informationselemente, sog. IFC Concepts, untersucht. Diese stellen eine Abbildungsstruktur zwischen den Prozessressourcen und IFC-Klassen zur Verfügung. Auf dieser Grundlage konnte die Integration von Prozess- und Produktmodellen erreicht werden. Um die IFC-Sichten zu realisieren, wurden auf der Grundlage des IFC-Sichtendefinitionsformats IFC-Konzepte und IFC-Instanzendiagramme entwickelt. Die Gruppierung in IFC-Konzepten ermöglichte die Implementierung von anpassbaren IFC-Sichten, die für die standardisierte Systemintegration erforderlich sind. Diese wird mit Hilfe einer formellen Spezifikation unter Verwendung der verallgemeinerten Subset-Definitionsschema-Methode (GMSD) erreicht.

Die Validierung erfolgte auf der Grundlage eines alphanumerischen Vergleichs, in dem ein ausgewähltes 3D-Produktmodell und die daraus entwickelte IFC-Sicht für das Produktkatalogmodell verglichen wurden. Es ergaben sich zwei Schlussfolgerungen. Im ersten Fall, der auch das Einheitspreisbeschaffungssystem betrifft, konnten die gewünschten Ergebnisse direkt durch Filterung der erforderlichen Daten erhalten werden. Beim Vergleich der Ergebnisse sowohl für Pauschal-, als auch für Entwurfs- und Baubeschaffungssysteme (Verträge) wurde jedoch festgestellt, dass für das IFC-Modell ein Erweiterungsbedarf besteht. Eine Lösung wurde über die Formalisierung der Kostendaten und Materialanalyseinformationen durch Erweiterung des IFC-Konzepts IFCBauRessource mit neuen Klassen und mit neuen Beziehungen erreicht. Somit erhält man ein allgemeines Informationsmodell auf der Grundlage des Datenschemas des IFC-Standards.

Preface

This thesis is the result of my research work at the Institute of Construction Informatics, Dresden University of Technology from June 2004 to June 2008.

This work comprises theoretical studies, industry studies, conference visits, literature studies and discussions during my 4 years stay at the institute.

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LIST OF ABBREVIATIONS

AAM	Application Activity Model
AEC	Architecture, Engineering, Construction
AIA	American Institute of Architects
AICs	Application Interpreted Constructs
AP	Application Protocol
ARIS	Architecture of Integrated Information System
ATS	Abstract Test Suites
BD	Bidding Department
BOQ	Bill of Quantity
BOT	Build Operate and Transfer
BP4WS	Business Process Execution Language for Web Services
BPM	Business Process Modeling
BPP	Bidding Preparation Phase
BPR	Business Process Re-engineering
BSAB	Bygghandens Samordning AB (Swedish for Building Coordination Centre)
CAD	Computer Aided Design
CALS	Continuous Acquisition and Life-Cycle Support
CD	Committee Draft
CDC	Committee Draft for Comment
ceEPC	Complemented Extended Event-driven Process Chain
CESP	Concurrent Engineering Services Platform
CGLCMP	Construction General Life-cycle Model Phases
CIC	Computer Integrated Construction
CIM-OSA	Integrated Manufacturing-Open System Architecture

CMPSI	Construction Management Phases for Software Interoperability
CPM	Construction Project Management
CRP	Customer Relation Procedure
DDS	Data Design System
DF	Design Firm
DIS	Draft International Standard
DSD	Data Structure Diagrams
DXF	Drawing Interchange File Format (Autodesk)
EDI	Electronic Data Exchange
EDIFACT	International Standard for the Definition of Electronic Trade Messages
EDM	Engineering Data Model
EAI	Enterprise Application Integration
eEPC	Extended Event-driven Process Chain
E-R Model	Entity Relationship Model
EPC	Event-driven Process Chain
EPISTLE	European Process Industries STEP Technical Liaison Executive
ERP	Enterprise Resource Planning
ESB	Enterprise Service Bus
FDIS	Final Draft International Standards
FDM	Functional Data Model
GARM	General AEC Reference Model
GMSD	Generalized Model Subset Definition Schema
GPP	Generic Process Protocol
GSP	General System Procedures
HIPO	Hierarchy Plus Input, Process and Output

HQ	Head Quarters
HP	Hewlett-Packard
HRAP	Human Resources and Administrative Procedures
HSE	Health Safety Environment
HVAC	Heating Ventilation Air Cooling
IAI	International Alliance for Interoperability
IBDS	Integrated Building Design System
IBM	Intelligent Business Machines
IC	International Council
ICAM	Integrated Aided Manufacturing
ID	Identity
IDEFØ	Integration Definition for Function Modeling
IDEF1x	Integration Definition for Information Modeling
IDEF3	Process Description Capture Method
IDM	Integrated Data Model
IFC	Industry Foundation Classes
IGES	Initial Graphics Exchange Specification
IRC	Intelligent Resource Planning
IRMA	Information Reference Model for AEC
IS	International Stand
ISO	International Organization for Standardization
ISDOS	Information System Design and Optimization System
IT	Information Technologies
ITM	International Technical Management Committee
ITMP	IT Management Processes

ITMDP	IT Management Design Process
ITMBP	IT Management BOQ Process
ITMSP	IT Management Scheduling Process
JDM	Jackson Design Methodology
LSE	Large Scale Engineering
MSG	Model Support Group
MRP	Materials Resource Planning
NIAM	Nijssen' s Information Analysis Method
NIST	National Standards and Technology
OMG	Object Management Group
OMP	Organizational Management Process
OMM	Organization Management Model
ORM	Organization and Resource Model
OMT	Object Modeling Technique
OOCAD	Object Oriented CAD
OOIE	Object-Oriented Information Engineering
PD	Planning Department
PDE	Product Data Exchange
PDM	Product Data Management
PDT	Product Data Technology
PDU	Product Definition Unit
PMI	Project Management Institute
PMP	Project Management Procedures
PMQL	Partial Model Query Language
PRM	Process Renewal Methodology

QM	ISO9001:2000 Quality Management
RPC	Remote Procedure Call
SDAI	Standard Data Access Interface
SADT	Systems Analysis and Design Technique
SC4	Subcommittee 4
SD	Structured Design
SDM	Semantic Data Model
SME	Small Medium Enterprises
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SOM	Semantic Object Modeling
SPF	Step Physical File
SSA/SD	Structured System Analysis and Structured Design
STEP	Standard for the Exchange of Product Data
SQL	Structured Query Language
TNO	Dutch Research Institute
TQM	Total Quality Management
UML	Unified Modeling Language
UREP	Unix Rscs Emulation Protocol
XML	Extensible Mark-up Language
VE	Virtual Enterprises
WSOI	Web Service Choreography Interface
WSCL	Web Services Conversation Language
WfMC	Workflow Management Coalition
WISDM	Web Information System Development Methodology

CHAPTER 1: INTRODUCTION

1.1 Information Technology in Construction

As we begin the twenty-first century, we find ourselves immersed in the age of technology. Electronic computation is impacting all fields of human endeavors. New technologies are playing a crucial role in the process of economic and social globalization. Computers, satellite-based communications and internet make possible an ever-expanding degree of information exchange and individual contact across the globe.

Along with the improvement of the world markets, the building industry is also influenced by the ongoing competitiveness. As one of the leading sector's participants, the building industry actors have started to improve the existing situation by utilizing IT tools in every step of every application such as the digital representation of buildings and the information about the buildings, as well as the design and construction process.

Existing technologies such as e-mail, electronic communication and electronic document management systems can be used for the building industry. But due to many factors such as the complexity and size of the end product; the need for visualization and technical analysis at the design stage; the variety of different know-how and materials needed to erect a building; the large number of interactions by stakeholders; the building product information; and the process operating on that information, cannot be adopted from elsewhere but must be generated by the building industry itself.

Moreover, there is also a need to interrelate and make trade-offs with the information of other disciplines (Haymaker et al. 2005).

From this standpoint to coordinate activities and intentions of all participants involved in the main objective and supporting actions of building information efficiently, the existing management and organizational structure of the construction environment should be examined precisely. Hence the embedded complex relations within the processes and applications, and their relations with information technologies which lead to seamless communications, can be formalized.

Along with the increased realization of construction projects in virtual enterprises comprised of physically distributed specialist teams, a growing interest in the introduction of advanced production methodologies and the use of innovative Information Technology (IT) solutions can be widely observed (Katranuschkov 2000). However, the effects of these solutions mostly in the practical side, have not reached the expected level. In some cases information is produced in an effective way rapidly but the information management is the same as in the past decades. This can be explained by the lack of capabilities of applications for utilizing each other's data directly in digital format. This is related to the fragmented formalizations of the construction management issues i.e. the process and product management.

In order to support comprehensive improvements, there is a need for integrated project communications framework and integrated industry-wide information.

In accordance with these briefly outlined issues, the major requirements of the proposed structure namely an integrated Construction Project Management (CPM) approach will be examined in details in the thesis.

1.2 Motivation

Computer Integrated Construction Project Management is the term used to denote the broad set of activities supported by multi-module application software that helps a contractor to manage the different work sections and processes of a construction project.

The purpose of computer-integrated CPM is to enable the efficient use of project resources (time, money, labor force and equipment) in order to complete the project in the shortest possible time, with adequate quality and within the available budget. This can be provided by managing CPM processes in an integrated way, reusing and not duplicating the available data. Moreover, there is a need to describe the building and its parts with multiple qualities. To formulate this description common concepts are required i.e. description of standardized building objects and standardized management processes.

Hence, the flexibility and availability of human expert resources, faster access to expert knowledge and improved collaborative work can be realized.

In order to achieve this:

- All the economic and technical aspects, that might and can affect the product and processes during their lifecycle, must be taken into consideration.
- Furthermore different types of domains have to be defined to establish a common comprehensive model for concurrent engineering.

Concurrent engineering is the way of developing and manufacturing complex products in a fast, efficient, faultless and competitive way. To gain a successful result, a comprehensive integration of currently isolated computing applications and actors in different phases of production that use the data exchange standards, for structuring the information describing buildings (building product data models) have to be taken into consideration.

The main aspects of concurrent engineering are dependant on time, space, domain and enterprises and these aspects can be defined in the context of, cooperative engineering, collaborative engineering, simultaneous engineering and e-commerce.

According to Scherer (2000):

- Cooperative engineering is the synchronized work of different domain experts working on the same part of a product in a parallel way. To achieve this concurrency within a synchronized structure, transformation, consistency checking, monitoring, control and notifications of different engineer views should be recognized.
- Collaborative engineering can be explained as a cooperation of the experts that working on the same product although they are situated in different places. This means that the teams are working as if on the same table in a virtual environment. This

requires a virtual enterprise organization that can coordinate the participants on one common objective.

- Simultaneous engineering is taking every phase of the design process into consideration by involving the human expert directly or using related tools to define the simulation of design.
- E-commerce is the virtual availability of any material and product which can be inspected, selected and tested in advance before it is finally ordered.

According to the supplementary issues of concurrency given above, the objective of concurrent engineering from integrated CPM point of view can be explained as to support a team and provide a team work with concurrent access of the team members to the same data in a synchronized way, although there is not a physical team due to separation in time and space.

In this sense, efficient CPM structure should use reliable tools which provide simultaneous access and modification of the same product items, with coordination of parallel streams of data, information and knowledge flow.

1.3 Problem Statements

Currently, in all industrial countries there exist solutions integrating design, resource planning and scheduling domains. Quite often general-purpose light-weight tools such as Microsoft Project (MS) are integrated with specialized in-house developments and/or more powerful Computer Aided Design (CAD) and Resource Planning (ERP) systems. There are also, design to cost developments offered by single software vendors (such as Nemetschek Germany, Avinal in Turkey, etc.) which provide more or less comprehensively the required functionality in the construction management domain. The major advantage of such solutions is in the combined use of construction site databases and head quarters' databases which leads to the following benefits.

- improved project/cost control;
- reduced operation costs;
- increased work efficiency of the site personnel;
- decreased dependency of key personnel on the process;
- quick response to change in the (1) construction environment (2) business operations and (3) market conditions.

However, whilst such systems offer the above mentioned advantages, they lack generality in terms of data and process interoperability. Thus CPM processes are defined in terms of the capabilities of the used applications and not on the basis of generalized industry requirements. Similarly, integration of product, process and cost information is based on the specific internal models of the used systems and not on a standardized data model. This significantly decreases flexibility, the information exchange between systems, multi-stakeholder collaboration and last but not least, inter-enterprise cooperation and knowledge transfer. In

spite of its potential, the upcoming common project models, such as the Industry Foundation Classes (IFC) of the International Alliance for Interoperability (IAI) are practically not used for construction management purposes.

On the other hand increasing demands of quality in the Architecture Engineering Construction (AEC) sector, force construction companies to observe established guidelines for better CPM and product outcome. Accordingly, most companies have been engaged with quality management standards and established their process structure in accordance with ISO 9001 Quality Management System. However this trend is yet purely supported by adequate software.

A further issue that deserves consideration is the internet. Collaboration through the internet supports concurrent management of construction activities and enables achievement of better quality and shorter time to market. During the last decade established and new start-up companies continuously increased their use of the Internet for management applications. However many business plans were not accepted as feasible because they were not grounded on a standard-based collaboration system.

Based on these outlined statements, there is a need observed for defining the CPM requirements which lead to IT based concurrency in CPM applications.

1.4 Research Objectives

The work in this research is grounded on the interoperability problems of the existing systems, the integration of CPM processes and the information exchange primarily within the design, resource planning and scheduling domain based on IFCs.

The objectives are defined as:

- 1 To generalize construction project management processes, and represent these processes in a formal language so that interoperability over a broad spectrum of applications is facilitated.
- 2 To develop a common formalized information model for construction project management based on the schema of the IFC standard, providing integration of product and process, cost and management data.

1.5 Approach

According to the identified objectives, an approach has been established based on using and appropriately combining methods for requirement analysis (e.g., quality function deployment, critical success factors, use case analysis), process modeling (Integration Definition for Function Modelling (IDEFØ), Architecture of Integrated Information System (ARIS)), and product modeling (Industry Foundation Classes (IFC)) in order to identify and formally define the necessary product data scope and in particular the IFC extensions.

In preparation for the actual work an extensive study of existing systems, earlier standardization efforts in the IAI, STEP and applicable integration methods have been performed.

The proposed solution is embedded in a conceptual CPM methodology which consists of 8 hierarchical steps as represented in **Figure 1.1**.

They are structured according to

1. Phases, where requirements concerning the Construction General Life Cycle Model and the IT capabilities are considered,
2. Processes, where the requirements of the ISO9001 Quality Management, the Procurement Systems and the IT capabilities are considered,
3. Product, where the requirements of the product description, i.e. product model data in particular the IFC model are considered.

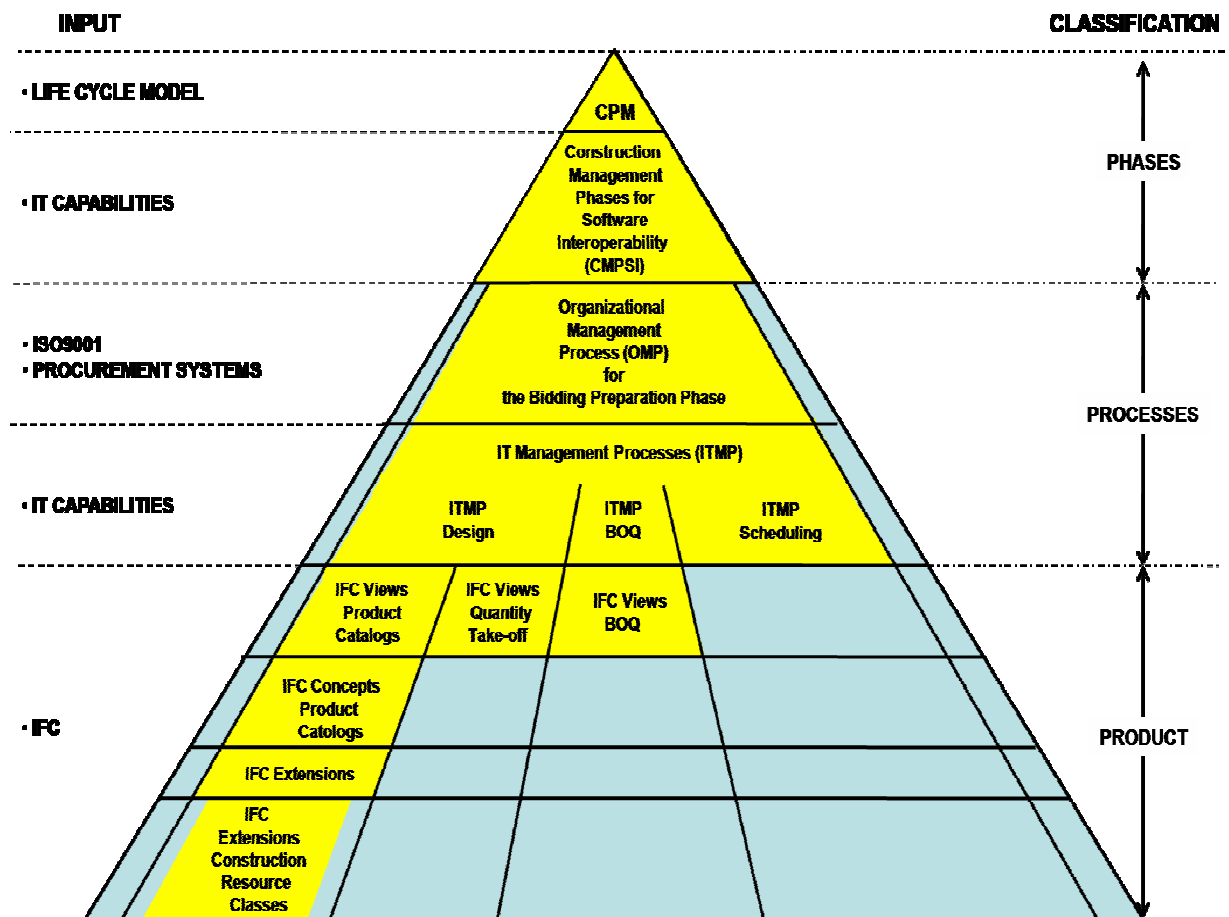


Figure 1.1 Scope of Thesis (yellow parts) and the Solution Steps to provide a Conceptual CPM Methodology

In order to narrow the context, the method developed in the thesis is worked out exemplarily for the Bidding Preparation Phase.

The newly introduced Construction Management Phases for Software Interoperability (CMPSI) layer dedicated to Software Interoperability is defined on the basis of state-of-the-art analysis of Construction General Life Cycle Model and Phase Formalization Structures using the IDEFØ function modeling methodology. The main aim of the CMPSI layer is to identify the necessary data and to provide them in a generic form so that they can be used by various types of IT domains in an integrated way for the CPM purposes. This data can be used to realize object-oriented data structures and enable the examination of the basics for seamless and co-ordinated work environments.

However to coordinate the work and to establish an adequate information and communication system, it is not only required to define the data and their formalization within an application domain but it is also required to represent how they flow within the organizational units, i.e. to show their use in the various processes. In this context ISO9001:2000 Quality Management System Procedures are applied for the specification of the existing real-world process for managing the management and quality requirements of the outcome.

The CMPSI is described by using IDEFØ which is a widely accepted effective modelling method. It obtains a detailing mechanism in terms of decomposition of high level processes to sub-defined activities of the general model. However the method shows limitations when the will-be processes are attempted. In this regard the ARIS method of Extended Event-driven Process Chain (eEPC) has been chosen for the definition of the generalized CPM model. The eEPC enables holistic consideration of functions, events and resources in their inter-relationship. However in order to design an interoperable software solution and to configure management processes and to support mapping between different but interrelated data based on the demands of the procurement system, organizational structures and services, requires some extensions. In this context each function, each event and the related resources are complemented by a notation developed in Chapter 6, and provide the mapping between the IDEFØ phase view and the eEPC process view.

The Organizational Management Process (OMP) is then defined as the core process model for the Bidding Preparation Phase. The OMP represents different views which are defined by a consistent Life Cycle approach developed for the OMP. The OMP brings together (1) the set of interrelated processes, (2) application methods determined by the type of the procurement system, (3) the organizational data, and (4) the software integration requirements predefined by the CMPSI. The goal is to coordinate the different type of views to provide an integrated information model for CPM. The set of interrelated processes is structured in such a way that one of the processes takes the role of the main process while the others are supporting processes. For the bidding preparation phase, the main process is the bidding preparation process which is supported by 7 further processes. Therefore the core process structure which includes various types of views can be accomplished.

The additional complementary IT Management Processes (ITMP) which are needed as a baseline for capturing the data flow i.e. for the IFC Views definitions, are derived from the OMP. They represent the integration of the design, resource planning and scheduling domain information and are based on the generic data which were defined in CMPSI model.

As illustrated in **Figure 1.1**, impact of IT on two levels can be observed, (1) The IT capabilities related to the Phase Definitions and (2) The IT capabilities related to the Process Models. The generic data which is provided within the Bidding Preparation Phase, is

represented in OMP formalizations with additional data derived from different views.. Thereby all resource attributes and all the resource relations can be identified. This explicit representation is needed to define a complete set of IFC Concepts which are required to implement the IFC Views.

The ITMP model in the case of bidding preparation is presented through three complementary partial models as (1) IT Management Design Process Model, (2) IT Management BOQ Process Model and (3) IT Management Scheduling Process Model. Each process model defines the integration of software regarding to a particular application domain i.e. integration of CAD, ERP and Scheduling software tools. These processes provide the required information in terms of resources needed to implement the IFC views.

Moreover in order to support completeness, a mapping structure between the three constitution models, the CMPSI, the OMP and the ITMP is developed. The interrelationship is controlled by instantiating scenarios based on different procurement systems (contract systems).

Thereafter, in order to realize IFC Views, a comprehensive study of the current IFC Model has been done to reveal entities, attributes and relations covered by IFC with regard to the identified ITMP models in order to identify gaps, and the related necessary modifications, extensions and re-structuring needs.

The main reason to divide the ITMP in three parts is to develop sub-views of the whole IFC structure. The implementation of individual model subsets is needed in order to produce meaningful applications and to reduce unnecessary information exchange which can cause efficiency problems. Therefore applications should always implement only the specific subsets of the full model. Such subsets are called IFC Views.

In our approach, adaptable views in terms of IFC Views are exemplarily developed based on the three ITMP partial models. These are (1) IFC View for Product Catalogs, (2) IFC View for Architectural Design to Quantity Take-off and (3) IFC View for Exchange of Bill of Quantity (BOQ) Information.

The implementation of IFC Views is constructed according to the ITMP information resources. The relevancies of the information resources in relation to IFC Objects are examined and detailed according to the IFC Model requirements. This provides a mapping structure between the process information resources and the IFC classes. On that basis process and product models integration is accomplished.

In order to formalize IFC Views, IFC Concepts and IFC Instance Diagrams are developed based on the IFC View Definition Format of the IAI. However, due to special requirements of our model such as the representation of classes in EXPRESS-G and also new formalization needs for the Instance Diagrams which have arisen, appropriate modifications are made in the formalizations.

Due to the management of cost data based on material analyses information in Design & Build and Lump-Sum Procurement Systems an extension is required in the IFC model to cover all information needed. In this context, the Construction Material Cost Information is extended with some new classes and with new relations in the frame of the 'IfcConstructionResource' Concept.

The IFC View for Product Catalogs subset has been chosen as an example to validate the consistency of the IFC Concepts. The above mentioned, grouping of IFC Concepts enables the implementation of IFC Views for Product Catalogs. The validation is carried out based on an alphanumerical comparison STEP physical file format (SPF) and a complementary 3D graphical representation. The selected 3D full-model and the developed IFC View for Product Catalogs model are then compared by eye. Two validations are carried out. In the first case the outcome is validated according to Unit Price Procurement System. Because the exchange of cost information is of great importance in our approach, a three tiered product catalog structure is suggested according to IFC model and Unit Price Procurement System requirements. Thereby the expected results are provided through our approach.

In the second case, the outcome was validated based on Design & Build and Lump-sum Procurement Systems. There, the validation was only possible on a conceptual level, because the above mentioned extensions of the IFC have been only developed on a schema level and are not yet implemented in available software tools. The development of software applications have not been part of the thesis.

1.6 Structure of Thesis

Chapter 1 as an introduction chapter comprises the main issues such as motivation, problems, objectives and the thesis approach. The definitions which will be addressed in the following chapters are provided and summarized in this regard.

Chapter 2 starts with reviewing generally accepted definitions of Project Management, Construction General Life Cycle Models and ISO Quality Management procedure models. As the research about Computer Integrated Construction Project Management is in its infancy, relevant management processes, construction management phases and procedural definitions based on ISO Quality Management are briefly reviewed to define the interoperability problem. In this context the EU research projects in particularly ToCEE, iCSS and ISTforCE are examined and related acquiesces are elaborated. Moreover procurement systems are briefly outlined and their impacts on process models are shown in Chapter 5, in this regard.

In order to formalize an integrated Construction Project Management (CPM) Model and to represent necessary requirements, building product and process models are examined in Chapter 3. ISO10303 Exchange of Product Model Data (STEP) and ISO/PAS 16739 Industry Foundation Classes are explained in detail. Moreover Design Methodologies and Process models are examined briefly. On the basis of phase and process formalizations, IDEFØ and ARIS Business Process modeling methods are analyzed in more detail.

Chapter 4 comprises a CPM model approach based on a logical conceptual schema. In order to construct the whole model, Phase and Process formalization structures which are composed of principles such as General Project View, Process Consistency, Phase and Process Reviews etc. are defined. These provide the basis for Construction Management Phases for Software Interoperability (CMPSI). Thereafter, Construction Management Phases are examined from a software integration point of view with regard to the integration of the three domains design, resource planning and scheduling. On that basis, phases such as Design, Bidding Preparation,

Planning & Construction are represented with IDEFØ function modeling methodology. Subsequently to monitor ongoing activities ISO9001:2000 Quality Management System is examined for CPM purposes and the four main procedures (1) General System, (2) Human Resource and Administrative Management, (3) Customer Relations and (4) Project Management are formalized to provide sub-procedures and interrelated sub-processes.

In Chapter 5 two principal process definitions based on ARIS-eEPC namely (1) Organizational Management Process (OMP) and (2) IT Management Processes (ITMP) are defined exemplarily for the Bidding Preparation Phase with regard to the Process Lifecycle Model and Integration Rules/Requirements. The Organizational Management Process is developed according to the Process Lifecycle Model which provides for the union of different views in one process structure. The IT Management Processes are defined based on design, resource planning and scheduling domain interoperability requirements with regard to CMPSI. These are derived from OMP. The IT Management Processes focused on Bidding Preparations are sub-structured in three sequenced and interconnected processes as (1) IT Management Design Process, (2) IT Management BOQ Process and (3) IT Management Scheduling Process. This helps to formalize IFC Views and to comprehend related information resources which are a guide to IFC Extensions. Furthermore the impact of the procurement systems namely Design & Build, Lump-sum and Unit Price are examined and the procurement system dependent process aspects which address OMP and ITMP are illustrated for relevancy.

Chapter 6 comprises a mapping structure between CMPSI, OMP and ITMP. The goal is to provide complete process definitions and to represent commonalities by providing 1-1 mappings. Each information resource is tagged with a notation which will lead to mapping of these information resources to IFC classes.

In Chapter 7, the three IFC Views based on the requirements of IT Management Processes, which are (1) IFC View for Product Catalogs (2) IFC View for Architectural Design to Quantity Take-offs and (3) IFC View for Exchange of BOQ information, are formalized. The goal is to construct process oriented information modeling methodology and the handling of different types of information in a standardized way. The IT Management Processes are used as a baseline to the defined functions and identify the information resources which are relevant for IFC Views. Thereafter these information resources are used as a guide to represent IFC objects/classes. For each identified Model Subset the IFC Concepts and the related IFC Instance Diagrams are defined based on the IFC View Definition Format of the IAI. This is done in EXPRESS notation and not in XML serving the requirements of GMSD. Furthermore, because exchange of cost data is also a priority, (1) a three leveled product catalog and (2) an extension to IFCs are suggested. The IFC class namely “IfcConstructionResource” is extended with new IFC classes and new object relations. This provides exchanging of building element cost information based on production resources and material analysis.

Chapter 8 comprises IFC views instantiation and validation. The instantiation of the IFC Views based on IFC Concepts and IFC Instance Diagrams are made with the General Model Subset Definition Schema (GMSD) method. A brief introduction of the GMSD and the IFC ViewEdit tool which are used directly to construct subset definitions are represented in this context. The validation of the concept is provided for the IFC View for Product Catalogs

using the GMSD method and the DDS IFC Viewer. Moreover to prove the concept, three procurement systems, Unit Price, Design & Build and Lump-sum Procurement systems are examined according to the selected 3D Model. In the first case, the outcome is validated for the Unit Price Procurement System. However, for the Design & Build and for the Lump-sum Procurement Systems due to the need for an extension of the IFC model concerning Construction Material Cost Information, the validation was only possible on a conceptual level.

Chapter 9 summarizes the main ideas and gives an outlook on open research problems.

CHAPTER 2: BACKGROUND

In this chapter the definitions of Project Management, Construction General Life-cycle Model, ISO9001:2000 Quality Management System and Procurement Systems are represented and they build the baseline of the suggested computer integrated CPM approach. From these models the relevant processes, construction management phases and quality management approach are extracted and examined in detail. In addition some selected R&D projects, which developed integration approaches like ToCEE, iCSS and ISTforCEE are given, and related acquiesce is elaborated.

2.1 Construction Management Approach

As one of the main industries, the building environment has been improving within throughout centuries. Current practices are the result of incremental adaptation and change within this period. These comprise many new construction methods, materials, and consideration of safety and environment with respect to changing societal issues and customs. In this ongoing process, the defining of the management systems has been attempted in a methodic way to designate the basic components more precisely.

There are many different types of applications that have appeared, but effective practices tend to be adopted generically. This not only provides to form the basis which supports the main requirements but also facilitates the realization of building standards.

Furthermore as a result of the rapidly changing nature of the work, management is driven by more and more collaboration, globalization, digital media, interactive devices and spaces, mobility and convergence of virtual and physical spaces. Hence the single anticipations are not enough to manage, transfer, and reuse complexity at present. The answer would be the consideration of divergences, and form them in common views to realize core structures.

One promising approach which provides to manage differences can be accepted as Concurrent Engineering. However, although broadly discussed, the principles and their implications to information technology in CPM are not yet well understood. Moreover, since every building is a one-of-a-kind product and almost every project is performed by a new virtual enterprise, within a distributed and heterogeneous information infrastructure, the difference in the potential for concurrent engineering work in the various participating enterprises is another factor that lowers the achievable level of concurrency (Scherer et al. 1997).

The lack of formal, standardized, comprehensive models limits both the capabilities and integration of CPM applications, as well as the successful information exchange and sharing in construction projects. In this context, the major achievements inhibiting the successful applications lie within the correct understanding of the real world expectations. Therefore expected conceptual models which would cover wide applications, can be successful.

In order to identify an integrated CPM approach the basis are examined where construction phases and processes are defined and widely accepted. These are Project Management Models, Construction General Life-cycle Model, ISO9001:2000 Quality Management (QM) System and Procurement Systems. In addition the result of some research projects dealing

with information integration namely ToCEE, iCSS, ISTforCEE are analyzed and evaluated precisely. In the first part, the project management system as defined according to the Project Management Institute (PMI), USA is selected as a baseline. The following the descriptions for Construction General Life-cycle Model are given based on the American Institute of Architects (AIA). For standard procedure definitions, procedure models and QM System are represented. Moreover Procurement Systems and the research projects which will lead to form the basis for the proposed integrated CPM approach are constituted subsequently.

2.2. General Overview on Project Management

Project Management covers a wide-range of perspectives which are addressed by different application areas. However due to the complexity in the construction industry, the definitions show considerable differences. In order to examine project management from CPM point of view, the definitions are given at the very outset. The purpose is to shed light on the basis which would be used for general implementation.

2.2.1 Definition of Project

According to PMI (PmBok 2000), a project is a temporary endeavor undertaken to create a unique product or service. The basic characteristics of a project are the people for management, the resources constrained by limits, and the managing components such as: planning and controlling.

In order to manage projects efficiently the main aspects of a project should be defined initially. Based on general acquiesces, these can be identified as follows.

- Projects are temporary formations; there is definite beginning and a definite end for every project.
- Projects are unique constitutions; the product or service has some difference aspects from all other products and services.
- Projects can be managed by a single person or many hundreds.
- The durations of projects are changeable; a few weeks to several years.
- Projects may involve a single unit of one organization or many cross boundaries.
- Projects are implemented to achieve the organization's strategic and business plans.

2.2.2 Project Management

Project management is consuming time, money and using labor, machinery and equipment in a most effective way to complete a project on time, with the right budget and with the highest quality.

Project management is composed through the use of processes such as: designing, planning, controlling, etc. The work is generally related with the, (1) partners with different needs and approach, (2) scope, time, cost, quality, (3) and related requirements.

Moreover it comprises different knowledge areas, describing project management knowledge and practice and their complimentary processes as illustrated in **Figure 2.1**.

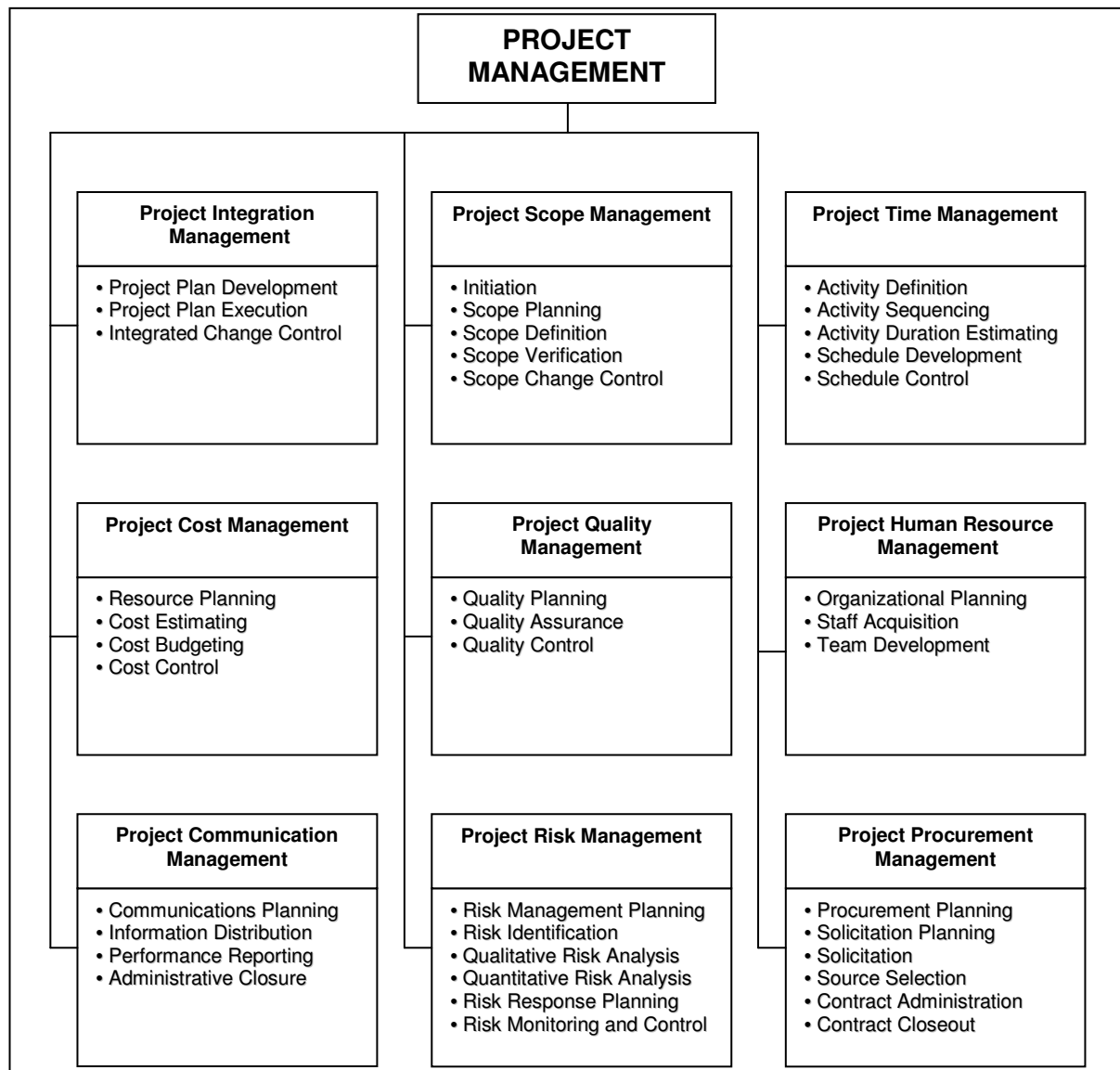


Figure 2.1 Project Management Knowledge Areas with the Related Processes (PmBok 2000)

These areas are defined as:

- *Project Integration Management* describes the processes required to ensure that, the initial work to start a project phase is supported. It consists of project plan development, project plan execution and integrated change control.

- *Project Scope Management* describes the processes required to ensure that the project phase includes all the work required, and only the work required, to complete the project phase successfully. It consists of initiation, scope planning, scope definition, scope verification, scope change control.
- *Project Time Management* describes the processes required to ensure timely completion of the project phase. It consists of activity definition, activity sequencing, activity duration estimating, schedule development, and schedule control.
- *Project Cost Management* describes the processes required to ensure that the project and related phases are completed within the approved budget. It consists of resource planning, cost estimating, cost budgeting, and cost control.
- *Project Quality Management* describes the processes required to ensure that the project and related phases will satisfy the needs for which they were undertaken. It consists of quality planning, quality assurance and quality control.
- *Project Human Resource Management* describes the processes required to make the most effective use of the people involved with the project and related phases. It consists of organizational planning, staff acquisition, and team development.
- *Project Communication Management* describes the processes required to ensure timely and appropriate generation, collection and dissemination, storage, and ultimate disposition of project information. It consists of communications planning, information distribution, performance reporting, and administrative closure.
- *Project Risk Management* describes the processes concerned with identifying, analyzing and responding to project risk. It consists of risk management planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning and risk monitoring and control.
- *Project Procurement Management* describes the process required to acquire goods and services from outside the performing organization. It consists of procurement planning, solicitation planning, solicitation, source selection, contract administration and contract close-out.

For better understanding and to find a generalized management way for project management, the given knowledge areas have to be considered, and also the broad view of project management context composed of project life cycle, project stakeholders, organizational influences have to be examined precisely.

2.2.3 The General Structure of Project Management

It is accepted that, the general structure of project management includes a broader environment than the project itself. It is important to identify the basic components and the participants in order to clarify the interactions within each other.

The projects are temporary and have unique interferences. Because of their complex structure they include some degree of uncertainty. The efficiency can be supported by dividing the system into small parts in terms of project phases to improve management control.

The Project Life-cycle determines the beginning and end of a project, and provides which sequential actions are represented within the project management. In this context, project phases can be described as the sub-management systems of the whole management structure. These are part of a sequential logic design of a project to ensure the proper definition of the product. To reach the desired level of management, each phase should include a set of defined deliverables.

For instance, when an enterprise agrees on to enter a new area; it examines generally the needs i.e. feasibility study, to obtain management parts of the system and to constitute the links of the ongoing operations of the performing task.

Most project lifecycle phases generally involve some form of information exchange within each other. Deliverables from the preceding phase are usually used in the next phase. This requires a collaborative approach to manage the whole life-cycle model.

The project life cycle phases generally define the;

- The project-life cycle contents;
- The technical work definitions and management strategy;
- The participants and the ability of the participants;
- The monetary applications;
- The risk identifications;
- Social-economic-environmental impacts;
- End-product definitions.

In many cases, project life cycles have similarities, with similar information needs. Even though some needs to define the whole management in one phase, the others have to define it in 5-10 phases according to requirements of the structure.

The construction management life-cycle model is generally composed of 5-8 main management phases and related sub phases as it is envisaged in the next sections.

On the other hand it is necessary to identify the project stakeholders who are individuals and organizations that are actively taking part in the project execution. The project management team has to consider the stakeholders and requirements to manage a project successfully.

Some of the key participants of a project can be defined as;

- *Project manager* is the person responsible for managing the project.
- *Customer* is the individual or organization that will use the outcomes.
- *Performing organization* is the organization directly involve in the project
- *Project team members* are the individuals who take a part in the project execution.
- *Sponsor* is the individual or group who provides the financial resources.

Additionally, there are many other participants with different identifications and with different roles involved in the project structure such as suppliers, contractors, controlling units, etc. These can be extended based on the project structure.

In general, projects are managed by the organizations, and the project decisions are taken based on the organization's management structures. Organizational structures can be defined in two categories:

- Organizations that gain their salaries from the on-going projects i.e. consultants, architectural firms, construction contractors, government contractors etc.
- The project adopted organizations (They adopt their system according to projects).

Also organizational cultures and styles display differences with respect to each other. Most organizations have unique and peculiar cultures and these formed according to shared values, norms, beliefs and expectations according to their policies and procedures.

Organizational structures are formed according to the rate at which resources become available to projects. There are several different types of organizational structures namely vertical functional, divisional, horizontal matrix, team and network based organizations.

- In the vertical functional organization, each employee has one superior. The people are grouped together in departments by common skills, such as engineering, planning, accounting etc. at the top level and further subdivided into functional organization that support the business of the larger organization.
- In the divisional organizations, departments are established based on the same product, program, or geographical region. They are composed of separate divisions. Common skills are the main link in this content.
- Horizontal matrix organizations are managed according to functional and divisional chains of command. The information flow is simultaneous and overlays one another at the same time. In some cases, employees report to two managers.
- Team-based organizations are composed of series of teams to complete the specific tasks and to manage the main departments. There are different types of teams that can be formed such as planning team, design team, etc.
- In the network organizations, the structure is formed according to a centralized communication system; a central hub connects the other organizations to facilitate the vital management and communication within the structure. In this approach departments are independent from time and location.

Each approach has advantages and disadvantages and serves a distinct purpose for the organization.

Another fundamental characteristic of an organization is to provide an effective management system. This comprises the activities such as leading the team, communicating-exchange of information within the participants, negotiating-talking with each others to reach a consensus on the topic, problem solving-defining the problem and making the relevant decision on the subject, influencing the organization-to make the people get things done.

Also like management skills, the socioeconomic influences are composed of a wide range of topics and issues such as standards and regulations, internalization, and social-economic-environmental sustainability.

For managing and completing the projects in a successful way, it requires forming a management structure comprising of main properties as mentioned in this section. The management discipline can be obtained by well formed organizations, and well defined processes. The achievement can be reached by understanding the basic components and relations in this context.

2.2.4 Project Management Processes

In order to understand the integrative nature of the system, and examine the intersections of the relevant aspects of project management, in terms of its component processes, have to be defined clearly.

Project Processes

Projects are divided into manageable pieces to control the whole in an effective way. The sequential and interrelated actions are taken within the framework of the system to reach the successful result by using and managing these pieces in a sufficient way. There are two main categories.

- Project Management Processes are defined in order to describe and organize the project.
- Product-oriented Processes specify and formalize the products of the project to complete project requirements.

Project management processes and product-oriented processes overlap and interact throughout the project. The interactions within the processes require a standard and concurrent approach in order to provide interoperability.

Process Groups

According to PMI (Pmbok 2000), the Project Management Processes showed in Figure 2.1 can be organized as following classes:

P1 Initiation Processes are the starting point for the project or phase, authorizing the processes.

P2 Planning Processes observe objectives of the project and select the best way from the alternatives and plan the related applications to reach the desired goal.

P3 Execution Processes manage the resources, to carry out the process.

P4 Control Processes monitor the project and the related processes for comparing the planned and applied practices to define the variances, so that a corrective action can be taken when necessary.

P5 Closing Processes check the project objectives and formalize the project acquiescence and end it in an appropriate way.

These processes are interlinked within each other as shown in **Figure 2.2** in IDEFØ notation. The result of one will be the input to another.

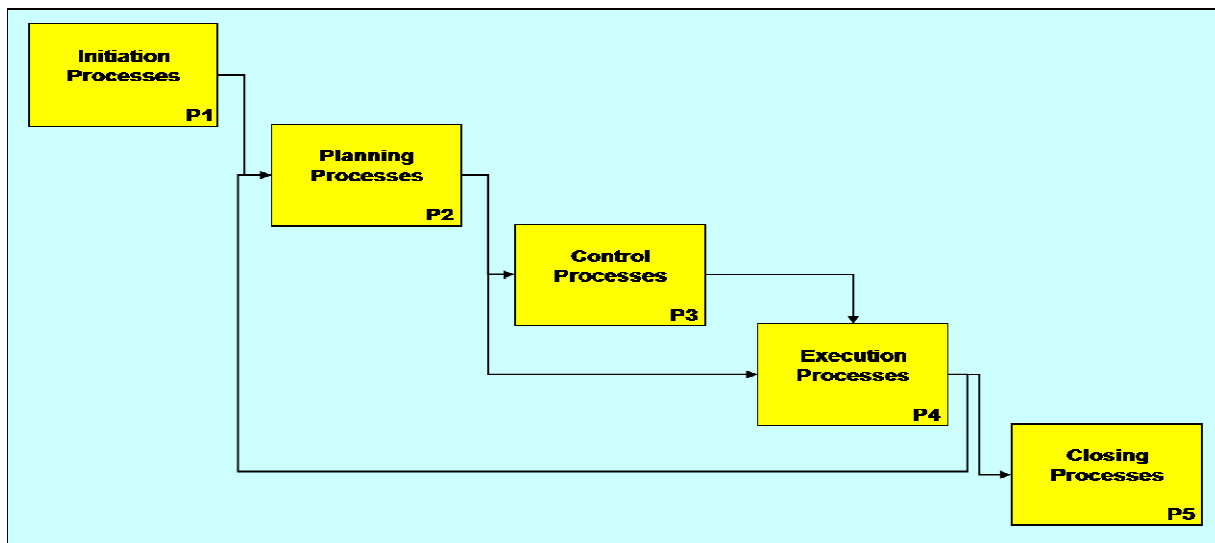


Figure 2.2 Project Management Processes

The project management process groups are not discrete, one-time events. They are overlapping activities that occur at varying levels of intensity throughout each phase of the project as shown in **Figure 2.3**.

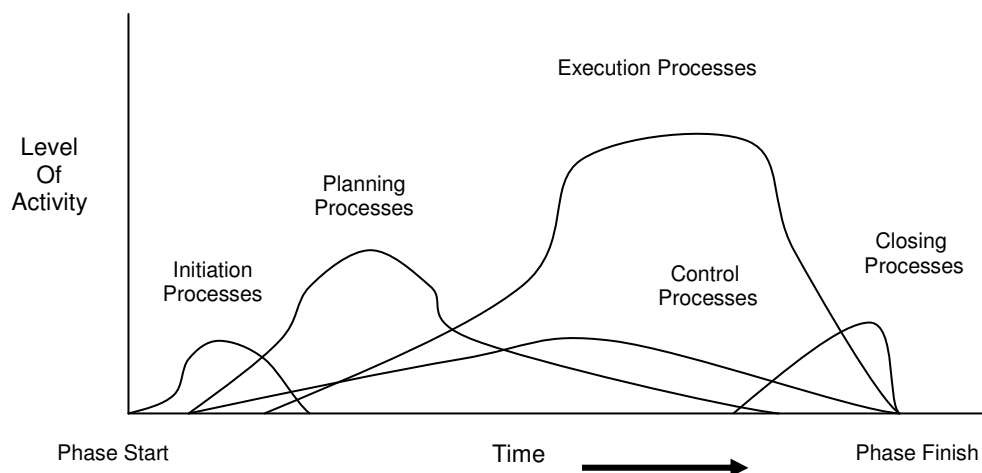


Figure 2.3 Overlap of Process Groups in a Phase (PmBok, 2000)

As a result, in each phase of the sequential process formalization it is necessary that the process groups also interact with other phase and provides an input to them. However PmBok has a general approach, in this context to show construction management phases which help to focus on the business and required goals in a structured way, the phase representations are provided according to Construction General Life-cycle Model and illustrated in **Figure 2.4**. It has to be considered that the inputs and outputs of the processes depend on the related phases. Nevertheless there are many overlaps within the applications.

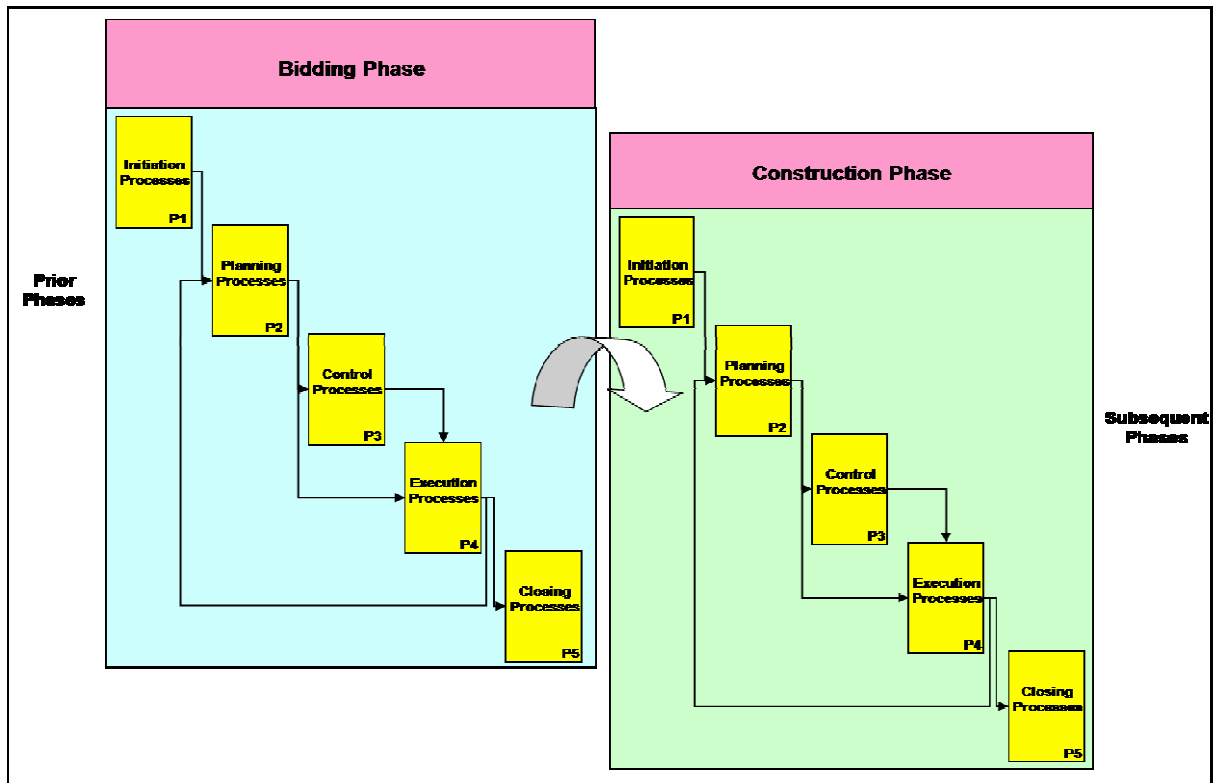


Figure 2.4 Interactions between Phases

2.2.5 Process Interactions

The creation of a project structure requires comprehensive processes including a large number of specialized components. In this context the Project Management Process Groups are examined and the necessary processes are possessed. This provides a clear picture to see the overlaps based on project management knowledge areas.

Because of complex relations observed in the planning, execution and controlling activities, the related processes are represented with two formalizations namely (1) core processes and (2) facilitating processes. Core processes provide the required processes to structure the main process groups. Also there is a need to identify facilitating processes which will be used as complimentary processes.

P1 Initiation Processes

Initiation is related with the project scope management knowledge area and represents the project authorization steps.

P2 Planning Processes

Because of being a unique and temporary application, the project has to be identified with all its stages. The structure of the planning processes is very important in this sense.

The planning processes include different types of application areas which have true interrelation with each other to define the steps within the project management. These are briefly identified as (PmBoK 2000):

Core Processes

The core processes comprise eleven processes, namely:

- *Scope Planning* improves a written scope format for the future project decisions.
- *Scope Definition* deciding upon the main project aspects and dividing them into manageable pieces.
- *Activity Definition* defines activities according to expected project outcomes.
- *Activity Sequencing* defines simultaneous and interrelated actions and their dependencies.
- *Activity Duration Estimating* provides to have decisions among the work periods to complete the job in a successful way.
- *Schedule Development* develops the work program, identifies activity sequences, activity durations and resource requirements.
- *Risk Management Planning* considers risks and plans a required approach.
- *Resource Planning* provides a decision regarding resources and related quantities to perform the project activities.
- *Cost Estimating* provides estimations and determines costs of the resources to complete the project activities.
- *Cost Budgeting* defines work packages composed of individual cost estimates.
- *Project Plan Development* establishes a consequent document according to results of the other planning processes.

Facilitating Processes

Facilitating processes are composed of ten processes, namely:

- *Quality Planning* determines quality standards relevant to the project and decides how to use them.
- *Organizational Planning* defines documenting and project participants' roles, their responsibilities, and reporting issues.
- *Staff Acquisition* decides the project working areas and attains the relevant participants to these places.
- *Communications* define relevant information and communication needs of the project participants: who needs what type of information and how it will be supported.
- *Risk Identification* defines possible risks that can affect the project and identifies their characteristics.

- *Qualitative Risk Analysis* defines qualitative risks and conditions and identifies their effects on the project objectives.
- *Quantitative Risk Analysis* measures the probability and effects of risks, moreover estimates their impacts on the project objectives.
- *Risk Response Planning* develops procedures, techniques to enhance opportunities to reduce threats to the project's objectives. Improves techniques and procedures to reduce the possible hazards to project objectives.
- *Procurement Planning* provides a production plan.
- *Solicitation Planning* documents product requirements and identifies potential sources. Moreover identifies of product needs and exploration of the relevant sources.

P3 Execution Processes

In order to construct a broad set of activities and to enable efficient use of project resources based on planning processes, executing processes are as given below.

Core Process

Core process represents a main execution process namely:

- *Project Plan Execution* provides to execute the project according to project plan by performing the activities.

Facilitating Processes

Facilitating process is composed of six supporting processes namely:

- *Solicitation* supplies quotations, bids, offers, or proposals as appropriate.
- *Source Selection* selects sources from the potential suppliers.
- *Contract Administration* manages the relationship with the supplier.
- *Quality Assurance* controls the project quality performance regularly to obtain the relevant quality standards.
- *Team Development* improves project participant skills to obtain the required project performance.
- *Information Distribution* supports information exchange between the project participants in a timely manner.

P4 Control Processes

In order to monitor ongoing activities, the controlling processes which are composed of core and facilitating processes are structured as:

Core Processes

Core Processes is represented by two processes namely:

- *Performance Reporting* examines project performance and disseminates the results such as status reporting, progress measurement and forecasting.
- *Integrated Change Control* controls and coordinates the changes within the entire project.

Facilitating Processes

Facilitating Processes represent six processes namely:

- *Scope Verification* verifies project scope acceptance.
- *Scope Change Control* controls changes related with the project scope.
- *Schedule Control* controls project schedule and provides necessary changes.
- *Cost Control* controls project budget and provides the changes.
- *Quality Control* controls project results and related quality standards if the standards are applicable and then finds ways to eliminate the unsuitable performances.
- *Risk Monitoring and Control* monitors risks that are identified, or identifies new risks, establishes of risk plans, evaluates effectiveness and reduces the risk.

P5 Closing Processes

The Closing Process composed of two processes namely:

- *Contract Closeout* supplies contract completion and delivers a solution for the open items.
- *Administrative Closure* forms, compiles and distributes information to constitute a phase or project; includes the evaluation and gets feedback for the other phases or projects.

2.2.6 Conclusions on Project Management

According to envisaged structure, project management knowledge is composed of 39 project management processes that are classified under process groups as illustrated in **Figure 2.5**.

These are identified generally, where the project management processes fit into both project management process groups and the project management knowledge areas.

To formalize an integrated construction management structure, these processes and interactions have to be taken into consideration. But due to complexity and variable structures occurring during the process, there is a need to form a generalized CPM approach which comprises different aspects and the prudence of private sector. Moreover, not all of the processes and related interactions will apply to all projects in this detail or some larger projects may need more detail. To provide this and to deal with different views in this context, construction general lifecycle models and related management phases will also be examined precisely.

<div> <div>Process Groups</div> <div>Knowledge Area</div> </div>	Initiation	Planning	Execution	Control	Closing
Project Integration Management		<ul style="list-style-type: none"> • Project Plan Development 	<ul style="list-style-type: none"> • Project Plan Execution 	<ul style="list-style-type: none"> • Integrated Change Control 	
Project Scope Management	<ul style="list-style-type: none"> • Initiation 	<ul style="list-style-type: none"> • Scope Planning • Scope Definition 		<ul style="list-style-type: none"> • Scope Verification • Scope Change Control 	
Project Time Management		<ul style="list-style-type: none"> • Activity Definition • Activity Sequencing • Activity Duration Estimating • Schedule Development 		<ul style="list-style-type: none"> • Schedule Control 	
Project Cost Management		<ul style="list-style-type: none"> • Resource Planning • Cost Estimating • Cost Budgeting 		<ul style="list-style-type: none"> • Cost Control 	
Project Quality Management		<ul style="list-style-type: none"> • Quality Planning 	<ul style="list-style-type: none"> • Quality Assurance 	<ul style="list-style-type: none"> • Quality Control 	
Project Human Resource Management		<ul style="list-style-type: none"> • Organizational Planning • Staff Acquisition 	<ul style="list-style-type: none"> • Team Development 		
Project Communications Management		<ul style="list-style-type: none"> • Communications Planning 	<ul style="list-style-type: none"> • Information Distribution 	<ul style="list-style-type: none"> • Performance Reporting 	<ul style="list-style-type: none"> • Administrative Closure
Project Risk Management		<ul style="list-style-type: none"> • Risk Management Planning • Risk Identification • Qualitative Risk Analysis • Quantitative Risk Analysis • Risk Response Planning 		<ul style="list-style-type: none"> • Risk Monitoring and Control 	
Project Procurement Management		<ul style="list-style-type: none"> • Procurement Planning • Solicitation Planning 	<ul style="list-style-type: none"> • Solicitation • Source Selection • Contract Administration 		<ul style="list-style-type: none"> • Contract Closeout

Figure 2.5 Project Management Matrix Classifying the Project Management Processes (PmBok 2000)

2.3 Construction General Life-cycle Model

Construction management applications are highly varied, depending upon organizational structures specific to work, regional practices and special conditions. However, in order to meet the organizational context and the information involved, the management life cycle model and related phases that operate on building information requires standard approaches i.e. standard phases.

A phase demonstrates a temporal period before a transition and designates the sequential and connected activities during that period. To obtain an interoperable communication of these connected activities within each other, the IT tools should be applied to building industry.

There are growing number of applications have been developed from the 50's that attempt to facilitate the tasks and processes within the building environment. These includes from simple drafting to more complex applications such as planning, controlling or material procurement during construction progress, or building simulation programs for facility management.

There are variable ways to name and partition the phases of construction's lifetime. Gielingh (1988a) proposed the lifecycle according to its major transition points. The periods of time, between these transition points are referred to as phases. Eastman (1988a) adapted his classification according to this model but mostly concentrated on the periods of time between the phases. Also the process modeling initiatives such as CALS, IRMA, GPP and the projects like eConstruct, OSMOS and ISTforCE can be identified as the major interferences to the standardization of concurrent model based working processes.

Based on AIA, the construction management phases can be seen in six parts. These are generally named as: Feasibility, Design, Bidding Preparations, Construction, Contract close-out, Operation & Management as shown in **Figure 2.6**, in IDEFØ notation.

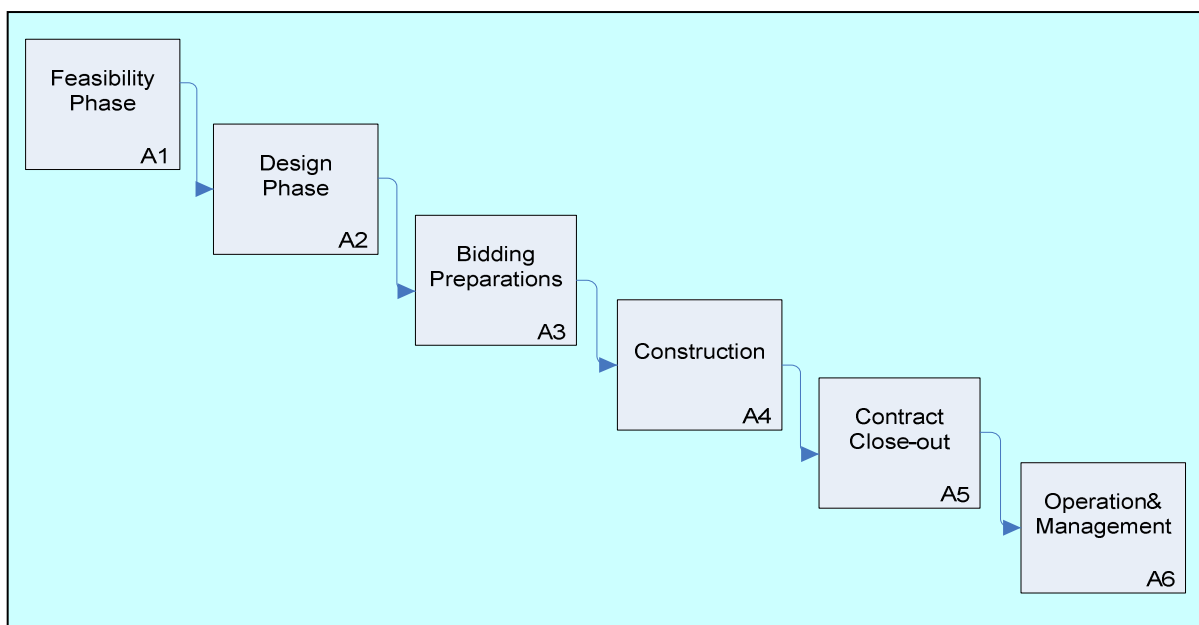


Figure 2.6 Construction General Life-cycle Model Phases, (CGLCMP)

Integration of different phases needs access to convenient data, explanation of results and iterative use and exchange of information with each other.

In order to develop a framework that includes main classes of construction results, activities, entities and entity parts, there is a need to define application processes and their interrelations within these phase structures.

2.3.1 Feasibility Phase

The feasibility study is the initial phase that defines the main required aspects from construction. When a project is concerned with the aims and expectations from the building, the quantitative issues such as; project money, geometry, qualitative issues such as; aesthetic form, space usage, functionality etc. are generally taken into consideration and it can be said that, feasibility studies rely on a quantitative representation of construction information.

In most cases, feasibility studies are composed of Analysis of Initial Situation, Project Analysis, Project Cost Estimation, Construction Time Estimation, Governmental Issues and Resource Estimations as given in **Figure 2.7**.

Based on these, the feasibility of the project can be estimated according to the given parameters. In general, these are the size of the project, the materials that can be used, the units of construction, cost in terms of money, time and other resources.

Moreover, different types of inputs such as: spaces, functional services, market research, operating costs, labor costs, cash flows, credit situations, project programs, environmental issues, material types and client's requests should also be taken into consideration.

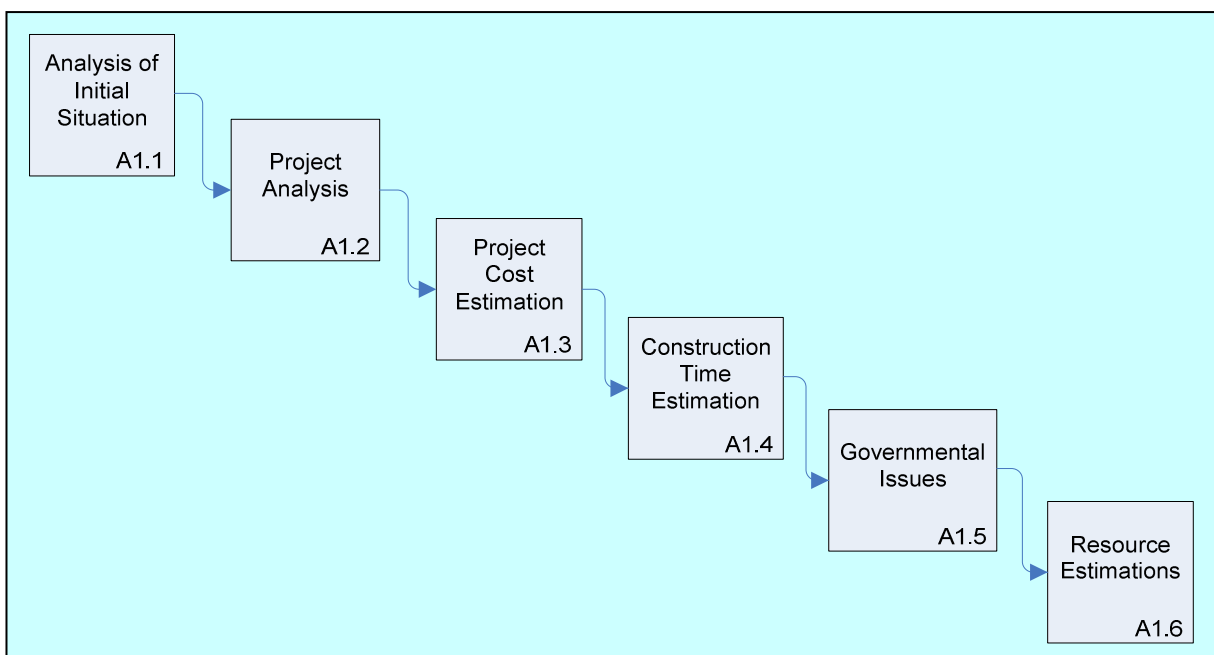


Figure 2.7 Feasibility Phase

2.3.2 Design Phase

Design of a project is formed based on client's requests, project scope and initial works in terms of feasibility study. The main tasks of the design phase can be identified in two parts:

- Defining the project distinctly to manage the construction and related activities;
- Realizing the requirements that are settled based on client expectations.

Currently, there are different type organizations that practice construction design, but in most cases, the architect, civil engineer, contractor, project consultant or project manager undertakes the responsibilities. This is occurs due to the project management system.

Design processes include complex stages, the American Institute of Architects (AIA) and most of the other international bodies, suggested seven standard stages of design as illustrated in **Figure 2.8**.

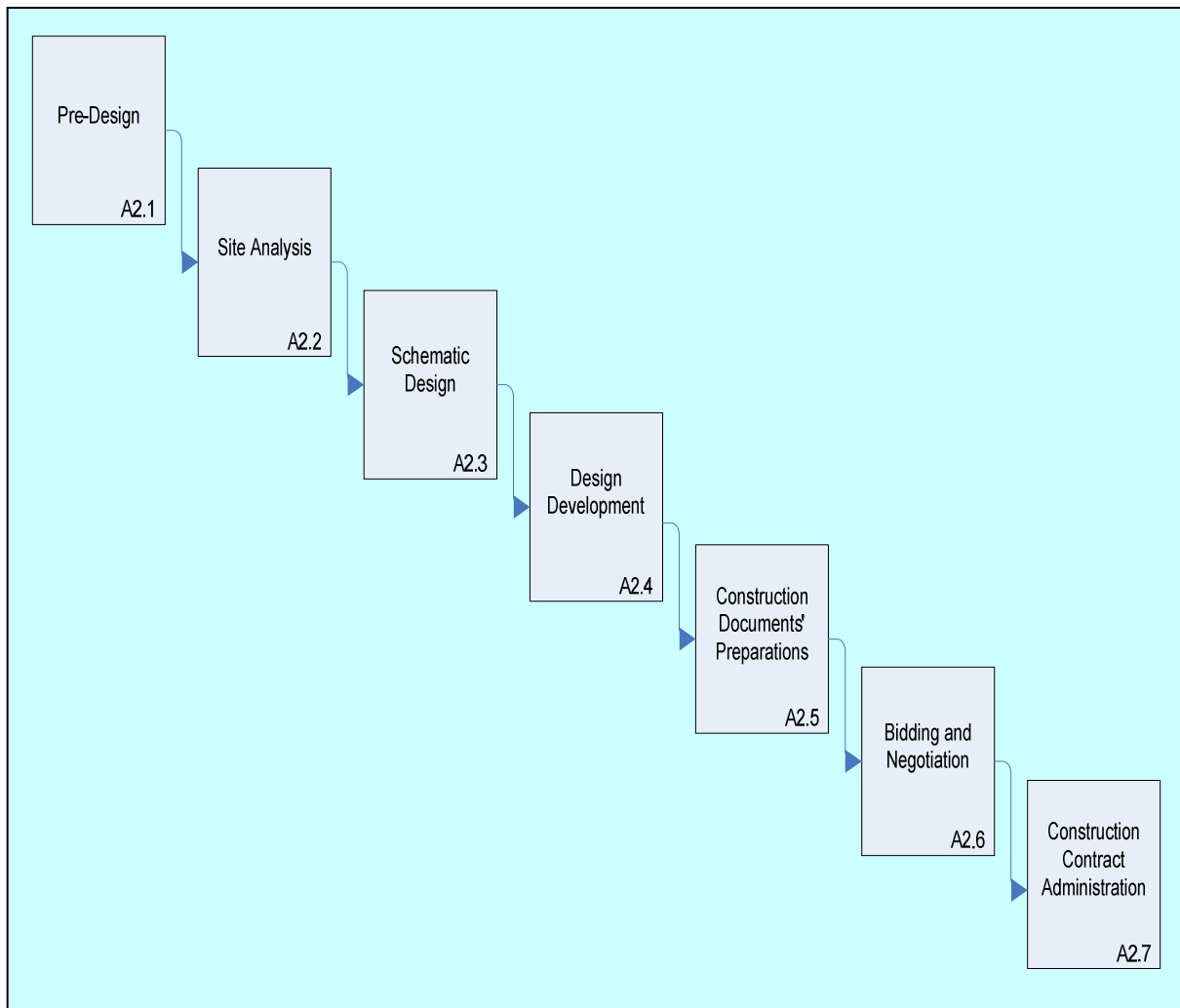


Figure 2.8 Design Phase

- *A2.1 Pre-design* represents the determination of space requirements, spatial relations, operating functions, future expansion or flexibility objectives; survey of existing facilities; marketing and economic feasibility studies; identification of context, neighborhood issues and environmental requirements; preparation of general project schedules and budget and finance.
- *A2.2 Site Analysis* comprises site analysis and selection, site development planning; site utilization studies; circulation and open space requirements.
- *A2.3 Schematic Design* concerns the site plan preparation showing building footprint and general landscape planning; paving and drainage; floor plan layouts that satisfy space requirements in program; equipment and furniture layout; sections and elevations showing vertical dimensions, candidate materials and finishes; structural system types and building sections; solar design and conservation studies; mechanical equipment spaces and duct and chase spaces; fire protection requirements; electrical, fire, security, power and communication system requirements and types.
- *A2.4 Design Development* represents grading, utility paving, demolition and landscaping plans; detailing of floor plans; roof plans, typical wall sections and typical details; 2D/3D models or drawings for review; room finish schedule, furniture and equipment selections including materials and finishes; interior elevations with material selection; structural system plan including framing and foundation plans with member sizes; outline of structural specifications; mechanical equipment plan schematics and schedules and approximate sizing; acoustical, vibration and visual impact study; approximate plumbing diagrams and plans; electrical and lighting plans; communication equipment plans; fire equipment plans; outline of material specifications.
- *A2.5 Construction Documents* concern detailed plans for demolition, utility, grading, site and paving with profiles, final calculations of all drainage, landscape and includes plant identification, paths, walls, strips irrigation plan; and also includes window, door framing, equipment and other details; all interior drawings and final specification; all structural plans and sections, schedules, final member sizing and joint detailing calculations; foundation plan with test locations, and results; all control and expansion joint details; they also define all clearances; show all notches and penetrations; add control systems, seismic anchorage, all points of connection; locate all pipe routing and controls with final sizes and calculations; equipment schedules with specifications; all power sizing calculations, sizing and installation details; conductor sizing; define circuits, panel boards; preparation of bidding documents.
- *A2.6 Bidding and Negotiation* represents organization of bidding conferences; review of alternatives/substitutions; review of bids; bid evaluation.
- *A2.7 Construction Contract Administration* provides coordination with other design/project members; construction observation and representation; preparation of supplemental documents; change order review; shop drawing review, record of payments; project close-out.

Design processes are complex and should be taken into consideration in detail. Pre-design and Site Analysis is mainly related with the feasibility stage and architectural design generally begins with Schematic Design in this regard.

In the Schematic Design stage, the general design concept for the building project is produced. This concept is based on the building's general form with interior spaces and related activities as illustrated in **Figure 2.9**.

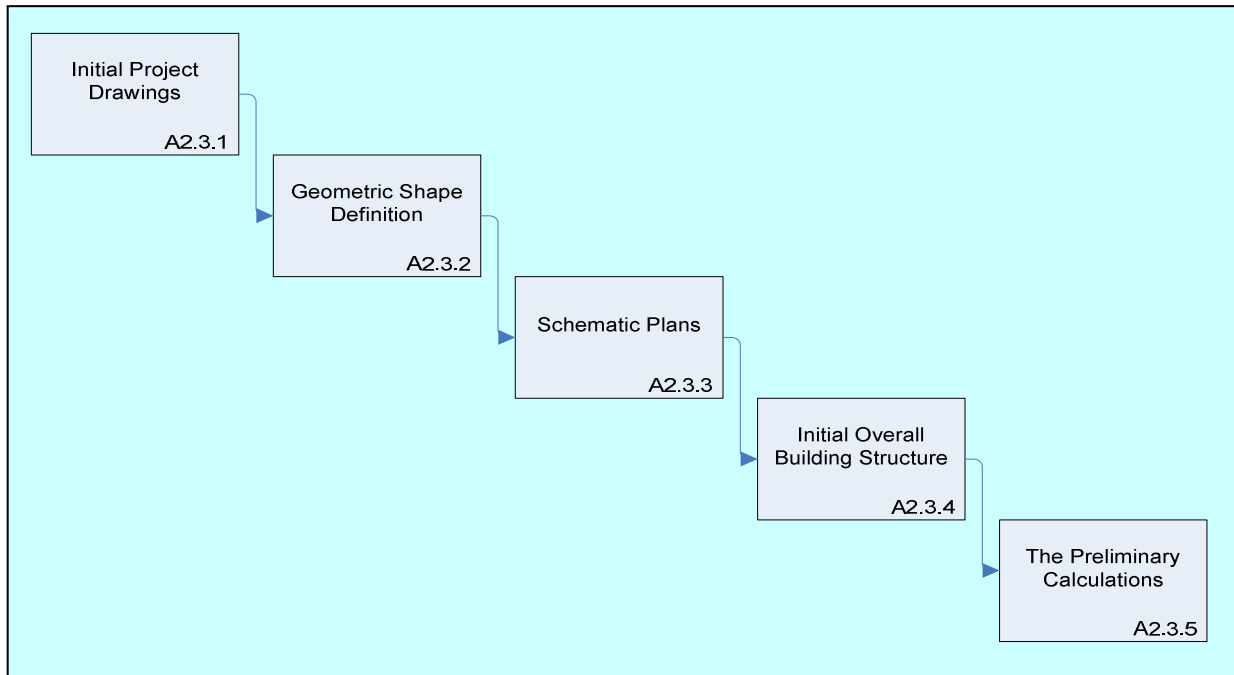


Figure 2.9 Schematic Design Phase

In this stage, the intentions of the project, as specified in the feasibility study, are drawn up. The geometric form of the structure is shaped according to earlier quantitative stage development. The schematic plans are established according to spaces that are responding to site issues. The overall building structure composed of floors related with, structural, mechanical and electrical assumptions is shaped. The preliminary calculations are made. The character of all major spaces is partially determined.

Design Development stage is formed according to schematic design and it comprises all construction materials, general details, structural, mechanical, and other systems and services. The major requirements and special issues such as sizes of the construction parts or acoustical performance of the spaces are determined in this phase.

While the building is recognized as highly innovative and a successful example of sustainable architecture (Leventhal 2001), different types of building systems are already defined by the analysis of the previous instances, many of the resources search for special building types that depend on the knowledge of architects and users. At this stage a team of specialist, identify the information in a collaborative way for the further applications as shown in **Figure 2.10**.

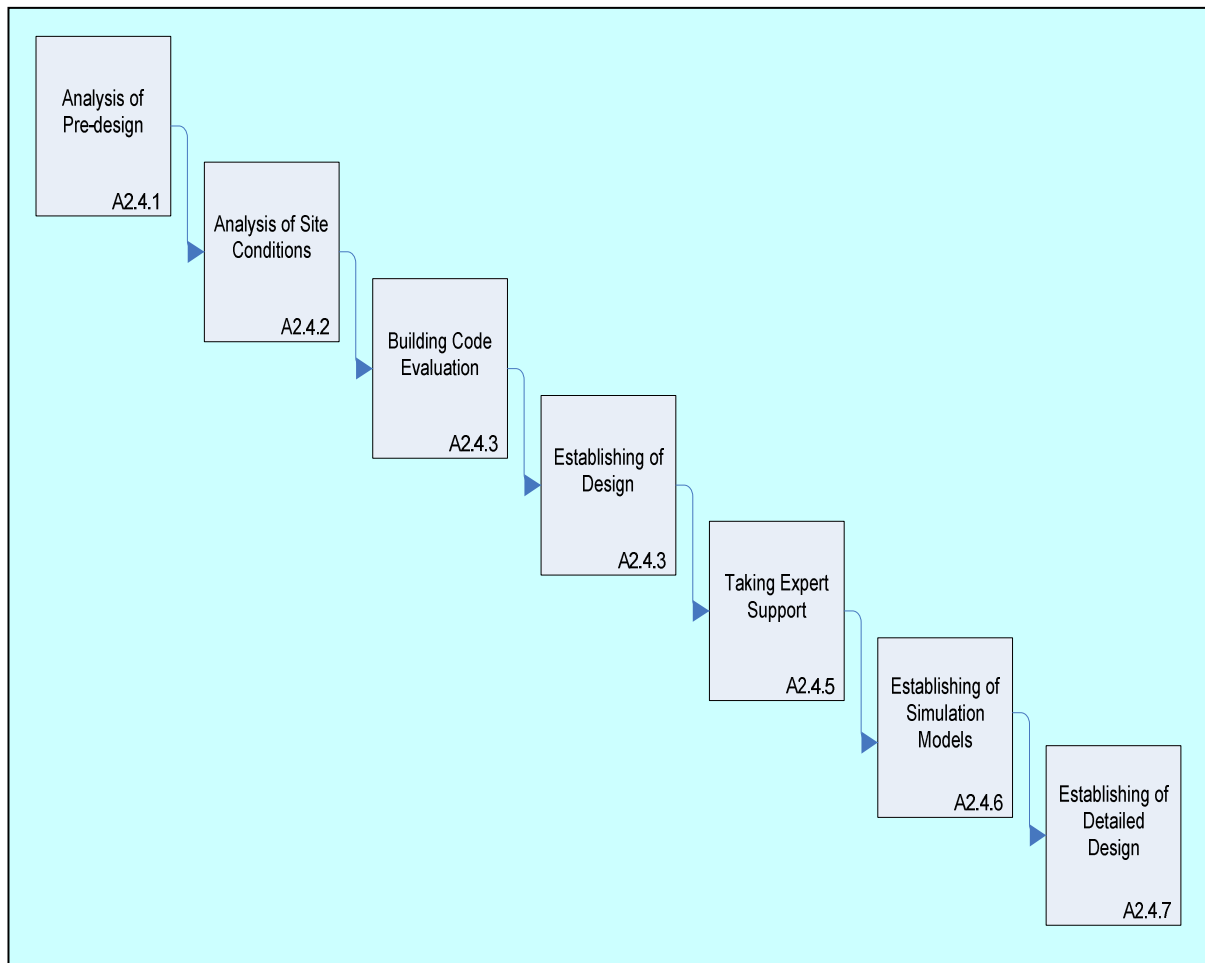


Figure 2.10 Building Design Development Phase

Building construction comprises a wide-range of construction systems. Different type of technologies which have different aspects, different rules and different methods and their combinations can be applied to building design. Computer applications support interactive or automatic design according to growing numbers of these technologies. In the mean time the CAD applications are concentrated on not only the information exchange but also on the data which is needed in the other stages of the construction management phases. The studies such as: the integration in 2D and the modeling in 3D (Anumba, 1989), graphical and non-graphical data (Anumba & Watson, 1991) integration of databases (Brandon & Betts, 1995), or 3D-4D modeling of construction projects between the 90s to present (J. Gao & M. Fischer; T. Tollefsen & T. Haugen, 2005) can be seen as the primary initiatives.

In this phase, after examining the pre-design and site conditions, the sequential processes, all related technologies and systems comprising the design are defined. The dimensions, layouts and significant building elements, materials specifications and critical procedures are specified. Related coding systems are established and the design is constituted, based on different expert and client expectations, all work is reviewed and possible simulation models are provided. Lastly after the approval of the client, the detailed design is realized.

In the Construction Document stage, all details related with design are checked to support the assembly of materials on construction site. The building parts that will be used such as doors, windows and other units including design details are addressed and matched with the system.

The temporary units and the demolition of existing site facilities are planned. The transport of materials, site clearance, related services, safety and environmental issues also have to be taken into consideration within this period. On the baseline, the construction document work flow is similar to design development stage but with a higher level of detail as shown in **Figure 2.11**.

Different partners collaborate until an effective design is established for the next phases. In the later stages, a large amount of information is developed that depends mostly on the actions of previous stages, but occasionally depends on the changed strategies.

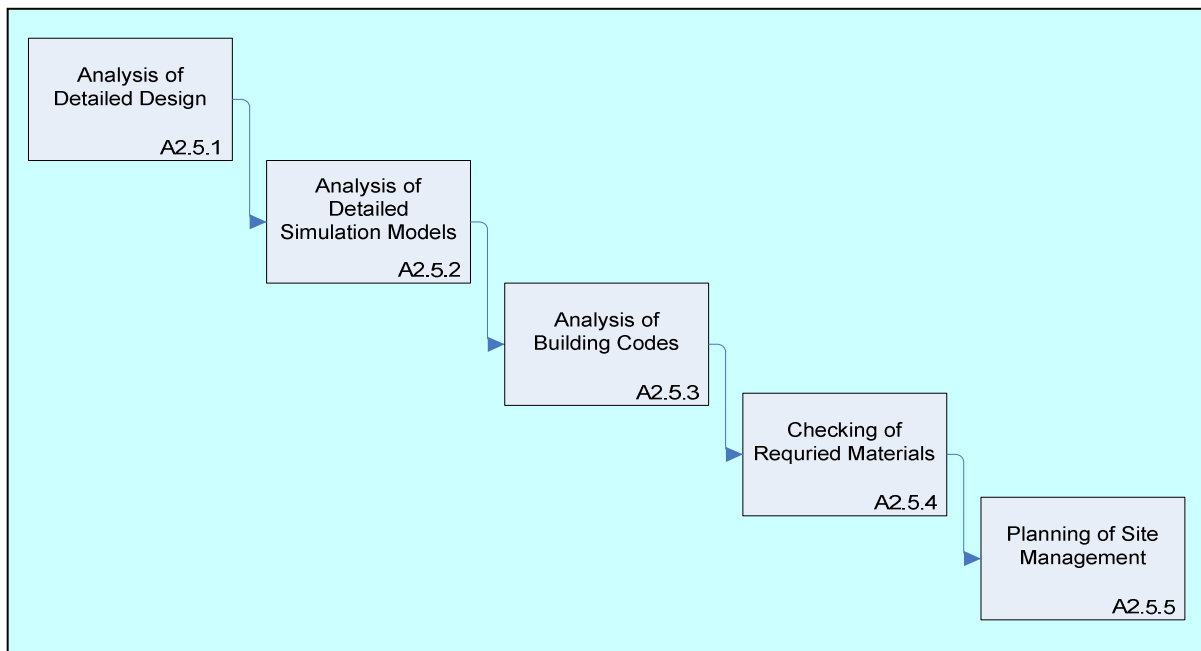


Figure 2.11 Construction Document Phase

On the other hand one of the most problematic topics of the construction document stage is, controlling the independent issues as mentioned above. The integration difficulties between specific information such as the project itself and external issues that will be used on the work progress have to be clarified precisely such as; between requirements information (Kiviniemi et al. 2005), between design information and analysis information (Kam and Fischer 2002), between design information and fabrication information (Haymaker et al. 2004), and between analysis information and decision information (Kam 2005).

Contract documents are mainly required in the form of drawings, written documents that specifying the quality of material and equipment specifications. The other contract issues involve contracting and construction supervision, are aspects of service.

Although the basic contracting features are prepared by the designers and client representatives from the client's point of view, the contractor's side also has to work in detail to win the bidding competition among their rivals.

Our hypothesis, as it was mentioned at the preliminary stage, includes these aspects from the contractor's point of view. Because of the increasing level of competition and an expansive range of active contractors within the global environment, it is necessary to define these processes in a clear way in this context.

As a summary in this stage the importance of information technologies which are used in the design phase can be represented by;

- Supporting the design team collaboration in different levels, such as communication and knowledge share.
- Supporting the basic aspects and knowledge that depend on design.
- Integrating multiple levels of detail that are used in developing stage.
- Supporting different and sequential processes followed by different partners.

2.3.3 Bidding Preparations Phase

In general, bidding preparations represent; improving a construction progress plan, the estimation of resources and their possible construction costs, and forming the bid, to win a construction contract. The contract documents produced during the design phase are a direct input in this context. Thus, the detailed lists such as, material and labor costs can be estimated according to drawings and contract specifications.

Tendering based on different forms and format of contract. These are identified as: unit price, lump sum, cost plus, fixed fee or schedule of rates in general.

Based on the general acquiesces, the start point for bidding preparation stage can be accepted as: controlling the design drawings, specifications and the related documents. According to these sources of information ,the quantity take-offs and resources are checked and the project's production resources are formed. At this stage, the main contractor may determine which components of the production are to be outsourced to subcontractors and producers. In general, the main contractor selects the subcontractors and produces the final integrated construction plan according to the information which is collected.

Moreover, big contractors often maintain their own production resource cost database. According to specifications and resource prices, the pre-work program related with the management supervision, site work can be established. Direct costs are determined and the mark-up is decided and applied to bid, based on the firm policy that depends on project risks, contingencies and expected profit.

There are different type of sequential processes that can be seen according to contract forms, but nevertheless the general processes can be defined widely as illustrated in **Figure 2.12**.

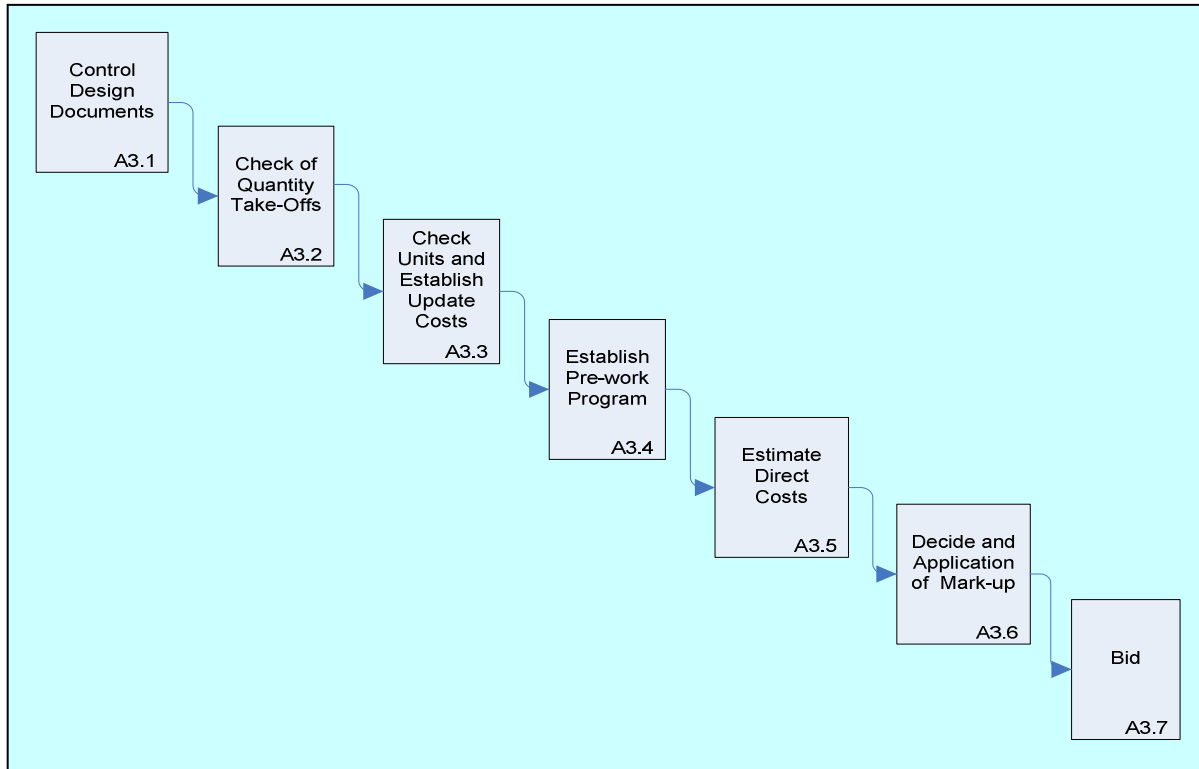


Figure 2.12 Bidding Preparation Phase

From an IT point of view, many different representations such as: scale drawings, mechanical and electrical diagrams and various datasets are becoming computerized and integrated. Moreover, the standardized integration between design and construction is one of the promising issues, in this context.

The process of information exchange between such activities has been studied within many researches and in many projects such as: ATLAS (Tolman et. Al. 1994), ELSEWISE (1998), CONDOR (Rezgui et al. 1997), CONCUR (Storer & Los 1997),

However, there is a long way left to go to form seamless information exchange based on standardized data.

As a summary, this phase involves detailing the earlier design representations to materials and related cost units, and units of time. Later this estimated project management plan is used as the target of actual construction.

2.3.4 Construction Phase

In the Construction Phase, based on the evaluation process, the winning contractor starts to establish the main aspects to form the project in the frame of contract conditions. The initial step for managing the project is planning the construction components in terms of processes, internal and external impacts, and resources based on construction documents.

The construction planning comprises identifying of construction sequences and assembly operations for each production unit. The construction activities can be derived from the production units determined in the construction planning phase. This phase also includes new and more detailed units of construction obtained from the construction drawings and specifications. According to the expertise of the contractor, which is known as ‘standards of practice’, the main characteristics such as; the manpower, equipment and materials to constitute the sequential operations, are defined to manage the jobsite as shown in **Figure 2.13**.

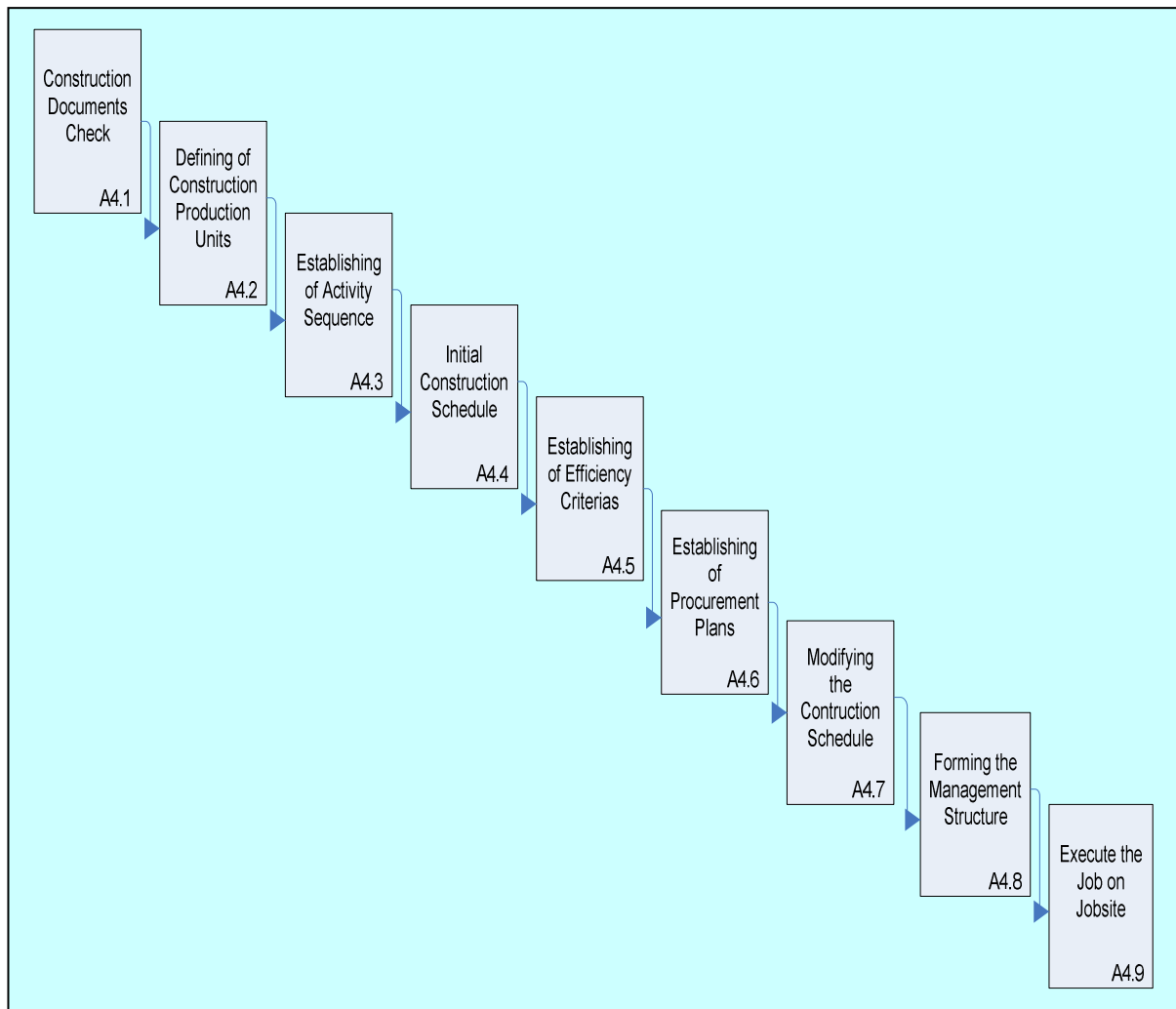


Figure 2.13 Construction Phase

Briefly, a construction schedule starts with identifying the individual units of construction, and the sequences and relations based on construction documents. The precedence ordering should be identified and should be applied to all tasks and additional schedule should comprise the whole operations, such as concrete pouring or storing of materials to manage the jobsite. According to established task sequences, the production resources in terms of

manpower, equipment, materials should be identified and attained to relevant tasks. Different type of strategies can be seen in these initial construction schedules.

It is necessary to identify the efficiency criteria such as balancing the labor, equipments, grouping specialists and the jobsite to find out the best way for managing the process. Application of the efficiency criteria forms a practical schedule. This is the starting point for detailed construction planning and management.

Also the procurement actions which are required to obtain all materials, equipment and components which are necessary to realize the construction schedule are formed at that point, moreover the project workers are chosen, the equipments are purchased and all the materials for each task are identified.

There is a sequence of procurement actions behind each unit of resources. Because of the high variety and complexity of construction units and their applications the virtual supply systems such as MRP (materials resource planning), IRC (intelligent resource planning) have been developed to monitor equipment orders. But in general the delays of materials from producers are well known issues. The construction schedules should be modified according to these delays and the gaps between the planned and actual situations can be closed according to the time delays.

There are different types of computer applications that can be used for managing the jobsite, and most of them support procurement, resource controlling, and equipment management within the coordination of scheduling programs. Primavera, Suretrak, Artemis and Ms. Project are the most common software for construction scheduling in this context.

As a summary, the construction project is constructed by applying the construction schedule, assigning the resources in terms of manpower, equipment and materials for related tasks, and by completing the outcome/building to an expected level.

2.3.5 Contract Closeout Phase

Contract close-out consists of documenting project results to formalize acceptance of the product of the project. It includes both product verification and administrative close-out, such as; checking the completed work whether it meets the expected goals of the project, updating of records and archiving them for future use.

While the construction is being constructed, a variety of data can be collected through the applications. These are supporting schedules, shop drawings, requested and approved contract changes in terms of change orders, technical documentations, performance reports, financial documents, invoices, payment records, actual costs, site inspections, and the as-built drawings of the structure.

In addition, employee skills in the staff pool database should be updated to reflect new skills and proficiency increases.

The general audits can be structured to monitor the ongoing work on jobsite. They support to identify successes and failures that warrant transfer to related items on the project or to future projects.

2.3.6 Operation & Management Phase

There are three sub areas which can be identified, concerning building operation and management after construction completion: (1) Management of facilities, (2) Operation of mechanical equipments and (3) Building maintenance and operation as shown in **Figure 2.14**.

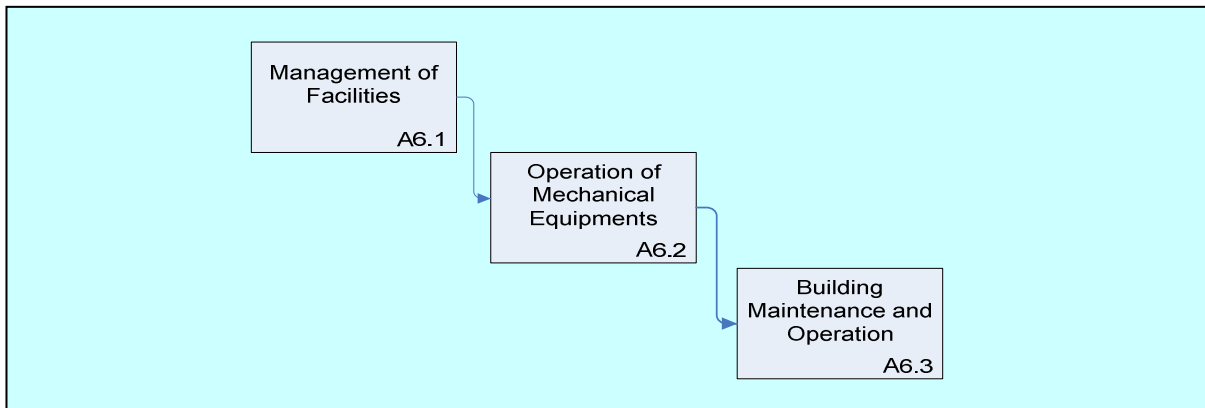


Figure 2.14 Operation & Management Phase

Management of facilities concentrates on the space of building and its usage. Basically it controls and manages the changes within spaces; changing of the area, adding or removing wall partitions, changing doors to obtain more efficient spaces. It also manages changes in the location of the people within these areas. Additionally, facility management supports locations of furniture and equipment, utility and telecommunications distribution within the building and other capital investments of the organizations.

For managing the facilities, schematic floor plans for space allocations, electrical and telecommunications diagrams for changes and data diagrams for equipment accommodations are required. This information has to be saved in a reachable building database.

The building mechanical components such as; elevators, air conditioning, and other mechanical equipments are the indicator of the buildings total efficiency. According to sizes of the buildings, energy consuming reaches noticeable levels. In the mean time, according to demand of reducing the operating costs, the AEC sector has been searching for a better way of using buildings with new design concepts and software tools.

Considerable developments can be identified within the projects such as Robert L. Preger intelligent Workplace (IW) within Carnegie Mellon University in Pittsburg with the support of Advanced Building Systems Integration Consortium (ABSIC) (Hartkopf et al. 2005) or the work on communications infrastructure for sensors and actuators within buildings specifications and products e.g. BACnet, LonWorks, (Bushby 1997; Sharples et al. 1999), or concurrent control of heating, ventilation and lighting within the EDIFICIO project (Guillemin & Morel 2001).

Building maintenance and repair actions comprise scheduled maintenance such as; cleaning filters, lubricating motors and repairing or replacing of broken equipment that is allocated to different parts of the building. To support such maintenance operations equipment location and technical data should be stored in the facility database. Also the information used in such activities help to define the maintenance dates for servicing different parts of the building, and repair records that document the type of problems which occur with building components and the frequency with which they occur.

As a summary, building operation and management phase is associated with space, material, locations and operating data and recording of these data to facilitate managing building components more efficiently.

2.3.7 Conclusions on Construction General Life-cycle Model

From the review of different building life-cycle phases as given above, it is apparent that the information used in one phase has interactions with the other phases. In this context, the integrated models should address the 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 workflow. Therefore the expected interoperability can be accomplished in each phase of the general lifecycle model in order to lead to an integrated construction project management. However without formalizing generic procedures and without possessing standard process and product models, the results can not reach desired levels.

2.4 Procedure Models

Procedure models have been discussed by number of researchers and practitioners such as, Weske et al. (1999), as well as Kwan and Balasubramanian (1998). These models define the extension of system analysis and design techniques. They dwelled upon workflow logic and task logic in order to emphasize their separation. Heilmann (1996) and Galler (1997) suggested explicit workflow life cycles. These models provide detailed guidelines for the build time aspect of a workflow application, but provide limited information about the system behavior at run time, especially the maintenance of resource information (zur Muehlen 2004). The WISDM methodology which is also developed by Kwan and Balasubramanian defines organizational perspective that contains resource information, but this is mainly referenced in the initial analysis of the development cycle.

Within the reference model of the Workflow Management Coalition, the management of resource information lies within the responsibility of the workflow enactment service. This reflects the facts that many workflow vendors have implemented proprietary resource management facilities for their workflow management systems, which are accessed through the workflow modeling environment, or through an auxiliary application (zur Muehlen 2004).

Managing the resources inside the workflow enactment service may causes problems, if several work flow management systems are used for the implementation of a complex process (Du et. al 1999). These systems cannot share common information which is required in different phase of the application. If the information is not structured in an accessible way, the efficiency can only be supported on local level. Furthermore this issue cause discussions on several platforms such as Object Management Group but there is no standard has been suggested up to now.

In order to extend these structures to explicitly represent the integrated management perspective on ongoing project activities and to realize efficiency potentials through the elimination of transport and wait times between process activities, and provide a detailed level of control over the assignment of work to process participants, there is a need for a procedural framework. The importance of human involvement in procedural applications are also important as recently pointed out by Moore (Moore et al. 2002) in this context.

2.5 ISO 9001:2000 Quality Management System

In order to form an integrated structure based on standard procedures in this research, the basic definitions are formulated according to ISO9001:2000 Quality Management (QM) System and the specific construction management procedures are constituted, and identified in details, in Chapter 4.

In this part, QM System and its approach to different sectors is considered generally to provide the basis, in this context.

2.5.1 ISO 9000 Standards

ISO 9000 is concerned with ‘quality management’. There it is outlined, what the organization should do to enhance customer satisfaction by meeting customer and applicable regulatory requirements and continually to improve its performance in this regard (ISO 2005).

In this context, considerable definitions for quality management have been made by Ishikawa (1972) as; quality is improving, designing, producing and servicing the most economic, most useful product that enhances the customer satisfaction, and by Evans (1981); quality is showing the required performance by an accepted price or appropriateness with the cost, and by Garvin (1991); quality defined with its dimensions as performance, attributes, reliability, appropriateness, resistance, usefulness, etc.

ISO9000 standards do not detail the inputs such as materials that will be used for particular products or the outputs specifications, but rather concentrate on successful negotiation and meeting with the desired specifications. For example, such a system would include subsystems for ensuring that testing is carried out and that employees have adequate training. Organizations whose facilities pass an independent audit may obtain a certificate showing they have complied with ISO 9000 standards.

2.5.2 The Usage aims of ISO9001:2000 Quality Management System

ISO 9001:2000 Quality Management (QM) System leads organizations to establish an effective quality system that will prove their customers that they give importance to quality and can meet their quality demands; they can document it and ensure its continuity. Therefore it is demanded as a tender condition by many official or private organizations at the present time.

The usage of QM System enables improvement in the management of organizations or businesses, better planning in the facilities, faster solutions for problems, increase in productivity, profits and esteem.

According to the standard, product and processes can be developed, and also it provides security against the problems that may introduced from recording systems which can be applied in each stage of production.

The structure of the organization, the used sources, responsibilities, applied procedures and processes all affect quality. Generally these are identified and documented for the related participants to facilitate the understanding and applications. Quality systems are continued processes due to meet controlling at every level.

The quality system must be planned and developed by considering other functions like relationships with customers and suppliers, purchasing, having a contract with the subcontractor firm and training also.

Quality planning must determine the updating requirements of quality control techniques, prepare them to be sufficient to carry out quality plans of personnel and requirements and form the related quality records.

2.5.3 Conclusions on ISO9001:2000 Quality Management System

To establish an integrated control system in terms of monitoring ongoing activities to ensure that they are consistent with the quality standards, a procedural definition is required.

This facilitates to form work activities, performance standards, and provide rules and regulations for guiding employee tasks and behaviors. Although, it is independent of strict rules that have been suggested in the main definition of QM System establishment, the practical and general applications for different aspects have made different sectors define a procedural system according to their application areas.

In this sense the construction management structure can be constituted according to identified interconnected procedures. In our case, these are basically identified as:

- General System Procedures,
- Human Resources and Administrative Procedures,
- Customer Relation Procedures, and
- Project Management Procedures.

These main procedures are represented with sub-procedures from which management processes can be derived. Because, these processes will be formalized based on a standard, the standard approach for construction management can be provided. The details are formed in Chapter 4, in this regard.

2.6 Procurement Systems

In the Architecture, Engineering and Construction (AEC) environment varieties of procurement systems such as Design-Build, Lump Sum Contracts, Turn-key Contracts etc. have been developed to formalize bidding preparations. Because large scale applications exist in this context, it is necessary to identify main procurement systems for precise formalizations. For a better drawing of the frame of the scope, in this research the information regarding to five procurement systems is examined briefly, according to Dikbaş (2005).

2.6.1 Design & Build

In a Design-Build system, all necessary design and construction expertise resides within one firm. The firm has both design and construction departments and staff.

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.

2.6.2 Lump Sum

In this type of an arrangement, 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 plans and specifications. The lump sum offered by the contractor is not supposed to change. Changes and extra work orders after the contract is signed 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. Subsystems of a building like a superstructure may be contracted out on a lump-sum basis. This would be a typical Turnkey Contract. It is, actually a variation of the lump-sum contract.

2.6.3 Cost Plus

In this contractual arrangement, the owner pays the contractor the costs that the contractor incurs in performing the work, plus a fee for managing the work and for profit. In this case,

the burden risk shifts to the owner. The advantage of this arrangement is that design revisions are allowed during the construction phase. In order to put some limit on what the cost of project will be under a cost-plus contract, many projects use a Cost Plus Fixed Fee with a guaranteed maximum price. Cost Plus contract can be used when the design is not complete, and when the project is a fast-track job.

Moreover, there are different types of contracts such as Cost Plus Percentage on Cost Contract, in which there are no incentives for the contractor to economize during construction. Indeed, an unscrupulous contractor may deliberately inflate the construction costs in order to obtain the corresponding increase in this percentage fee. There are some precautions taken against this tendency. A Cost-Plus Fixed Fee Contract with a Profit Sharing Clause allows the contractor to receive a share of any savings if the actual cost should be less than the original estimate. Another variation of the cost-plus contract is the Cost-Plus Contract with a Guaranteed Ceiling Price. The owner may place a maximum limit on the cost of the work. That is the contractor is reimbursed for the actual cost of the work plus his fee, provided that the total amount does not exceed the maximum limit established in the contract. If the total amount exceeds the maximum limit, the contractor is held responsible for the excess and receives no compensation over the guaranteed ceiling price.

Alternatively the contractor's fee may change proportionately to the actual cost of the work. This arrangement is called Cost Plus and Incentive Fee or Cost Plus a Sliding Scale of Fees. These may be used as an incentive to the contractor. The fee or percentage may be increased for various increments of cost greater than the original estimate.

2.6.4 Unit Price

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. Variations may be made in the amount of the work. 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.

2.6.5 BOT (Build Operate and Transfer)

This particular system involves the undertaking of design, finance, construction and operation of revenue producing projects and at the end of the pay-back period, turning the facilities over the owner. Generally, the project is a public one. In this case, private developers design,

finance, construct and operate revenue producing public projects which will eventually be turned over to the community. The main benefit offered by this approach is that a service which a government or a municipality cannot afford to fund is provided. The owner is able to procure, at no capital cost, an asset which will provide a public service, promote economic growth and development and provide some revenue. The contractor, on the other hand, does not pay a price for the real property. Collection of the necessary data to support a BOT bid will obviously form a necessary part of the initial stage of a feasibility study. BOT projects are, by their nature very long term ventures (49-99 yrs). This period is called the “concession period”. On completion of the concession period, the client will look to acquire an asset which will produce enough revenue to cover the costs of operating and maintaining the asset. For the contractor, accurate assessment and qualification of the risks involved is quite important, especially in complex projects. It is important therefore to write detailed contracts.

2.6.6 Conclusions on Procurement Systems

The lack of definitions based on the procurement system dependent process aspects affect the CPM negatively. In order to comprise different views which illustrate different perspectives, the procurement system application needs should be presented within the definitions of the CPM procedures and processes.

In this context 5 main Procurement Systems have been represented and taken into account in each step of the implementation process of the suggested integrated CPM structure. Moreover procurement system dependent process aspects are examined in Chapter 5 to prove the concept.

2.7 Research Projects

It has been attempted to address the creation of an IT environment providing comprehensive concurrent engineering, by initiatives such as the research projects COMBI, ToCEE, ISTforCEE and iCCS.

ToCEE, ISTforCEE and ICCS projects exerted considerable influence on the work presented in this thesis. The brief definitions are possessed in the following paragraphs.

2.7.1 ToCEE

ToCEE (Towards a Concurrent Engineering Environment in the Building and Civil Engineering Industries) is one of the few projects that examined the principal construction of an IT framework for concurrent engineering. It was a 3 years EU, ESPRIT project which was completed between the years 1996-1999.

The main goal was to constitute system's information exchange and management in support of concurrent engineering. It addressed the following issues that are essential for a successful concurrent engineering approach (ToCEE 2007).

- Distributed product and document modeling including intra and inter-model operability,
- Conflict management,
- Information logistics,
- Version management,
- Legal issues related to electronic documentation,
- Monitoring and forecasting,
- Cost control.

In this context the first product model server in the construction industry was implemented and several domain problems were considered to provide integrated multi-client/multi-server prototype environment. The layered framework of COMBI project was enhanced with two additional layers and encompassed a broad spectrum of data, including information about the information system itself (Scherer 2000, Turk et al. 2000).

However, many aspects related to model-based product development in the line of concurrent engineering methodology remained without due consideration in the ToCEE project as well, and there was little work done for the systematic modeling of interoperability aspects w.r.t the overall system (Katranuschkov 2000).

The examination of such issues and related problems represents the main part of the work presented in this research. Therefore to expose interoperability aspects and to reach standardized product and process integration, a new approach has been established and will be presented in the following chapters.

2.7.2 iCSS

iCSS (Integrated Client- Server- System for a Virtual Enterprise in the Building Industry) (Juli & Scherer 2002) was a three year project which ran within years; 2000-2002 with eight partners. It was supported by the Ministry of Education and Research, 'Bundesministerium für Bildung und Forschung (BMBF)' Germany.

The main objective was the development of an integrated client-server system encompassing all team members in an entire construction project which would enable seamless co-ordinated work and on-line as well as temporarily off-line information exchange over the internet.

The basic requirement is represented as forming of an adequate information and communication system thus smaller and medium-sized design companies can possess a powerful virtual enterprise.

The iCSS system was developed as an open system: Therefore the regulations and general standards comprise an important part in the implementation. The system framework was

realized based on a shared building-model repository which enabled seamless electronic exchange of building product.

Moreover, it was attempted to support the co-ordination of fragmented design team members via the Internet, i.e. project and conflict management, transparency of the work progress and distribution of responsibilities was also attempted.

In order to provide these, following components were suggested (iCCS 2007):

- information logistics system as the kernel of the iCSS,
- project management system (extended workflow),
- building model server (product model server),
- building project related document server,
- contract model server,
- conflict management server.

These components are constituted as object-oriented data structures, integrated into one complex, and logically consistent IFC and STEP/EXPRESS-based object-oriented system.

Furthermore, in order to connect user applications, the clients with the central system services which enable access to fragmented, domain specific data, were provided. The user applications clients and WWW-enabled clients were separated in this regard. These were designed to comprise complex application-specific and domain-specific querying, filtering, retrieval and modification functionality and featured ergonomic aspects concerning human work in general, as well as specific operational and technical processes. In addition, these seek to be adequate for the increased intra and inter-domain interaction and co-operation processes that may even span across different regions.

The structure was formed to plug various (existing and future) clients for various tasks. In the project fully operational generalized example clients for the product model server, for the contract model server, for the project management server and for the conflict management server, as well as user application dependent clients for CAD-architecture and CAD-structural engineering have been developed.

However, because of a lack of definition of standardized processes which includes resources and which defines interaction between those cause synchronization problems. Therefore access of different participants to the virtual environment cannot be controlled based on pre-defined workflows and these cause conflicts on the management of the process.

Another issue is also related with the definition of IFC Views which would directly lead to examine product data. Without structured interactions between different software which could only be derived from IT Management Process Definitions, domain problems are also caused. The exploration of such issues form also a major part of the work presented herein.

2.7.3 ISTforCE

ISTforCE (Intelligent Tools and Services for Construction Management) was a three years of EU-IST project, which spanned from 2000-2002 with 10 partners.

The main goal was to provide a generic workplace, which is easily configurable based on demand, and equipped with intelligent tools (Katranuschkov et. al 2002). This approach is not only support to manage, multi-project participation in different virtual enterprises with different client-server systems also allows easy access to rental engineering services on the web, such as special engineering software or design code repositories.

Furthermore, it was been attempted to provide e-commerce and e-payment, including proper authorization according to the employee status of each engineer.

In this context, a novel human-centred Concurrent Engineering Services Platform (CESP) for multi-project participation has been developed by plugging servers of different virtual enterprises, which also provides access to the electronic market place and support e-commerce as a business model. The user-relevant information, such as information and knowledge management data, tried to be kept on the platform, whereas data storage itself could be outsourced. Hence the first ASP and web service system based on a SOA architecture was developed and implemented in the construction industry.

The benefits expected from this project are (ISTforCE 2007):

- To provide a long-term stability of the ways of working with the platform's services for its users,
- To save efforts for the personal configuration of interfaces and the ways of interaction with the services in an accumulating way,
- To prevent the user from wasting investments for configuration efforts due to being subject to the rapidly evolving and changing IT paradigms and tools and the continuously changing virtual enterprises and projects.

However, lack of pre-defined tools and their sufficiently defined inter-action procedures which was not in the scope of the project cause interoperability problems. Different needs of different tools which would take part in the process should be clarified in advance. This could only be provided by examination of CPM tools such as; CAD, ERP, Scheduling etc., and defining how they are acting in the process within Construction Management Lifecycle.

2.8 Conclusions

The creation of a generalized Construction Management System can be expected to include a large number of specialized components and processes of great complexity. As these are identified.

Moreover, many aspects have been separately investigated in previous research efforts and reliable solutions have been structured. However, a core CPM model which comprises

different views has not been represented, in the expected granularity. This requires taking into account different aspects and properties of different approaches, and fulfilling the gaps by use of variable resources in this context.

In this research, the basics which are learned from the existing solutions are interpreted as (1) Project Management General Structure and Related Processes, (2) Construction General Life-cycle Model, (3) ISO9001:2000 Quality Management System, and (4) Procurement Systems.

The definitions of different organizations' and researchers' diagnosis are accepted as baselines and the identified models are constructed with modeling a core management structure.

Moreover, the projects ToCEE, iCCS and ISTforCEE which tried to form concurrent engineering environments were explored and the related acquiesces are elaborated.

On that basis, the main objective in this research is proposed to form a core CPM Structure to support interoperability over a broad spectrum of applications and to develop a common formalized model to facilitate information exchange based on standard models. The approach should comprise the IT Management Processes which define software applications and their interoperability.

In this regard, a conceptual schema and integrated model definitions are provided and represented in the following chapters.

CHAPTER 3: STANDARDIZATION EFFORTS FOR CONSTRUCTION

In this chapter building product and process models are examined. Product Models are provided within two models namely (1) Minimal Models and (2) General Explicit Models. ISO Standard for the Exchange of Product Model Data (STEP) and Industry Foundation Classes (IFC) are presented in detail, in this context. The System Design Methodologies and Process Models are given briefly. Moreover, on the basis of phase and process formalizations, IDEFØ and ARIS Business Process Model are analyzed in detail.

3.1 Introduction

The systems and the methodologies for building descriptions have improved over many decades ranging from simple sketching to computer integrated models. From 60's to present day, the use of IT within the processes of design, engineering and manufacturing has been developing in the context of computer hardware and software technologies, and the method statements have been formed based on the information exchange needs of AEC actors.

In this context, several methods have been provided to define the basic attributes of processes and products to support efficient management of construction applications.

Business Process Re-engineering (BPR), Total Quality Management (TQM), several ISO Standards, Electronic Data Exchange (EDI), Product Data Exchange (PDE) and Product Data Management (PDM) etc. are well known application techniques that are used world wide.

GARM (Gielingh 1988b), IBDE (Fenves et al. 1989), AEC Building Systems Model (Turner, 1990), DICE (Sriram 1991), EDM, (Eastman 1992), OOCAD, (Seren et al. 1993), ATLAS (Böhms & Storer 1994), COMBINE (ed. Augenbroe 1995), CIMsteel (Watson & Crowley 1995), COMBI (Scherer & Sparacell 1996), EPISTLE Core Model (Angus 1996), ISO 10303 AP225: Building Elements Using Explicit Shape Representation (ISO/TC184/SC4 1996b), AP230: Building Structural Frame: Steelwork (ISO/TC184/SC4 1996c), and Part 106: Building Construction Core Model (ISO/TC184/SC4 1996a), CONCUR (Storer & Los 1997), and IFC, Core Model (IAI 2005) are accepted as important initiatives for structuring the information for building products and processes.

But due to these activities, IT in construction has so far been used mainly as a means of facilitating the production of traditional types of documents and has had limited impact on the information content of the documents. Therefore the efficient use of IT such as the use in automotive or banking sectors has not reached to expected levels.

Because of differences as: complex structures, variable disciplines, overlapped processes, customized products and different organizational approaches are examined in construction, the integration and harmonization of CPM requires an advanced interoperability and an essential ontology solution. From this standpoint the research studies such as; ToCee and ISTforCE have started to focus not only storing of data and also focus to support the work flow within the processes, the retrieval and the distribution of information within the participants. These methods and research works have been showing that, integration can be

achieved with generalized standards commonly agreed by developers on the basis of clearly expressed industry requirements (Storer 1997).

BSAB, DXF, EDIFACT, IGES, ISO CAD-layer, STEP and IFC standards and de-facto standards have been achieved to support building information in this context. The integration initiatives undertaken in the frame of ISO, as STEP and by the IAI's IFC are the most common standards for product and process definitions in construction environment. The international Standard for the Exchange of Product Model Data (STEP) standardization work, an ISO activity for defining a standard for the representation and exchange of product model data, was initiated in 1985 and still continuing and the Industry Foundation Classes (IFC) is an IAI (International Alliance for Interoperability) activity aimed specifically for the construction industry (IAI 2005). IDEFX, NIAM and EXPRESS-G are the accepted information models as tools to formally specify the conceptual requirements. Additionally, EXPRESS language has been developed as an intermediate-level specification language for defining the logical structure of a model, separate from its physical implementation.

The identifiable conceptual modeling methods, object-oriented modeling languages, structured design and modeling methods for business processes began to appear between 1960 and the late 2000s as various methodologists experimented with different approaches to object-oriented analysis and system design.

Systems Analysis and Design Technique (SADT), Data Structure Diagrams (DSD), Jackson Design Methodology (JDM), Structured Design (SD), ISDOS (Information System Design and Optimization System), Pseudocode, Hierarchy Plus Input, Process, and Output (HIPO), Warnier-or methodology, Walkthroughs, Entity Relationship Model (E-R Model), Semantic Data Model (SDM), Integrated Definition Method (IDEFØ), Unified Modeling Language (UML), Architecture of Integrated Information System (ARIS), Process Renewal Methodology (PRM), Six Sigma DMAIC, UREP Methodology, Petri Nets etc. can be defined within this scope.

IDEFØ, UML and ARIS have a range of application areas for definition of construction processes. IDEFØ was derived from SADT language as a standard for function modeling. The UML has been developed as a standard language for specifying, visualizing, constructing, and documenting the artifacts of software systems by OMG (Object Management Group) and ARIS is focused generally on defining of business processes.

From this standpoint, in order to constitute the generic CPM model and to represent needed requirements in this research, the information structures related with building product models: ISO STEP and IFC definitions and with System Design Methodologies: IDEFØ and ARIS methods will be defined briefly in the following sections. Also the minimal building models and explicit models will be examined briefly in this context.

3.2 Product and Building Models

Product Models can be defined in two models as: (1) Minimal Models and (2) General, Explicit Models. The Minimal Models can be seen as Meta Models which have attributes defining the individual building objects.

General Models/Explicit Models define the building objects, relationships and attributes for all building aspects and creates clear definitions.

There are four different approaches that can be identified in this scope:

- Minimal approach- project level decisions (Minimal Models);
- Minimal approach- maintained by classes (Minimal Models);
- Layered approach- with aspect models (Minimal Models and Explicit Models);
- Comprehensive model- comprises all classes and relations (Explicit Models).

3.2.1 Modeling Concepts

Minimal Models:

EPISTLE, GARM, EDM OOCAD-Object Oriented CAD and the Minimal Approach can be identified as minimal models.

EPISTLE Core Model

EPISTLE (European Process Industries STEP Technical Liaison Executive) was founded in 1993. The aim was to identify collaboration potential, between parties involved in developing standards for the exchange of technical information in the process industries (Angus 1996). It has formed to establish the basis of ISO10303 (STEP) Parts (Application Protocols). The main idea is the definition of a data modeling framework for conceptual data models. EPISTLE models comprise three principles: (1) Definition of the objects related to a basic underlying technology, (2) Enabling the description and identification of things in multiple ways (3) Maintaining fine grains versions of data related to time. The Core Model does not include fully elaborated entity types, but provides a set of entity types from which a set of application-specific generic entity type is derived from the EPISTLE Core Model by sub-typing it from precisely one sub type from each of the four orthogonal sets-subject, instantiation, life cycle reality (Angus 1996). Moreover EPISTLE models are data driven, not process dependent and they effectively only provide a framework for data storage which is specialized for a particular purpose by a class library (Bailey 1997).

GARM

GARM (General AEC Reference Model) is an initiative of TNO (Dutch research institute) and was developed by Gielingh (Gielingh 1988a). GARM focused on all AEC applications but it doesn't comprise of specific product extensions. The aim is to provide a general high level abstraction/reference model. Complex products are implemented by specifying their functionality as a whole. Then solutions are realized which also contains design problems. Moreover it includes general decomposition model where a part can be part of a system and a system can be a part of another system etc. Product Definition Unit (PDU) is the basic class and can be formed as a whole product, a sub-system, an element, a component, a part or a

feature of a product. The related information to a PDU is composed of collection of characteristics, which are related to an aspect like strength, cost etc. (Tarandi 1998).

EDM

EDM (Engineering Data Model), can be identified as a generic product data modeling language and developed by Eastman (Eastman 1992). The aim is to manage the design information, related with the conventional building information, in spite to restrictions within the CAD systems for structural and architectural design. Thereby relations are identified operationally in a structure which also provides a control mechanism. The EDM is realized based on low level primitives such as: domain, aggregation, constraints, design knowledge etc. thereby the data sets and the relations are represented as design data according to these primitives. Also with using of these primitives three form types are established: (1) defining of data objects and relations between them, (2) conceptual data information (3) low level production information.

OOCAD-Object Oriented CAD

The OOCAD project was launched by VTT, the Technical Research Center of Finland, and was formed according to RATAS-II project (Enkovaara et al. 1988). The results are identified as neutral exchange format 'OXF' and OOCAD data model. The OOCAD model is developed according to composition of objects with part-of relationships. Moreover it is composed of three generic relationships as hierarchy, links and grouping. The basic concepts related with this approach are: (1) Type object which defines common properties of several occurrence objects, (2) Occurrence object which defines an occurrence of a type object, (3) Group-occurrence object which belong to multiple groups, (4) Attribute set which defines properties of object and (5) Relationship which links between occurrence objects (Tarandi 1998).

The Minimal Approach

The Minimal Approach was structured to provide data exchange between different systems and to support communication within each other. It was formed in 1991 (de Vries 1991). All product models are identified with low level objects. The communication is provided also in this level. Besides, data structure proposed at Meta level in which application objects fit. The building element is formed as main class and has relations with other building elements. However, the application class which can hold all kinds of information not described in minimal model. The information exchange between different schemata is based on mappings that comprise one to one and cross reference mappings.

Explicit Models:

Explicit Models are formed based on a consensus which defines concepts and details in terms of standardization initiatives by the construction actors. In this context: STEP AP225, AP230, Part 106, CIMsteel, AEC System Model, COMBINE, IRMA, ATLAS, PISA will be defined briefly.

STEP AP225: Building Elements Using Explicit Shape Representation

AP225 was realized to describe shape related building elements. It is a STEP application protocol ISO/DIS 10303-225 (AP 225) for the exchange of building designs between architecture, engineering and construction application systems using 3D explicit shape representations (ISO/TC184/SC4 1996b). The functional classifications of element's shapes, element classification and grouping are represented as a part of complex configurations. Building shapes are demonstrated as analytic, elementary or a free form shape. AP225 also identifies the changes, change requests, approvals and qualifications in this context.

STEP AP230: Building Structural Framework

AP230 is a STEP AP for the exchange of information relating to structural steel frames (ISO/TC184/SC4 1996c) lunch from a large European EUREKA project called CIMsteel. The aim was to provide advance information integration within the structural steel industry, and provide a challenge with the development of product models and integration prototypes. It addresses applications for analysis, member design, and detailing functions etc. In 1994, the CIMsteel product model was promoted as a STEP AP project covering construction steelwork frame design, analysis and detailing, and fabrication.

STEP Part 106: Building Construction Core Model

The first version of the Building Construction Core Model was a result of the European ATLAS project (Poyet et al. 1995) and subsequent development of ISO STEP Part 106. The Building Construction Core Model is a model that describes common objects like beam, column and floor in such a way that more detailed objects can be described by specialization, *i.e.* a hollow concrete floor can be modeled as a subtype of floor (Edwin 2002). Development of the large model comprising Building Construction semantics did not suit in well with the ISO standardization process hence the progress was slow. This led to the start of the IFC project. Following IFC's start, development of Building Construction Core model has ceased (Sander 2000).

CIMsteel

The overall aim of the CIMsteel Project (Watson & Crowley 1995) was to improve the efficiency and effectiveness of the European construction steelwork industry. The focus was the application of Computer Integrated Manufacturing Techniques to steel fabrication. The goal is the establishment of an "open standard" for structural steelwork in order to provide global use. The CIS (CIMsteel Integration Standards) resulting data exchange standard, have already been widely implemented. The work on CIMsteel based on IDEF1X as a conceptual modeling language and on the use of STEP technology. The idea was to realize and test a series of prototypes which would evolve into a STEP-compliant model. The first release of the CIS (CIS/1) specifications was first made available to software developers in late 1995. CIS/1 is relied on Version 4 of the Logical Product Model (LPM), a model which was developed and tested by CIMsteel project. The LPM comprises the engineering information that arises in the design, fabrication and erection of steel framing in construction.

AEC Building Systems Model

This model presents a high level conceptual schema of an AEC product model (Turner 1990). The aim is to realize general concepts like geometry, property as building model concepts. The general system from which sub-systems (building systems) are derived is accepted as the basic conceptual schema. The systems support human or natural needs e.g. security, environmental protection etc. The AEC Building System model has the concepts of flow system, associative system, static and dynamic system etc. Although it is accepted as a well approach, because the parts as spatial and topological characteristics in combination with types and classification are missing, it has difficulties for practice use.

COMBINE

In the scope of the European JOULE program, COMBINE project was started in 1990 (ed. Augenbroe 1995). The main aim is to use Product Data Technology (PDT) in the building industry and to represents the benefits of it to AEC actors. The framework has comprised of STEP and usage of existing design applications in an integrated framework. In the first phase, the research has focused on data integration using a central common repository. The Integrated Data Model (IDM) has been established in this phase to formulate Aspect Models for different applications. Aspect models represent Design Tool specific (DT) information. Each aspect model is addressed by an IDM sub-schema which is also a subset of IDM. In this sub-schema all information which is derived from IDM that is used or influenced by the DT, is identified. The IDM realize exchange of information between DT. In the second phase the combination of first phase results has been adopted to an operational structure and Integrated Building Design System (IBDS) has been formed.

IRMA

IRMA (Information Reference Model for Architecture, Engineering and Construction) is a project comprising participating researchers' models. The conceptual schemata is realized based on the 'Unified Approach Model' (Björk 1992), the 'General Construction Object Model' (Froese 1992), the Building Product Model' (Luiten & Bakkeren 1992) and the 'ICON Method- Modeling Perspectives' (Cooper et al. 1992). The aim is to form a common reference model for the future work. The conceptual schema basically defines generic relationships between products (results), activities, resources and participants in the building processes. It is identified as a reference model for specific applications.

ATLAS Large Scale Engineering Project Type Model

The ATLAS Project provides development, demonstration, evaluation, and dissemination of architectures, methodologies and tools for Computer Integrated Large Scale Engineering (LSE) (Tolman et al. 1994). It is specialized for different engineering sectors with using of STEP resource models and supports information exchange between them. The structure is composed of three layers. In the top layer the large-scale engineering (LSE) model provides an integration mechanism between different sectors of the construction industry. One layer below, the building model and process model provide an integration mechanism between

disciplines of their own sectors. Again one layer lower a number of discipline models (Architecture, structural engineering, HVAC engineering in the building case) provide an integration mechanism between different applications of the discipline (Tolman 1999).

PISA

PISA, ESPRIT III project is launched to provide integration of various information models for product and process modeling. This is achieved in part, through the PISA product and process model which contains general principles for product and process modeling and which shows how these principles are interrelated (Williems 1993). The objects, which might be products, resources, planning objects, control the processes. Processes carry out activities according to tasks which can cause the occurrence of events.

3.2.2 ISO 10303 - STEP

ISO initiated a Technical Committee, TC184, which deals with Industrial Automation Systems and Integration, to provide a neutral format for product data exchange. Further, within this technical committee a sub-committee known as Subcommittee 4 (SC4) was established to develop a standard called ISO10303-Industrial Automation Systems Product Data Representation and Exchange in well known name STEP (Standard for the Exchange of Product Model Data).

In this initiative nineteen countries participate in the development of ISO10303 (STEP). The initial organizations involved with STEP can be classified into two areas, the development bodies such as: ISO TC184/SC4, IPO (IGES/PDES Organization), University of Karlsruhe, and organizations concerned with implementing STEP10303 such as: PDES Inc. (Consortium of 32 Industrial Companies), STEP Tools Inc, National Institute of Science & Technology (NIST), etc. The initial release of STEP was approved for publication in September 1994.

STEP is the first data exchange standard that comprises product data in the exchange, e.g. assembly instructions, design criteria thresholds used/evaluated, color, weight etc. to address the required to real time data exchange and maintenance. The main aim is to produce standards that can be used in industrial applications. STEP consists of parts which are realized in different categories according to their purposes:

- ***Descriptive Methods (Parts 11-12)***: These methods include Part 11, the EXPRESS Language (ISO/TC184/SC4, 1993a)
- ***Implementation Methods (Parts 21-29)***: These methods include two different implementations. One is information transfer using the physical file format, Part 21 (ISO/TC184/SC4, 1993b). The other one is information sharing via a Standard Data Access Interface, SDAI, Part 22 (ISO/TC184/SC4, 1993c)
- ***Conformance Testing Methodology Framework (Parts 31-39)***: Application Protocol, (AP) should give the definition of testing an operation within specific AP's

- **Integrated Generic Resources (Parts 41&99, parts 101-199):** These are composed of common schemata elements from which the different APs are defined. These are two kinds, generic resources (Part 41-99) which do not have an application context, and application resources (Part 101-199), which define data entities that are common for a given application area.
- **Application Protocols APs (Parts 201-299):** The APs are the products of STEP such as Part 201 AP: Explicit Draughting, Part 202 AP: Associative Draughting, etc.
- **Abstract Test Suites, ATS (Parts 301-399):** These are identified as conformance testing groups and they describe how products that are claimed to conform to a specific AP shall be tested.
- **Application Interpreted Constructs, AICs (Parts 501-599):** They are conceptual schemata within an application context that represent the building blocks for APs together with the integrated resources.

And also there are recognized stages in putting a STEP standard together are outlined below:

- **Application Activity Model (AAM) Phase:** This phase comprises the user requirements and to document the industrial need.
- **Committee Draft for Comment (CDC) Phase:** This phase improves users view in terms of application reference model (ARM), and validates the AAM by consensus.
- **Committee Draft (CD) Phase:** The primary software model, application-interpreted model (AIM) for the AP is developed in this phase.
- **Draft International Standard (DIS) Phase:** AP's technical maturity and stability is documented in this phase and also the software vendors begin to develop commercial products to implement these AP.
- **Final Draft International Standards (FDIS) Phase:** This phase comprises of editorial processes only and technical changes are not considered.
- **International Standard (IS) Phase:** This final phase is for the AP registration as a standard.

Furthermore, a modular approach is used to develop subsets of the needed standards which are organized into an Application Protocol (AP) based structure.

Specific data formats can be classified in Application Protocols (AP). Each AP is designed to be used either for a particular industry or is used across common applications such as CAD systems and AP201, 202 and 203. The standard also allows a structure for implementing a standard in the form of shared databases and archives using the Standard Data Access Interface SDAI defined in Part 22.

Express & Step

EXPRESS is a textual data specification language. It is based on the Entity–Attribute–Relationship of data also it is computer-interpretable and human-readable. EXPRESS defines the product data and it is used as a conceptual data model in the context of STEP.

Current Status and Step's Future

Today a few APs have application reference model based exchange formats standardized outside of ISO TC184/SC4: (1) PLM-Services within the OMG for AP214, (2) ISO 14649 *Data model for computerized numerical controllers* for AP238 and (3) PLCS-DEXs within OASIS (organization) for AP239 (Wikipedia 2007).

Despite the many successes of STEP there is still a question in user's minds about the speed of its development and deployment (Hardwick 2004). The expected results, related with the increasing use of Product Data Management (PDM) systems that requires STEP enabled management and transfer of the data will be achieved in the next years.

3.2.3 IFC

To provide different software applications work together, 12 companies in USA formed an organization called International Alliance for Interoperability (IAI) in 1994. The aim was to identify the specifications and enabling interoperability between AEC/FM applications from different software vendors and publish them as Industry Foundation Classes (IFC). IAI released the first full IFC Information Model; IFC Release 1.0 in January 1997. Several further Releases as: IFC 1.5, IFC 1.5.1, IFC 2.0, IFC 2x, IFC 2x3 have been issued since.

IFC Model Architecture

IAI defined the model requirements as: (1) disciplines within the AEC/FM processes (2) Life-cycle stages of the projects (3) Level of details (4) Software application and a model architecture, the 'model schemata' (IAI 1999) as given in **Figure 3.1**.

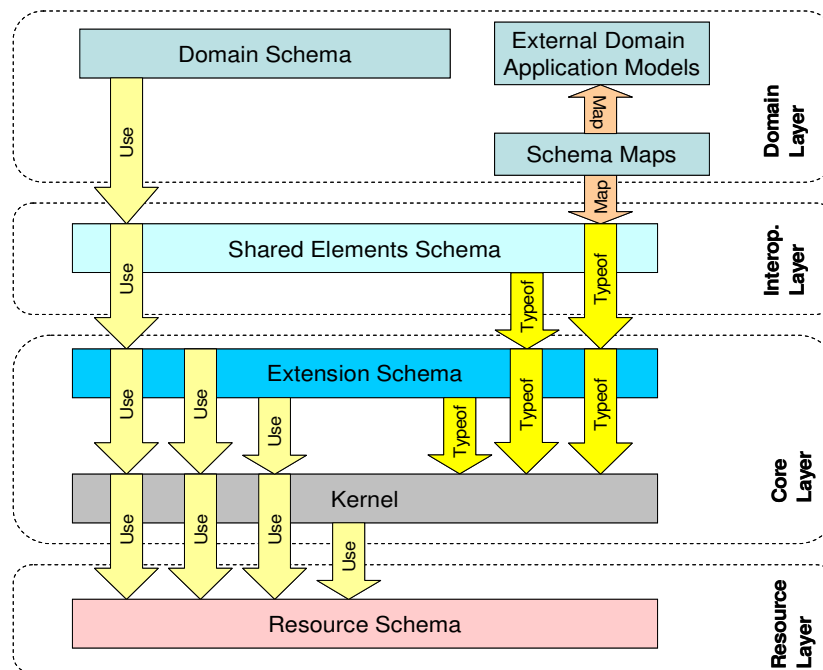


Figure 3.1 Layering Concept of IFC Structure (IFC Technical Guide, 2007)

Resource layer

Resource Layer forms the lowest layer in the IFC Model Architecture and can be used or referenced by classes in the other layers (IFC Technical Guide 2000). Resources can be defined as general purpose, low level concepts or objects that are independent of application. All resources represent business concepts. Resources can be identified under general resources (measure, actor etc.), geometry resources (explicit and implicit), and business concepts (material, cost etc.) generally.

Core Layer

Core Layer classes can be referenced and specialized by all classes in the interoperability and domain layers (IFC Technical Guide 2000). The Core Layer includes two levels of generalization namely: The Kernel and Core Extensions. The Kernel provides basic concepts like objects, relationships, type definitions, attributes, roles and it also determines the model structure and decomposition. The Kernel can be identified as the foundation of the core model. Core Extensions, provide extension or specialization of concepts defined in the Kernel (product, process etc.). Each Core Extension is a specialization of classes defined in the Kernel and develops further specialization of classes rooted in the IfcKernel. Additionally, primary relationships and roles are also defined within the core extensions (IFC Technical Guide 2000).

Interoperability Layer

Interoperability Layer determines of schemata that define concepts (or classes) common to two or more domain models. These allow interoperability between different domain models. The plug-in model approach is used in this layer. The multiple domain models can be plugged into IFC Core in the schemata defined in this layer (IFC Technical Guide 2000)

Domain Layer

Domain Layer provides further model detail within the scope requirements for an AEC/FM domain processes or a type of application (IFC Technical Guide 2000). They reference the classes defined in the Core and Independent Resource layers. The aims of these models are to provide 'leaf node' classes that enable information from external property sets to be attached appropriately (IFC Technical Guide 2000).

IFC is delivered in different releases, the following diagram **Figure 3.2** shows the complete set of IFC 2x Edition 3 Model schema.

The entire schema is named in a manner that enables identification of their architecture (IFC Technical Guide 2000):

- Schema at the resource layer is suffixed with term 'Resource'.
- Schema at the core extension layer is suffixed with the term 'Extension'.
- Schema at the interoperability layer is suffixed with the term 'Elements' (other than the Kernel schema which is considered to be a special case).
- Schema at the domain layer is suffixed with the term 'Domain'.

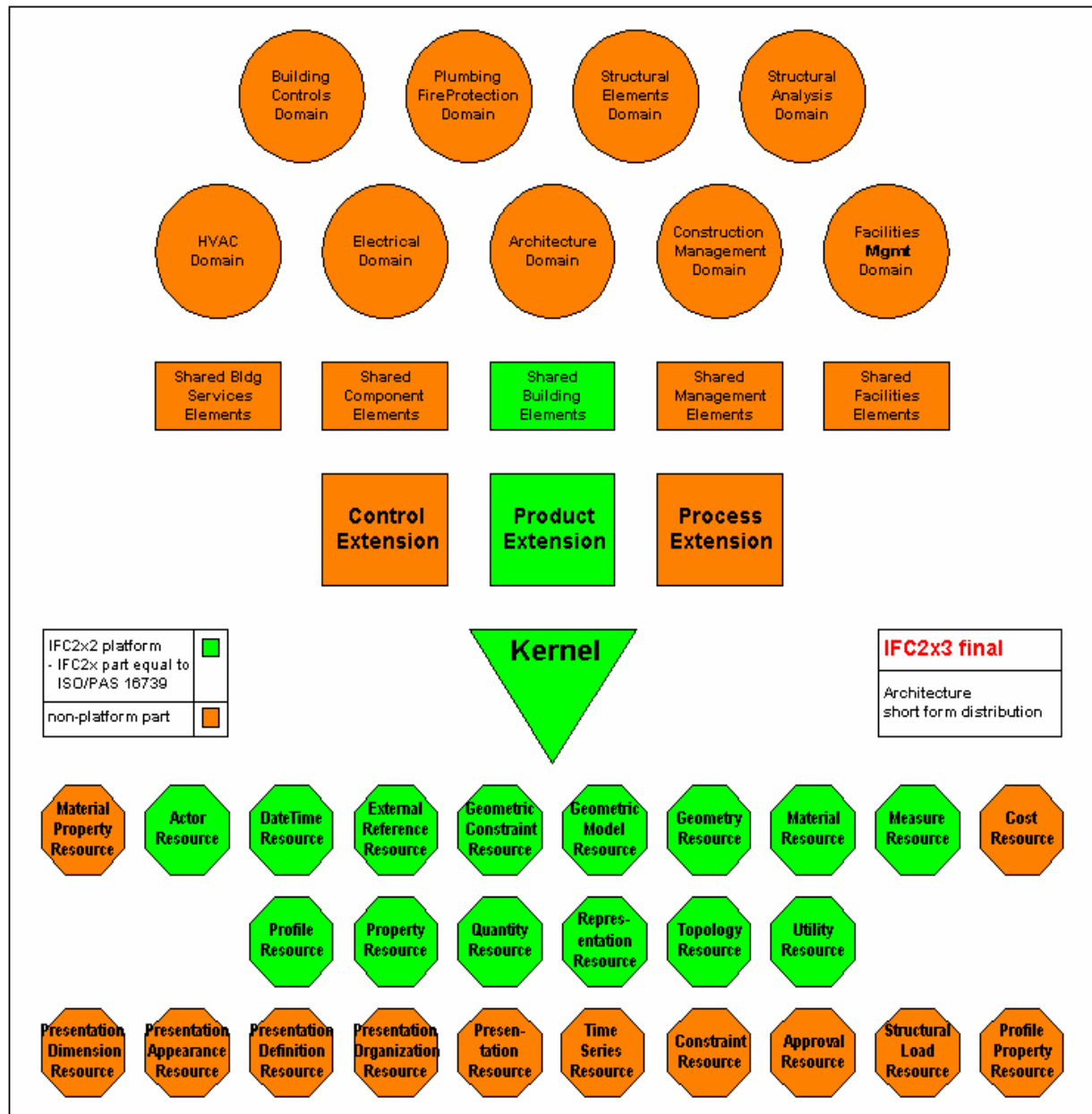


Figure 3.2 IFC 2x3 Overall Architecture (IAI 2007)

3.2.4 Conclusions on Product and Process Models

To develop product models, a numbers of efforts have been made as given in the previous sections. Although there have been different type of approaches examined in this context, the common aim can be realized as to develop an information standard. However, an international classification system has not yet succeeded. The main problem can be seen as defining the levels as common classes. Thus different views within AEC/FM environment make a generalized approach difficult. Never the less, ISO-STEP Construction Building Core Model and IAIs IFC Core Model can be identified as the main efforts for standardization of Product Models of AEC/FM sector.

3.3 System Design

3.3.1 Design Methodologies and Process Models

In the last decades many tools and techniques have been improved to contribute to the design process. Because of the complexity and variety of design approaches, the scope here limits the number of design methodologies and process models with brief introduction to their features, benefits and limitations.

Structured Analysis and Design Technique (SADT), Structured System Analysis and Structured Design (SSA/SD), the Jackson Design Methodology (JDM), Hierarchy Plus Input, Process, and Output (HIPO), Entity Relationship Model (E-R Model), Data Structure Diagram (DSD), Unified Modeling Language (UML) and some of Semantic Data Models can be seen briefly in the next paragraphs.

In the particular interest of this research, the Integration Definition for Function Modeling (IDEFØ) method which is also a preferred notation for the creation of graphical process model for the IFC specification and the Architecture of Integrated Information Systems (ARIS) Business Process Model which is an expressive visual modeling language to model the business processes will be given in more detail.

Structured Analysis and Design Technique (SADT)

SADT was realized in 1970s by Doug Ross at SoftTech, Inc. SADT is used for large and complex systems therefore system activities, data and their interrelationships can be constituted in this technique. It provides to analyze a system from top-down and decompose the structure into subsystems with using a precise notation to communicate analysis and design results. This approach possessed the decomposition of data flow diagrams and also be used for both systems analysis and design. These structured activities facilitate to focus on a single level of detail and the relationship between the data representation and activities. It is too complicated that the SADT diagrams may over helm the user and prevent their understanding of the system as a whole.

Structured System Analysis and Structured Design (SSA/SD)

Structured Systems Analysis/Structured Design, (SSA/SD) which was lunched by Lary Constantine in 1974 has been used as analysis and design method since the 1970s.

SSA/SD is realized among independent modules by dividing the system. These modules do not affect each other within modification and implementation. The coarse program structure is realized based on DFD. This structure represents similarities like an organization chart and composed of units and modules. The achievement can be completed by decomposition of this coarse program structure into modules and defining the relationships and combinations within each other. Module independence can be defined with 'coupling' which is the strength of

relationships between modules and ‘cohesion’ which is the measure of the strength among the elements in the same module.

Jackson Design Methodology (JDM)

The JDM has been developed as a design methodology by Jackson in the 70s. It comprises three sequential design techniques phase.

It is represented with structuring the data components, the relationships between these components and one-to-one correspondences between these data structures. Secondly, the program logic based on data structures in terms of processes and relationships are realized. Finally, the tasks to be performed in terms of elementary operations are identified and assigned to suitable components of the program structure. The system development is a very detailed and comprehensive method. Although it can not be used as a top-down method for computer systems and the structure charts can only be drawn after action at the lowest level, it represents the data structure in the program. Because of difficulties are observed to obtain program structures from all data structures, it is not using for large complex systems in general.

Hierarchy Plus Input, Process, and Output (HIPO)

IBM developed a functional graphic technique as a design tool called ‘HIPO’ in order to describe a system and to document functions of programs. The main idea is representing of hierarchy diagram namely Visual Table Contents which is similar in tree-like structure to an organization chart, which defines the basic functions to be performed by the system and decomposes those functions into sub-functions. The simplicity and effectiveness as a communication tool and visual description of input, functions and outputs of the system facilitate to use it, however it is not useful to represent large systems with HIPO diagrams.

Entity Relationship Model (E-R Model)

The Entity-Relationship (ER) model was launched in 1976 (Chen 1976) as a way to unify the network and relational database views.

It is basically used for data base design and supports to describe entities in an enterprise which are related to one another. It represents ‘one-to-one’, ‘one-to-many’, or ‘many-to-many’ relationships. It is needed to correct the semantic synonyms (one entity referred to by two different names) or semantic homonyms (two different entities referred to by the same name) after model completion. The logical schema of the data which will contribute to greater processing efficiency can be controlled in order to improve the model.

Data Structure Diagram (DSD)

DSD was realized by Charles Bachman in 1964. It presents the Integrated Data Store (IDS), which can be accepted as the first database management system.

DSD addresses data relationship which is used in data base design and supports algebra of entities and relational options and constraints imposed on those entities. The DSD notation determines relationships among records. The record relationship obtained by the DSD notation and the content of these records are documented in data dictionaries. Record names appear in boxes connected by arrows to show relationships with boxes representing entities and arrows. DSD diagrams can be identified as Network diagrams, most useful for graphic means for documenting entities and their relationships. There are several extensions from the original diagrams that can be observed in recent years, such as the Entity Relationship Diagrams and the Partnership Diagrams. These extensions in diagramming have followed the enrichment and refinement of their data models.

Semantic Data Models

There have been initiatives to develop Semantic Data Models since 70's. There are two different approaches that can be represented as: (1) attributes (functions) applied on objects and (2) data types, moreover constructor types (classification, aggregation, generalization, and association) way of accessing and constructing data that can be added, in this context.

There are several models developed as (1) General Semantic Model by Hull (Hull 1987); which provides the general characteristics supported by SDM to capture structured data, (2) by Hammer (1981); a model which is based on typical class structure of OOPL in which objects and functions that can be applied and defined in the class construction, (3) by Brodie (1982); a model which specially emphasis was laid on incorporating behavioral aspects on objects, in addition to support all the constructors required to create new objects, (4) by the Shipman (1981); first version of the Functional Data Model (FDM) which emphasis has been laid on derived data, which are treated by functions applied directly on attributes and objects.

UML

The "Unified Modeling Language (UML) is a graphical language for visualizing, specifying constructing, and documenting the artifacts of a software-intensive system. It was developed by Grady Booch and Jim Rumbaugh (1997) based on unifying efforts of Booch and OMT (Object Modeling Technique) methods under Rational Software Corporation in 1994. UML can be identified as a standard language which addresses the collection of best engineering practices of industry in the modeling of complex systems. It can be accepted as an important tool for improving object oriented software and software system modeling. In this context, the core concepts can be extended and specialized.

Moreover, it is independent of particular programming languages and development processes. It determines higher-level development concepts such as collaborations, frameworks, patterns and components to integrate best practices. It comprises elements such as packages, classes, and associations and defines various diagrams which can be used to visualize the static and dynamic parts of computer systems.

3.3.2 Integration Definition for Function Modeling (IDEFØ)

Integration Definition for Function Modeling (IDEFØ) is a method designed to model the decisions, actions, and activities of an organization or system.

It was implemented based on a well-established graphical language, the Structured Analysis and Design Technique (SADT) during the 70s as part of the U.S. Air force program for Integrated Aided Manufacturing (ICAM) and was realized by publication of the IDEF manuals in the early 80s. In 1993, the U.S. National Institute of Standards and Technology (NIST) documented the notation as Federal Information Processing Standard 183 (IAI 2005).

The main aim of this initiative was to develop a function modeling method for analyzing and communicating the functional perspective of a system. This approach can help to organize the analysis of a system and to facilitate the communication between activities. It can be considered as a communication tool that domain expert involvement and consensus decision-making through simplified graphical devices can be obtained. Also as an analysis tool, it can assist to define the performed functions, the requirements to perform these functions, and assessment of the current system. In this sense, IDEFØ models are one of the first tasks of a system development effort.

IDEFØ provides modeling in terms of detailing the system structure for function models and also provide of sufficient communication between the processes. The processes can be described with their inputs, controls, outputs and mechanisms (ICOMs). Also the detailing mechanism in terms of decomposition supports high level of sub-defined activities of the general model. The structure is constructed on a hierarchical nature that AS-IS top-down representation, models based on bottom-up analysis also can be achieved easily. The process of forming an IDEFØ structure starts with grouping the close activities through this process thereby a hierarchy structure emerges.

Two types of approach namely functioning and organization approaches can be identified. The functional architecture design of a company (often referred to as TO-BE modeling), requires top-down construction in general. Beginning with the top-most activity, the TO-BE initiative can be described via a logical decomposition. The desired level can be obtained continuously. When an existing initiative is being analyzed and modeled (often referred to as AS-IS modeling), observed activities can be described and then combined into a higher level activity. This process also continues until the highest level activity has been described. In this sense the basic elements have to be defined precisely.

IDEFØ Elements

The IDEFØ method has composed of basic elements given below to describe the process activities in a logical way.

The Graphic Representation

A function is shown in a function model as a 'rectangular box' graphic diagram and the interfaces to or from the function can be identified as 'arrows' entering or leaving the box. To express functions, activities should be followed by other activities in terms of sequential functions, with the interface arrows. There are four basic arrows can be identified, as input, output, control and mechanism. Basically input has a label that describes information used by the function, the 'output' describes information delivered by the function, the control is related with the constraints on the functions, and the 'mechanism' can be identified as an actor, a database or software in the formed structure. The basic diagram for an IDEFØ model is shown in the figure below **Figure 3.3**.

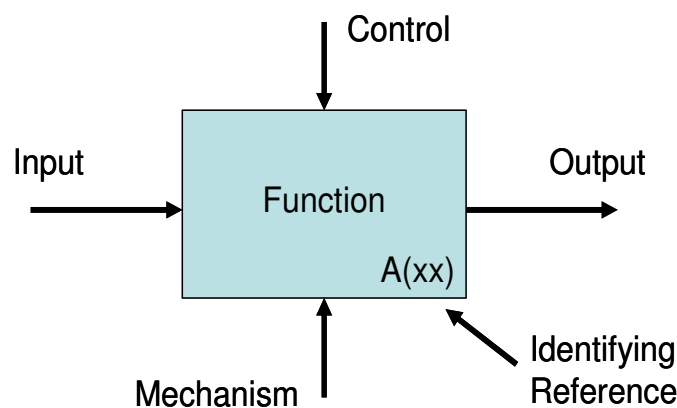


Figure 3.3 IDEFØ model basic diagrams

Communication

Communication in IDEFØ is based on the diagrams as simple box and arrow graphics. To describe boxes, arrows and glossary English text labels are used, a hierarchical structure for detail featuring is structured, and a 'node chart' that provides a quick index for locating details are applied. The limitation of detail no more than six sub-functions on each successive function

Basic Rules

The rules of IDEFØ require clean definition to satisfy needs. IDEFØ should control the details at each level (three to six function boxes at each level of decomposition), the context should be clarified precisely that no omissions and out of detail can be seen, the diagram interface and data structure connection should be obtained, unique labels and titles should be used for each functions, syntax rules are applied truly, the rule of the data has to be determined, minimum labeling rules has to be considered, all functions have at least one control has been provided and all models satisfy a purpose to support reasoning.

Organizational and Functional Approach

The organization and function has to be considered separately and it should be included as the purpose of the model and it is carried out by the selection of functions and interface names during model development.

Sequence and Timing Independence

Application of the IDEFØ method results in an organized representation of the activities and the important relations between these activities in a non-temporal fashion. IDEFØ does not support the specification of a recipe or process.

General Assessment about IDEFØ

IDEFØ models represent a sequence of functions. The functions are placed in a left to right sequence and connected with the flows in terms of arrows. It is clear that to order the functions left to right because, if one function outputs a concept that is used as input by another function.

But in some cases, it is not easy to define the activities within a workflow in the IDEFØ model. All needed functions cannot be included in the model due to envisaged restrictions. Thereby the readers of the model may be tempted to add such an interpretation to the model. This issue is the problematic way of IDEFØ. The structure would lose the meaning within these correction efforts. The abstraction away from timing, sequencing, and decision logic allows concision in an IDEFØ model. However, such abstraction also contributes to comprehension difficulties among readers outside the domain. This particular problem has been addressed by the IDEF3 method (**Fehler! Hyperlink-Referenz ungültig.**).

3.3.3 ARIS -Architecture of Integrated Information Systems

ARIS Architecture of Integrated Information Systems is developed by Scheer (IDS 2007) and commercialized by IDS Prof. Scheer GmbH as a business process engineering tool in the 90s'. ARIS as a modeling method provides semi-conceptual methods of describing process-organizational issues.

It supports custom applications, standard software solutions and component software assembly. The ARIS concept creates a guideline for developing, optimizing and implementing integrated application systems. At the same time, it shows business administration specialists how to view, analyze, and document, and implement information systems. Moreover it provides a reference guide for systematic and complete business process modeling by improving semi-conceptual graphic methods such as organization charts and network diagrams. ARIS concept divides complex business process into separate views and integrating these views to realize the whole structure.

ARIS Views

In order to structure business process models, the components and relationships are grouped into views as given in **Figure 3.4**. Separating the views provides the advantage of avoiding

redundancies, which can occur when objects in process model are used more than once. ARIS views which are created according to the semantic correlation similarity criterion (Scheer 2000) and explained as:

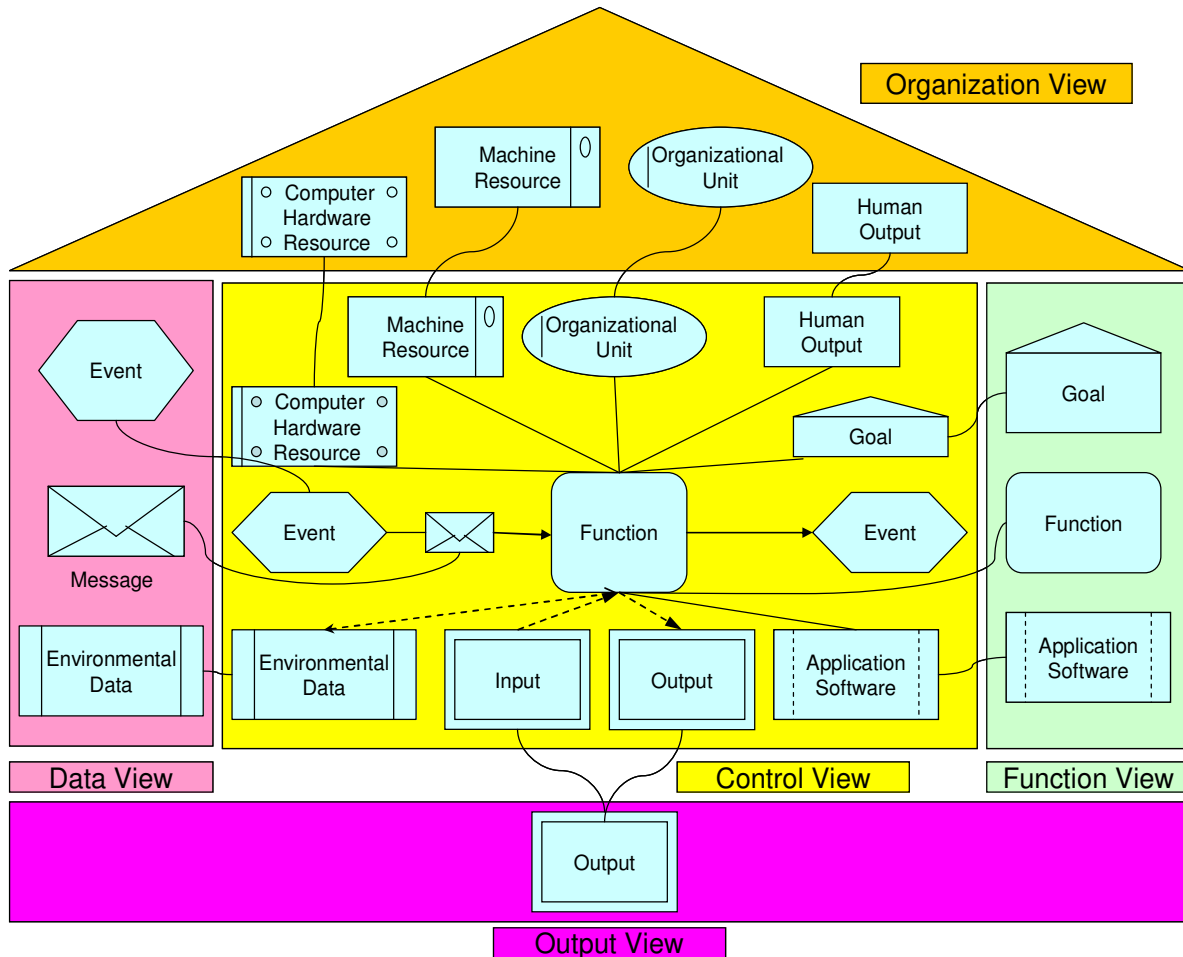


Figure 3.4 Views of the Aris House (Scheer 2000)

- **Function views:** The processes transforming input into output are grouped in a function view. Due to the fact that functions support goals, yet are controlled by them as well, goals are also allocated to the function views because of the close linkage. In application software, computer aided processing rules of a function are defined. Thus, application software is closely aligned with functions, and is allocated to function views.
- **Organization views:** The class of organization views creates the hierarchical organization structure, also known as the organization view. Organization views are created in order to group responsible entities or devices executing the same work object. On that basis, the responsible entities “human output”, responsible devices, “financial resources” and “computer hardware” are allocated to the organizational view.

- **Data view:** Data views comprise the data processing environment as well as the messages triggering functions or being triggered by functions. Preliminary details on the function of information systems as data media can also be allocated to the data names. Information services objects are also implicitly captured in data views. However, they are primarily defined in the output view.
- **Output views:** output views contain all physical and non-physical input and output, including fund flows.
- **Control views/Process views:** The views where the respective classes with their view-internal relationships are modeled. Relationships among the views as well as the entire business process are documented in the control or process views, creating a framework for the systematic inspection of all bilateral relationships of the views and the complete process description.

The Control View

The relationships between the views as expressed by the arrows in the process model are restored by introducing a control view. The control view is an essential ARIS component that distinguishes it from other architectures such as computer Integrated Manufacturing-Open System Architecture (CIM-OSA), Semantic Object Model (SOM), or Object-Oriented Information Engineering (OOIE) (Keller, 1998). This view is typically represented by using eEPCs (Extended Event-driven Process Chains)-see e.g. Wienberg 2001.

It links functions, organization and data. It unites the design results, which were initially developed separately for reasons of simplification. The functions, events, and the process resources are connected into a common context by the process flow. Thus the eEPC serves as a description method in the control view to show the flow of the process.

eEPC Notation

The strength of eEPC lies on its easy-to-understand notation that is capable of portraying business information system while at the same time incorporating other important features such as functions, data, organizational structure and information resources.

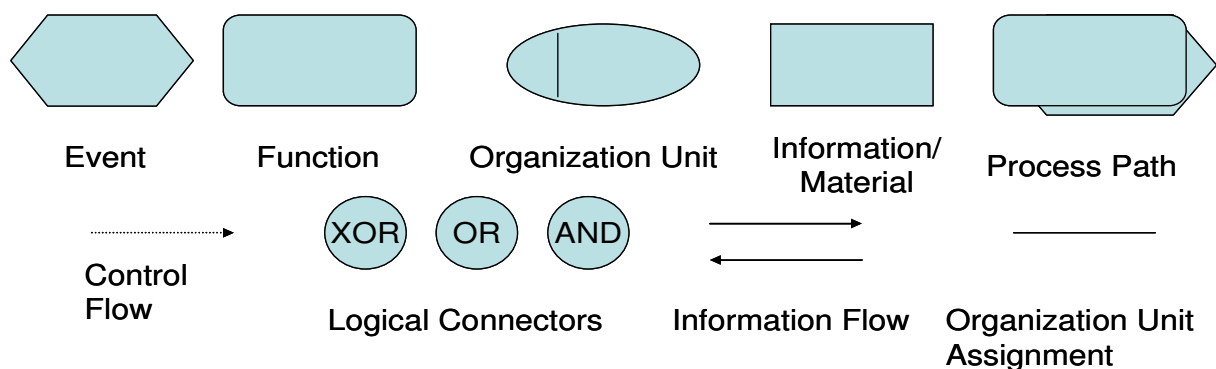


Figure 3.5 Elements used in eEPC Diagram

- **Event:** Events are passive elements in eEPC. They define the state of function and describe under what circumstances a function works/completed. In the eEPC Graph an event is represented as hexagon.
- **Function:** Functions are active elements in eEPC. They describe the tasks or activities within the organization. Functions define transformations from the beginning to an ending state. Different ending states can be provided. The selection of the respective ending state can be described explicitly as a decision function using logical connectors. Functions refined to another eEPC. In this case it is called hierarchical functions. In the EPC Graph a function is represented as rounded rectangle.
- **Organization Unit:** Organization units describe the person or organization within the structure of a company which is responsible for a specific function. It is represented as an ellipse with a vertical line.
- **Information, material, or resource object:** The information, material, or resource objects represent the objects in the real world, for example documents, services etc. which can be the input data providing the basis for a function, or output data produced by a function. In the eEPC graph such an object is represented as rectangle.
- **Process Path:** Process paths act as a navigation aid in the eEPC. These represent the connection from or to other processes. A process path is represented in eEPC as a 'function and event' symbol
- **Control Flow:** A control flow is issued to connect events with functions, process paths, or logical connectors creating a chronological sequence and logical interdependencies among them. A control flow is represented as a dashed arrow.
- **Logical Connector:** In the eEPC, the logical relationships among elements in the control flow, which are events and functions are described by logical connectors. By utilizing the logical connectors it is possible to split the control flow from one flow to two or more flows and to synchronize the control flow from two or more flows to one flow. There are three kinds of logical relationships represented in eEPC as: (1) Branch/Merge, (2) Fork/Join and (3) 'OR'.

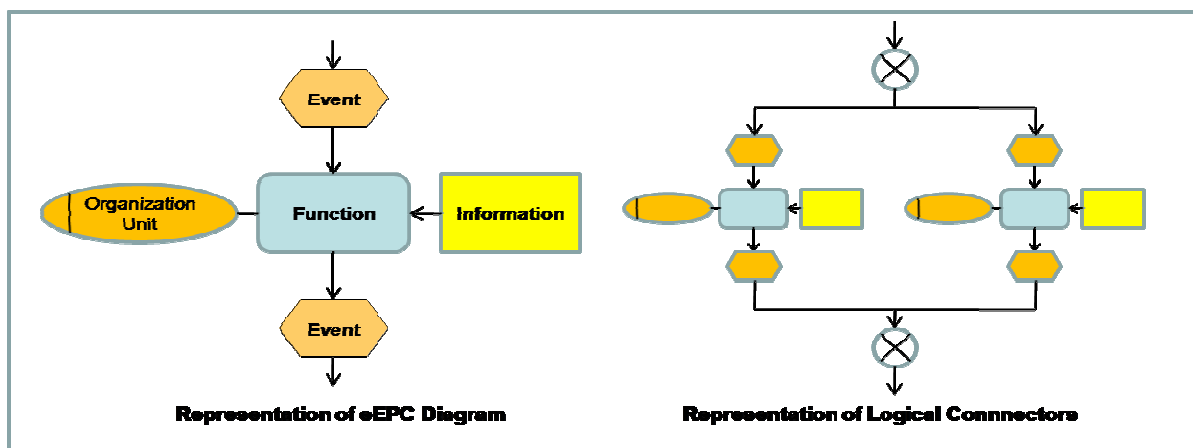


Figure 3.6 Representations of eEPC Diagram and Logical Connectors

3.3.4 Conclusions on Design Methodologies and Process Models

The design evolves from observing, modeling, and thinking about the problem, it is a mental process, a kind of thinking. To identify the system, data and their interrelations within each other several types of approach have been developed. The common aim of these given methods is to facilitate the use of variable aspects and to support perceiving of interconnection between sequential processes and activities.

In this research, IDEFØ and ARIS methodology is used as a baseline. The main reason for utilizing IDEFØ is to represent functions which occurs within phase information integrations, however due to limitations to define complex process interactions ARIS-ceEPC suggested (see Section 5.7). In this context to provide process and product integration each eEPC element is tagged with a notation (see Chapter 6). The new structure is named as “complementary eEPC” (ceEPC). This enables holistic consideration of processes, events, resources and organizational structures and helps greatly to design an interoperable software solution and to configure Organizational and IT Management processes.

3.4 Conclusions

In this chapter the standardization initiatives within process and product models are analyzed in detail and the process methodologies are examined..

Although the increasing interoperability efforts between IT tools have been achieved with using of standards such as STEP or IFC, the successful applications within the practical area have not been reached to expected level.

The standardization efforts can only be succeeded identifying of many dependent and independent factors with variable degrees of impact on that process. The market conditions and vendor strategies, the technology approach, the structure of the business, method statements etc. and many more can be counted to support of forming a standard in terms of a core structure.

As it is mentioned above, it is too complicated to gather these factors and to establish a form that comprises each application and each structure of the existing construction environment. However, the complexity can be managed by examining of different views in this context.

In this sense the general requirements have to be considered in terms of application functions, the inputs and outputs precisely.

Based on the literature studies, projects and the best practices, the main frame should be constructed on a standardized lifecycle model. In chapter two, a construction general lifecycle model has been issued and the requirements have been examined. A standardized general lifecycle model for construction management can only be identified with using of standard products and process definitions. Thus, the management frame has to be drawn very attentively that it should balance both the complexity of the structure and the serviceability for the practical applications. Additionally, it should be reliable for the existing software that are used commonly in the sector.

Regarding to these issues:

- 1) The general construction model for software interoperability can be identified using of IDEF0 method in general.
- 2) The general model can be divided into application phases such as feasibility or preliminary phases and can also be identified in IDEF0.
- 3) To support concurrency within different software applications each phase can be identified in a detailed way using the ARIS methodology and the inputs and outputs as resources can also be mapped with IFC models.

In the next chapter the integrated CPM approach and the functional requirements for process modeling and information exchange will be examined to find out a way to support the interoperability.

The general hypothesis in terms of 'IFC based integrated construction management' can be formed, regarding to defining of basic attributes and the common aspects of given structures of differentiated topics.

CHAPTER 4: PROPOSED INTEGRATED CPM APPROACH

In this chapter, an integrated Construction Project Management (CPM) approach is presented. The Construction General Life-cycle Model Phases (CGLCMP) which are represented in Chapter 2, and the phase and process definition principles introduced in this chapter are used as a baseline to define basic principles for phase formalization structures. The suggested approach is named 'Construction Management Phases for Software Interoperability' (CMPSI) and is dedicated to the Construction Company view. CMPSI represents software integration with regard to design, resource planning and scheduling in the Construction General Life Cycle Model Phases. The main aim is to realize the basic data from software integration point of view which can be used later on for the implementation of IFC Views. The phase representations are provided in IDEFØ. This representation facilitates to reveal CPM resources which are one of the two inputs to construct Organizational and IT Management Processes developed in Chapter 5. Moreover to monitor ongoing activities ISO9001:2000 Quality Management (QM) System is examined for CPM purposes and four main procedures namely (1) General System, (2) Human Resources and Administrative, (3) Customer Relations and (4) Project Management procedures are formalized to provide sub-procedures and interrelated sub-processes. This provides the second input of the two inputs.

4.1 Introduction

The development of an integrated CPM model is a complex process which requires a holistic consideration of many cross-domain aspects. Generically, these can be identified as: (1) sector requirements, (2) end-user needs of specific disciplines, (3) technical requirements to models, (4) operability requirements such as data management, (5) available technology, (6) hardware and software resources and (7) relevant data processing standards. Moreover there is a possibility of different solutions which emphasize more or less suggestions.

The requirements of an interoperable model in our approach are refined based on the efforts which are undertaken in the ToCEE, ISTforCE and iCSS projects. Although they reflect differences within applications, the visions are generally the same, e.g. (Katrashnikov 2000):

- 1 To provide a flexible framework capable to support a wide range of engineering applications.
- 2 To enable the use of not fully harmonized data models, taking into account the heterogeneous, fragmented and multidisciplinary nature of AEC.
- 3 To enable independent work on local model views as appropriate for the different discipline-specific tasks involved in the building design process.

From this standpoint, to provide a solution to a number of interoperability problems and to develop a comprehensive approach which comprises building products and CPM processes, cross-domain aspects as:

- 1 The IFCs (Industry Foundation Classes) of the IAI initiative for a hierarchically structured product model,

- 2 ISO Quality Management (QM) System for the specification of the existing real-world process and managing the quality requirements of the outcome,
- 3 An integration methodology, encompassing the product and process information exchange within the CAD, ERP and Scheduling systems that support IFCs,

are examined in this research.

On that basis, the research formation in this chapter is structured as in the following:

- 1 Develop Phase and Process Definition Principles.
- 2 Develop CPM Phases from the Software Integration point of view, named CMPSI.
- 3 Develop QM System Procedures for CPM Purposes.

4.2 Phase and Process Definition Principles

In order to formalize an integration methodology, encompassing the product and process information exchange, the below described six principles have been developed. This approach also provides the basis for CMPSI. In each principle, the main acquiescence is provided to support model structure to facilitate understanding and to guide modeling steps.

The envisaged Phase and Process Formalization Structure are constituted based on the Key Principles of the Process Protocol (Kagioglou et al. 2000) which is an outcome of a research that was carried out at University of Salford UK.

General Project View

Most generally, any attempt to either develop a general phase definition will have to cover the whole 'life' of a project from considering of the initial needs, to the operation of the finished facility. This approach ensures to support different aspects in terms of technical and business point of views and obtains suitable solutions regarding to client's requests by defining interdependency of activities throughout the duration of the CPM processes.

From this standpoint, the construction management phases are formalized to obtain software interoperability in this approach. In order to support integration from technical point of view, operational phases such as design, bidding preparations etc. are examined in a detailed way. Through consideration of all issues regarding to the examined phases and the different views such as QM, Procurement Systems, Services etc. Organizational Management core process and from this, IT Management sub-processes are structured based on ARIS methodology.

Process Consistency

Due to fragmentation of construction applications, the little consistency can be recognized by defining of construction processes. Luck & Newcombe (1996) encountered the problem and described the 'role ambiguity' commonly associated with construction projects. The generic process protocol provides the potential to establish its consistent application. In terms of reducing the ambiguity and to facilitate a process of continual improvement in CPM processes, a standard approach is required.

In order to obtain process consistency from organizational point of view, QM System procedures are formalized. In accordance with these, the related organizational management processes are established regarding to prescribe procedure definitions. The related processes are then put together in a Life-Cycle Model for Processes, including different views to provide a core management process structure. From this standpoint, the IT management processes which address software integration are developed.

Phase and Process Reviews

Conventionally, 'stage gate' approach which is used for manufacturing by Cooper (1994) and the 'phase gates' of the Generic Process Protocol which are specific to CPM phases are envisaged approaches to support phase and process reviews. Consequently, phase reviews are conducted at the end of each phase, and used for planning the next phase of the CPM. Phase gates are classed as either soft or hard. In this sense 'soft gates' allow the potential for concurrency in the process, whilst ensuring that the key decision points in the process are respected. The potential benefit of this approach is fundamentally the progressive fixing and/or approval of information throughout the process (Kagioglu et al. 2000).

In this context, consistent planning and review procedure throughout the phase and processes are formalized under Life-Cycle Model for Processes. This model is composed of 5 phases which also includes 'Process Control/Check' and 'Process Evaluation Phases'. The mapping between Phases and Processes is also provided to support reliable changes when it is necessary. The envisaged structure depends on progressive fixing and approval of the information by auditing the process formalizations. This not only ensures consistency of the existing processes and also supports improvement of the organizational management.

Co-ordination

As it is mentioned by many reviews of the industry such as Banwell (1964), Latham (1994), Egan (1998), Scherer (2007) synchronized co-ordination is perceived as one of the biggest problem in the AEC sector.

In order to find a solution for the co-ordination problem, a software interoperable model, based on IFC and a process formalization structure depended with QM System procedures are formalized. The required co-ordination within the phases and processes are done by the responsible actors according to QM system processes. Furthermore, the use of software is defined by sub-processes based on organizational management process structure.

Participation

In order to develop a construction project, group of participants, in terms of construction management team are assembled conventionally. In general it is difficult to assemble the same participants on more than one project as Sommerville & Stocks (1996) argued. This causes performance and contribution problems. A concurrent approach is required to overcome this problem. The structured definition of phases through the adoption of process roles should ensure that appropriate actors are informed earlier in the process chain. The concurrent involvement of all project partners, especially in the early phases of a

construction project may simultaneously help to foster a team structure and support timely interaction.

It is generally accepted that the pre-structured process definitions support to formalize organizational management charts. This facilitates to attain the responsible to a process before it starts functioning. From this standpoint in this work, to inform project participants, a process sequence, which comprise management roles are developed. This facilitates to follow which participant take in place, in which state of the project progress.

Feedback

The progress can be obtained by assessment of both success and failure, however the fragmented nature of the construction industry prevents the benefits of shared best practice being utilized (Kagiloglu et al. 2000). In order to show a progress by application of new approaches in which learned from the ex-project faults and profits, there should be a mechanism realized. Therefore at the end of each project there should be a feedback mechanism, proposes the use of the existing legacy archive which acts as a central repository or information spine (Sheath et al. 1996).

The proposed software integration structure comprises feedback phase. The mechanism within developed resource planning domain acts as a central management of information and also work as a central information repository. All the related data such as BOQ information, material analyses etc. are stored within this structure. Regarding the project progress on job site, the information should be changed according to present situation. The differences between the planned and existing conditions are used as the main input in this context.

4.3 The Construction Management Phases for Software Interoperability

In this research to provide a systematic approach to the integrated design of products and their related processes, and to take into consideration of the economic and technical aspects that can affect these during their lifecycle from software integration point of view, the Construction Management Phases for Software Interoperability (CMPSI) are suggested, which are deduced from Construction General Life-cycle Model Phases (CGLCMP).

These are:

1. Design,
2. Bidding Preparation,
3. Planning & Construction,
4. Project Payments,
5. Evaluation of the Outcome and Feedback.

In Chapter 2 the CGLCMP (see Figure 2.6) are represented in six sequenced Construction Management Phases and defined from a general perspective. In our case, the Construction Management Phases are represented from a constructor point of view. Therefore not all defined 6 phases are over taken for the CMPSI phase definition,

<i>Construction General Life-cycle Model Phases</i>		<i>CMPSI Phase Definitions</i>
Feasibility Phase	→	Out of Scope
Design Phase	→	Design Phase
Bidding Preparations Phase	→	Bidding Preparations Phase
Construction Phase	→	Planning and Construction Phase
	→	Project Payment Phase
Contract Close-out Phase	→	Evaluation and Feedback Phase
Operation & Management	→	Out of Scope

In the construction company monitoring the project progress and the monetary situation has a major importance to see the detriment. This provides examining the existing situation. Thereby the necessary reactions can be taken to overcome the existing problems during project progress. Moreover to make links to accountancy is widely required. Therefore the new phase as 'Project Payment Phase' (see Section 4.3.4), has created from CGLCMP. The basic model is shown in **Figure 4.1**. The detailed definitions based on IDEFØ can be found in the following paragraphs.

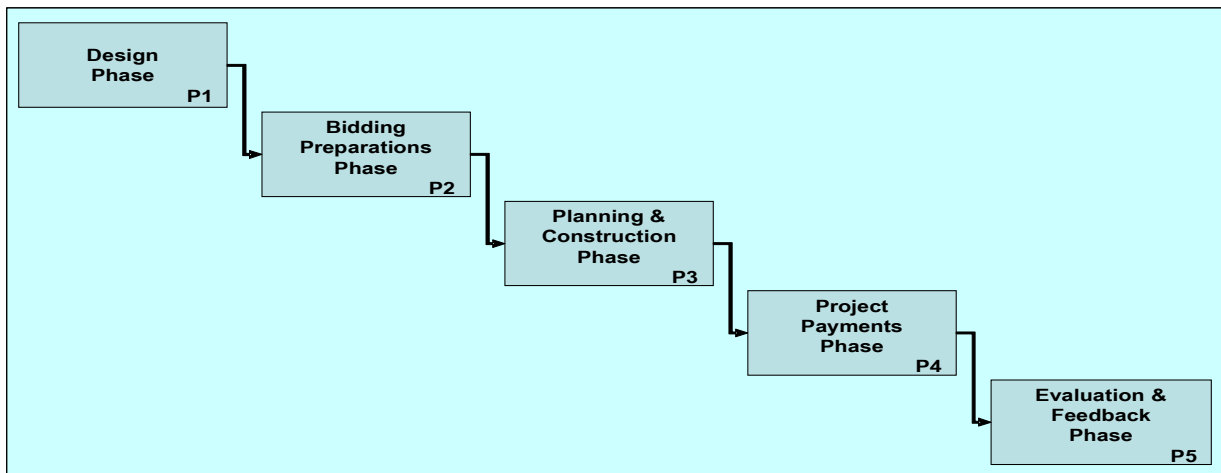


Figure 4.1 Construction Management Phases for Software Interoperability

Moreover the general statements are provided as in the following:

- These phase definitions may vary for different countries, but the basic principles are the same. In all stages specific databases and algorithms are used. All these databases must keep the information about their function and content in suitable structures and algorithms so that they can be further re-used by the other stages whenever required.
- According to the given model the functions based on software interoperability should be supported in the proposed integrated CPM model. These are also to be covered by the whole life cycle model of a building. In this broad scope, various types of information entities have to be considered in their interrelationship: (1) the information about the constructed facilities, construction products, processes,

documents and regulations (2) the information about the model itself including the information representation (databases), the information processes and the components of the environment such as servers, and clients, and (3) the information about the information, including concepts like ownership, access control and versioning.

4.3.1 Design Phase Definition

Design Phase is the initial phase which comprises the general analysis and design activities of the project. Conventionally, regarding to CGLCMP, Design Phase is composed of pre-design, site analysis and schematic design, etc., as given in Chapter 2.

Although these functions are generally identified as given above, a system that comprise the general management skills, existing CAD applications, information exchange and relevancy to IFC product model, requires a new model according to best practices. To see all attributes regarding to this approach, the system is appropriately structured in IDEFØ as given in **Figure 4.2**. Moreover five functions are explained in the following paragraphs.

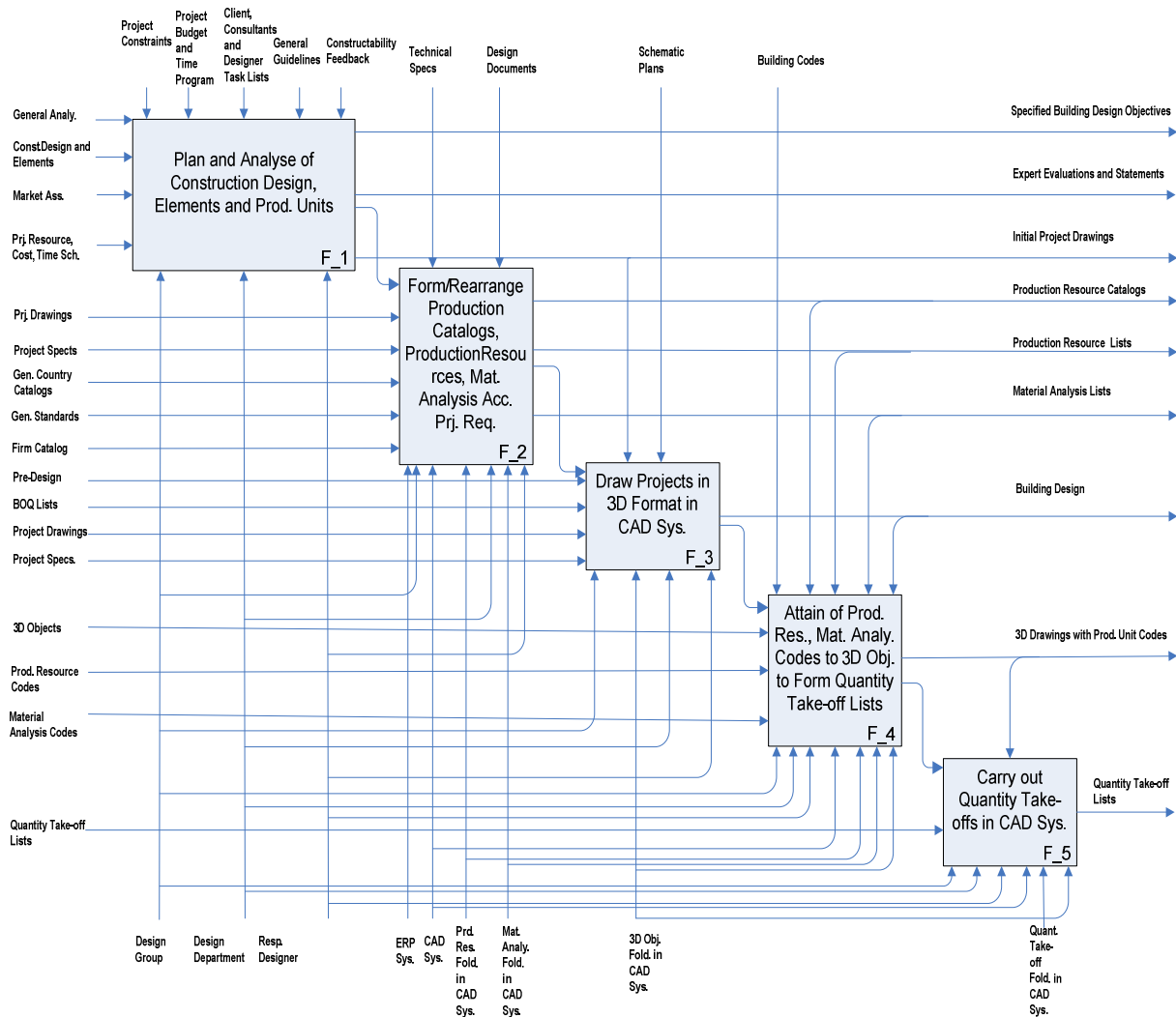


Figure 4.2 Design Phase, CMPSI – P1

F_1: Plan and Analyse Construction Design, Elements and Materials

This function considers some of the feasibility activities such as identifying the project requirements, construction constraints, market assessments, etc. Construction design can be done according to project constraints, project budget, and general guidelines. They can also provide to control the activity. Moreover several organizational entities and actors are taken a part such as design group, design departments and designer to fulfil the requirements.

F_2: Form / Rearrange Production Catalogs, Production Resources and Material Analysis According to Project Requirements

This function is the milestone of the proposed management structure. For managing all the activities, a product catalogue composed of production resources with their ID's and prices has to be identified. These catalogs can be national, international or firm's private catalogs. The information exchange based on production resources can be managed with these IDs.

F_3: Draw Projects in 3D Format in CAD System

The drawing structure is composed of architectural, structural, HVAC drawings and the installation schemes which provide the database of the initial processes of the project. These schemes and drawings are the inputs for the technical applications defining the construction details, the quantity take-offs and the section lists. Quantity take-offs and section lists can be achieved with the help of 3D drawings. In this context 3D drawings can be used as the initial information of the other phases.

F_4: Attain Production Resource and Material Analysis Codes to 3D Objects to form Quantity Take-off Lists

The production resource codes in terms of IDs can be taken from national/international product catalogues/libraries according to identified production resources. These production resource codes can be attained to 3D drawings in order to reach Quantity take-offs. These also can be used in each phase of the envisaged model, to formalize production resource prices, material analysis, BOQ lists, scheduling activities, cost analysis and procurement etc.

F_5: Carry out Quantity Take-offs in CAD System

3D drawings allow visualizing a project three dimensionally. These drawings generally support production resources codes and the quantity take-offs formalization in a desired format which can be used in other stages of the CPM process. In the envisaged model, this is done by using of design domain in terms of CAD systems which have ability to form 3D drawings which can report the quantity take-offs in suitable forms.

4.3.2 Bidding Preparation Phase Definition

According to implied structure in CGLCMP, the Bidding Preparation Phase is generally composed of controlling of design documents, checking of quantity take-offs, formalizations of pre-work program, estimations of direct cost etc.

In our case, the Bidding Preparation Phase is represented in six functions namely form pre-work schedule, form market material analysis, form preliminary budget, form cash flows and work order lists, form general expenses, form construction BOQ as shown in **Figure 4.3**.

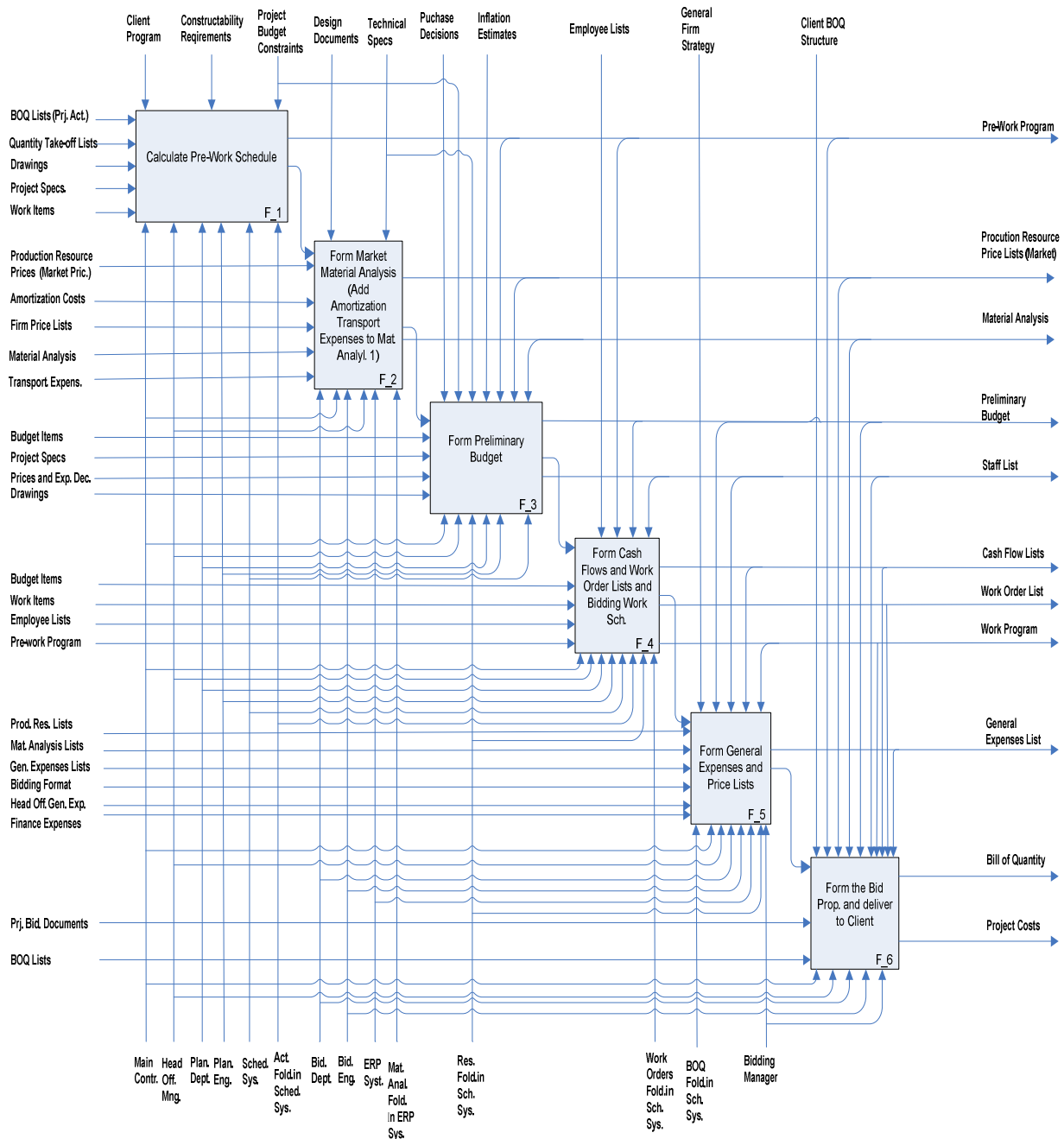


Figure 4.3 Bidding Preparation Phase, CMPSI – P2

In the Bidding Preparation Phase, after the quantity surveying is finished, cost estimations can be established. These estimations, typically prepared on the basis of the construction diagrams and the technical specifications. In this context a proposal should be prepared based on the cost estimation and conforming 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, the budget and cash flow tables have to be considered regarding to a pre-work schedule. This requires inter-connected work in the company. One group performs the quantity surveying and creates the quantity take-off database, another one does the market research and creates

the production unit price database, a third one makes the construction cost analysis with respect to the company standards, and a fourth one prepares the work schedule and creates the budget and cash flow tables. These databases have to be inter-related. Each data produced in one group is needed by another group, i.e. highly cooperative work is required. Hence, an approach of integrated construction management tools is required which can support reliable bi-directional information exchange between the design and scheduling domains.

F_1: Calculate Pre-work Schedule

Pre-work Schedule is formalized with using relevant scheduling systems by considering project activities, client requests and project situation. The activities can be structured according to sections which are formed in the design phase.

F_2: Form Market Material Analyses (Add Amortization, Transport Expenses to Material Analyses)

According to used product catalogues in the design phase, the production resource price lists, and material analysis can be formed based on the market prices. This item provides to change existing catalog prices with the market prices to form update costs of the procurement items.

F_3: Form Preliminary Budget

Preliminary budget can be settled according to: material analysis, human resources, procurement decisions, prices, and the project pre-work schedule. It facilitates to forecast project budget situation and to form project cash flows.

F_4: Form Cash Flows, Work Order Lists and Bidding Work Schedule

In this function, cash flows are formalized based on the budget items. Additionally the work order lists are constituted based on the work items and employee lists. The cash flows and employee numbers facilitate to reach pre-defined project expenses. Furthermore Bidding Work Schedule can be formalized in this context.

F_5: Form General Expenses and Price Lists

According to firm general strategy indirect costs, general expenses, mobilization and finance expenditures and price lists are planned and formed in this function. These are used as the main input of the general expenses for BOQ preparations.

F_6: Form the Bid Proposal and Deliver to Client

The Bid Proposal is formed according to combination of the given items as: Project Bid Documents, BOQ Lists and Structure, Production Resource Price Lists, Material Analysis, Preliminary Budget, Staff List, Cash Flow List, Work Order List, Work Program and General Expenses List.

4.3.3 Planning & Construction Phase Definition

Conventionally, the Construction Phase is composed of functions such as construction documents check, defining of construction units, establishing of activity sequences, initial construction schedule, establishing of procurement plans etc.

In this context, the planning and construction processes are combined and Planning & Construction Phase is constituted in order to support integration between planning and construction activities to facilitate flexible management structure. It is composed of sequential processes such as: schedule work program, carry out budget and cash flows, carry out material requirement lists, carry out material buying and payment plans etc. as shown in **Figure 4.4**.

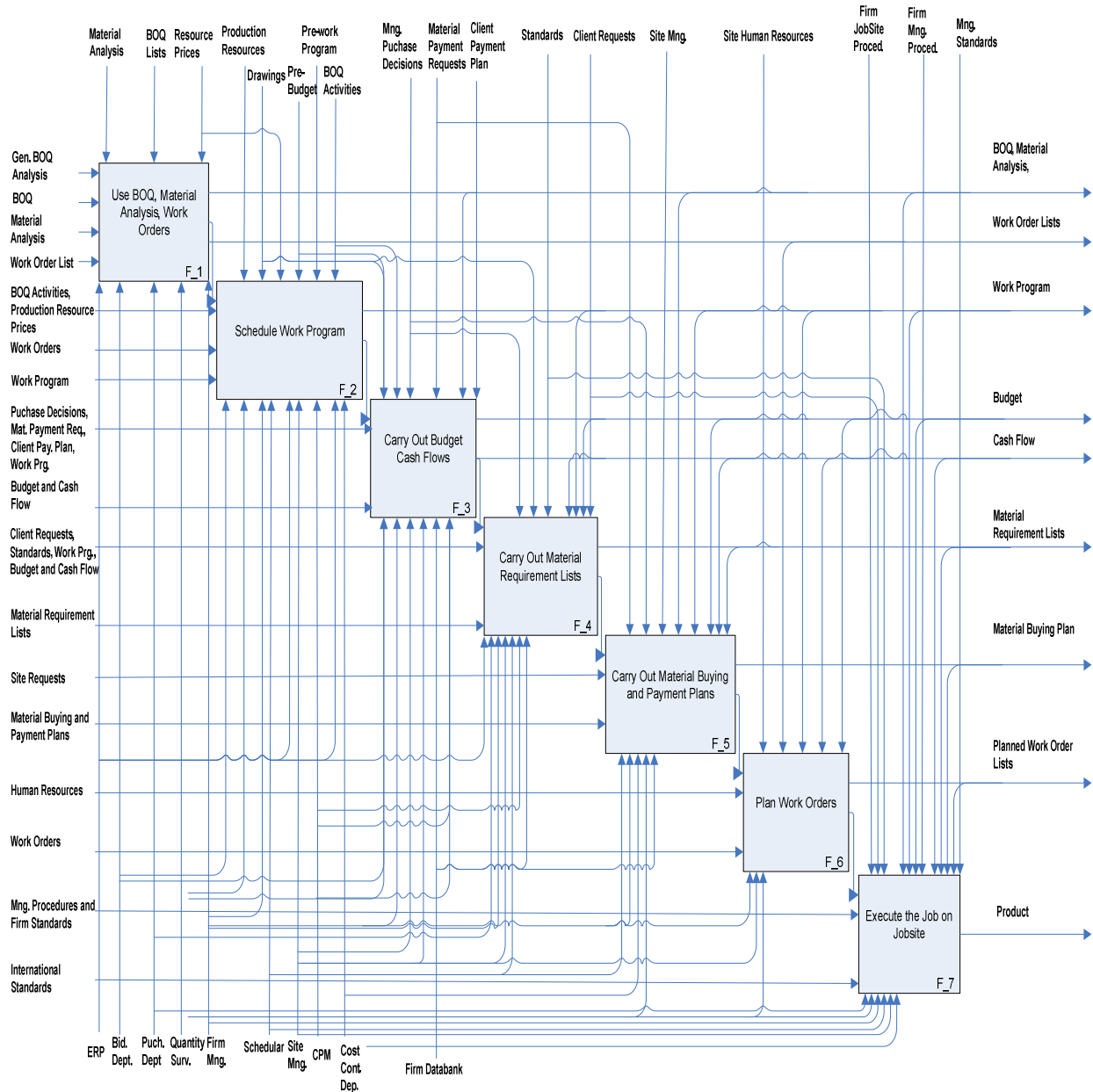


Figure 4.4 Planning & Construction Phase Definition, CMPSI – P3

In the Planning & Construction Phase the planning of the activities or designation of the work order (pursuing of work order), identification and assignment of the appropriate labour and material resources, determination of the pre-budget and determination of the real-budget for the progress payment is done. For managing of the application processes on jobsite the quality management, technical inspection, and HSE management procedures should also be followed.

F_1: Use BOQ, Material Analysis, Work Orders

Scheduling Programs (Primavera, Suretrak etc.) can be used to schedule and to allocate the resources. To achieve that, activities should be defined with (1) the quantities of their resources and, (2) monetary values of these resources. These items can be received from the bidding preparation phase as BOQ and material analyses information. These are the main inputs to formalize the budget and cash flows of the construction project. Also the work orders are used to define the labour which can be connected with the project schedule.

F_2: Schedule Work Program

The project schedule activities can be formalized according to BOQ lists and can be detailed according to materials which can be used within the project progress. The activity periods should be calculated according to material, labour and site conditions. The pre-work schedule can be used as a baseline for the detailed work schedule.

F_3: Carry Out Budget Cash Flows

Pre-budget can be formed according to income and expenses which are already determined in the proposal. The income is related to the production and the sales price of the production on the construction process. The distribution of the production over time is determined in the work schedule. The material requirement which is also determined in the work schedule is the budget expense and can be retrieved and reported periodically. To calculate the real budget, the resource costs of the activities, the estimation of the inflation, and the sales prices of the productions are required in this context.

F_4: Carry Out Material Requirement Lists

It is important to have a decision about material purchasing. It should be known which material is going to be used when and in what amount. The material requirement lists with the amount and work program, received from scheduling programs which support to take material purchase decisions, so that a payment plan can be easily created. Also the client's requests and standards have to be taken into consideration before purchasing.

F_5: Carry Out Material Buying and Payment Plans

As it is defined, material buying plan is connected with the material requirement lists. The materials can be procured according to time schedule. The site management can do their program according to time schedule and can procure the related materials. The payment plans can be formed according to project schedule related with the material buying plans.

F_6: Plan Work Orders

In construction practice, most projects are easily managed according to scheduling programs by continuously consulting the work orders. Such work orders can be reported automatically every morning. They provide the lists of tasks to be performed during the day or week by any unit or technical personnel, and they can be reported and received easily.

F_7: Execute the Job on Jobsite

The items that are examined under project, cost and period have the dimensions of quantity, money and time and can be formed using of data evaluation programs based on arithmetical algorithms. The job on jobsite can be executed by using of reliable systems in this context.

Concepts of quality and HSE should be considered as the project aspects that are expected and determined by the agreements and standards. There are no formal arithmetical algorithms for their determination, but they are conforming to heuristic rules and methods. For better managing the construction processes the structure can be formed according to these written rules. In this context these rules in this research are examined based on the ISO9001 Quality Management System Procedures and will be discussed in the following sections.

4.3.4 Project Payments Phase Definition

In most approaches, construction phase is defined according to jobsite processes. But in terms of increasing of competitions in all fields and the decreasing of profit margins requires detailed budget pursuing. In this regard, the project payments phase is formed under three basic functions namely carry out realized payment, carry out realized budget, carry out progress payment to see the detailed money transactions between the project partners in terms of client, main contractors, material suppliers, subcontractors etc. as given in **Figure 4.5**.

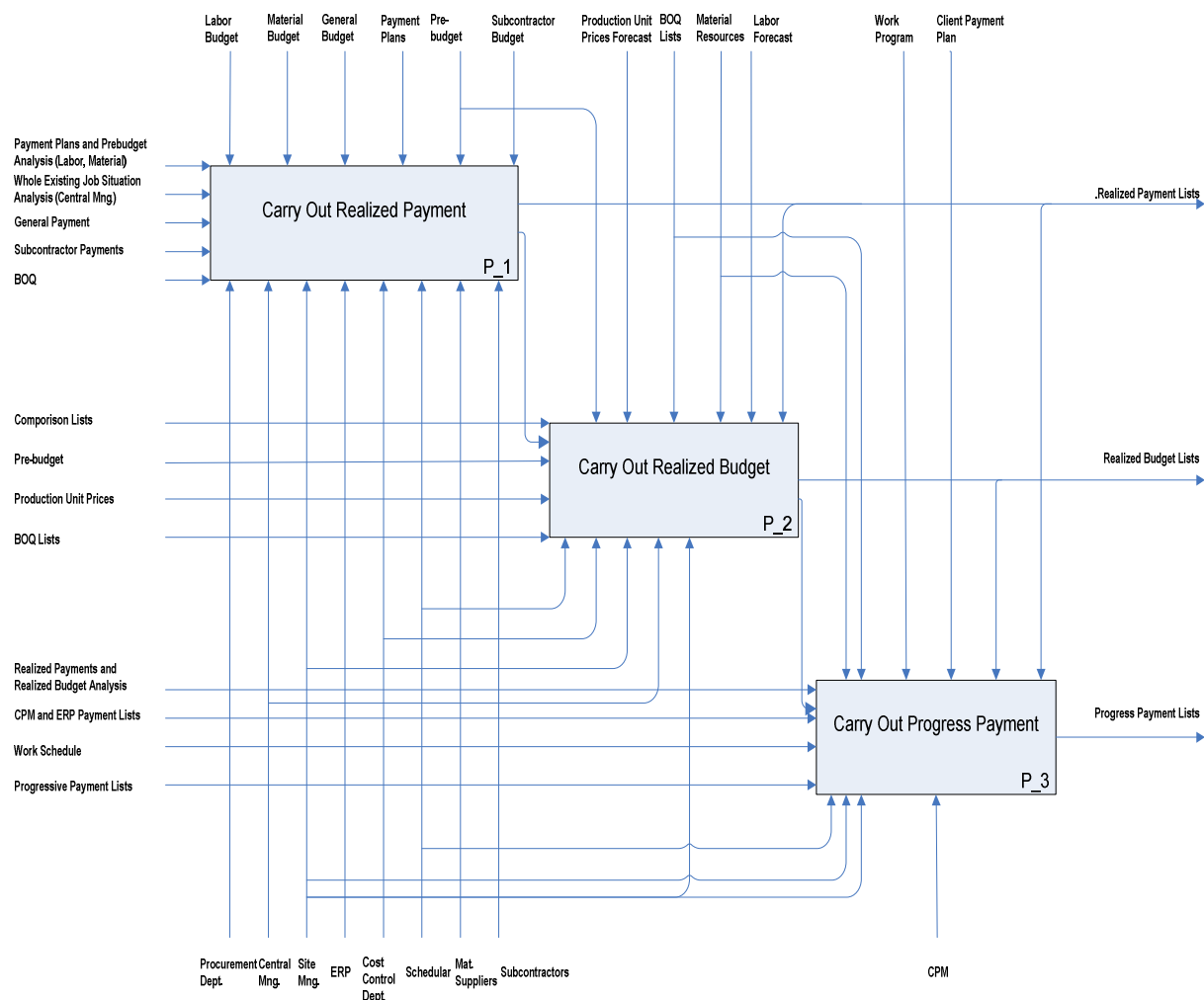


Figure 4.5 Project Payments Phase, CMPSI – P4

F_1: Carry out Realized Payment

The creation of realized payments depends not only on the estimated budgets and the demands of the construction site but also the demands of the headquarters management. From headquarters point of view all projects are considered as a whole, and the payment plan is organized depending on the degree of importance.

The realized payment can be structured according to payment plans and pre-budget, whole existing job situations, general payment and BOQ lists in this regard. The pre-planned budget items are also used as the main control aspects of the system.

F_2: Carry out Realized Budget

The real budget is formed according to headquarter management decisions and site requirements. It can be structured according to pre-budget, production unit prices, BOQ lists, which are determined in the bidding preparation phase.

However, it is hardly possible to compare the planned budget, the required budget and the real budget and to inform the management about these. This lack of comparison causes a management problem. Therefore, ad-hoc co-operation forms should be set up so that all participants in the project can reach their own project data and can easily share this with the other units.

F_3: Carry out Progress Payments

Progress payments can be identified as partial payments regarding to accomplished work phases. The realized payments, realized budget analysis, payment lists and work schedule are the incomes of progress payments.

The work schedule can also be used as the source database of the progress payment reports. Using of reliable scheduling program supports to realize of production amounts, i.e. the portion of the construction completed within a certain period. The progressive payments can be formed according the prices in the analysis or unit price database which are formed in the bidding preparation phase.

4.3.5 Evaluation & Feedback Phase Definition

It is important to evaluate the project situation in order to see the problems and their effects. A project evaluation structure can facilitate the further actions not to face problems in terms of money and time lacks.

In our approach it is separated into six main functions to follow up the existing situation of the project namely as carry out invoices, carry out stock control, carry out material costs, carry out payroll etc.

According to outcomes of these functions, evaluation in terms of profit and detriment situation can be seen and the required actions can be taken before project completion.

These functions are represented in **Figure 4.6** in detail, as in the following.

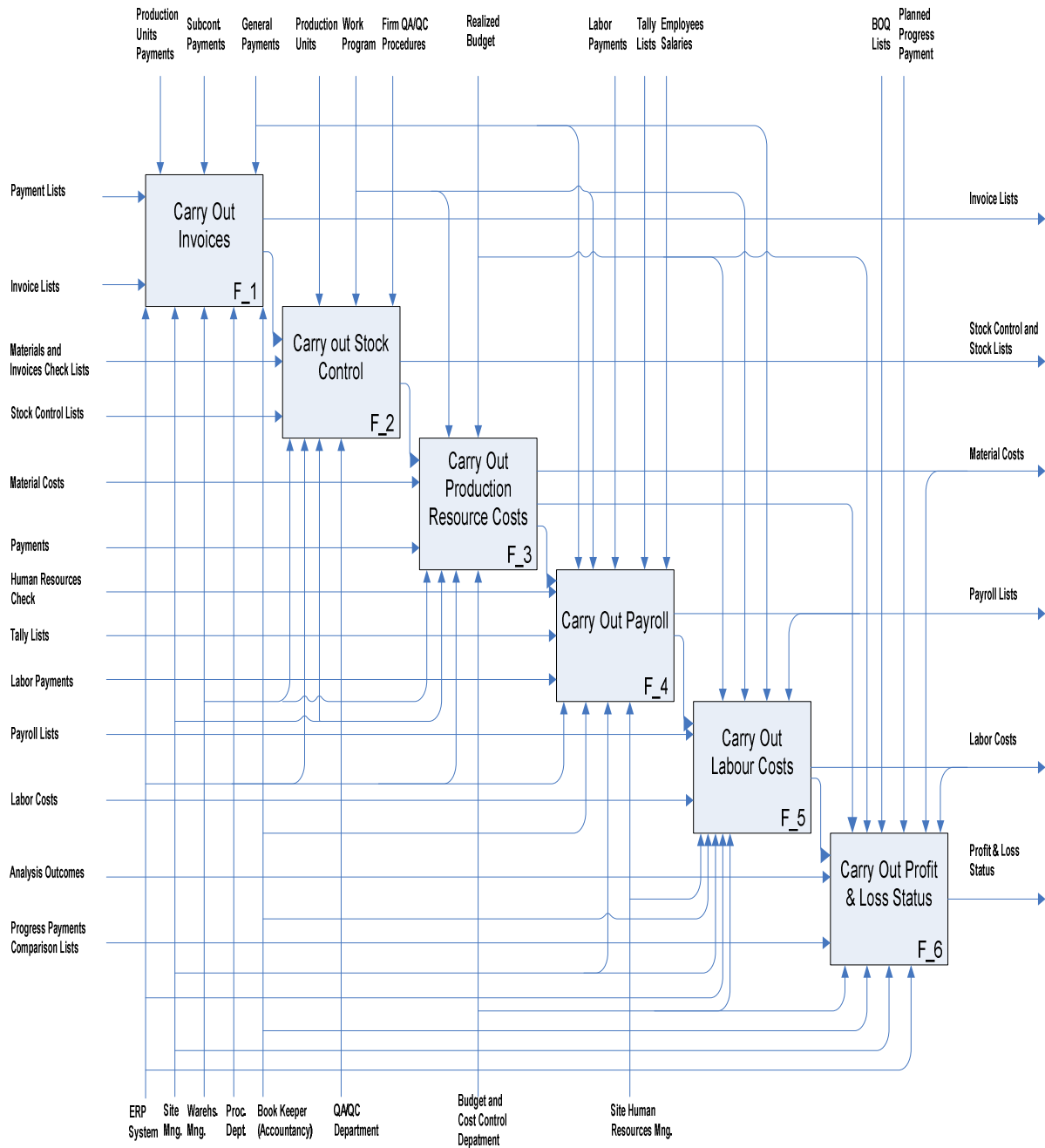


Figure 4.6 Evaluation & Feedback Phase, CMPSI – P5

F_1: Carry out Invoices

The invoices reflect the actual situation of the project progress. It is important to realize the invoice lists for each construction item. It is used to control the project costs in terms of monitoring the material on jobsite and related labour. The basic components to formalize invoices are the payment lists, according to completed project activities.

F_2: Carry out Stock Control

Following the real stock movements enable to determine the production units' costs in those analyses better, and support to follow purchases and material amounts more precisely.

The main inputs are invoices. This facilitates to make comparisons between present project situation and planned one.

F_3: Carry out Production Resources' Costs

The cost of each construction item is defined in the agreement. The invoice lists are facilitating to follow-up the existing use of production units on jobsite. The determination of the real costs of the resources reveals the real values of the production analysis as estimated in the proposal. This can be used as a comparison criterion to see the project situation at the end of the project.

F_4: Carry out Payroll

One of the problems of the existing construction sector is identifying the real labour force on jobsite. These information are the basic components of the material analysis in terms of identifying the real cost of the construction activities. If tallying can be followed-up in an appropriate form, i.e. which worker worked for what construction item on which day, these information can be used for the bidding preparation phase to construct the BOQ for the future projects.

F_5: Carry out Labour Costs

Employee payments are taking an important part of the project overall costs. According to payroll and tally lists, labour costs can be calculated. They are used as baseline for material analysis, comparison of the existing situation and for the new proposals.

F_6: Carry out Profit & Loss Status

According to outcomes of the given actions above as: invoice lists, stock lists, material and labour costs, payroll lists, construction conditions can be matched between the proposal and the existing close-up. This comparison clearly shows the profit or loss during the construction.

Feedback

The information which is gained from the project should be entered in a database system for the future proposals. In each project, recording the new findings ensures a strong basis, for future proposals and decisions of the company. It enables the users to conveniently access various types of information such as material analyses, production unit/resource prices, technical specifications, method statements, scheduling aspects, budget, stock, payroll, profit and loss records.

The Construction Management Phases for Software Interoperability is a framework model which is capable of representing diverse target of different software involved in an interoperable process. Therefore a mechanism, by which the systematic and consistent interfacing of the envisaged software systems supported, can be facilitated.

The generalisation within the structure allows flexible application. This is achieved at a variety of strategic levels across a variety of scales projects using combinations of software in an interoperable structure. The main aim underlying of this approach is to find a standardized structure for managing processes and building products.

4.4 The ISO9001:2000 Quality Management System CPM Procedures and Processes

To detail the functions defined by IDEFØ, further information is needed which may come from procedural models (see Sections 2.4, 2.5). Thereby the concurrent control system in terms of monitoring ongoing activities can be provided.

This should include assessment of current work activities which relies on performance standards, rules and regulations for guiding employee tasks and behaviors.

From this standpoint, to support required aspects and to obtain a generic procedure model, ISO9001:2000 Quality Management (QM) System is examined in detail for CPM purposes.

Although it has been observed that the implementation of QM System requires flexible rules, the practical and general applications for different needs require a procedural structure.

In this context, to support a conceptual framework, the envisaged integrated CPM model is constituted based on the inter-related management procedures, referencing QM system requirements.

The following four main procedures from QM System is suggested:

- General system procedures,
- Human Resources and Administrative Procedures,
- Customer Relation Procedures, and
- Project Management Procedures

The main goal in creating these is to identify organizational structures, management functions, events, interactions and interrelations within and between processes. This facilitates to synchronize management tasks and support a concurrent CPM. Moreover, these procedures provide to identify sub-procedures and inter-related sub-processes subsequently.

4.4.1 General System Procedures

General System Procedures (GSP) are detailed according to construction company needs and following the QM System regulations. Thereby the general management skills and the basic management processes are realized.

GSP composed of seven sub-procedures from which the related processes are derived. These maintain company applications to renovate and to go forward. These are created as follows:

Company Performance Monitoring and Improvement

‘Company Performance Monitoring and Improvement’ is related with the establishment of the firm’s ‘Key Performance Indicators’, analyzing of the existing processes, forming of firm’s objectives, preparation of related action plans, and controlling of company’s quality system.

Process Analyses and Improvement

‘Process Analyses and Improvement’ defines evaluation of processes, selection of performing tasks and related analyze performing.

System Audits

‘System Audits’ comprises planning of audits, notification of audits, preparation to audits, auditing outputs, evaluation, corrective actions, reporting and review.

Management of Non-conformance, Corrective and Preventive Activities

‘Management of Non-conformance, Corrective and Preventive Activities’ defines classification of non-conformance, evaluation of corrective and preventive actions, initiation of corrective and preventive actions, follow-up and results, case closure, and reporting.

System Documentation Management

‘System Documentation Management’ is composed of contents of internal documents, review of procedures, procedure and instruction numbering, approval and validation, distribution and revisions, follow-up for forms and instructions, follow-up for outsourcing documentation.

Recording Management and Archiving

‘Recording Management and Archiving’ define establishment of filing system, filing locations, filing period, archiving rules, archiving layout and control, securing records on firm’ s IT system, information protection and standby.

Communication Management

‘Communication Management’ processes are composed of communication with clients and authorization, firm’s head office and job site meetings’ reporting, paperwork recording system, notification systems, correspondence formats.

4.4.2 Human Resources and Administrative Procedures

Human Resources and Administrative Procedures (HRAP) are designed in QM System to manage human resources and related activities. HRAP comprise three sub-procedures from which human and administrative management processes are constituted. These are:

Human Resources

‘Human Resources’ defines new employee requests and qualification, preparation of work descriptions, notification and data collection, review of applications, employment, assigning personnel, personnel documents, orientation, reporting.

Personnel Management

‘Personal Management’ comprises establishing of organizational structure and job descriptions, forming employee files, general rules, payments and served rights

Personnel Training Management

‘Personnel Training Management’ defines personnel training requests, determination of compulsory personnel training (topic & repetition period), training planning, training, training records, review of training efficiency.

4.4.3 Customer Relation Procedures

Customer Relation Procedures (CRP) are designed in QM System to manage relations with the clients. CRP composed of three sub-procedures from which customer related processes structured to fulfill customer expectations. These are formalized as:

Job Development

‘Job Development’ comprises processes as: follow-up for business/project opportunities, job development process, job development system sources of information, conformity research, and review of pre-qualification conditions.

Bidding Preparation

‘Bidding Preparation’ defines obtaining tender documents and preliminary evaluation, country/region visits and reporting, bid preparation and allocation of responsibilities, study on specifications and determination of basic data for the offer, obtaining of price quotations, tender preparation, review and presentation, tender follow-up, contract performing, contract revisions follow-up.

Monitoring of Customer Satisfaction

‘Monitoring of Customer Satisfaction’ is composed of processes as: records of complaints/suggestions and classification, research of complaint reasons, negotiation with client, corrective action planning, satisfaction analyses and reporting.

4.4.4 Project Management Procedures

Project Management Procedures (PMP) are designed in QM System to manage projects efficiently.

PMP comprise twelve sub-procedures from which CPM processes are derived. These are means to clarify information content and management requirements of organizational applications. These are constituted as:

Establishment of Project Organization and Management Planning

‘Establishment of Project Organization and Management Planning’ defines determination of project organizational structure, scopes of job and responsibility, project organization manual, organization notification, content of ‘Project Master Plan’, preparation of ‘quality plan’, approval of quality plan and updating.

Coordination of Design Activities

Coordination of Design Activities' is composed of processes as assignment of responsible project design manager, design plan preparation, drawings review, distribution of drawings, as-built detailing and filling of drawings.

Work Program Scheduling and Follow-up

'Work Program Scheduling and Follow-up' sub-procedure defines processes as preparing tender work schedule and target work schedule, updating of work schedule during project and reporting.

Cost Planning/Control Management

'Cost Planning and Control Management' defines review of tender budget, evaluating master budget, data collection, comparison of actual budget and master budget and reporting to top management.

Procurement

'Procurement' comprises basic data (project data, purchasing schedule, budget and cash flow data, approval of material request, all the related specifications, tests and guaranties), and preliminary studies (market research, marketing survey for subcontractors, selection of choices about material).

Current Planning

'Current Planning' is composed of quality approval, client approval, test results, purchasing approval), conclusive planning (material purchasing, contract with subcontractor, material delivery and data forwarding to the related departments).

Warehouse Management

'Warehouse Management' defines processes as: material acceptance-exit rules at warehouse, acceptance criteria, storage conditions, warehouse periodic checks, and delivery transportation methods.

Subcontractor Management

'Subcontractor Management' comprises processes as determination of job items (product/service) in subcontractors' scope, quotations and reviewing, contract agreement with subcontractor, performing control/monitoring activities and reporting, finishing activities and handing over, subcontractor performance follow-up and performance review.

Project Handing-over Review

'Project Handing-over Review' is composed of processes as companies headquarter's review, job site review, vendor, subcontractor, designer and client reviews.

Machinery and Equipment Management

'Machinery and Equipment Management' sub-procedure defines processes as: planning, requests for new equipment, machinery/equipment allocation for projects, machinery/equipment delivery, transfer activities, machinery performance review and reporting, new machinery/equipment maintenance methods, existent maintenance method and plan review, maintenance and fixing operations, records and reporting.

QA/QC Activities

‘QA/QC Activities’ is composed of control and surveying activities, calibration of surveying equipment and setting out accuracy, preparation of ‘Method Statements’.

Site Management

‘Site Management’ comprises machinery/equipment list, laboratory tests, list of vendor-subcontractor, site local purchasing, and site control plans, material delivery plans.

The principles of QM System can therefore be summarized as a framework system which is capable of representing the diverse interests of all parties involved in the management process, which is sufficiently definable to allow CPM and information management.

From this standpoint, CPM processes which are based on procedural definitions are modeled in ceEPC Model in Chapter 5 to reflect management activities in a respective form. The simplicity and stability of the envisaged procedural definitions allow their interpretation and flexible application. This is achieved at different variety of construction projects, using of these procedures and processes with combining them in an integrated structure.

According to main items that are given above, the establishment of a QM System displays some differences according to organizational structures. Nevertheless, the forming steps should include these basic items in this regard.

4.5 Conclusions

In this chapter, an integrated CPM model based on a logical conceptual schema starting with the specification of CPM along a number of well-defined steps is outlined.

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 state-of-the-art design, resource planning and scheduling domains’ interoperability concepts, a novel formalization and integration approach for QM System procedures, and an acknowledged holistic business process modelling methodology (ARIS) as can be seen in the following Chapters are brought together.

To construct the whole model, Phase and Process Formalization Structure which composed of principles as General Project View, Process Consistency, Phase and Process Reviews etc. are defined. This approach provides the basis for Construction Management Phases for Software Interoperability (CMPSI).

Subsequently, Construction Management Phases are examined from software integration point of view and phases as Design, Bidding Preparation, Planning & Construction, Project Payments, Evaluation and Feedback Phases are defined with using of IDEFØ function modeling methodology. The clear benefits of the integral treatment of IT Management aspects are identified with regard to design, resource planning and scheduling integration.

Currently such systems integration are supported as the in-house definitions of the producers and not depended on standards such as STEP or IFC. In this context, the envisaged models define the basics which may open a path to possess a standard model for IT Management.

Furthermore to identify organizational structures and interrelations within and between CPM processes and to detail functions defined by IDEFØ, QM System is examined for CPM purposes. Moreover four main procedures namely General System, Human Resources and Administrative, Customer Relations and Project Management are established to provide sub-procedures and inter-related sub-processes.

From this standpoint, two main process definitions as Organizational and IT Management Processes are constituted to support grounded confidence, in the following sections.

CHAPTER 5: INTEGRATED CPM PROCESSES FOR BIDDING PREPARATION

The integration of CPM processes requires the specification of the process structure as well as the definition of the resources involved in the execution of these processes. In this chapter the integrated CPM process structure from the organizational and the technical point of views is developed, focused on the Bidding Preparation phase of CMPSI. The main resources are defined in order to provide IFC Views. The structure is built on two principal process definitions namely (1) Organizational Management Process (OMP) and (2) IT Management Processes (ITMP). OMP is considered as a core process structure composed of different aspects. They are identified in the Life-cycle Model for Processes and represented with the complemented eEPC (ceEPC) modeling method. The complemented eEPC method is described in detail in Chapter 6. This provides synchronizing of technical products, processes, documents information flows and actors in their inter-relationships. Subsequently, the IT Management Processes are derived from OMP with regard to CMPSI. The IT Management Processes are sub-structured in three sequenced and interconnected processes namely (1) IT Management Design Process, (2) IT Management BOQ Process and, (3) IT Management Scheduling Process. This provides the basis for formalizing the IFC Views and representing related resources which identify the IFC Extensions in Chapter 7. Moreover the impacts of the procurement systems and the procurement system dependent process aspects which address OMP and ITMP are examined for relevancy.

5.1 Introduction

In the last number of years, a sizeable demand has arisen to model generalized AEC processes which are a central aspect in supporting net-work based coordination among project partners. To formalize generic management processes which are characterized by such significant aspects as the defining of great complexity and the dynamical behavior, a holistic approach is necessary. Furthermore it is accepted that, to realize a fully interconnected, computer supported engineering environments, is not only relevant to components, but also related to the conceptual model and operational definitions by means of management processes itself.

In order to maintain an integrated generic process structure in this research, a management configuration based on a flexible process management system which comprises different levels of interconnected processes is developed. Moreover, in order to obtain holistic consideration, the system is designed to be supported by an IFC product model in order to formalize the interactions within management processes and construction products.

On that basis, the research structure in this chapter is developed as in the following:

- 1 Impact of the Procurement systems such as Design-Build, Lump Sum, Cost-Plus, etc., are examined for relevancy.
- 2 Process Integration Requirements are examined to structure the main aspects.
- 3 Software Integration requirements within the process definitions are detailed to gain a general perspective.

- 4 The Life-cycle Model for Processes is developed to bring together different views and CPM aspects in generic process constitutions.
- 5 The Main and Supporting Processes based on QM, for the Bidding Preparations are examined.
- 6 A Modeling Framework “complemented eEPC” is designed to model standardized, generic processes.
- 7 The Organizational Management Process as a core process is formalized with using of developed Life Cycle Model for Processes.
- 8 IT Management Processes are developed with regard to design-resource planning and scheduling integration needs and derived based on OMP.
- 9 Design & Build, Lump-sum and Unit Price Procurement systems dependent process aspects which address OMP and ITMP are examined in order to obtain proof of the concept.

5.2 The Impact of Procurement Systems

There are five main procurement systems which are used generally worldwide, as represented in Section 2.6. When these systems are examined in detail, three of them such as Design-Build, Lump Sum, and Unit Price are found convenient systems for the suggested integrated CPM processes for the Bidding Preparations.

The reason can be explained briefly;

- 1 The proposed integrated CPM structure is connected with the material codes and the exact specifications of the project design which are requested in the design phase,
- 2 The information exchange within software is based on the material IDs.

These two main items which are the backbone of the structure are provided in different levels and in different forms in these formalizations.

For example: Design and Build systems require detailed drawings which comprise material specifications initially, in order to submit a lump-sum amount which should remain fixed, the detailed contract documents are also a necessity for Lump-sum contracts, in Unit Price contracts the precise calculations and quantity take-offs which are derived from drawings are absolutely helpful in winning the bidding. In spite of this, Cost-Plus contracts which are used for fast track projects may not be reliable for our structure. The main point here is that the design of the project is not complete and can be changed according to clients' requests within the project progress. Moreover, because the BOT projects require detailed feasibility studies, which are out of scope in this research, this contract constitutions are not taken into account in this context.

To represent integrated CPM process aspects within procurement systems, three scenarios for Design-Build, Lump-sum and Unit-Price contracts are structured which address OMP and ITMP processes in the following sections. This facilitates to prove reliability of the proposed processes, in these systems' use.

5.3 Requirements for Integrated Processes

The start point for process management solutions can be found in the early 70's with the office automation prototypes (Zisman et al. 1977) which generally focused on the automation of human-centric processes. Recent developments in the area of web services choreography have discounted the organizational aspect of workflow solution and focus exclusively on the coordination of control flow structures (zur Muehlen 2004). Furthermore, the proposed standards such as: WSCI (a subset of BPML), (Arkin et al. 2002), WSCL (Banerji et al. 2002) and BPEL4WS (Curbera et al. 2004) do not contain any notion of human activity performers. Instead they are focused on the technical coordination of inter-enterprise processes with limited or no human intervention. While some initiatives focus on the automation of mainly technical processes, such as the automated data exchange between different applications, some vendors stress the organizational aspect of their solutions (Orlowska et al. 2003).

From this standpoint, to enhance, harmonize and eventually standardize CPM process patterns for initializing and operating construction process, and to support technical coordination with human intervention which is also not provided yet, a need is observed for an integrated process approach. To formalize this structure, various requirements have to be considered.

According to Keller et al. (2003) these can be identified as:

- 1 Analyze the requirements for the underlining technical and organizational aspects,
- 2 Design of workflow language to model standardized, generic management processes,
- 3 Identify the context parameters which influence the instantiation and operation of project activities,
- 4 Improve domain specific process pattern that identify resources linked to each other through the construction role.

In order to provide answers to these acquiesces through this research:

- 1 Technical aspects are analyzed based on software integration requirements and the CMPSI.
- 2 A modeling framework based on ceEPC is developed in order to model management workflow.
- 3 Context parameters and organizational aspects are defined according to QM procedures, sub-procedures and sub-processes.
- 4 The process patterns which comprise related resources are defined based on developed Life-cycle Model for the Processes which formalize different views in one structure.

5.4 Software Integration Requirements within the Process Definitions

Integration means to form, coordinate, or blend something into a functioning or unified whole by ending existing segregation (Meriam-Webster 2002). From the operational point of view,

integration means the ability of the system components to work together in a coherent way for the solution of complex tasks.

According to Rosemann (1996), two different types of integration can be seen. (1) Integration through connection, which supports a system created through the creation of links between different structures although they are logically connected systems. (2) Integration through combination, which is combined of similar system elements, thus leading to a decreased number of elements and relationships within the system.

Integration through connection can be summarized as integration of existing systems. In our case, this refers to the integration of existing design, resource planning and scheduling domains by using reliable interfaces. Integration through combination defines integration through conceptual design of an information system. As an example the development of a complex application as design, resource planning and scheduling domain integration structure, for the transport of application data.

The conceptual design of a process application regarding software interoperability requires a definition of integration rules. Zur Muehlen (2004) identifies these as (1) Internal and (2) External requirements.

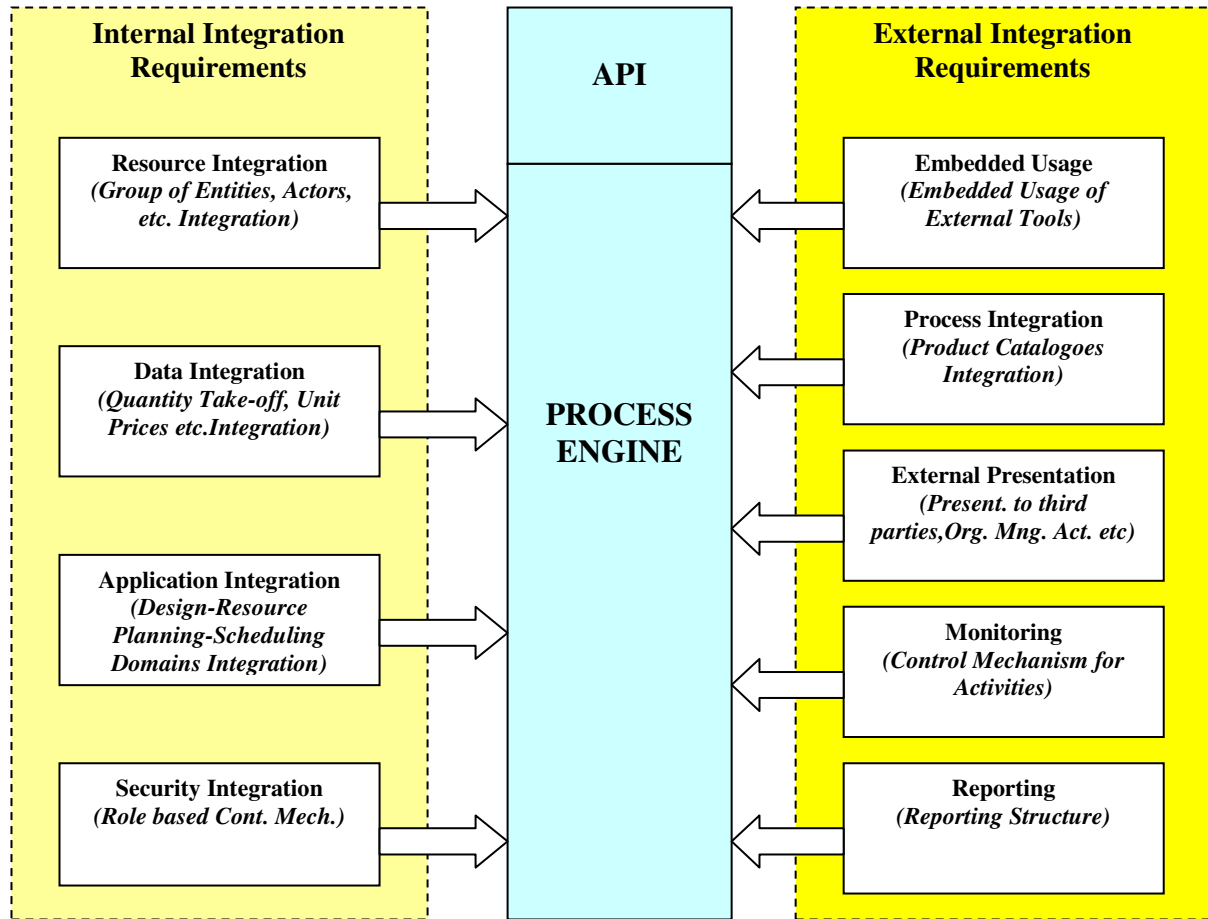
Internal integration requirements are defined under four sub-systems as (1) resource integration which is required by the process system to keep track of the participants available for activity assignment, (2) data integration which makes process relevant data accessible to process structure, thereby connecting the system to databases used by external application systems, (3) Application integration which describes the ability of the process system to invoke external application systems during the control of a process and (4) Security integration which relates to the use of existing authentication and authorization mechanisms through the workflow system, such as single-sign-on, role based access control mechanisms and public key infrastructures.

External integration relates to the fact, that a workflow system is an application system in itself. External applications may be required to call the services of a workflow engine from outside, invoking workflow instances, querying the status of activity instances, or handling resource assignments through external scheduling mechanisms.

In our case, Internal Integration Requirements are formed of (1) Resource Integration which provides organization participants such as: group of entities, actors etc. that are directly involve in the process, (2) Data Integration which refers to data that is directly used by these participants, (3) Application Integration which reflects design, resource planning and scheduling domains integration and related requirements, (4) Security Integration which refers to role based control, that is granted to organization participants.

External Requirements are composed of (1) Embedded Usage which comprises embedded usage of external tools such as product catalogs, external databases etc., (2) Process Integration which reflects the ability of an integration process belonging to an external source of integration, (3) External Presentation which represent the system capabilities such as status of 'their' workflow instances or the reliability of external system management tools with use of services (e-mail, Web etc.) to relate with third parties, (4) Monitoring which defines a control mechanism in order to control process activities and (5) Reporting which comprises report of audit trail information by external applications.

In this context, internal and external integration requirements are formalized in a graphical notation as illustrated in **Figure 5.1** from an internal and external perspective.



Source: Modified from Zur Muehlen, (2004)

Figure 5.1 Application Domains Integration Requirements

In spite of the requirements for the integrated processes and the software integrations which are examined in detail and lead to an integrated CPM approach for the construction companies, there is no single way to organize an enterprise as Galbraith (1973) expressed in his contingency theory.

The effecting factors in this case can be defined as client demands, market positions and obligations, which can reflect differences due to various situations. But never the less, to manage fragmented structures and to formalize optimal processes, there is a need, to identify well constructed resources along with their relationships, which can facilitate activities and work, as complementary aspects. Furthermore, to combine various types of views such as procurement system requirements, services, procedures etc. which are prerequisite for completing different aspects in a generic process structure, a model is required. On that basis to blend all these requirements and to represent a holistic consideration which comprises different views in one generic structure, a Life-cycle model for processes is constituted in this regard.

5.5 Life Cycle Model for Processes

To complete identified CPM aspects, to develop integrated process patterns and to define a process formalization structure, a Life Cycle Model is implemented for OMP formalization purposes, based on Zur Muehlen's (2004) process life cycle approach, as illustrated in **Figure 5.2**. QM processes, CMPSI and Procurement System requirements are brought together in this structure, thereby exposing an integrated model which meets the envisaged interoperability.

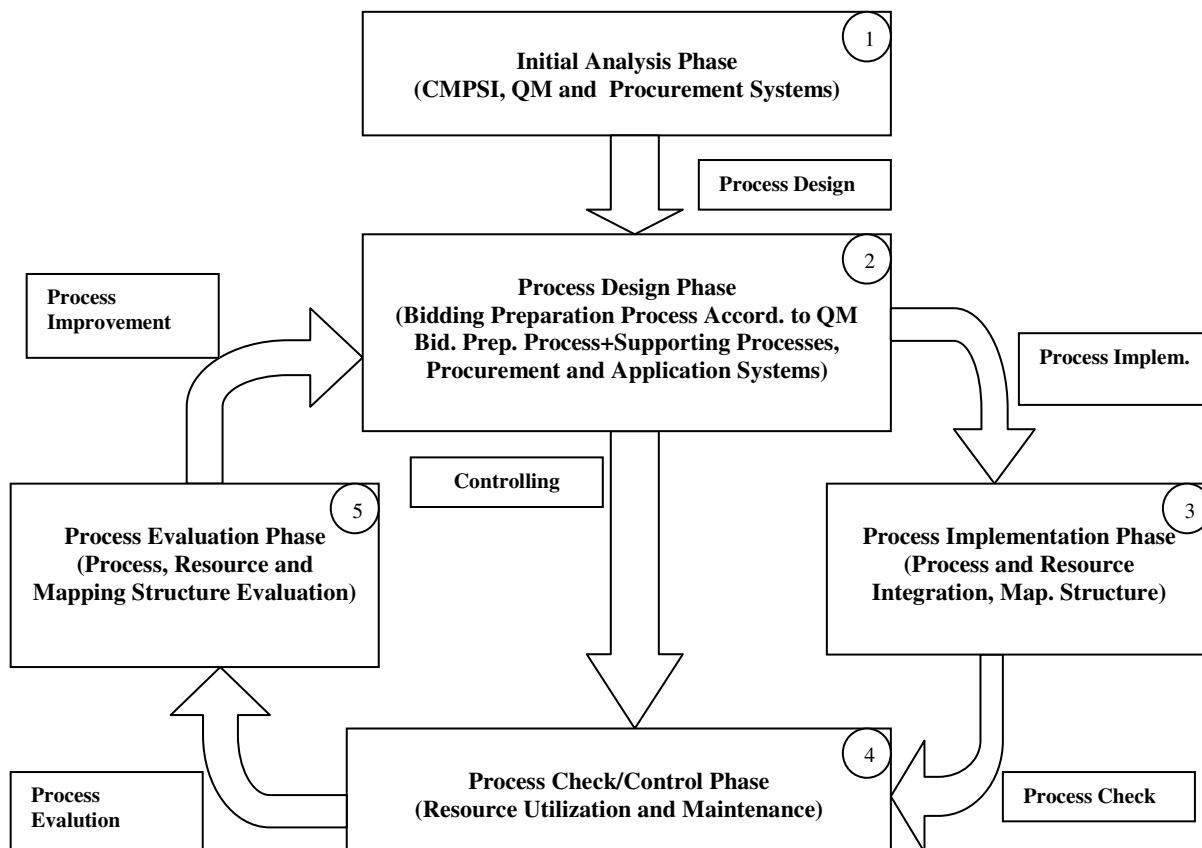


Figure 5.2 Life Cycle Model for Organizational Management Process

The formalization starts with (1) initial analysis of bidding preparation phase of CMPSI, related QM procedures and processes, and the Procurement Systems. This phase is followed by (2) a process design phase, during which the overall process structure is engineered, the resulting process model is designed, the resources involved and the mapping methodology is decided. This includes the modeling of the organizational units and the application system integrations. In the third phase (3) the designed processes are implemented. In our case, ceEPC model is used to formalize process sequences. The main process is defined according to QM's Bidding Preparation Process (M) which is identified under customer relation main procedure. The supporting processes such as job development (S1), design coordination (S2) processes etc. are also defined and used partially within bidding preparation process in order to obtain an integrated generic process structure. This new structure is named as

‘Organizational Management Process’. In order to support procurement systems, an organization chart which is required by ISO is also formed in this context. Internal process participants (which are part of the process-enabled organization) are notified of this through their work lists. The related application systems are defined and attached to process sequence in order to formalize IT management processes and the mapping structure. After implementation of the work flow, (4) established processes are checked/controlled to see whether they are supporting generic integration comprising seamless information flow within processes. The formalized resource consistencies are controlled and the mapping structure is scrutinized in this regard. The processes, resources and mapping structure are (5) evaluated in the next phase. The required improvements are suggested and these are designed and implemented again according to these suggestions.

5.6 The Main and Supporting Processes based on Quality Management System

To support QM requirements and to provide a generic structure, the OMP is constructed based on the Bidding Preparation Process (M) as a main process.

It is extended with seven supporting processes, procurement system requirements and application systems based on the CMPSI.

The supporting processes are used partially within the main process to fulfill the required integration.

Bidding Preparation Process as Main Process (M)

Bidding preparation process represents the way of obtaining tender documents and preliminary evaluation. Moreover it comprises country/region visits and preparation of the related reports, bid preparation sequence, determining of responsibilities, working on the project specifications, providing the basic data, obtaining price quotations, review and presentation of the bid, tender follow-up, performing of contract and the contract revisions.

Supporting Processes

The Following processes are interacting and hence supporting the main process.

Job Development Process (S1)

Job development process considers pursuing business/project opportunities and examines job development system and sources of information. Conformity research and review of pre-qualification conditions are also undertaken at this stage.

Design Coordination Process (S2)

Design Coordination process commissions a responsible project design manager who possesses design preparation experience. This process pursues drawings review, distribution of drawings, as-built detailing, and filing of drawings.

Defining of project Organization and Management Planning Process (S3)

Defining the project Organization and Management Planning process provides project organizational structures and scopes of the job and the responsibilities. Project organization manual, organization notification, content of “Project Master Plan” are also considered as the main items for this process definition. According to obtained information, “Quality Plan” and the updating are also formalized in this process.

Human Resources (S4)

Human Resources process represents the way new employee requests and preparations of the requested qualifications are dealt with. Moreover it comprises preparation of the work descriptions, notification and data collection, review of applications, employment, personnel placement, personnel documents, orientation and reporting.

Work Program Scheduling and Follow-up Process (S5)

Work Program Scheduling and Follow-up process comprises preparing of the tender and the target work schedule, updating of work program during project progress, and comparing the planned work schedule with the existing situation on jobsite.

Purchasing Process (S6)

Purchasing process defines basic data such as project data, purchasing schedule, budget and cash flow data, approval of material request, all related specifications, tests and guaranties during the procurement process. The preliminary studies such as: market research, marketing survey for subcontractors, selection of choices about material is also required.

Subcontractor Management Process (S7)

Subcontractor management process identifies job items (product/service) in subcontractors' scope, quotations and reviews, and contract agreement with subcontractor. It formalizes performing and control/monitoring activities, reporting, finishing activities and handing over. Subcontractor performance is pursued and reviewed also in this process.

5.7 Modeling Framework

The overall modeling framework is established on the basis of the ARIS-eEPC modeling method which provides holistic modeling of processes, resources and organizational structures in their interrelationship.

However to the support of designing an integrated CPM solution, in order to define organizational and management processes for the actual procurement system used, a notation structure is provided in Chapter 6 and each resource is tagged with an identifier. The new model is named as “complemented eEPC” (ceEPC) model. Thereby the common functions, events, actors and objects which are constituted both in Organizational and IT Management Processes are identified in a logical mechanism. This greatly helps to obtain a mapping structure between interrelated data and functional definitions. Furthermore, this enables the management of all CPM phases in a collaborative way and contributes so that organization units are better informed.

A ceEPC describes processes by creating a chronological sequence of functions, events, and their logical interdependencies using logical connectors, and related performing actors and services, in terms of resources as shown in **Figure 5.3**. The detailed representation of the notation structure will be given in Chapter 6.

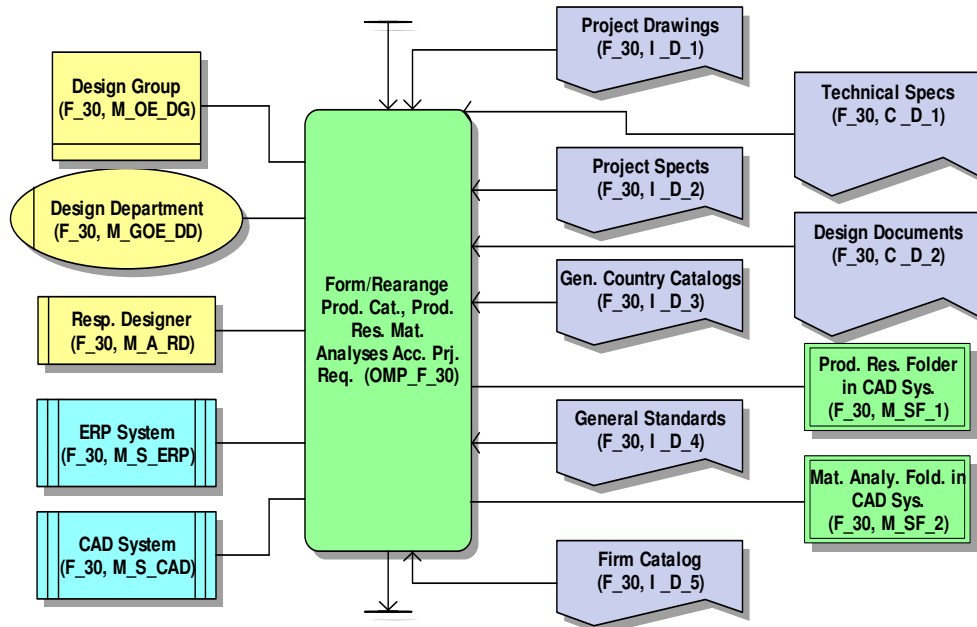


Figure 5.3 ceEPC Model Structure (A cut-out example of OMP)

A resource represents a technical or human process participant. The role entity is a named privilege granted resource, or a capability exhibited by a resource (Zur Muehlen 2004).

Capability can be defined as a direct property and directly related with the resource. Even though there is a change in the enterprise, it remains as it is.

A privilege can be defined as a property of an organizational position. It can be occupied by one or more resources. The positions are directly associated with these privileges.

In order to formalize process functions, there is a need for referencing combined capabilities and privileges of a process participant in this context.

In the envisaged ceEPC structure, several types of resources are formalized as: organizational entities, group of organizational entities, actors etc., as it is represented.

- Organizational entities are the main milestones of the organizational structure of an enterprise. It symbolizes an entity such as: main contractor, client etc. in a workflow. The participants of organizational entities are commissioned to perform the related activities as granted authorities.
- Group of organizational entities form organizational units, such as departments (permanent units) or project teams (temporary units). It is formed of company participants in terms of actors, in order to support unique aspect of a process.

- Actors are the formal organizational positions granted to organizations' participants. They are commissioned to possess the required work within group of organizational entities.
- Services are used to support activities. These services can be classified based on design, resource planning and scheduling domains. They are meant to facilitate the process and support integration with company actors. In our eEPC model, design domain is represented by a CAD system, resource planning domain is represented by an ERP system and scheduling domain is represented with Scheduling System.
- System folders comprise the data which is exposed by services. This data can be used by actors and other services, in order to work out related tasks.
- Documents are direct resources, which are used to complete related tasks; these can be forms, reports, etc.
- System interfaces solve seamless data flow by supporting integration between different systems. The main idea is to obtain seamless integration in order to obtain complete data.

In this context, due to lack of existing models' capabilities which are envisaged in the previous chapters such as: limitations for 'will-be' processes as it is seen in IDEF0, or lack of representation of all process participants within a process sequence as it is observed in UML activity diagrams etc., and after several attempts in this context, ceEPC model provides to capture the integrated CPM Processes.

On that basis OMP, which is composed of different types of views and aspects, can be constituted in the following paragraphs.

5.8 Organizational Management Process

Organizational Management Process, as a core process, is developed based on the implemented Life-cycle Model for Processes. This helps us to establish a concurrent control system in terms of monitoring management activities for the Bidding Preparation Phase.

Based on four main procedures mentioned in Chapter 4.4, namely (1) General System Procedures, (2) Human Resources and Administrative Procedures (3) Customer Relation Procedures and (4) Project Management Procedures, the sub-procedures are constituted.

These are then put in functional and temporal relationships to respective technical and support processes such as: Job Development, Design Coordination etc. by using ceEPC Model. The basic aim is to obtain a coherent management structure which will define organizational management processes comprising related participants and resources.

In order to avoid changes within the basic design, QM procedures and processes are used. The structure is formed based on the ceEPC to enhance understanding, documentation and to facilitate modeling of holistic constitutions.

In order to constitute an integrated process formalization to provide a persistent structure, application systems namely CAD, ERP and Scheduling systems and the required basic data are represented within the OMP formalizations based on the CMPSI.

However, in order to define the behaviors between organizational units and the workflow regarding the application sequence of these systems, QM procedures and processes are used partially. QM defines the procedures and processes in a general context and represents the work flow with the company participants according to application areas and generally based on departmental applications i.e. purchasing processes for purchasing department or work program scheduling and follow-up processes for planning department, etc. However, when the integrated processes require representation of bidding preparations, the use of supporting QM processes, such as purchasing, design coordination, human resources, etc. is required to complete the bidding preparation process.

Moreover QM definitions do not consider CPM phases and represent these procedures according to departmental needs. The extraction of the required parts of these processes based on the CPM phases is also needed in this context. Thereby these parts can be used in a generic structure to fulfill the expected process integration.

QM defines the organizational structures, organizational units and the workflow sequence, however it does not define application systems and the related data in a level of detail which are provided within the CMPSI. In order to form the IFC Views contents, the application sequence of the CAD, ERP and Scheduling systems within the workflow which are used by the organizational units should be represented. This provides to illustrate the object relations in the IFC Concept constitutions.

In **Figure 5.4** three columns which are (1) Application Systems, (2) IT Management Processes and (3) Main and Supporting Processes are illustrated.

The QM processes are represented in column three under the main and supporting processes. They are realized in a generic sequence.

The IT systems are illustrated under the first column, under application systems and matched with the envisaged processes according to the application sequence.

The second column represents IT management processes. The constitution of IT Management Processes (ITMP), both represent the QM System processes and application systems integration according to CMPSI, i.e. a part of QM System design coordination process as a supporting process and the integration of CAD and ERP systems based on CMPSI are realized under IT Management Design process (see Figure 5.4).

The combination of these views in a logical order represents Organizational Management Process. The ITMP is illustrated in OMP in order to provide the basic data for the IFC object and relation definitions.

The ITMP divided based on the needs of organizational units e.g. work program and scheduling process is illustrated in two parts (see Figure 5.4). Therefore these process definitions should be gathered again to reach persistent data definitions. On that basis they are derived from OMP and represented as (1) IT Management Design (2) IT Management BOQ and (3) IT Management Scheduling Processes in the following paragraphs and used for the IFC Views constitutions.

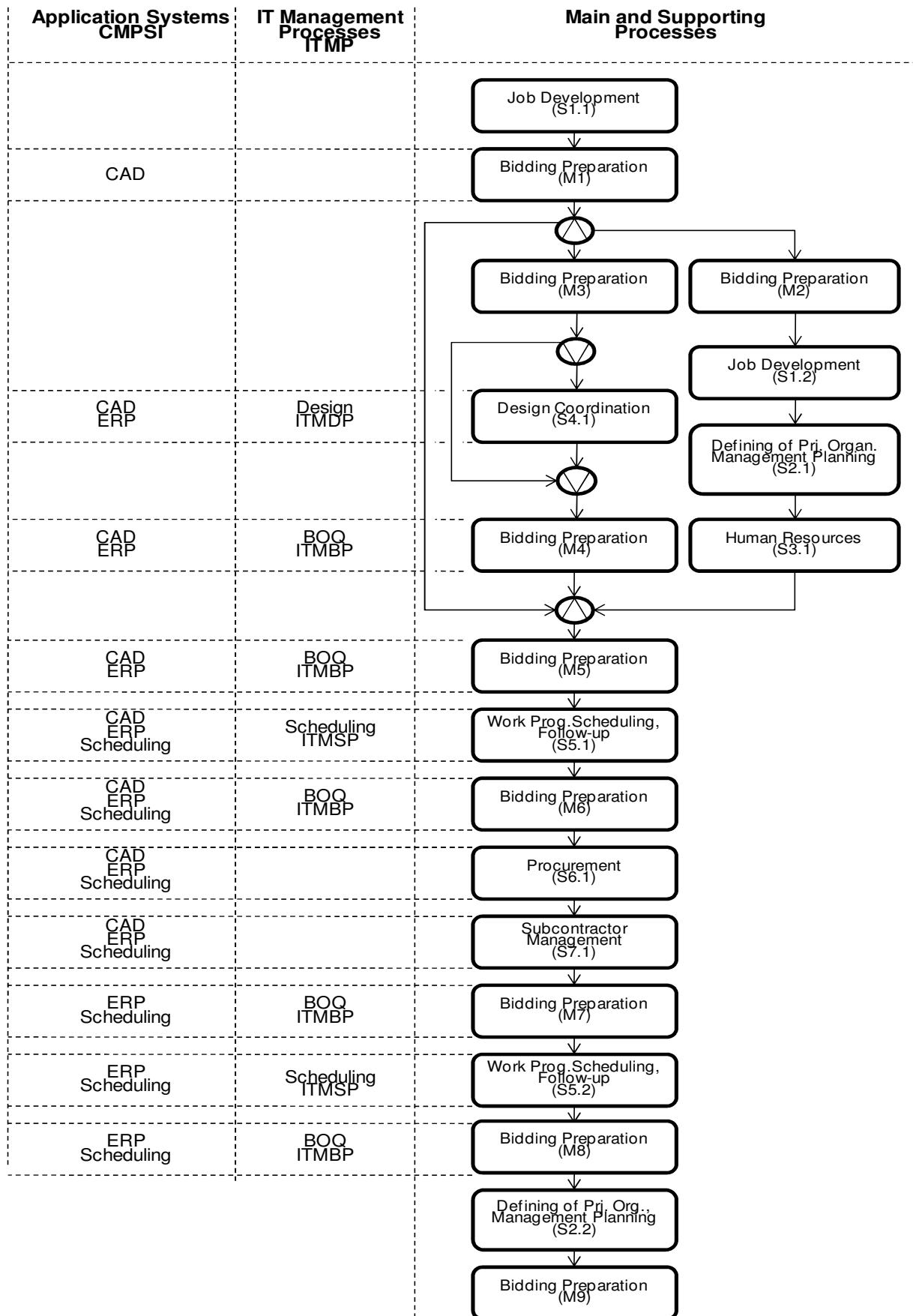


Figure 5.4 Generic Representation of OMP

The detailed model is represented in section 5.9 and in Appendix A. The related integration mechanism, with regard to different views such as procurement systems, organizational structures etc., is provided in Chapter 6.

The whole OMP is formed from 3 organizational entities namely main contractor, client, design group, 9 different groups of organizational entities namely bidding department, procurement department, finance department, etc., 14 different actors namely bidding manager, responsible designer, procurement manager, etc., and 117 sequenced functions and events, 91 different documents under input, 44 different documents under control and 3 interconnected software systems. Furthermore seven supporting management processes are referenced and used partially.

From this standpoint, after examining ways of structuring and possessing the required formalizations, the envisaged models can be provided. In this case, the Organizational and IT Management Processes are defined concisely in the following sections.

5.9 Formalization of the Organizational Management Process in ceEPC

In order to clarify Organizational Management Process, a brief explanation which describes functions, events, resources and their inter-relations is identified in ceEPC model, given in Appendix A. In order to ensure clarity, the related (main and supporting) processes given in Figure 5.4 are illustrated before the related definitions.

Job Development Process (S1.1)

Organization Management Process starts with the decision of top management to join a bidding (OMP_{F_1}) and requires a Job Development Process, conformity reports and pre-qualification conditions.

Bidding Preparation Process (M1)

In order to obtain bidding documents, the bidding department (BD) is informed (OMP_{F_2}) according to this decision. Based on the information which is received from the client (OMP_{F_3}), BD informs top management about tender conditions (OMP_{F_4}). If it is required, this department also prepares a pre-sufficiency folder according to client requests and delivers it to client side (OMP_{F_5, F_6, F_7, F_8}). For site investigation, BD attains a responsible engineer (OMP_{F_9}) to examine existing site conditions. Based on collected evaluated information (OMP_{F_10, F_11, F_12}), the project is studied (OMP_{F_13}) and a plan is made by BD (OMP_{F_14, F_15}). If there is a detailed design required (OMP_{F_17}), a designer from outside is found (OMP_{F_19, F_21}) according to Design Coordination Process.

Bidding Preparation Process (M2)

Within this process chain BD informs other main departments (OMP_{F_16}).

Job Development (S1.2), Defining of Project Organization and Management (S2.1), Human Resources (S3.1) Processes

Departments, such as job development, project management and human resource prepare the required project information (OMP_{F_18, F_20, F_22, F_35, F_36, F_38, F_40, F_41}).

Bidding Preparation Process (M3)

Afterwards, BD starts to form new (empty) projects' production resource, material analysis and quantity take-off folders, in ERP System (OMP_{F_23}). Also basic management groups (OMP_{F_24}) and building details are defined initially (OMP_{F_25}). In order to support price structure; product catalogs, production resource and material analysis folders are formed additionally (OMP_{F_26}). BD can supply these from different resources (via copying the detailed external resource lists to new production resource and material analysis folders) such as: firm databanks, general country catalogs etc. After forming these in ERP system, these are sent to CAD system (OMP_{F_27}), to be used in the design phase. Subsequently, the project specifications, planned materials, production resources etc. are delivered to the design firm by BD (OMP_{F_28}).

Design Coordination Process (S4.1)

From these sources, Design Firm (DF) plans and analyzes construction design, related elements and production units (OMP_{F_29}) which are sent from ERP system to CAD system. Moreover DF forms/rearrange production catalogs, production resources and material analysis based on project requirements (OMP_{F_30}) According to suggested software integration structure, design firm should make the drawings in 3D format (OMP_{F_31}) using reliable CAD systems. Following the completion of work, production resource and material codes are attained for 3D drawings (OMP_{F_32}). After attaining these codes, the quantity take-offs can be established in CAD System (OMP_{F_33}). In order to constitute BOQ lists, these quantities are transferred from CAD system to ERP system (OMP_{F_34}). Subsequently after completion, the Main Contractor is informed about the 3D drawings and quantity take-offs (OMP_{F_37, F_39}).

Bidding Preparation Process (M4)

Based on this, the BD organizes/arranges drawings, production resource and material analyses folders and forms the measurement structure in ERP system (OMP_{F_42, F_43}). However, if the detailed design was given by the client initially, the BD can also convert the drawings into the 3D format so that the quantity take-offs support the integration structure. This is directly related with the procurement systems.

Bidding Preparation Process (M5)

Based on drawings and quantity take-off lists, the BD calculates the necessary and additional measurements and makes these lists available to the ERP system and informs the Bidding Manager (OMP_{F_44}). After completion of calculations, the bidding manager informs the planning department about project general information (OMP_{F_45}) (quantity take-offs, drawings, and work program etc.).

Work Program Scheduling and Follow-up Process (S5.1)

Planning department plan a pre-work program (OMP_{F_46}) according to Work Program Scheduling and Follow-up Process using CAD system for drawing checks, ERP system for quantities check, exchange of resources in terms of unit prices etc., and Scheduling system for scheduling. In this case scheduling process starts with the opening of a scheduling module in ERP system (OMP_{F_47}). This module is required to update the work program in order to form progressed payments, realized budget, labor and material costs etc. for the next phases. After opening the scheduling module in ERP system, the activity pose numbers are arranged

(OMP_{F_48}) by the Planning Department (PD) to be used in the Scheduling System. The BOQ Lists which can be used as an activity list is sent (OMP_{F_49}) from ERP system to Scheduling System by using a XML interface. The activity descriptions are rearranged (OMP_{F_50}) in a scheduling system by PD subsequently. The main idea is structuring the activities according to construction processes. After formalizing the structure, the durations are estimated and attained to activities (OMP_{F_51}). To form the program, the activities which affect each other are connected (OMP_{F_52}) and, the pre-work program is calculated (OMP_{F_53}). Subsequently, bidding manager is informed about completed pre-work program (OMP_{F_54}).

Bidding Preparation Process (M6)

According to derived information, the bidding manager informs the procurement department about general project information (quantity take-offs, material lists, drawings etc.) (OMP_{F_55}).

Procurement Process (S6.1)

In order to make a project plan based on Procurement Process and Subcontractor Management Process, the procurement manager makes a buying plan (OMP_{F_56}) which is derived from material lists, specifications, measurements, drawings, pre-work program using CAD, ERP and Scheduling Systems. The Procurement department carries out this market research (OMP_{F_57}) in order to select possible material suppliers and subcontractors. After selecting reliable project procurers, they are informed about project specifications (OMP_{F_58}). The collection of prices and comparison (OMP_{F_59}) follows subsequently.

Subcontractor Management Process (S7.1)

Afterwards, decision upon subcontractors is constituted and BD is informed about the conclusion (OMP_{F_60}).

Bidding Preparation Process (M7)

In order to form BOQ, the basic items which can be used in the overall management of the suggested structure are constituted, in this level. Initially the possible responsible person lists are formed (OMP_{F_61}) in order to use them for main scheduling within project progress. We need different folders to support project's specific aspects. Therefore the material folder which is structured in the design process is opened (OMP_{F_62}). Subsequently, to support project data, a new production resource1 (OMP_{F_63}) and a new material analysis1 (OMP_{F_64}) folders are formed in ERP system. Material analysis folder which is structured according to country product catalogs or firm databank etc. are copied to material analysis1 folder (OMP_{F_65}) to support information exchange within the structure. These analyse the composed production resources which are used as the basic items to form production resource1 lists. Therefore production resource1 folder is opened (OMP_{F_66}) and subsequently these are sent to production resource1 folder (OMP_{F_67}) to form project specific production resources. According to project needs, the market prices are possessed according to Procurement Process which would have been concluded previously. Sequentially, the market prices are accessed to production resource1 (OMP_{F_68}) folder. In order to structure new analysis for market prices, these prices are sent to material analysis1 folder (OMP_{F_69}, F₇₀ F₇₁). Based on top management decision, amortization and transport expenses are added (OMP_{F_72}) to these material analyses. After completion of external information, material analysis1 folder is rearranged (OMP_{F_73}), according to new data. In order to construct BOQ list we need quantity

surveying. In this sense, the established measurement folder in ERP system is opened (OMP_{F_74}) and the calculated quantity take-off lists, which are taken from CAD system to ERP system in IT Management Design Process, are used in this context. The quantity take-offs which can be formed in CAD systems are directly related with the ability of the CAD programs. If the necessary quantity take-offs could not be obtained within CAD systems, these measurements can directly be accessed by the ERP system i.e. by hand, in this regard. According to our research investigations rc-bars, profiles, electrical and mechanical measurements are not yet supported by CAD systems in a required format, in terms of establishing quantity take-off lists: rc-bars quantity take-offs (OMP_{F_75, F_76}), mechanical quantity take-offs (OMP_{F_77, F_78}), electrical quantity take-offs (OMP_{F_79, F_80}) can be entered manually to measurement folder to fill this gap. After all quantity take-offs are entered according to project specifications, they are arranged (OMP_{F_81}) in main section quantity take-off folder tables and then sent to BOQ folder (OMP_{F_82}). To form the BOQ list, production resource1 and material analysis1 lists are required. In order to establish the BOQ folder, these lists are opened and sent to this folder (OMP_{F_83, F_84}) and then used for calculation of the proposal.

Furthermore, there are other important issues which also have to be taken into consideration. The material requirement lists and buying lists are the main items for purchasing/procurement process. These are used to purchase project materials according to project schedule. Most of the CPM systems such as Primavera, Suretrak, Artemis etc. have the ability to calculate the material requirement and buying lists if the project resources are entered into the system in a correct way. But as it is known, access of resource data to the system is not an easy task for planners. In the proposed structure this data is imported directly from production resource1 and material analysis1 lists from ERP system. Based on these, BD sends production resource1, material analysis1 and work order information to Scheduling system and informs (OMP_{F_85}) planning department about BOQ lists, production resource1 and analysis1 and work order lists.

Work Program Scheduling and Follow-up (S5.2)

Subsequently according to established structure, requirement lists (OMP_{F_86}) and buying lists (OMP_{F_87}) can be calculated easily by the PD. Also the preliminary budget (OMP_{F_88}), cash flow diagrams, work order lists and bidding work schedule (OMP_{F_89}) can be derived from Scheduling System subsequently. After calculation of the work schedule and taking the necessary tables, lists and diagrams. The work schedule, budget, cash flows and work order lists are sent (OMP_{F_90}) to ERP system. Sequentially, the planning department informs (OMP_{F_91}) BD about work schedule, budget, cash flows and work orders.

Bidding Preparation Process (M8)

Afterwards, BD rearranges the work schedule (OMP_{F_92}) in ERP system. This helps to form stock and cost control tables (OMP_{F_93}) in this context. To arrange the cost control tables, the existing production resource 1 folder is opened (OMP_{F_94}) and copied (OMP_{F_95}) to cost tables which are a component of the cost module in ERP system. Subsequently, a cost control folder/module is opened (OMP_{F_96}) and related pre-budget, and cash flow situation of the project, are calculated (OMP_{F_97, P_98}) according to a weekly or monthly work schedule in the ERP system. According to information, which is gained from the procurement manager, BD prepares general expenses tables and informs top management (OMP_{F_99}) subsequently. Top

management decides upon general expenses and informs BD ($OMP_{F_{100}}$) afterwards. BD adds general expenses to BOQ and finalizes it ($OMP_{F_{101}}$). To prepare production resources, general expenses, BOQ, material analysis and prices according to required bidding form, BD collects all information from related departments i.e. finance, purchasing etc. ($OMP_{F_{102}}$). After completion of work, bidding manager informs top management ($OMP_{F_{103}}$) about price lists and project BOQ. After this process, top management decides upon profit and informs bidding manager ($OMP_{F_{104}}$). Following the completion of necessary information, BD collects all bid documents and forms the Bid ($OMP_{F_{105}}$), and delivers it to client ($OMP_{F_{106}}$). If the decision will not be given according to existing bid proposal ($OMP_{F_{107}}$), BD has to follow up the evaluation process and answers client's questions and makes the related corrections ($OMP_{F_{108}, F_{109}}$). However, if there will be a special request from the client (about the prices, about the conditions etc.), BD informs top management ($OMP_{F_{110}}$) and arrange the bid according to their suggestions. The client has to decide ($OMP_{F_{111}}$) and inform the contractors ($OMP_{F_{112}}$) about their proposals. If the firm wins the tender, top management, bidding manager and project coordinator get in contact with the client ($OMP_{F_{113}}$).

Defining of Project Organization and Management (S2.2)

According to project specifications a project manager is attained ($OMP_{F_{114}}$) with reference to the Defining of Project Organization and Management Planning Process by top management.

Bidding Preparation Process (M9)

Based on project specifications, project manager searches for contract conditions and informs top management ($OMP_{F_{115}}$). Subsequently, top management evaluates the specifications ($OMP_{F_{116}}$) and signs the contract with the client. Project manager is the responsible person to follow-up the contract changes and negotiates the new items with the client ($OMP_{F_{117}}$).

5.10 IT Management Processes

IT Management Processes (ITMP) are defined in accordance with the design, resource planning and scheduling domains' interoperability needs and derived based on the OMP.

This includes the application sequence of the involved IT tools, their relations to processes, performing actors, input and output and control information, and their general systemic interrelations in the IT environment. To show different level of system integration, Bidding Preparation Phase is organized in three subsequent structures as:

- 1 IT Management Design Process, (ITMDP)
- 2 IT Management BOQ Process, (ITMBP)
- 3 IT Management Scheduling Process, (ITMSP)

The main aim of diverse IT management structure is to construct three application areas which are preparation of design, BOQ and scheduling, according to the envisaged software.

This approach facilitates the observation of common functions, events, resources and objects which are used in these processes and the use of cases for IFC View Definitions. One important issue is also, to formalize a mapping structure to provide synchronized activities.

Furthermore, Design-Build, Lump Sum Contracts, Turn-Key Systems dependent process aspects which address OMP and ITMP are examined in detail.

5.10.1 Formalization of the IT Management Design Process in ceEPC

Design is a complex activity and the design process lies within scientific, social, economic and cultural context at the same time (Laaroussi 2005). Different perceptions of this complexity can cause different consequences. In order to reduce ambiguity, to reach stable decisions and to construct seamless connections within project stakeholders by use of reliable software, a holistic process definition is necessary.

In order to formalize an integrated view from the Design perspective in this regard an IT Management Design Process using ceEPC model is formalized, (see Appendix B1).

In detail the IT Management Design Process starts with the opening of a new production resource, material analysis and measurement folders in ERP system (ITMDP_{F-1}). Also basic management groups (ITMDP_{F-2}) and building details (ITMDP_{F-3}) are defined initially. These are arranged according to project specifications by the bidding department (BD). In order to support integration, production resource and material analysis with their codes (these are not restricted regarding to project needs and comprise all catalog information) are formed (ITMDP_{F-4}) in ERP structure. Bidding department (BD) can form these items from different sources such as, firm databanks, general country libraries etc. After establishing these items in ERP system, they can be used in CAD systems (ITMDP_{F-5}) to form common structures. If it is a Design and Build contract, after having the detailed project specifications, Design Firm (DF) plans and analyzes construction design, related elements (ITMDP_{F-6}). Subsequently DF forms production catalogs, production resources and material analysis according to project requirements (ITMDP_{F-7}). In the envisaged model, the drawings should be constituted in 3D format (ITMDP_{F-8}) (if not already received in 3D format), to take the quantity take-off lists. This can be done either by a design firm (in Design and Build system) or by BD (in Lump-sum and Unit Price systems) based on the procurement systems' requirements. Subsequently converting the drawings into a 3D structure, production resource lists and material analysis with their IDs are attained to these drawings (ITMDP_{F-9}) based on the project specifications. These IDs are the milestones that are used in each phase of the envisaged model. The production resources, material analysis, BOQ lists, scheduling activities, cost analysis, and procurement etc. can be structured according to these IDs. Subsequently, after attaining these codes to drawings, the quantity take-offs are formed (ITMDP_{F-10}) in the CAD system.

In order to form the BOQ lists, these quantities are transferred from the CAD system to the ERP system (ITMDP_{F-11}) using a reliable interface. The aim is to export the quantity surveying and the section analysis in a desired format that these can be used in other phases.

Although considerable developments for CAD systems have been maintained up to now and most of the items can be supported in a 3D format by CAD developers, there are special issues observed which are not provided by CAD programs. In order to formalize information exchange between CAD and ERP systems, the given statements have to be fulfilled.

- Information exchange between CAD-ERP systems are connected to the ability of the existing CAD and ERP systems. Thus, while choosing the software, this requirement has to be completed.
- According to the defined 3D model aspects in CAD applications in general, we only focus on structural and architectural quantity surveying to support an efficient CPM.
- Some construction items are not constituted in CAD systems because of the lack of capabilities of the existing drawing programs. These items can be defined in ERP system and quantity take-offs can be added to measurement lists in ERP structure.
- The mechanical and electrical quantity take-offs can also be added in ERP system.
- The use of ERP-CPM integration and process sequence can be changeable according to the procurement system. Never the less to support a generic approach, the formalized processes are developed to comprise identified procurement systems as Design-Build, Lump Sum and Unit Price Contracts.

As it is given in statements, data exchanges between different software is dependant on the ability of the existing programs. But in order to close these gaps with regard to quantity surveying, the ERP measurement structure can be formed in a flexible way so that the external measurement information can also be added to conclude the integration. In the next paragraphs, the detailed identification of this flexibility is shown for the BOQ process.

5.10.2 Formalization of IT management BOQ process in ceEPC

IT Management BOQ Process (ITMBP) comprises the estimation of construction resources and their possible construction costs to form the BOQ. The information which is used in this process was produced during the design phase. Thus the detailed estimations can be carried out prior to drawings and contract specifications. To finalize a BOQ and to support integration between CAD and CPM systems a ITMBP model is realized. To derive the project BOQ, all possible systems are considered and an integrated structure based on OMP is formed according to ceEPC Model. The brief explanation of the envisaged system is given in the following section and the detailed representation of the process is illustrated in Appendix B2.

IT Management BOQ Process starts with identifying the basic items which are used in the overall management of the suggested structure. Initially, the possible responsible person lists are formed (ITMBP_{F_1}) to use them in the planning phase within project progress. The production resources and material analysis are the milestones of the information exchange.

To support project's specific aspects, there is a need for different folders (production resource, material analysis etc.). Therefore material analysis folder which is structured in the design process is opened (ITMBP_{F_2}). Afterwards, to support project data, a new production resource price1 (ITMBP_{F_3}) and a new material analysis1 (ITMBP_{F_4}) folder is structured in ERP system. Material analysis according to country products catalogs or firm databank etc. are copied to material analysis1 folder (ITMBP_{F_5}) from material analysis folder to support information exchange within the structure. These analyses, which are composed of production resources, are used as the basic items to form the new production resource1 lists. Thus

production resource1 folder is opened (ITMBP_{F_6}) and subsequently these are sent to production resource1 folder (ITMBP_{F_7}) to form project specific production resources. According to project needs, market research regarding Procurement Process is carried out and the market prices are accessed to production resource1 (ITMBP_{F_8}) folder. In order to form new analysis with market prices, these prices are sent to analysis1 folder (ITMBP_{F_9, F_10, F_11}). According to the decision of top management, amortization and transport expenses are added (ITMBP_{F_12}) to these analysis. After completion of external data, analysis1 folder is rearranged (ITMBP_{F_13}) according to new information. In order to form a BOQ list we need quantity surveying. In this sense, the calculated quantity take-off lists, which are taken from CAD system to ERP system in IT Management Design Process, are used while opening the measurement folder in ERP system (ITMBP_{F_14}). As it is mentioned above the quantity take-off that can be formed in CAD systems are related too much with the ability of the particular CAD system. If the necessary quantity take-offs could not be obtained within the CAD system, these measurements can directly be accessed to ERP system i.e. by hand, in this regard. In our approach rc-bars, profiles, electrical and mechanical measurements are not yet supported by CAD systems in a required format, in terms of establishing quantity take-off lists: rc-bars' quantity take-offs (ITMBP_{F_15, F_16}), mechanical quantity take-offs (ITMBP_{F_17, F_18}) electrical quantity take-offs (ITMBP_{F_19, F_20}) can be accessed manually to measurement folder to fill this gap. After all measurements are formed according to project specifications, they are arranged (ITMBP_{F_21}) in a main section measurement table and then sent to BOQ folder (ITMBP_{F_22}). To form BOQ list, production resource1 and material analysis1 lists are required. In order to establish the BOQ folder, these lists are sent to this folder (ITMBP_{F_23, F_24}) and used for calculation of the proposal.

Although a road map is given based on the preparation of BOQ lists and the basic statements are given in the design phase, additional considerations are necessary in this context.

Statements:

- To support data exchange between CAD and ERP systems, the production resource lists and analysis lists should be obtained in reliable formats.
- The rc-bars, electrical and mechanical measurement lists are taken into account as if they are made by external sources in terms of by hand or other related software.
- The interface between CAD and ERP systems is assumed as if it would have been written in XML format.

Furthermore planning is also considered as a requirement for the Bidding Preparations. In this context to fulfill all requirements from a generic view, IT use in the planning processes is examined in detail in the following section.

5.10.3 Formalization of IT Management Scheduling Process in ceEPC

The IT Management Scheduling Process (ITMSP) defines the scheduling of project pre-work program using reliable scheduling systems namely Primavera, Ms-Project, or Artemis. These systems have the ability to report the allocation of the resources (Gokce et al. 2005).

In order to formalize a holistic structure, ITMSP process is constituted based on ceEPC. The detailed process definition can be found in Appendix B3.

Supporting the data exchange between ERP and Scheduling systems can reduce the scheduling time and improve the quality of the information such as: work schedule, cash flows, work orders and budget etc. However, the existing solutions are far from forming generic models, because these are not supported by pre-defined IT management processes. Thus, the systems which are expected to support IFC have not appeared yet.

IT Management Scheduling Process starts with opening of scheduling module in ERP system (ITMSP_{F_1}). This module is required to update work programs in order to form progressed payments, realized budget, labor and material costs etc. for the subsequent phases. The activity sequence is the milestone for scheduling. The activity IDs that are used for BOQ list can also be used as activity poses for pre-work program. These IDs should be arranged before data exchange between ERP and scheduling systems happens. After opening the scheduling module in ERP, the activity pose numbers should be arranged (ITMSP_{F_2}) by the Planning Department (PD) to use them in scheduling systems. The BOQ lists, which can be used for activity lists are sent to (ITMSP_{F_3}) the scheduling system. The activity descriptions are arranged (ITMSP_{F_4}) in scheduling system afterwards. The main idea is formalizing the activities regard the construction process. After formalizing the structure, durations are estimated (ITMSP_{F_5}) and attained to activities. To set-up the program, the activities which affect each other are connected (ITMSP_{F_6}). This helps us to calculate the work program and to see the critical path in terms of red lines of the project progress. After completion of connection of the activities, the work program is calculated (ITMSP_{F_7}). The material requirement lists and buying lists are the main items for purchasing/procurement process. These are used to purchase project materials according to project schedule. Most of the CPM systems such as Primavera, Suretrak or Artemis have the ability to calculate the material requirement and buying lists if the project resources have access to the system. But as it is known, access of resource data to the system is not an easy task for planners. In our proposed structure this data is imported directly from unit price1 and analysis1 lists from ERP System. According to established structures within the system, requirement lists (ITMSP_{F_8}) and buying lists (ITMSP_{F_9}) can be calculated easily in this context. Also the preliminary budget (ITMSP_{F_10}), cash flow diagrams and work order lists (ITMSP_{F_11}) can be derived from Scheduling System. After calculation of the work schedule and taking the necessary tables, lists and diagrams. The work schedule, budget, cost and work order lists are sent (ITMSP_{F_12}) to ERP system with using an XML interface and arranging them there (ITMSP_{F_13}). This helps to form stock and cost control tables (ITMSP_{F_14}) within ERP system. To arrange the cost control tables, the existing production resource 1 folder is opened (ITMSP_{F_15}) and copied (ITMSP_{F_16}) to cost tables which are a component of cost module in ERP system. Afterwards, cost control folder/module is opened (ITMSP_{F_17}) and related budget and cash flows are calculated (ITMSP_{F_18, F_19}) according to weekly or monthly work schedule in ERP system. This helps to formalize the cash flows and formalize the BOQ in a structure.

Construction projects comprise detailed activities. In order to support detailed scheduling, pre-work program is used as a baseline. In the envisaged planning and construction phase, general work program should be scheduled which also represent detailed activities. The main activity definitions can be taken from pre-work program and can be divided into sub-

activities. This helps to manage the job site efficiently and to derive progressive monthly payments.

In this context, the principles of IT Management Processes can therefore be summarized as a generic approach which is capable of representing diverse but interconnected aspects that are used within bidding and jobsite applications. However to provide reliability, a definition of system use is required for different application areas. Thus, in order to provide generality, procurement system dependent process aspects are examined in this regard.

5.11 Procurement System Dependent Process Aspects

Due to the comprising variety of structures, depending on different type of aspects in bidding preparations, a frame should be drawn to limit the context. In order to prove the concept for different conditions, OMP aspects, according to various procurement systems, are formalized. Generally different types of procurement systems are consented like Design & Build, Lump-Sum, Cost Plus, Unit Price and BOT as described in Chapter 2.

Three of the systems, namely Design & Build, Lump-sum and Unit Price, are compatible with our structure (see section 5.2) due to initial requirements of the complete design. However Cost Plus and BOT systems do not suit with the envisaged model because the design can change during the project progress in the Cost Plus system and the BOT requires the feasibility work which is out of the scope of this thesis.

Moreover part of the Generic Representation of OMP (see Figure 5.4) is given to guide the realization of procurement system dependent process aspects, in **Figure 5.5**.

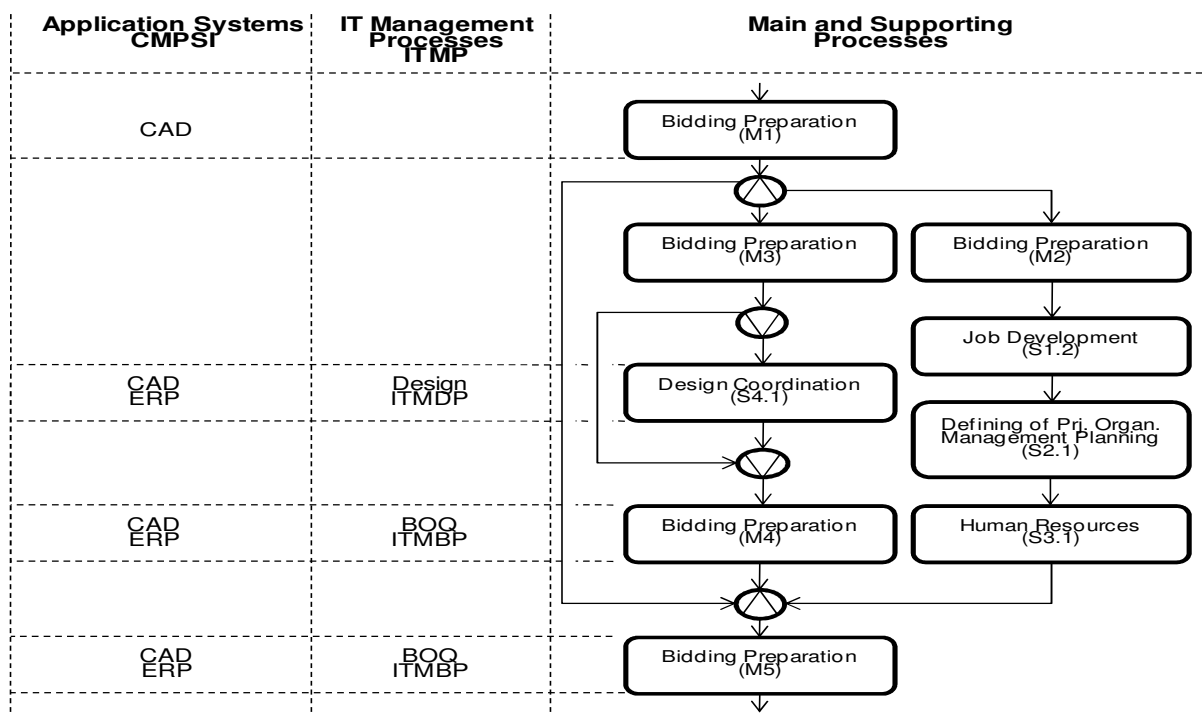


Figure 5.5 Part of the Generic Representation of OMP

The main aspects are defined in detail and the common items which are constituted in OMP are used as it was constituted.

The process definitions according to envisaged systems are identified based on SME's (small, medium enterprises) management structures. Possible head office and site organization charts are given below in **Figure 5.6** and **Figure 5.7**.

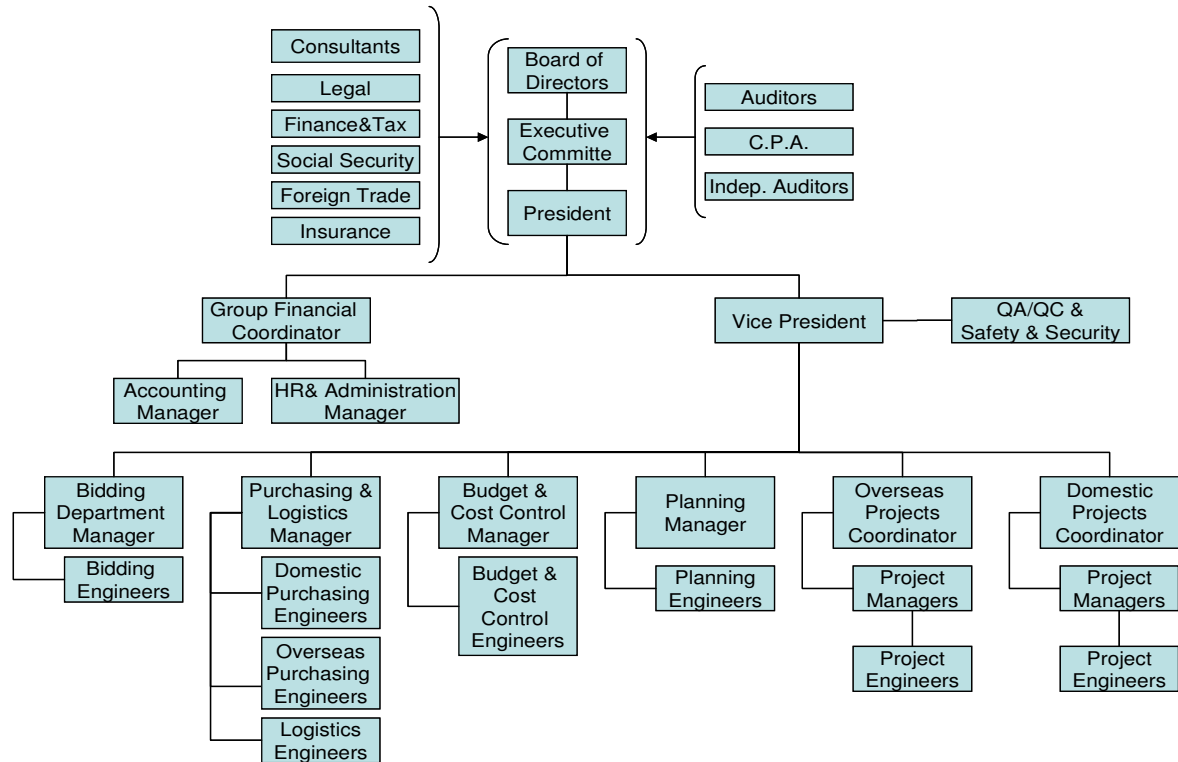


Figure 5.6 Possible Head Office Organization Chart

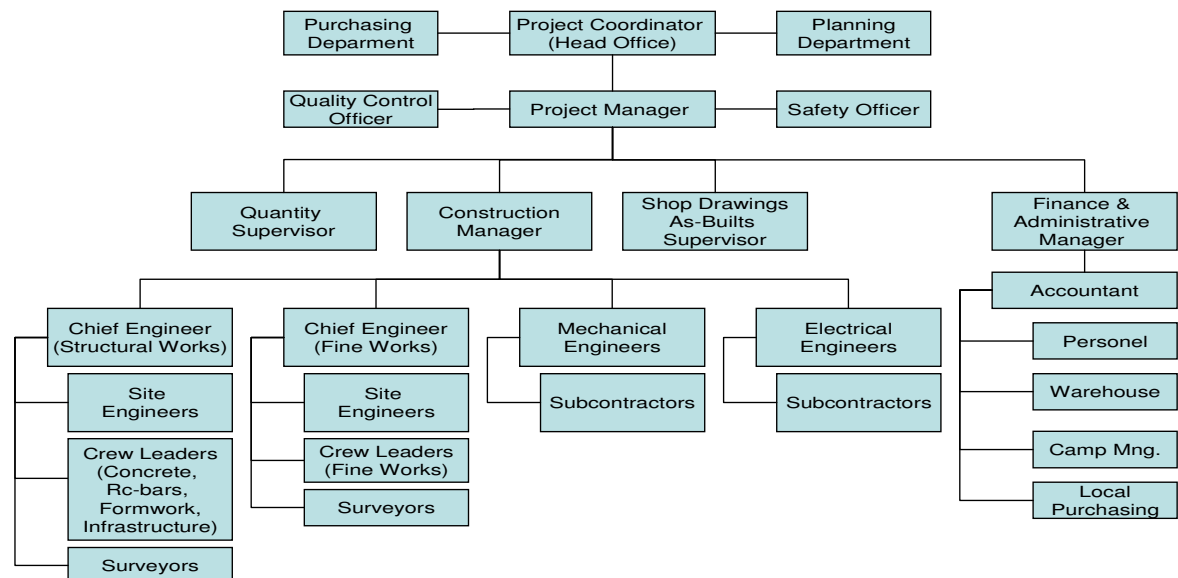


Figure 5.7 Possible Site Organization Chart

5.11.1 Organizational Management Process and IT Management Processes for Design & Build Procurement System

As it is described in the introduction of the procurement systems (see Section 2.6), the proposed processes best suit the Design & Build Procurement System. According to the statements that are given in the previous sections, the interaction between OMP and ITMDP starts with the requirement of the design process within the OMP sequence. As it is mentioned, the OMP Structure is referenced by 8 other QM processes. In order to ensure clarity the related (main and supporting) processes given in Figure 5.5 are illustrated before the related definitions.

Bidding Preparation Process (M1)

In this context, if the process comprises design activities (based on the bidding documents which do not support our structure), the bidding manager chooses a designer from “Selected Subcontractor Lists” according to QM Design Coordination Process. After choosing the design firm, the bidding manager informs the designer about project specifications and makes the related agreements.

Bidding Preparation Process (M3)

According to the Design-Build Procurement attributes, possible project requirements, construction constraints, market assessments, and construction elements etc. are considered initially. From a software integration point of view, for managing the activities, the product catalogs composed of production resources with their ID's should also be identified in the first stage. These catalogs can be national, international or the firm's private catalog, as it is mentioned.

In order to formalize these aspects within ITMDP, the process sequence starts by opening a new project, unit price, quantity take-off list folders in ERP System (ITMDP_{F_1}). Following this, groups and subgroups (ITMDP_{F_2}) and building detail groups (ITMDP_{F_3}) are identified. Subsequently new production resource, material analysis and quantity take-off folders, are formed in the ERP structure in order to use them for the CAD system (ITMDP_{F_4}). The following function “Send Unit Price Libraries from ERP System to CAD System” illustrates, the systems ability to contact each other using XML interface (ITMDP_{F_5}).

Design Coordination Process (S4.1)

After obtaining the detailed project specifications the Design Firm (DF) plans and analyzes (ITMDP_{F_6}) construction design and the related elements. Subsequently, the DF possesses production catalogs, production resources and material analysis (ITMDP_{F_7}) according to the project requirements.

After completion of the information exchange, the 3D design which is an essential part of this approach is taken up within the OMP as a function “Do the Design in 3D Format Attain the Project Materials and Calculate Quantity take-offs” (ITMDP_{F_8}).

Regarding information, the Responsible Designer starts to draw the project drawings in 3D format and appoint (ITMDP_{F_9}) the unit prices to related drawing items in the CAD system within the ITMDP. It is required for the calculation of the Quantity Take-off. After finalizing design and taking the quantity take-off lists (ITMDP_{F_10}), the designer send this list to the

ERP system (ITMDP_{F_11}). Sequentially DF informs the main contractor about the 3D drawings and measurements within the OMP (OMP_{F_37, F_39}).

Bidding Preparation Processes (M4, M5)

As it is mentioned in the previous sections, the Quantity Take-offs can be calculated in a CAD system according to the 3D modeling attributes, and the ability of the existing connection aspects. In order to formalize all quantity take-offs without any loss, the measurement lists within the systems should be checked and the additional measurements have to be added to ERP structure (OMP_{F_43, F_44}).

After completion of the measurements, the process sequence follows the structure both for Organizational Management Process and IT Management BOQ and Scheduling Processes.

5.11.2 Organizational Management Process and IT Management Processes for Lump-Sum Procurement System

In Lump-sum procurements system, the client must have a complete design before soliciting bids. The plans and specifications have to be defined very precisely that the contractor submits a lump-sum amount to perform the work required in the documents.

Bidding Preparation Processes (M4, M5)

Because the detailed planned work like drawing of the projects, calculation of quantity take-offs, assumption of the project resources, materials etc. is done by the client side, the OMP starts with function F_42 “Arrange Quantity Take-off, Drawings, Production Unit Price and Material Analysis Folders and Form Quantity Take-off structure in ERP System”. However, there would be a need to form additional Quantity Take-offs (OMP_{F_43, F_44}) for precise calculations.

After completion of the related calculations, the process sequence follows the OMP sequence which is also the same for the Design & Build Procurement System approach.

On the other hand, when the existing situation is examined in the construction industry, drawings are made in 2D formats, the project units are working separately and the measurements are done by hand before solicitation. This approach causes considerable problems to reach proper quantity take-offs and to form correct BOQs.

Bidding Preparation Processes (M4, M5)

In this case, the bidding department forms production resources in an ERP system initially and send these to a CAD system. After forming or converting the 2D drawings to 3D drawing format in CAD system, these units are attained to these drawings as it is envisaged within the function “Arrange Quantity Take-off, Drawings, Production Unit Price and Material Analysis Folders and Form Quantity Take-off structure in ERP System”. This facilitates to have the correct quantity take-off with their unit identifications. ITMDP which is given within Design & Build Procurement System describes this approach in a detailed way.

After completion of production resources, quantity take-offs and material analysis the process sequence follows the OMP developed in Chapter 5.

5.11.3 Organizational Management Process and IT Management Processes for Unit Price Procurement System

Generally, Unit Price procurement system is used by the Public Sector. Because of dependence on fixed rates determined by the Ministry of Public Works, the project production resources can be taken from these lists to use them as production resource prices in the ERP structure. The important issue is that 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.

From the contractor point of view, precise calculations on quantity take-offs and prices is absolutely helpful to win the bidding. These requirements are supported by referencing of developed processes.

Bidding Preparation (M1-M3), Design Coordination Process (S4.1)

In this context, to provide precise quantity take-offs, the process sequence follows ITMDP functions, (ITMDP_{F_1}, F_2, F_3). Based on the definition of Unit Price procurement system, product catalogs, production resources and material analysis folders can be structured according to fixed rates of the client (ITMDP_{F_4}) and can be used within CAD system (ITMDP_{F_5}). According to the outcome of this, the drawings can be converted to 3D (ITMDP_{F_8}), and subsequently the production resources and material analysis can be attained (ITMDP_{F_9}) to 3D drawings to have quantity take-off and then the quantity take-offs are formed (ITMDP_{F_9}) and transferred to the ERP system.

After completion of related calculations, the process sequence follows the general process definition regarding OMP which is the same for Design & Build and Lump-Sum Procurement Systems too. Based on the fixed rate prices, the BOQ can be established precisely.

In Design & Build, the design functions including 3D drawings, forming of procurement resources, attaining of codes to these drawings etc. are done by Design Firm but in Lump-sum procurement system, because the design is provided by the client, converting the system (if it is given in 2D) to 3D and attaining fixed procurement resources to 3D is done by the contractor, in terms of the Bidding Department.

As it is mentioned, differences can be seen within the structures, the applications overlapped in some points. As a generalized model which is offered in this research, it comprises most of the activities from contractor and preparation of bidding structure point of views.

5.12 Summary and Conclusions

The principal process definitions; 1) The Organizational Management and (2) The IT Management Processes were structured to define the Bidding Preparation Phase.

The main aim of the suggested approach is to enable handling various types of information coherently, including product, process and management data to formalize a conceptual framework and to reach an integrated structure.

In order to provide this, the Organizational Management Process was developed based on an implemented Lifecycle Model for the Processes, which brings different views together in one process structure.

Subsequently, IT Management Processes are described in accordance with the CAD-ERP-Scheduling interoperability needs according to Construction Management Phases for Software Interoperability and Organizational Management Processes.

The ceEPC Model was used to establish the overall framework. This helps greatly to design and interoperable software solution and to configure business and technical management functions for the actual procurement system used. Moreover, it can be used to formalize the mappings between the different but interrelated data and functional definitions. The details are given in Chapter 6.

According to the defined process activities, resources can be mapped with the required IFC objects or, where necessary, these resources can provide new entities within an IFC model extension for the CPM. Details are given in Chapter 7.

Based on the formalized models, Design-Build, Lump-Sum Contracts, Turn-Key Contracts have been examined to specify system dependent process aspects. It is shown that the suggested model is also complementary for three envisaged Contract Types.

The methodology shown at the example of Bidding Preparations can be applied to any of the other phases of the CPM.

CHAPTER 6: MAPPING BETWEEN PHASES AND PROCESSES

In order to support completeness between Construction Management Phases for Software Interoperability (CMPSI), Organizational Management Process (OMP) and IT Management Processes (ITMP), a process mapping structure is proposed in this chapter. The goal is to provide complete process definitions and to illustrate commonalities by providing 1-1 mappings.

6.1 Introduction

Due to increasing demands for CIC (Computer Integrated Construction) models in the AEC sector, integration between CPM processes, organizational structures, and management aspects have become an important part of information system design.

The integration of CPM processes requires the specification of process structures as well as the definition of resources involved in the execution of these processes. However, the observations within existing initiatives prove the lack of integrations among intelligent agents, technical resources and process activities.

A resource also known as actor, performer, or process participant (WFMC 1999) is an entity that is assigned to a function and is requested in runtime to perform work in order to complete the objective of this activity (Zur Muehlen 2004).

A resource model is composed of human and technical resources which are involved in formalizing the processes. In order to represent all different entities taking part in a process sequence, there is a need for a mechanism which represents all resources in an appropriate format.

Several initiatives have been performed to identify resources and resource models such as: Role-based Access Control by Goh et al. (1998) in order to represent an alternative to traditional approaches to handling access control information systems, the Organization and Role Model (ORM) by Cheng et al. (1999) which aims at a separation of organization and roles in the context of electronic commerce applications, An Independent Resource Management Facility by Huang et al. (1999) which was implemented in the workflow management system HP Changengine, The Resource Meta Model by van der Aalst et al. (2003) which consists of a UML class diagram and a corresponding XML rendition for the specification of workflow resources, etc.

As it is observed from the prior process and resource models, a generic concept which brings together different but complementary views and aspects such as application systems, QM procedures and processes, organizational units, procurement systems, has not been constituted up to now.

In this context, in order to fulfill this gap and to provide a generic concept which identifies resources that can be addressed by CPM processes, a mapping structure is possessed between Construction Management Phases for Software Interoperability (CMPSI), Organizational Management Process (OMP) and IT Management Processes (ITMP).

This help us to examine IFC views which will be used to implement an IFC based management approach.

6.2 Approach

The precise representation of relations among functions, events and resources through the definition of the related attributes and the properties is of great importance in obtaining process accuracy.

In order to provide this, in our approach, a mapping configuration is formalized according to the given acquiesces.

- 1 The Construction Management Phases for Software Interoperability (CMPSI) which are identified in IDEFØ, and the Organizational Management Process (OMP) and IT Management Processes (ITMP) which are identified in ceEPC are examined to provide a mapping structure.
- 2 A Mapping structure which includes CMPSI, OMP and ITMP are formalized to support consistency.

6.3 Mapping for Construction Management Phases for Software Interoperability and Organizational Management Processes

The mapping between CMPSI and OMP can be achieved with a 1-1 mapping.

The main idea is to use CMPSI functions as core-functions which are referenced by OMP functions as sub-functions. Also resources which are characterized in IDEFØ under Control, Input, Output and Mechanism are referenced by OMP resources as sub-resources.

In order to express the mapping, a mapping language is needed.

In this context, a general notation structure, process entity notations and resource entity notations are formalized to provide a common structure.

6.3.1 Construction Management Phases for Software Interoperability Notations

The CMPSI structure is composed of three levels.

Level 1, is the phase level and level 2 is the function level. The resources on level 2 may be of various types and hence comprised a 3rd level.

In the following, the notations for the 3 levels are given.

The CMPSI comprises 6 phases. The related Notations are summarized in **Table 6.1**.

Table 6.1 CMPSI Phase Notations

Phases	Notations
Design Phase	DP
Bidding Preparation Phase	BP
Planning & Construction Phase	PCP
Project Payments Phase	PP
Evaluation & Feedback Phase	EFP

The Construction Management Phases for Software Interoperability (CMPSI) are represented with the IDEFØ modeling methodology in Chapter 4.

The IDEFØ modeling methodology is composed of 5 entities which are: function, input, output, control and mechanism.

The abbreviations of the entity notations defined in Section 3.3.2 are given in **Table 6.2**.

Table 6.2 CMPSI Entity Notations

Entities	Notations
Function	F
Input	I
Control	C
Mechanism	M
Output	O

The notations for the two levels are combined in the following way so that level 1 is the leading one and level 2 notations is appended to level 1 notation as an index.

“Phase Notation_{Function_Number}”

To illustrate the chosen structure an example is given:

Design Phase: DP

Function 2: “Form/Rearrange Prod. Catalogs, Production Resources and Material Analysis According to Project Requirements”: **F_2**

Notation: DP_{F_2}

In order to represent related resources within process formalizations and to show mappings within CMPSI and OMP, a structure is constructed according to function entity notations.

According to ceEPC model the resource entity notations are abbreviated in **Table 6.3**.

Table 6.3 Resource Entities and Notations based on ceEPC

Resource Entities	Notations
Organizational Entity	OE
Group of Organizational Entity	GOE
Actors	A
Services	S
System Folder	SF
Document	D
System Interface	SI

To represent resource mappings, a notation structure is formalized based on 3 notation components separated by underlines as illustrated in **Figure 6.1**. The resources which are given in the ceEPC model are represented according to the roles based on the OMP. Therefore the roles such as Organizational Entity, Group of Organizational Entity, Actors and Services types are represented as resource role. On the other hand, because the envisaged process structure comprises different types of documents, forms, folders etc., System Folders, Documents and System Interfaces are expressed with an expression number.

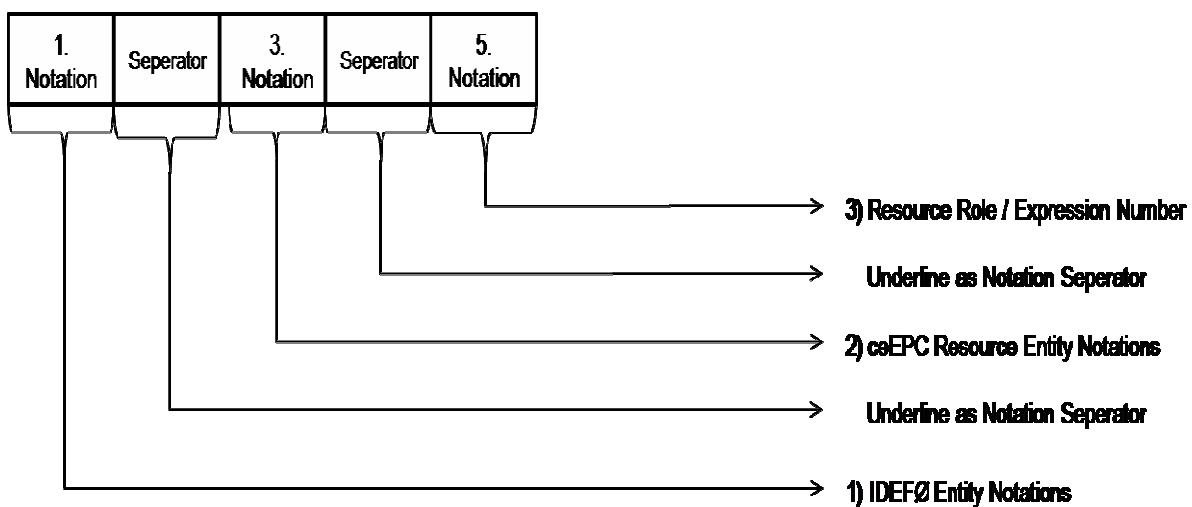


Figure 6.1 Notation Structure for the Representation of Organizational Entities,

According to envisaged notation the Resource Entities and the related Notations for CMPSI are given in **Table 6.4**.

Table 6.4 Resource Entities and the Notations for CMPSI

Resources	Notations
Organizational Entity under Mechanism	M_OE
Main Contractor	M_OE_MC
....
Group of Organizational Entity under Mechanism	M_GOE
Bidding Department	M_GOE_BD
....
Actors under Mechanism	M_A
Bidding Manager	M_A_BM
....
Services under Mechanism	M_S
CAD	M_S_CAD
....
System Folders under Mechanism	M_SF_1, M_SF_2...M_SF_n
Documents under Input	I_D_1, I_D_2...I_D_n
Documents under Control	C_D_1, C_D_2...C_D_n
Documents under Output	O_D_1, O_D_2...O_D_n
System Interface under Mechanism	M_SI_1, M_SI_2...M_SI_n

In order to represent resources based on CMPSI definition the following notation is used.

“Phase Notation_{Function_Number, Resource}”

To illustrate the introduced notation an example is given below.

Design Phase: DP

Function 2: “Form/Rearrange Prod. Catalogs, Production Resources and Material Analysis According to Project Requirements”: **F_2**

DP_{F_2} is given in **Figure 6.2**.

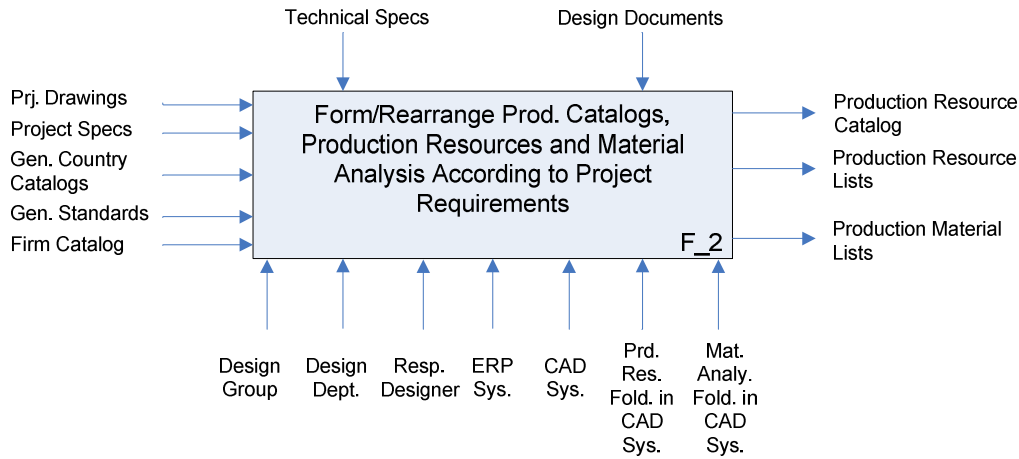


Figure 6.2 CMPSI Function 2

In this function, under Mechanism; one Organizational Entity (Design Group), one Group of Organizational Entity (Design Department), one Actor (Responsible Designer), two Service Systems (ERP, CAD), two System Folders (Production Resource and Material Analysis Folders), under Input; five documents (Project Drawings, Project Specs, General Country Production Catalogs, General Standards, Firm Production Catalogs), under Control; two documents (Technical Specs, Design Documents) and under Output; three documents (Production Unit Libraries, Production Unit Lists, Production Material lists) are structured. The resource notations for DP_{F_2} are given below.

DP_{F_2} Resource Notations

In the following only one entity of each type is shown for convenience.

Organizational Entities under Mechanism for DP_{F_2} :

- Design Phase, Function_2, Mechanism_Organizational Entity_Design Group:

$DP_{F_2, M_{OE_{DG}}}$

Group of Organizational Entities under Mechanism for DP_{F_2} :

- Design Phase, Function _2, Mechanism_Group of Organizational Entity_Design Department:

$DP_{F_2, M_{GOE_{DD}}}$

Actor Entities under Mechanism for DP_{F_2} :

- Design Phase, Function _2, Mechanism_Actor_Responsible Designer:

$DP_{F_2, M_{A_{RD}}}$

Service Entities under Mechanism for DP_{F_2} :

- Design Phase, Function _2, Mechanism_Services_ERP:

$DP_{F_2, M_{S_{ERP}}}$

System Folder Entities under Mechanism for **DP_{F_2}**:

- Design Phase, Function _2, Mechanism_System Folders_1, (Pd. Res. F. in CAD S.):
DP_{F_2}, M_SF_1

Document Entities under Input for **DP_{F_2}**:

- Design Phase, Function_2, Input_Document_1, (Prj. Drawings):
DP_{F_2}, I_D_1

Document Entities under Control for **DP_{F_2}**:

- Design Phase, Function_2, Control_Document_1, (Technical Specs.):
DP_{F_2}, C_D_1

System Folder Entities under Output for **DP_{F_2}**:

- Design Phase, Function_2, Output_System Folders_1, (Production Res. Catalog):
DP_{F_2}, O_SF_1

6.3.2 Organizational Management Process Notation

The OMP Notations are constituted as given below in **Table 6.5 - 6.7**.

Table 6.5 Process Notation for Organizational Management Process

Process	Notation
Organizational Management Process	OMP

According to established ceEPC structure the process entity notations are formalized as given in **Table 6.6**.

Table 6.6 Function and Event Entity Notations

Entities	Notations
Function	F
Event	E

In our structure, Processes and Events are represented with using of numbers based as given in **Figure 6.3**.

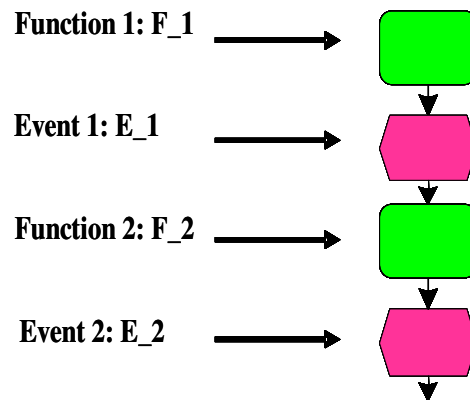


Figure 6.3 Function and Event Notations

In order to represent functions and events based on the OMP a structure is formalized below:

“Process Notation_{Function_Number}”: **“OMP_{F_2}”**

“Process Notation_{Event_Number}”: **“OMP_{E_2}”**

In order to provide an easy notation for the mapping between CMPSI and OMP, the Resource Entities and Resource Notations for the OMP use the same notation as in the CMPSI Resource Representations which are given in **Table 6.3** and **Table 6.4**.

As it was envisaged in the previous chapters, OMP comprises different views. To construct a holistic approach which is defined by these views requires the identification of the related resources.

In order to formalize these resources, the resource notation structures which are given in **Figure 6.1** and in **Figure 6.2** are used.

“Process Notation_{Function_Number_Resource}”: **“OMP_{Function_Number, Resource}”**

In order to illustrate the introduced notation for OMP an example is given.

Organizational Management Process: OMP

Function 30: “Form/Rearrange Prod. Catalogs, Production Resources and Material Analysis According to Project Requirements”: **F₃₀**

OMP_{F₃₀} is given in **Figure 6.4**.

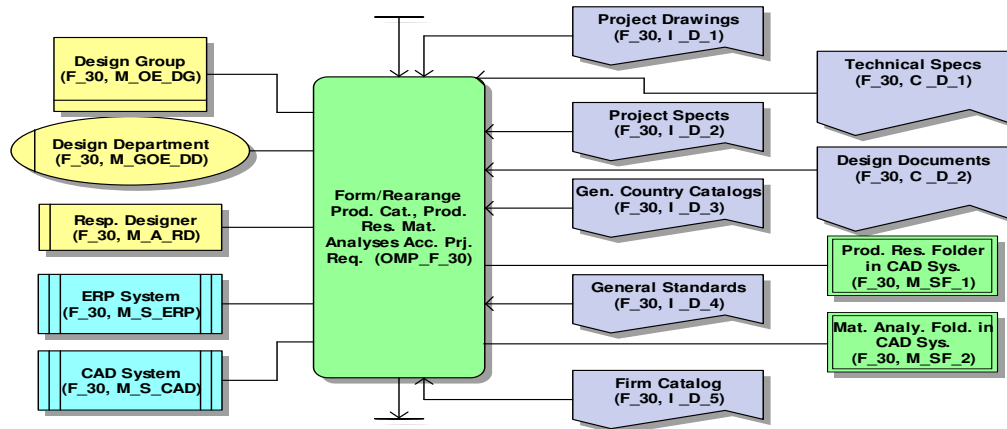


Figure 6.4 OMP Function 30

In this function, under Mechanism; one Organizational Entity (Design Group), one Group of Organizational Entity (Design Department), one Actor (Responsible Designer), two Service Systems (ERP, CAD), two System Folders (Production Resource and Material Analysis Folders), under Input; five documents (Project Drawings, Project Specs, General Country Production Catalogs, General Standards, Firm Production Catalogs), under Control; two documents (Technical Specs, Design Documents) and under Output; three documents (Production Unit Libraries, Production Unit Lists, Production Material lists) are involved.

The IDEFØ resources which are identified under input, mechanism, control and output are referenced by ceEPC resources. Input, mechanism and control resources are accepted by direct resources, the outputs of preceding functions can be used as inputs or control resources to formalize processes sequence in this regard.

OMP_{F_30} Notations

In the following only one entity of each type is shown for convenience.

Organizational Entities under Mechanism for OMP_{F_30}:

- Organizational Management Process, Function_30, Mechanism_Organizational Entity_Design Group:

OMP_{F_30, M_OE_DG}

Group of Organizational Entities under Mechanism for OMP_{F_30}:

- Organizational Management Process, Function _30, Mechanism_ Group of Organizational Entity_Design Department:

OMP_{F_30, M_GOE_DD}

Actor Entities under Mechanism for OMP_{F_30}:

- Organizational Management Process, Function _30, Mechanism_ Actor_Responsible Designer:

OMP_{F_30, M_A_RD}

Service Entities under Mechanism for **OMP_{F_30}**:

- **Organizational Management Process, Function _30, Mechanism_ Services_ERP:**
OMP_{F_30, M_S_ERP}

System Folder Entities under Mechanism for **OMP_{F_30}**:

- **Organizational Management Process, Function _30, Mechanism_ System Folders_1, (Production Resource Folder in CAD System):**
OMP_{F_30, M_SF_1}

Document Entities under Input for **OMP_{F_30}**:

- **Organizational Management Process, Function_30, Input_ Documents_1, (Prj. Drawings):**
OMP_{F_30, I_D_1}

Document Entities under Control for **OMP_{F_30}**:

- **Organizational Management Process, Function _30, Control_ Documents_1, (Technical Specs):**
OMP_{F_30, C_D_1}

6.3.3 Mapping Structure between Construction Management Phases for Software Interoperability and Organizational Management Process

In order to represent appropriateness, a process mapping structure, between CMPSI and OMP is realized.

An example is formalized based on CPMSI Design Phase Function 2 and OMP Process Function 30.

Function Mapping	: DP_{F_2} = OMP_{F_30}
Organizational Entities Mapping under Mechanism	: DP_{F_2, M_OE_DG} = OMP_{F_30, M_OE_DG}
Group of Org. Entities Mapping under Mechanism	: DP_{F_2, M_GOE_DD} = OMP_{F_30, M_GOE_DD}
Actor Entities Mapping under Mechanism	: DP_{F_2, M_A_RD} = OMP_{F_30, M_A_RD}
Service Entities Mapping under Mechanism	: DP_{F_2, M_S_ERP} = OMP_{F_30, M_S_ERP}
System Folder Entities Mapping under Mechanism	: DP_{F_2, M_SF_1} = OMP_{F_30, M_SF_1}
Document Entities under Input	: DP_{F_2, I_D_1} = OMP_{F_30, I_D_1}
Document Entities under Control	: DP_{F_2, C_D_1} = OMP_{F_30, C_D_1}

Because the resource notation structure do not change between CMPSI and OMP, in the following mappings only the notation for the functions are given.

Based on a 1-1 mapping, the CMPSI and OMP are mapped as:

Phase to Process Mappings:

$$DP_{F_i} = OMP_{F_{28+i}} \quad i = 1, 5$$

$$BP_{F_1} = OMP_{F_{53}}$$

$$BP_{F_2} = OMP_{F_{72}}$$

$$BP_{F_3} = OMP_{F_{88}}$$

$$BP_{F_4} = OMP_{F_{89}}$$

$$BP_{F_5} = OMP_{F_{101}}$$

$$BP_{F_6} = OMP_{F_{105}}$$

6.4 Mapping for Organizational and IT Management Processes

The mapping between OMP and ITMP depend on 1-1 mapping formalization.

The main idea is to use OMP functions as main-functions which are referenced by ITMP functions as sub-functions. Also resources which are characterized within OMP are referenced by ITMP resources as sub-resources.

The goal is to identify interrelations within and between processes to form the model for software interoperability. This approach clarifies information content, exchange requirements and other aspects of interoperability in terms of related processes and as such is the first step towards achievement of a common model.

6.4.1 IT Management Processes Notations

In order to construct processes and resource integration between OMP and ITMP, a notation structure is formalized. ITMP Notations are structured as given, in **Table 6.7**.

Table 6.7 Process Notation for IT Management Processes

Processes	Notations
IT Management Processes	ITMP
IT Management Design Process	ITMDP
IT Management BOQ Process	ITMBP
IT Management Scheduling Process	ITMSP

Function and event notations are expressed in the same way as in the Section 6.3.2, namely:

“Process Notations $\text{Function_Numerical}$: **“ITMDP_{F_2}”**,

“Process Notations $\text{Function_Numerical}$: **“ITMDP_{E_2}”**.

In order to provide integration between ITMP, OMP and CMPSI the Resource Entities and Resource Notations for the ITMP are used in the same way as in the OMP and CMPSI Resource Representations as given in **Table 6.3** and **Table 6.4**. Moreover to formalize these resources the resource notation structure which is given in **Figure 6.1** is used. In order to represent resources based on ITMP, a structure is formalized below.

“Process Notations $\text{Function_Number, Resource}$: **“ITMP_{Function_Number, Resource}”**

To represent resources based on the ITMP an example is formalized below:

IT Management Design Process: ITMDP

Function 7: “Form/Rearrange Prod. Catalogs, Production Resources and Material Analysis According to Project Requirements”: **F₇**

Notation : **ITMDP_{F_7}**

In this context, the OMP resources are referenced by ITMP resources as sub-resources. The mapping structure is illustrated in the following paragraphs.

6.4.2 Mapping Structure Between Organizational Management Process and IT Management Processes

An example is formalized based on OMP Function 30 and ITMP Function 7.

Process Mapping	: OMP_{F_30} = ITMDP_{F_7}
Org. Entities Mapping under Mechanism	: OMP_{F_30, M_OE_DG} = ITMDP_{F_7, M_OE_DG}
Group of Org. Ent. Mapping under Mech.	: OMP_{F_30, M_OE_DD} = ITMDP_{F_7, M_GOE_DD}
Actor Entities Mapping under Mechanism	: OMP_{F_30, M_A_RD} = ITMDP_{F_7, M_A_RD}
Service Entities Mapping under Mechanism	: OMP_{F_30, M_S_ERP} = ITMDP_{F_7, M_S_ERP}
System Folder Entities Mapping und. Mech.	: OMP_{F_30, M_SF_1} = ITMDP_{F_7, M_SF_1}
Document Entities under Input	: OMP_{F_30, I_D_1} = ITMDP_{F_7, I_D_1}
Document Entities under Control	: OMP_{F_30, C_D_1} = ITMDP_{F_7, C_D_1}

Because resource notation structures do not change between OMP and ITMP, in the following mappings only the notations for the functions are given:

OMP_{F_22+i} = ITMDP_{F_i} i=1,5

OMP_{F_23+i} = ITMDP_{F_i} i=6,11

OMP_{F_60+i} = ITMBP_{F_i} i=1,24

OMP_{F_46+i} = ITMSP_{F_i} i=1,7

OMP_{F_47+i} = ITMSP_{F_i} i=8,12

OMP_{F_48+i} = ITMSP_{F_i} i=13,19

6.5 Summary and Conclusions

In this chapter, the mappings between Construction Management Phases for Software Interoperability, Organizational Management and IT Management Processes are examined.

The goal is to formalize complete process definitions and show commonalities within the different structures.

To provide this, CMPSI phases which are formalized in IDEFØ are examined and functions, input, output, control, mechanism and entities (arrows) were structured to reference OMP functions and resources which are constructed in eEPC.

The 1-1 mapping structure between CMPSI functions and OMP functions were developed. The CMPSI functions and related resources were referenced by OMP functions as sub-functions and sub-resources.

OMP provides a main structure from which IT Management Processes are constituted. In this case a 1-1 mapping was obtained too. OMP functions and resources are referenced by IT Management functions as sub-functions and sub-resources. There is a top-down structure which can be realized in this complexity. CMPSI referenced by OMP and OMP is referenced by ITMP. This provides a complete structure and facilitates to establish connections between three different but interrelated structures.

Because, OMP originates from different aspects, a need is observed in this case to expose the process sequence in terms of formalizing CAD-ERP-Scheduling Integration. Based on this, ITMP are formalized as IT Management Design Process, IT Management BOQ Process and IT Management Scheduling Process. This helps us to realize IFC Views in Chapter 7 and to figure out related resources which can be used for IFC extensions.

CHAPTER 7: METHOD TO ESTABLISH GENERIC IFC VIEWS FOR CONSTRUCTION

A method is developed to define generic IFC Views for the information demand in the bidding preparation phase, captured by the information resources identified in the related process models. For convenience the development is focused on the two identified processes in Chapter 5, IT Management Design Process (ITMDP) and IT Management BOQ Process (ITMBP). Two IFC views namely (1) IFC View for Product Catalogs and (2) IFC View for Architectural Design to Quantity Take-offs are worked out for the ITMDP, and one IFC View namely (3) IFC View for Exchange of BOQ Information for ITMBP. The aim is to structure various type of information in a standardized way in relation to the underlying processes. On that basis the information resources of ITMDP and ITMBP which are relevant to IFC Views are examined. An information resource defines one or several partial IFC View, where each partial IFC View contains one to several IFC Classes. Usually classes in Product Models cannot be used as single entities, but they are embedded in a network of classes. These networks are defined as IFC Concepts. Therefore an IFC View consists of several IFC Concepts, which define the complete set of IFC Classes needed. IFC partial views are classified according to their application for exchanging information from one to another domain. These IFC Views are named according to these domains. In addition, for product catalogs (1) a three leveled structure and (2) an extension to IFCs are suggested. The IFC class namely “IfcConstructionResource” which is defined under the “Construction Resource Extension” Concept is extended with new IFC classes and with new object relations. These provide the exchange of building element cost information based on the production resources and the material analysis.

7.1 Introduction

The IFC model is particularly aimed at achieving interoperability between application systems that are used in the entire lifecycle of a construction project.

The majority of AEC software developers have IFC API 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).

Furthermore there are considerable problems which have been addressed in the “PM4D Final Report” (Kam & Fischer 2002) as 1) the different information content in different software products makes it impossible to maintain all the data, when transferring a building product model between different software applications, 2) the instantiated models are large, which makes the file exchange of the model time-consuming although usually only a smart part of the model has changed and transferring the whole model would not be needed, if the partial exchange would have been available, and 3) versioning and controlling user right in file exchange is practically impossible.

In order to find a solution to these problems several initiatives have been suggested such as Process Matrixes which are based on a modified application of Generic Process Protocol,

coupled with the dedicated usage of the Unified Modeling Language (Liebich et al. 2002), IFC-compliant integrated AEC systems using smart objects (Halwafy et al. 2005), Process oriented information modeling methodology for IFC model development (Chen 2006) and project ProIT, which addresses the development of product model based process and modeling its data exchange, compiling design guidelines necessary for product modeling and establishes model structures for the re-use of product libraries (cf. ProIT2004) etc.

However the goal of lossless, incremental data flow through different application systems has not yet been achieved.

In this research, in order to find a solution to seamless data flow between different application systems based on the IFC and to provide a process oriented information modeling methodology, IT Management Processes which are defined in ceEPC model are used as a baseline. Subsequently, the relevancy of the process resources (information resources) to IFC classes are examined and mapped to IFC classes to have IFC Concepts and related IFC Instance Diagrams. The grouping of IFC Concepts provide implementation of IFC Views which are required to represent CAD-ERP and Scheduling systems integration based on IFC.

In this context a conceptual schema which represents the suggested methodology is realized, based on the partial model exchange requirements.

7.2 Partial Model Exchange Requirements

The IFC Object Model as a product data model has a quite large scope that individual end-user applications need to implement the subset of the IFC totality (ProIT cf. 2004). Therefore, for implementation, only the partial models of the IFC Object Model which focus on the specific aspects of the building objects are relevant.

Among the examples for using IFCs in real projects such as The Headquarters for the Danish Broadcasting Corporation (Karlshøj 2002), LBNL E-Lab Building (Bazjanac 2002) and in the project reports of Helsinki University of Technology Auditorium Hall (HUT 600) Project (Kam et al. 2002) in which IFC-based data exchange took place among architects, mechanical engineers, construction managers and 4D research collaborators using IFC release 1.5.1, the necessity of the partial IFC model exchange were strongly emphasized.

Partial IFC Models, also named IFC Views allow each discipline to read data that is particular to it. Furthermore, partial data exchange should have the potential to minimizing the risks of erasing or corrupting other idle project data (Nour 2007).

Eastman and Jeng (1999) indicated that the model evaluation is the transition of a model with one structure or schema to the same or different model with a different structure or schema. In this context, four types of model evaluation were suggested as (1) model translation, (2) view generation from the central model, (3) modification of a single integrated model, (4) mapping between the application and the central product model. In this research as the focus is on the IFC View definitions, the model translation and view generation from the central model is taken into account. Eastman and Jeng (1999) indicated that model translations are most appropriate between the phases of the construction life cycle, i.e. at the end of the construction to generate a maintenance model.

The persistent IFC Views are generated by model translation and under the following conditions (the translated) model can also be called the model view (Isikdag et al. 2007):

- 1 The view should not be a superset of a predefined (base) information model. The view can be a subset of the model or the model itself.
- 2 The view should provide a snapshot of the information model (or its subset).

The model views e.g. IFC Views which are generated from the central model e.g. IFC Model can be used whenever there is a need to exchange a subset of the BIM between different domains or when there is a need to exchange a snapshot of the BIM in one stage of the project (Isikdag et al. 2007). Moreover it is important to examine the relations from a general perspective, where the end user's value chain requirements and procurement system's demands are the driving factors.

On that basis of providing IFC based data exchange between application systems envisaged in CMPSI and ITMP in our approach, the IFC partial models in other words IFC Views are defined based on the view generation from the central model. The detailed method is underlined in the following conceptual.

7.3 Conceptual Schema

Today IFC still 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 ceEPC 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 within the related application systems the following procedure is applied:

- 1 The information resources defined in the ceEPC model are examined with regard to IFC partial views that can or should be related to them.
- 2 For each identified information resource the relevant IFC classes and their relevant relationships are determined. An information resource identifies one or several partial IFC View, where each partial IFC View contains one to several IFC Classes.
- 3 Generally classes in Product Models cannot be used as single entities, but they are embedded in a network of classes. These networks are defined as IFC Concepts. Hence an IFC View consists of several IFC Concepts, which define the complete set of IFC Classes required.
- 4 Partial IFC Views are classified according to their application for exchanging information from one in another domain. These IFC Views are named according to these domains for instance for product catalogs, the suggested IFC View is named as IFC View for Product Catalog.
- 5 In order to formalize IFC Views, General Model Subset Definition Schema (GMSD) developed at the TU Dresden is used for the formal specification of the subset content (e.g. IFC Concepts) on class level (Weise et al. 2003).

- 6 Runtime 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 only some requirements and hints are provided to the user. **Figure 7.1** below illustrates the principal ideas.

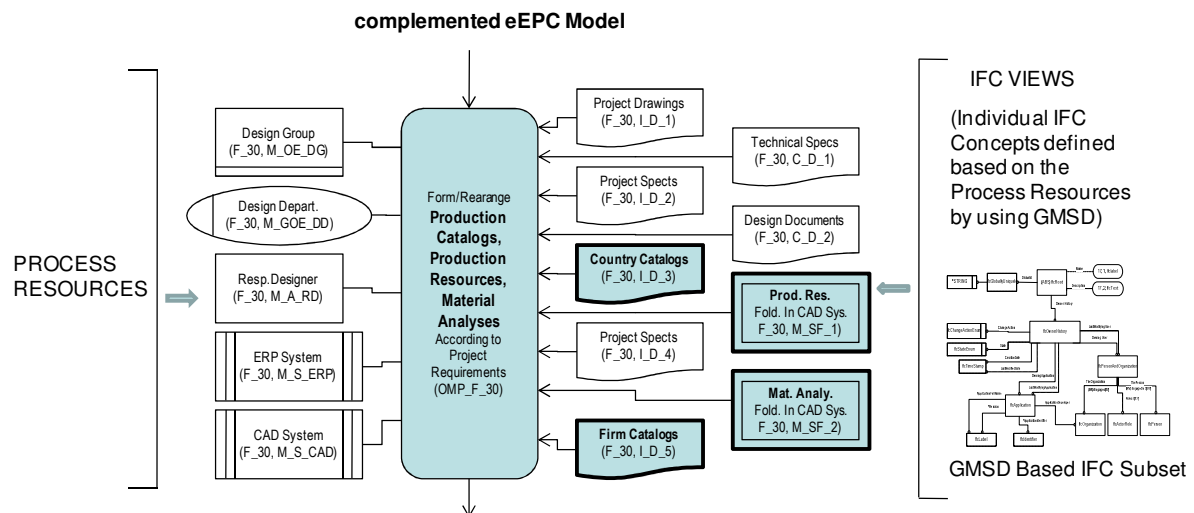


Figure 7.1 Schematic Presentation of the Association of IFC Data to the CPM Model

7.4 Processes and Information Model for the Integrated CPM Definition

Information models comprise complementary aspects which are used to identify information which is required by the engineering processes. Thus a model that references both information models and process models can facilitate better understanding of the whole structure.

However, very little research has been suggested in this context. The initiatives such as Process Matrix proposed by Wix and Liebich (2002) is based on a modified application of the Generic Process Protocol (GPP), coupled with the dedicated usage of the Unified Modelling Language (UML). It dwells upon on sending and receiving information, together with a detailed illustration of this process. But, the content of information is not well defined. Chen et al. proposed a process-oriented information modeling methodology with integrated IDEF0 and with the enhanced IDEF1. But because of the lack of IDEFØ modeling structure the required resources which are used for IFC Class mappings cannot be supported sufficiently.

Hence, to discover a process oriented integration methodology CMPSI is formalized in IDEFØ to see basic components addressing CPM phases from the software integration point of view. Although IDEFØ determines an effective detailing of the system activities, for showing the resources, actors and attributes, a combination of these items within IFC definitions in a common format requires an another methodology. In this context, a ceEPC model is realized. In this case, the established process sequence is used to identify the required information thereby it can reflect the existence of relationships and clarify the types of relationships. This is a new approach for information requirement analysis which supports IFC model development in an efficient way which helps to provide definitions for the IFC Concept formalizations.

In order to narrow the scope and manage the diversified structure, Bidding Preparation Phase and related processes in terms of IT Management Processes are addressed. For example, the IT Management Design Process (ITMDP) reflects information exchange between CAD and ERP systems for design and project's resources data integration, the IT Management BOQ Process (ITMBP) supports information exchange within CAD-ERP systems and exchange of bill of quantity information within ERP Systems, and the IT Management Scheduling Process (ITMSP) obtains BOQ and product data exchange within ERP-Scheduling Systems. Based on these acquiesces to formalize IFC views, according to formalized data as given in **Figure 7.2**, ITMDP and ITMSP definitions are examined in detail in the following sections.

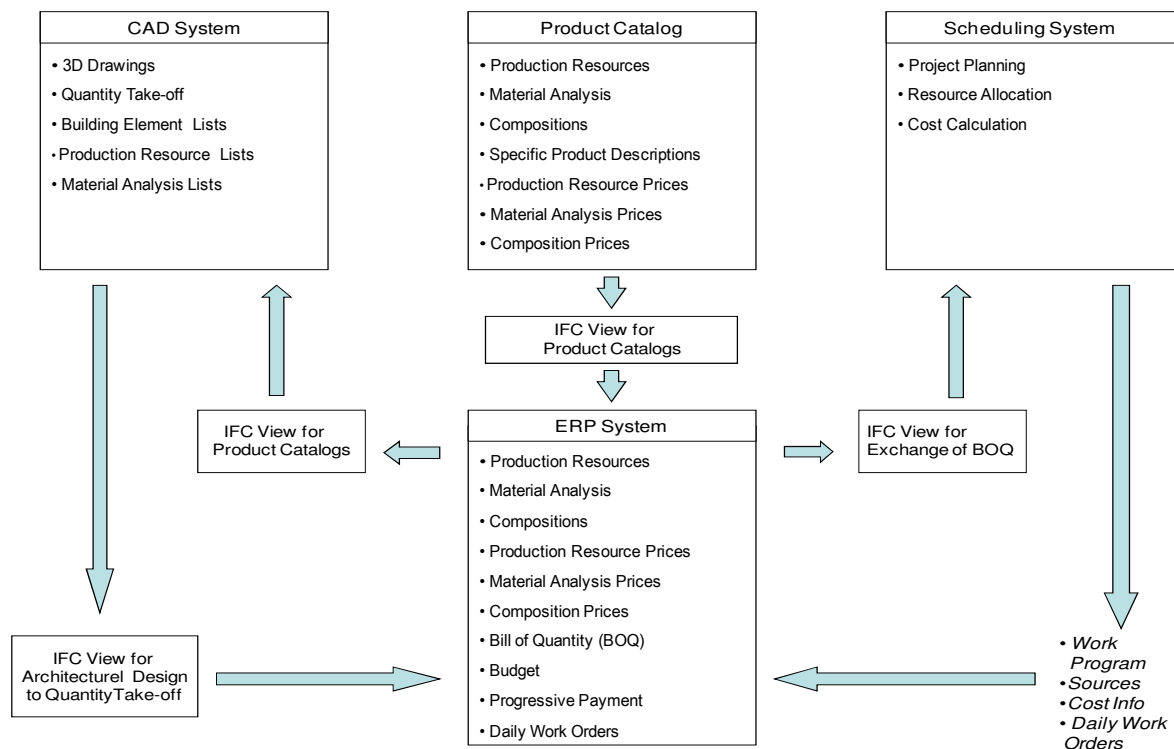


Figure 7.2 CAD, ERP and Scheduling System Information Structure and Related IFC Views Representation

7.5 Product Catalog Formalization

Although there are several type of product catalog formalizations which can be seen, a need is observed to realize a new type of structure based on the model requirements.

In order to construct a detailed description of the production resources which also support production resource prices, building production codes are formalized which are sub-structured according to property definitions of the materials. The building production codes in terms of product IDs should consist of digits for each different classification item. The Coding structure representation is provided as taxonomy. Therefore it facilitates understanding while formalizing material analysis and compositions for IFC mappings. The digit number is limited to ten digits.

To support production resources prices, a ‘Three Leveled Classification System’, composed of (1) Production Resources, (2) Material Analysis for Construction Work Entities and (3) Building Element Compositions is proposed. The use of Catalog Data based on the CAD and ERP systems is proposed as it is given in **Figure 7.3**.

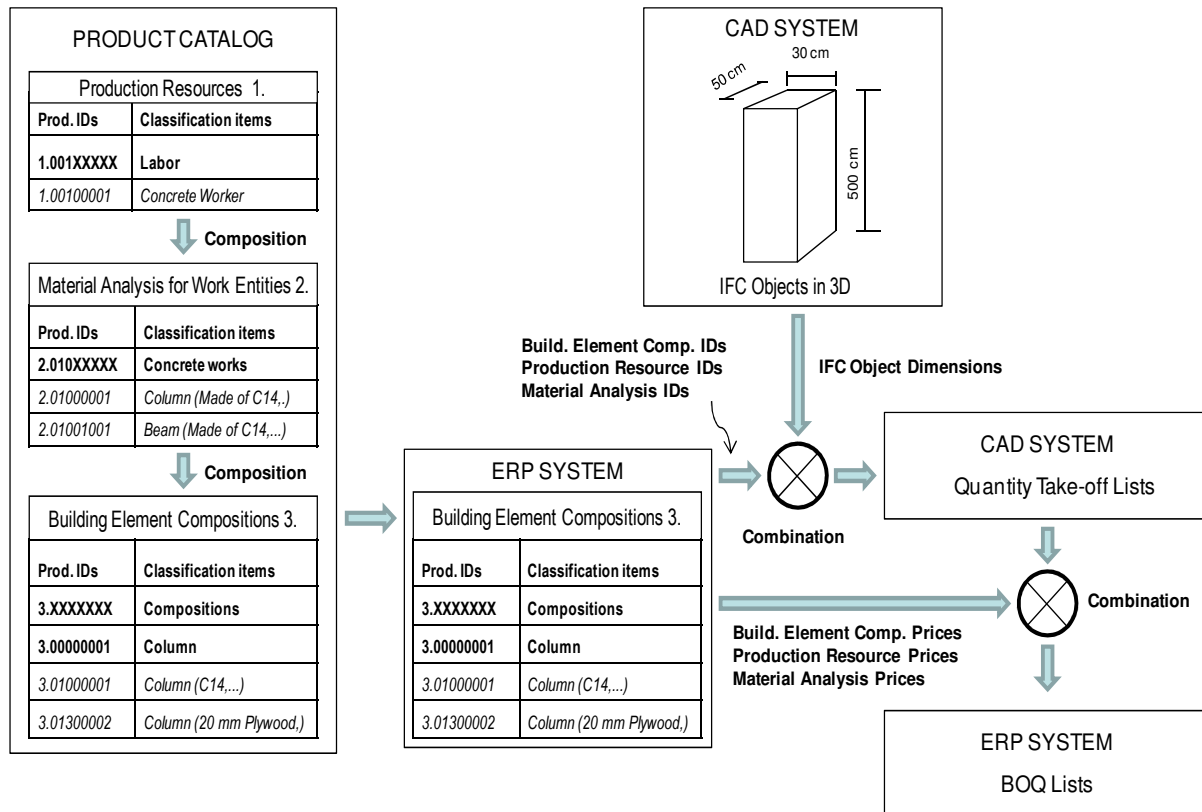


Figure 7.3 The Representation of Product Catalog Data on the basis of CAD and ERP Systems Integration

The first level classification items provide building production resources with their prices and specifications. The Production Resources can be identified such as concrete worker and concrete craftsman as labor, crane and concrete mixer as vehicles, welding and bending machines as machinery and nail and cement as production components. The gathering of these resources supports the realization of material analysis for the production units.

The second level classification item provides Material Analysis for the Construction Work Entities and is used by the Building Element Compositions. It is composed of two complimentary structures as given in **Figure 7.6**. In order to formalize these analyses, the main construction work entities are defined under concrete works, rc-works, insulation works, etc. Under these, the building elements such as column, wall, stair etc. are possessed. For instance under concrete works, a column is defined with concrete class as Column made of C14 Concrete. This represents the building element column made of C14 concrete class. In this context, C14 concrete class forms production resources according to production recipes. These recipes are generally given within catalog standards so that the material analysis can be formed based on these formalizations.

The third level classification items provide Building Element Compositions. The main building elements with main construction work entities are brought together to form compositions. These can be directly used to derive costs and can be mapped with IFC Objects. To provide these, a coding system for Production ID's is structured in a hierarchical way as given in the following sections.

Production Resources (Level 1)

The first digit '1' identifies that it is 'production resources'. The 'point' is used to formalize the structure according to classification system. The following three digits represent the main production types such as 001-Labor, 002-Vehicles, etc. as illustrated in **Figure 7.4**.

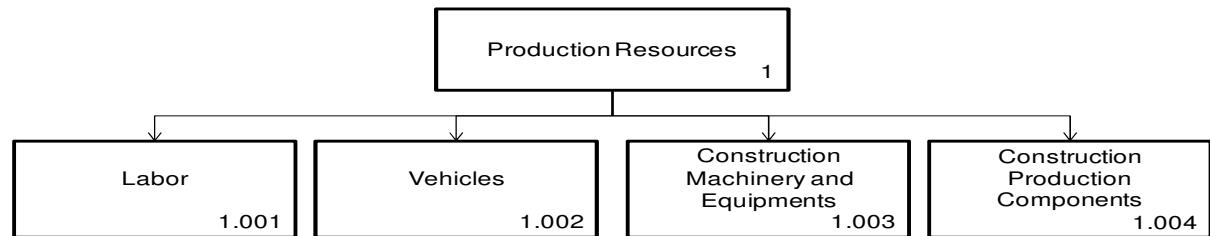


Figure 7.4 Production Resources (Level 1)

The labor represents the actors who take part in the construction process. The vehicles represent the construction vehicles which are used for construction purposes. The construction machinery and equipments represent the construction tools which are used by construction actors to process construction activities. The construction production components represent the basic construction components which are used to obtain material analysis for the construction work entities.

Each of these production resources should comprise unique production IDs, unique properties and production unit prices. In order to provide this a mechanism is provided as given in **Figure 7.5**.

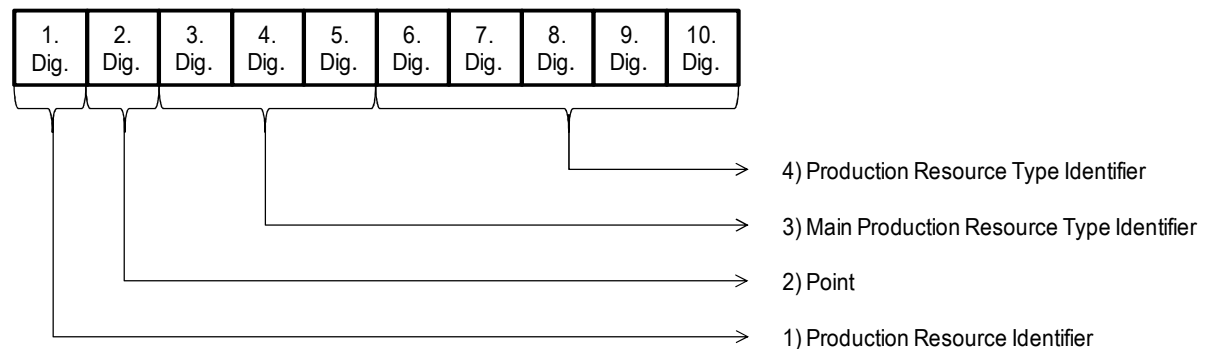


Figure 7.5 Production Resource Digit Representations

The structure is composed of ten digits. The first digit (1) is used as a production resource identifier. The second digit is a separation point (2). After the point three digits (3) are used to identify the main production resource type for the material analysis. The following five digits (4) formalize the production resource types as illustrated in **Table 7.1**.

On that basis, it is possible to represent '99.999' different types of production resources under the main production resource types.

Table 7.1 Production Resources

Production IDs	Classification items for Production Resources
1.001	Labor
1.00100001	Concrete Worker
1.00101001	Concrete Craftsman
1.002	Vehicles
1.00200001	Concrete Mixer (8 m3, Truck,...)
1.00202000	Crane (Liebherr, 5 tones Crane,...)

Material Analysis for the Construction Work Entities (Level 2)

The first digit '2' represents that it is the 'material analysis for the construction work entities'. The following three digits from '005' to '999' until point represent that it is the 'construction work entities'. This structure identifies the main construction work entities such as 010-Concrete, or 020-Plaster etc. Under the main construction work entities the main building elements like column, beam, wall etc. are formalized as illustrated in **Figure 7.6**.

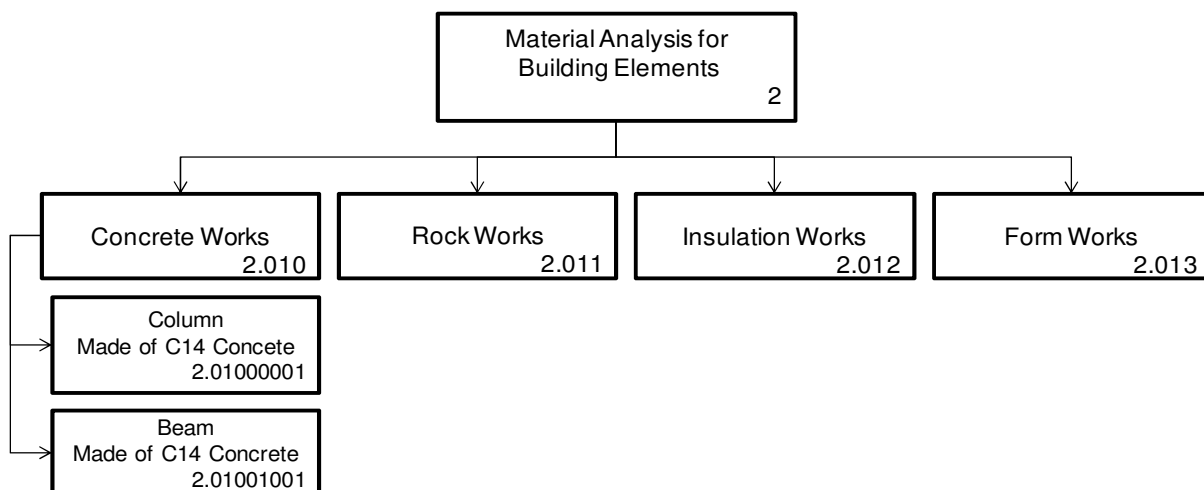


Figure 7.6 Material Analysis for the Construction Work Entities (partial schema)

The main building element types are represented with the following five digits as illustrated in **Figure 7.7**.

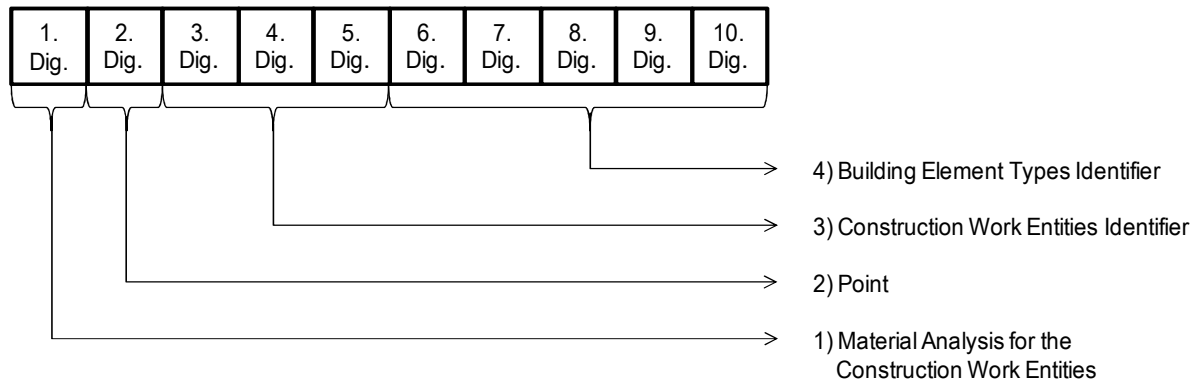


Figure 7.7: Material Analysis for the Construction Work Entities Digit Representations

The structure is composed of ten digits. The first digit (1) is used as an identifier for the material analysis for the construction work entities. The second digit is a separation point (2). After the point three digits (3) are used to identify the main construction work entities which represent the building element's main properties. The following five digits (4) formalize the building elements types according to main construction work entities.

The formalization is structured below.

2.010 → show that it is *Concrete Works*. Under this item,

2.01000001 → show that it is a *Column (made of C14 Concrete)*,

2.01001000 → show that it is a *Beam (made of C14 Concrete)*,

Within '001'-'999' IDs there are 999 different types of Column can be identified according to main construction work entities (concrete types), also '1001'-'1999' there are 999 different types of beam can be identified according main construction work entities, in terms of property definitions. The **Table 7.2** illustrates the main structure below.

Table 7.2: Material Analysis for the Construction Work Entities

Production IDs	Classification items for Material Analysis for the Construction Work Entities
2.005	Transportation
2.006	Loading and Unloading Activities
2.007	Mortar Works
2.008	Excavation works (free excavation by hand)
2.00800001	Excavation (by hand on Sandy Ground, 2 m deep,...)
2.009	Excavation works (excavation with machinery)
2.00900001	Excavation (Sandy Ground 2 m. deep with X type Excavator,...)
2.010	Concrete works
2.01000000	Column (General)
2.01000001	Column (Made of Concrete, C14,...)
2.01001000	Beam (General)
2.01001001	Beam (Made of Concrete, C14,...)
2.011	Rock Works
2.01100000	Wall (General)
2.01100001	Retaining Wall (Made of Clay Stone,...)

Building Element Compositions (Level 3)

The first digit '3' shows that it is 'Building Element Compositions'. In building element compositions, where the relationship between material analysis main construction work entities and building elements is expressed by using the same digit 3-10 as a common key. This approach provides to map main building elements to IFC Objects.

The ID intervals between main buildings elements are represented with 999 different types, based on different components i.e. material analysis as illustrated in **Figure 7.8**.

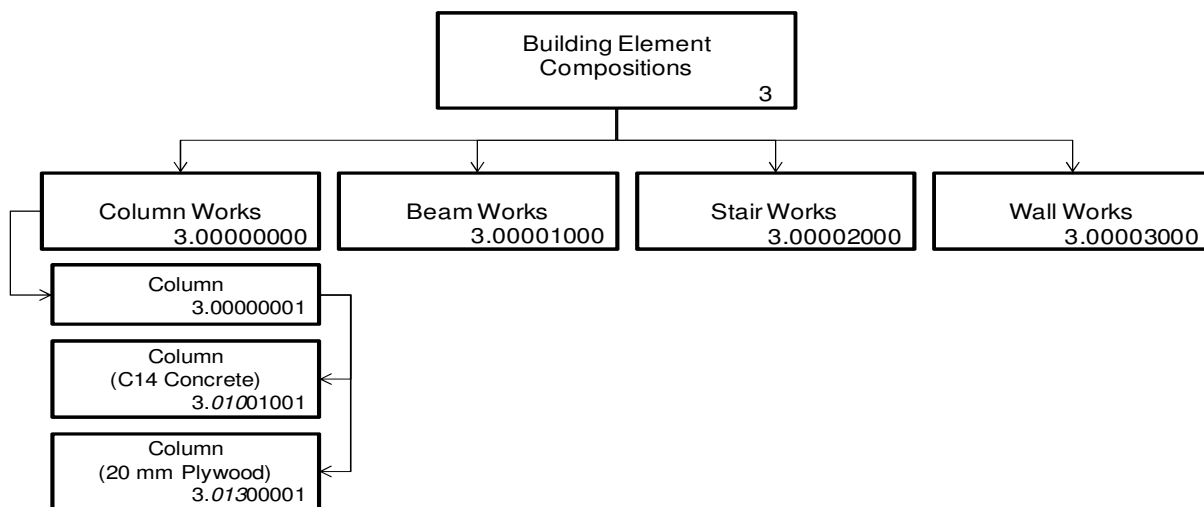


Figure 7.8 Building Element Compositions

In order to show material analysis under compositions a digit formalization mechanism is settled as given in **Figure 7.8**.

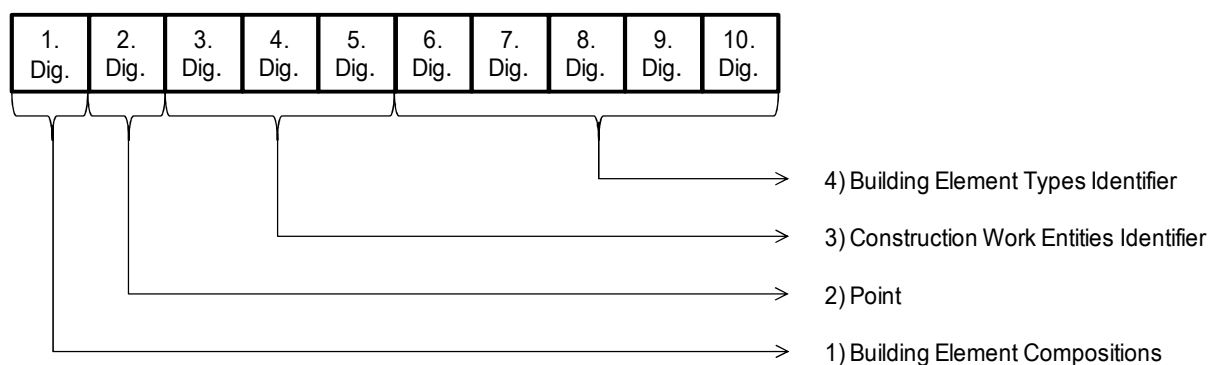


Figure 7.9 Building Element Compositions Digit Representations

The structure is composed of ten digits. The first digit (1) is used as an identifier for the building element compositions for the IFC mappings. The second digit is a separation point.

After the point (2) three digits (3) are used to identify the main construction works. The following five digits (4) formalize the building element types according to the construction work entities. Based on this main construction elements with their attributes can be used to implement building element compositions.

For example a Column tagged with 3.00000001 can be made of C14 concrete, 20 mm Plywood, St37 ϕ 12, and Acrylic Paint, etc. C14 Concrete Column is tagged under material analysis for building representations as 3.01000001. In order to represent it within Compositions the first digit as '3' is used at the beginning of the composition. The **Table 7.3** shows a partial column representation below.

Table 7.3 Classification Items for Building Element Compositions

Production IDs	Classification items for Building Element Compositions
3.00000000	Column Works
3.00000001	Column
3.01000001	<i>Column (Made of C14,...)</i>
3.01300001	<i>Column (Made of 20 mm Plywood,...)</i>
3.01600001	<i>Column (Made of St37, ϕ12,...)</i>
3.01800001	<i>Column (Made of Plastic based Acrylic Paint,...)</i>
3.02000001	<i>Column (Made of Cement based Plaster,...)</i>
3.02100001	<i>Column (Made of Waterproofed Gypsum, 1 mm thick,...)</i>

In order to allow individual representations, the range between main building elements is represented with 999 different types, 800 of them are accepted as pre-structured building elements (within production catalogs). Therefore the rest 199 building element types can be defined based on the project specifications, project needs and market prices.

Based on these formalizations statements are constituted as below.

- The Product Catalog Structure is formalized as taxonomy to provide information exchange within a hierarchy.
- The ten digits provide minimum cost information exchange requirements based on the IFC specification. It can be more than ten however this lowers flexibility, besides less than ten digits restrict intervals between construction elements and attribute definitions.
- The formalization is structured based on building elements in order to map them with IFC Classes.

Mapping between Building Element Compositions and IFC Classes

In order to map compositions and IFC Classes, a mapping structure is formalized. In this case the Building Element Compositions in which the detailed complimentary production resources and the material analyses for the construction work entities are mapped with IFC classes. This also supports to derive IFC based cost information.

When it is examined from a practical view the IFC building objects such as IfcWall, IfcSlab, IfcBeam can be identified within CAD systems e.g. Autocad, Allplan or Graphisoft. The structured building element compositions therefore can be mapped with these objects to derive quantity take offs based on production IDs.

From process sequence perspective, the formalized production resources, material analysis for the construction work entities and building element compositions within product catalogs can be taken to ERP system (ITMDP_{P_4}) and used there as it is, related with the Unit Price Procurement System (ITMDP_{P_4}) or used there to form project production resources and project material analysis regarding to Lump-sum (ITMDP_{P_5}) or Design & Build (ITMDP_{P_7}) Procurement Systems. Afterwards, these can be used within CAD systems and attained to 3D drawing objects (ITMDP_{P_9}) to have quantity take-offs. These objects are also identified with IDs based on IfcRoot. Therefore each IFC Object can be mapped through Product Catalogs' IDs to IFC Objects IDs as given in **Table 7.4**.

Table 7.4 Building Element Compositions Mapping to IFC Classes

Production IDs	Classification items for Building Element Compositions, for IFC Mapping	IFC Object IDs	IFC Classes
3.XXXXXXX	Compositions		Objects
3.00000001	Column	3DwF3zyUj9bgjuviHLMq55	IfcColumn
3.01000001	Column (Made of C14,...)		
3.01300001	Column (Made of 20 mm Plywood,...)		
3.01600001	Column (Made of St37, Φ 12,...)		
3.01800001	Column (Made of Plastic based Acrylic Paint,...)		
3.02000001	Column (Made of Cement based Plaster,...)		
3.02100001	Column (Made of Waterproofed Gypsum,...)		

In the exposed structure, building element compositions are formalized by using structured ID formalizations. For example Column which is identified with ID-3.00000001 is composed of materials such as C14 Concrete with the ID-3.01000001 (for compositions), 20 mm Plywood with the ID-3.01300001 (for compositions).

The Way to Combine Building Element Compositions, ERP and CAD systems based on the Unit Price Procurement System to reach IFC Cost Data

As an example, in construction projects different type of columns composed of different type of materials can be constituted. These can be formed directly from pre-structured columns (800 different types of column combinations are proposed) which are structured within product catalogs.

By identifying 800 different types of prepared columns (as building element combinations) with their prices (including production resource and material analysis prices) which are embedded within their IDs can be sent from Product Catalogs to ERP system. After project requirement's examination (selecting of necessary columns), these can be used directly within

ERP, based on the Unit Price Procurement System. Latter the selected columns with their production resources and material analysis can be sent with their IDs to CAD system. The IDs of the production resources and material analysis can be attained to 3D drawings/IfcObjects to realize quantity take-offs according to the structured building element compositions in the Product Catalogs. After the combination of the IFC Object quantities (volume, length) which come from 3D drawings and the production resource and material analysis which are embedded in the Building Element Compositions, they are sent to ERP system from CAD system. Based on the IDs, quantities and the prices can be combined in ERP system to reach the IFC Object Cost data.

The Way to Combine Building Element Compositions, ERP and CAD Systems based on the Design & Build and Lump-sum Procurement Systems to reach IFC Cost Data

However, based on Design & Build and Lump-sum Procurement System requirements, the formalizations of material analysis and the related prices can be changed. But one important issue to be considered here is; reserving the structure of IDs. The interval between columns and beams are constituted according to 999 different types of combinations. Based on process definitions, after taking 800 different types of columns from product catalog to ERP system, 199 different types of columns can be established based on structured ID formalization according project requirements with market prices.

In order to form new material analysis within the ERP system with their prices the market prices should be established. In this case each production resource has to be defined according to unit quantities such as: kg, hour, unit etc., as given in **Table 7.5**.

Table 7.5 Production Resource Prices

Production IDs	Classification items for Production Resources	Example Prices (Euro)
<i>1.00100001</i>	<i>Concrete Worker, (1 hour price)</i>	<i>5</i>
<i>1.00200001</i>	<i>Concrete Mixer, (8 m3 Truck), (1 hour price)</i>	<i>40</i>
<i>1.00300002</i>	<i>Welding Machine, (Elect. Arc Weld. Mach.), (1 hour price)</i>	<i>15</i>
<i>1.00400001</i>	<i>Construction Nail, (Made of Steel, 10 cm,..), (1 kg)</i>	<i>3</i>
<i>1.00402001</i>	<i>PC40 Cement (Portland), (1 tone)</i>	<i>100</i>
<i>1.00403001</i>	<i>Sand (2 cm Granula), (1 m3)</i>	<i>30</i>

In this context material analysis prices can be formalized based on the production resources' prices, by bringing them together according to established recipes. For instance to form 1 m³ C14 Concrete for Column; cement, sand, water etc. are brought together as can be seen in **Table 7.6**.

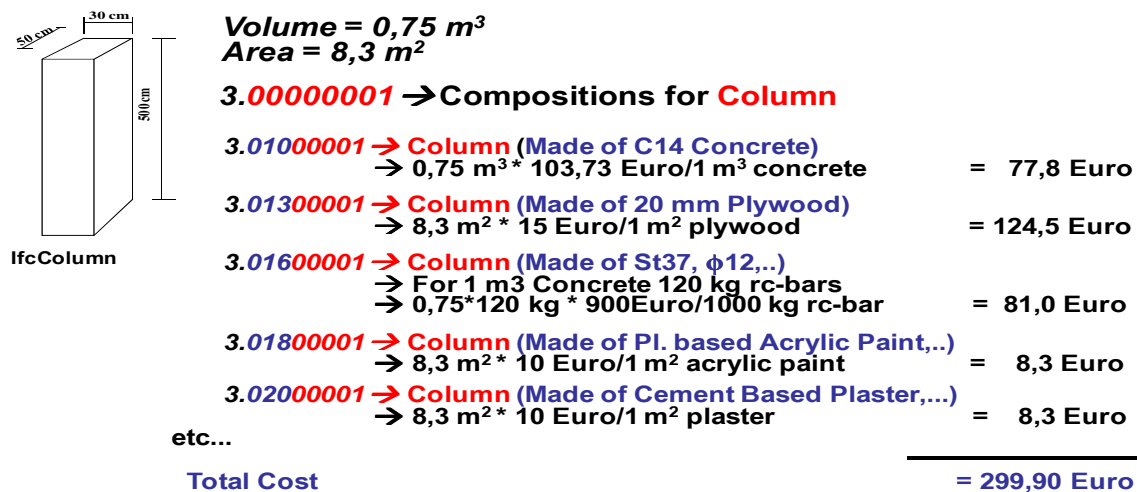
Table 7.6 Material Analysis Prices

Production IDs	1 m3 C14 Concrete	General Prices (GP) (Euro)	Amount (A)	Calculation (GPxA)	Analyse Exp. Prices (Euro)
1.00100001	Concrete Worker, (1 hr. price)	6	6	6x6	36
1.00101001	Concrete Craftsman, (1 hr. price)	8	0,5	8x0,5	4
1.00305001	Concrete Mixer, (1 hr. price)	15	0,25	15x0,25	3,75
1.00305050	Concrete Vibrator, (1 hr. price)	3	0,15	3x0,15	0,45
1.00401001	Gravel (2-3 cm Granula), (1 m3)	25	0,72	25x0,72	18
1.00401100	Sand (2 cm Granula), (1 m3)	30	0,5	30x0,5	15
1.00402001	PC40 Cement (Pc325), (1 tone)	100	0,25	100x0,25	25
1.00410001	Water (1 tone)	3	0,51	3x0,51	1,53

The total price of 1 m³ C14 Concrete for Column is constituted as 103,73 Euro (example price) in this regard.

Based on the procurement systems, only prices can be changed with market prices and the existing material analysis can be used directly. Moreover, production resources and material analysis with their prices which are represented in building element compositions can be attained to CAD objects i.e. column to find out the price of the building element. Latter these can be used in ERP system to reach Project BOQ.

For instance the Column (given in Table 7.4) composed of production resources and material analysis can be mapped to IfcColumn (in the CAD system) and the established (from 3D drawings) dimensions can be used to find the related quantities. After having the quantities such as volume, area based on the building element compositions in CAD system, these can be sent to ERP system to form the costs as shown in **Figure 7.10**.

**Figure 7.10 Cost Representations of Compositions**

From this standpoint the mappings between compositions and IFC objects can be accomplished as seen in **Figure 7.11**. However the existing IFC 2x3 model specification do not provide the required cost information exchange for the Design & Build and Lump-sum Procurement Systems. Therefore an extension to IFCs is suggested in this context.

Production IDs	Compositions for IFC Mappings	Price,Euro	IFC Class
3.00000001	Column	299,90	IfcColumn
3.01000001	Column (Made of C14 Concrete)		
3.01300001	Column (Made of 20 mm Plywood)		
3.01600001	Column (Made of St37, φ12,...)		
3.01800001	Column (Made of Plastic based Acrylic Paint,)		
3.02000001	Column (Made of Cement Based Plaster,...)		
etc.,			

Figure 7.11 Cost Mappings between Compositions and IFC Classes

7.6 IFC Views for IT Management Design Process

IT Management Design Process comprises 2 IFC Views namely 1) IFC View for Product Catalogs and 2) IFC View for Architectural Design to Quantity Take-off.

Views have two purposes: first of all they act as guidelines for implementations in computer applications, and secondly they define the scope, requirements and information to be exchanged in data exchange transactions in practice, in construction projects.

According to the implied model in this context, common items which are used for CAD-ERP and Scheduling systems are based on reliable external sources in terms of production resources and material analysis. Generally bidding departments can form these items from different sources such as; firm databanks, country 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.

In this regard to get reliable forms for architectural design and BOQ information exchange, the first view, 1) IFC View for Product Catalogs is established based on the exchange of Product Catalog Information according to the given product Catalog structure in the previous sections. This also provides IFC based cost data integration. Subsequently, quantity take-offs for cost calculations are taken into consideration in the second view 2) IFC View for Architectural Design to Quantity Take-off. In order to formalize data exchanges between design to quantity take-offs, the Architectural Design to Quantity Take-off view is constituted as it is given in the following paragraphs.

7.6.1 IFC View for Product Catalogs

In order to obtain IFC based information exchange for product data, IFC View for Product Catalog is possessed.

The main goal for this formalization is to provide lossless, incremental product data exchange between product catalogs and software applications.

In the proposed model to prove related process requirements defined for CAD and ERP systems integration, and to determine the main elements of product catalog information, the basic definition and content of the view is formalized specifically. Moreover, the IFC Specification (IFC 2x3 Addendum 1 release) is chosen in this regard.

Because, the need for detailed definitions for Quantity-take offs, is observed in process definitions, the proposed Product Catalog information is structured to cover all general product, production, and maintenance data in digital format. This provides information exchange, between product catalogs and software applications in a substantial way.

When the existing building product catalog structures are examined in detail, it can be observed that the related information is generally composed of: (1) identification of products with product IDs, (2) classification of products as production resources, (3) description of composition structure of assembled products and (4) detailed characteristics of product in terms of special figures. But there is also one issue that should also be considered in this sense which is as Production Resource Prices. Identification of production resource prices in the first stage will be used not only in the view definitions for Design to Quantity Take-off but also to provide cost information which is required to form Bill of Quantities. In order to provide the exchange of production resource price information in this research, a new type of formalization for Product Catalogs is suggested.

In this context, the implemented IFC Views do not define any responsibility, management, etc. issues concerning the data issues, besides that they are represented within process sequences.

Realization of the structure should require a detailed definition of the parties and applications, the main roles can be identified as in two parties as Information Provider who supports digital Product Catalogs, that may be available on the internet, and Information Receiver who uses this Product Catalog information.

According to notification of the importance of the product catalogs for product classifications, projects such as: RINET (cic.vtt.fi/rinet), CONNET-MPS (www.connet.org), PROCAT-GEN and ARROW (Newnham and Amor 1998) which possessed to demonstrate product model approach to product information, eProCon which aims to provide a domain model for enriched catalogue and product information (demonstrated in a 'Product Portal') and services that enable access to information providers (manufacturers and suppliers) for producing and maintaining product catalogues, were provided.

Moreover, product catalog standards such as: BMEcat-Format (www.bmcat.org) were developed with the objective of standardizing and simplifying the exchange of product data catalogs, which are used by suppliers and purchasing organizations and also eCI@ss (www.eclass.org) classification schema and which support a standard classification schema that helps buyers and suppliers in communicating their product information, were constituted.

In this research, the IT Management Design process is used to formalize a process based methodology in terms of supporting process based information model. For a better definition

of the interoperability between software systems, a Product Catalog is realized which is derived from a process sequence.

To obtain seamless information exchange within product catalog information and to identify the information content in a detailed way the process resources are identified based on IT Management Design Process, Function 4 (ITMDP_{F_4}) as 'Form/Rearrange Production Catalogs, Production Resources, Material Analysis according to Project Requirements'.

From this standpoint, the main requirement is the realization of Production Catalogs within the process sequence. Moreover the basic process resources for product catalogs can be organized as: (1) Production Resources and (2) Material Analysis.

Furthermore, all production resources in terms of objects should be uniquely identified, (Production Resource's IDs). This approach is the major milestone for information exchange within CAD, ERP and Scheduling Systems. In the envisaged model, all required data according to production resources are sent using a Production Unit's ID. However, a need is observed to form a new type of ID which provides a mapping between process resources and IFC objects in order to support exchange of cost data. Hence, a product catalog structure is possessed in the previous sections. Moreover process resources are structured according to requirement analysis of the IFC specification to formalize a substantial view definition. In order to reach this acquiesces the statements have to be realized in this regard. To support Product Catalog Information Exchange, statements are established such as:

- There should be a mechanism in product catalogs which supports information exchange through data exchange files or a data access interface.
- The software using the product catalogs in our case ERP systems needs to be able to communicate via reliable interfaces.
- There is a need to provide a common classification for the building and equipment element types in terms of reliability of the information both for applications and product catalogs.

7.6.2 IFC View Implementation for Product Catalog Information

In this section, basic concepts to support data exchange representation and format of the implementation are formalized. In order to identify the basic content of the IFC product model, the minimum components have to be clarified precisely. The product model should contain the product objects and its attribute values. To support minimum requirements, all needed attribute values and possible relationships of objects have to be modeled. To provide mapping from process functions to IFC Views a formalization structure is provided as given in the **Figure 7.12**. In the figure each ITMP function (represented in ceEPC) related with the product catalogs is collected, and used as a primary key which lead to form related ITMP resources (as foreign key) in **Table 7.7**. On that basis, these process resources (as primary key) which lead to structure related IFC Classes (as foreign key) are used in **Table 7.8**. Subsequently, the formulated IFC Classes (as primary key) which are used for same issues are represented in IFC Concepts. Subsequently these concepts are gathered to reach related IFC Views for Product Catalogs in **Table 7.9**.

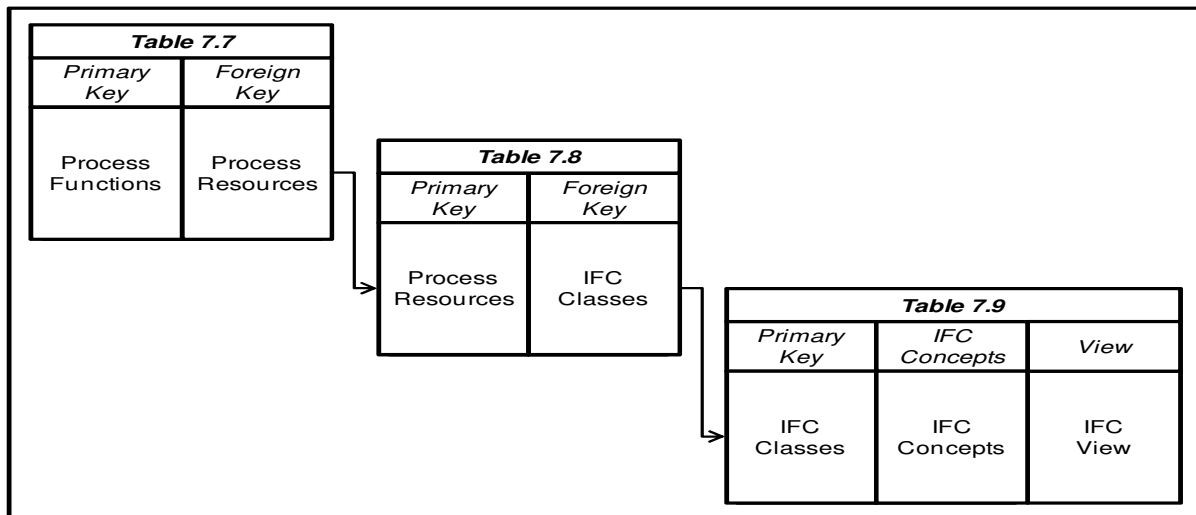


Figure 7.12 Table formalization from ITMP functions to IFC View Formalizations.

On that basis, **Table 7.7** in which ITMP functions and related resources are represented is given in the following. Each ceEPC function reference 1 or many (1:n) ITMP resources related with the product catalogs.

Table 7.7 ITMP Functions and Resources Referencing IFC Classes

ITMP Functions where left Resources are Input	ITMP Resources Referencing IFC Classes in the Context of the Product Catalogs
ITMDPf_i, i=1,3,5,6,7,9 ITMBPf_j, j=2-13,23,24	Product Catalogs,
	Product IDs
	Production Resources
	Material Analysis
	Compositions
	Material Properties
	Classification
	Grouping
	Production Resource Prices
	Material Analysis Prices
	Composition Prices

IFC documentation which also comprises IFC specification defines production resource's attributes. It also defines property sets, and properties which complete the characteristics of the objects that are defined by the object classes.

The IFC Property Set Mechanism and IFC Cost are flexible means to extend the object characteristics and object prices (production resources) by commonly agreed properties, without changing the IFC Object Model Definition.

One important issue that has to be considered also from the Contractor point of view while preparing the Bidding Structure is the replacing of existing catalog prices with the market prices. From this standpoint two solutions will be proposed in this research.

Based on the Figure 7.12, ITMP resources for product catalogs which are structured in Table 7.7 are used as primary keys to formulate related IFC classes in **Table 7.8** after examination and considering of IFC Model. Each ITMP resource is using 1 or many (1:n) IFC classes.

Table 7.8 Mapping of ITMP Resources into IFC Classes

ITMP Resources as Collected in Table 7.7	IFC Classes Referenced by the ITMP Resources
Product Catalogs	* <i>IfcLibraryReference</i> * <i>IfcDocumentInformation</i>
Product IDs	* <i>IfcRoot</i>
Production Resources Material Analysis	* <i>IfcMaterial</i> * <i>IfcConstructionResource</i>
Compositions	* <i>IfcBuildingElement</i> , <i>IfcBuildingElementType</i> * <i>IfcDistributionElement</i> , <i>IfcDistributionElementType</i> * <i>IfcComponentElement</i> , <i>IfcElementComponentType</i> * <i>IfcTransportElement</i> , <i>IfcTransportElementType</i> * <i>IfcFurnishingElement</i> , <i>IfcFurnishingElementType</i>
Production Resource and Material Analysis Properties	* <i>IfcPropertySet</i>
Classification	* <i>IfcClassification</i>
Grouping	* <i>IfcGroup</i>
Production Resource Prices Material Analysis Prices Composition Prices	* <i>IfcCostValue</i> * <i>IfcCostSchedule</i> * <i>IfcCostItem</i>

7.6.3 IFC Concepts for Product Catalogs

In this section different parts of the IFC product data model are provided as IFC Concepts. An IFC Concept is a grouping of an IFC product data model subset so that one IFC Concept describes an object such as a building element's objects, certain specific characteristics or bundled properties (ProIT 2005). In this context, IFC Concepts are developed based on the proposed IFC View Definition Format (Hietanen 2006) of the IAI. The detailed rules are given in Chapter 8.

Based on the collected IFC Classes referenced from ITMP resources, the concepts are listed in **Table 7.9** which are required for the implementation of IFC View for Product Catalogs. Each IFC Concept is using 1 or many (1:n) IFC Classes in its constitution i.e. in Type Object Concept. On the other hand IFC Classes can be represented in 1 or many (1:m) concepts to support different demands i.e. in IfcClassification, arrangement of objects into classes and assignment of classification notation to objects should be represented separately. According to the proposed catalog structure, the supporting instance diagrams provide the basis and facilitate understanding. The detailed IFC Concepts and Instance Diagrams are given in Appendix C.

Table 7.9 IFC Concepts for the IFC View for Product Catalog

IFC Classes Referenced by the ITMP Resources in Table 7.8	IFC Concepts for Product Catalogs	IFC Views
* <i>IfcLibraryReference</i>	* <i>Library</i>	IFC View for Product Catalog is the sum of 16 Concepts
* <i>IfcDocumentInformation</i>	* <i>Document</i>	
* <i>IfcRoot</i>	* <i>Identity</i>	
* <i>IfcMaterial</i>	* <i>Material Concept</i>	
* <i>IfcConstructionResource</i>	* <i>Construction Resource Extension</i>	
* <i>IfcBuildingElement</i>	* <i>Building Element</i>	
* <i>IfcDistributionElement</i>	* <i>Distribution Element</i>	
* <i>IfcComponentElement</i>	* <i>Component Element</i>	
* <i>IfcTransportElement</i>	* <i>Transport Element</i>	
* <i>IfcFurnishingElement</i>	* <i>Furnishing Element</i>	
* <i>IfcBuildingElementType, IfcDistributionElementType, IfcElementComponentType, IfcTransportElementType, IfcFurnishingElementType</i>	* <i>Type Object</i>	
* <i>IfcPropertySet</i>	* <i>Properties</i>	
* <i>IfcClassification (arrangement of an object into a class)</i>	* <i>Classification</i>	
* <i>IfcClassification (to assign a classification notation to objects)</i>	* <i>Construction Type Classification</i>	
* <i>IfcGroup</i>	* <i>Group</i>	
* <i>IfcCostValue</i>	* <i>Cost</i>	
* <i>IfcCostSchedule, IfcCost Item</i>	* <i>Cost Item and Cost Schedule</i>	

7.6.4 Extension of the Class IfcConstructionResource

In order to form Product Catalog View related to Design & Build and Lump-sum Procurement Systems, IFC is extended with new classes and object definitions within the Concept namely “Construction Resource Extension” as provided in the following.

The related existing classes based on the IAI are given under Entity Type Definitions. These are namely:

- (1) IfcResource
- (2) IfcConstructionResource
- (3) IfcCrewResource,
- (4) IfcLaborResource,
- (5) IfcSubContractResource,
- (6) IfcConstructionProductResource,
- (7) IfcConstructionEquipmentResource,
- (8) IfcConstructionMaterialResource,
- (9) IfcClassification.

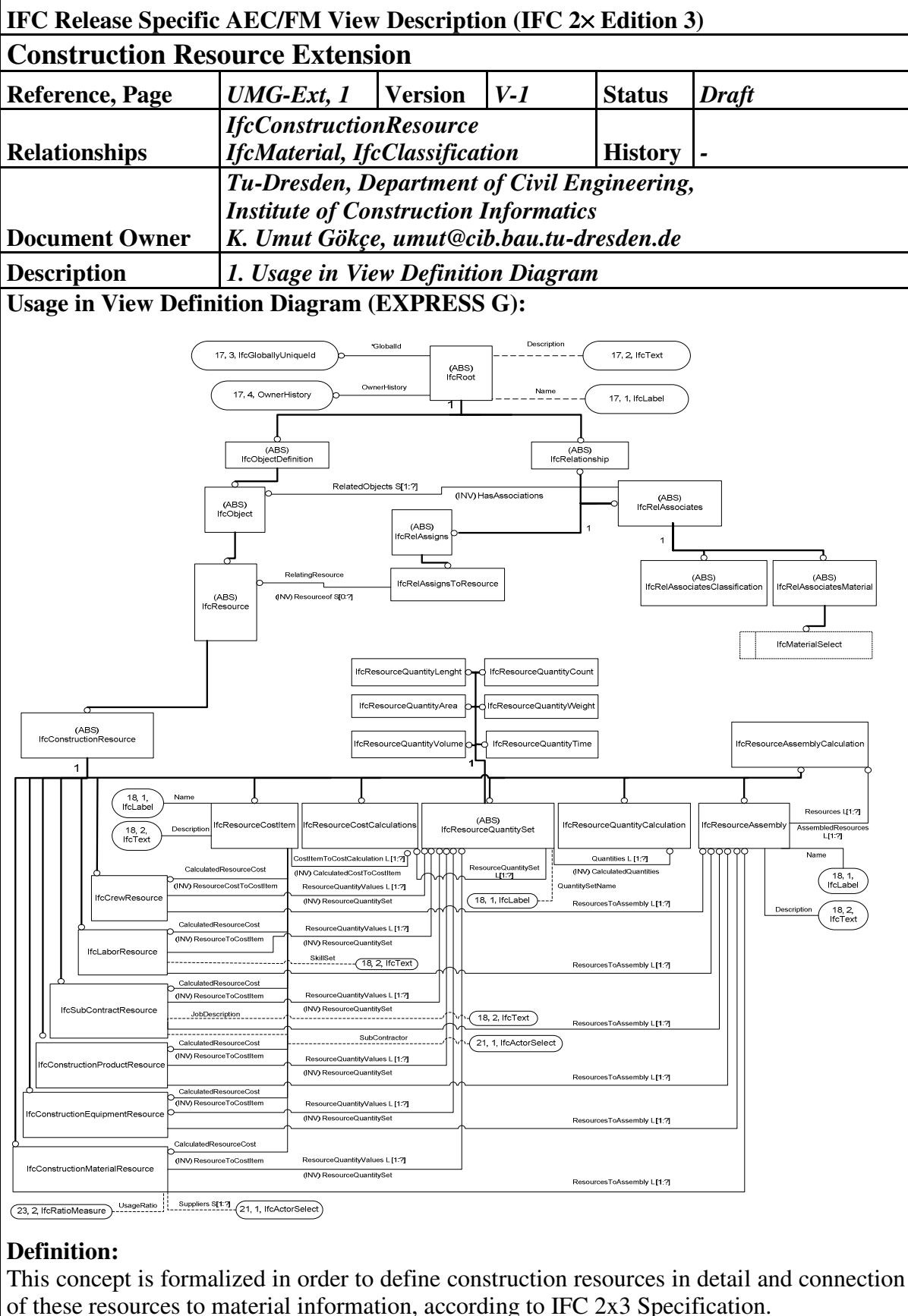
The suggested New Classes which have relations with the existing classes are defined under New Entity Types. These are namely:

- (10) IfcResourceCostItem,
- (11) IfcResourceCostCalculation,
- (12) IfcResourceQuantitySet,
- (13) IfcResourceQuantityLength,
- (14) IfcResourceQuantityArea,
- (15) IfcResourceQuantityVolume,
- (16) IfcResourceQuantityCount,
- (17) IfcResourceQuantityWeight,
- (18) IfcResourceQuantityTime,
- (19) IfcResourceQuantityCalculation,
- (20) IfcResourceAssembly,
- (21) IfcResourceAssemblyCalculation.

The detailed definitions of the existing classes and the suggested new classes are given within the Concept below.

Moreover the relations between the existing to new classes and the relations between the new classes to new classes are represented within the Detailed Entity Type Definition.

These are instantiated under instantiation diagram on the example of an object (column) with its basic material information which includes basic resources with their quantity and cost data.

EXPRESS-G Definition, Page 1

Entity Type Definitions, Page 2

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/1	Version	V-1	Status	Draft
Relationships	IfcConstructionResource, IfcMaterial, IfcClassification			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):

IfcResource (1)
The *IfcResource* contains the information needed to represent the costs, schedule, and other impacts from the use of an item in a process. It is not intended to use *IfcResource* to model the general properties of the items themselves, an optional linkage from *IfcResource* to the items used can be specified (i.e. the relationship from subtypes of *IfcResource* to *IfcProduct* through the *IfcRelAssignsToResource* relationship).

IfcConstructionResource (2)
An *IfcConstructionResource* is an abstract generalisation of the different resources used in construction projects, mainly labor, material, equipment and product resources, plus subcontracted resources and aggregations, such as a crew resource.

IfcCrewResource (3)
An *IfcCrewResource* represents a type of resource used in construction processes, i.e. construction crew resource. A construction crew resource typically includes labor resource, equipment resource, material resource, subcontractor resource, as well as other crew resources. Construction crew resources are partially or wholly consumed, or occupied in a construction process (i.e. *IfcTask*). Since *IfcCrewResource* represents the resource types, individual persons are not required to be identified and linked to the crew resource, while they can be associated if needed.

IfcLaborResource (4)
An *IfcLaborResource* is used in construction with particular skills or crafts required to perform certain types of construction or management related work. Labor resources do not identify individual persons (i.e. *IfcActors*) for cost estimating purpose.

IfcSubContractResource (5)
An *IfcSubContractResource* is a construction resource needed in a construction process that represents a type of sub-contractor. An *IfcSubContractResource* can be used in cost estimating and work planning without specifying the subcontractor. However, it can be associated with an actor fulfilling the subcontractor role when detailed work planning is performed. The type of subcontractor can also be identified in a construction crew resource.

IfcConstructionProductResource (6)
An *IfcConstructionProductResource* defines the role of a product that is consumed (wholly or partially), or occupied in the performance of construction. Occurrences of products that are used as product resources are instances of *IfcProduct* since they result from some processes. For instance, formworks can be instantiated as products resulting from the process ‘constructing formwork’. However, they are used as resources in the process ‘pouring concrete’ in a later stage of the project. The product that is used as a construction resource is referenced using the *IfcRelAssignsToResource.RelatedObjects* relationship.

Entity Type Definitions, Page 3

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/2	Version	V-1	Status	Draft
Relationships	IfcConstructionResource, IfcMaterial, IfcClassification			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):

IfcConstructionEquipmentResource (7)
An IfcConstructionEquipmentResource is a type of construction equipment that is used as resource to assist in the performance of construction. Construction Equipment resources are wholly or partially consumed, or occupied in the performance of construction. There are differences in the IfcEquipmentElement and IfcConstructionEquipmentResource.

IfcConstructionMaterialResource (8)
An IfcConstructionMaterialResource identifies a material resource type in a construction project. Occurrences of IfcConstructionMaterialResource are consumed (wholly or partially), or occupied during a construction work task (i.e. IfcTask).
Similar to IfcConstructionProductResource, sometimes items such as 5000kg of gravel are already instantiated as an IfcProduct because it is a result of a work task e.g. ‘transporting gravel’. In this case, the instance of IfcConstructionMaterialResource can be associated with the product instance ‘5000kg of gravel’ to provide more information for resource uses. Nevertheless, IfcConstructionMaterialResource should only be used to represent resource types, e.g. ‘gravel’, but not product substances, e.g. ‘5000kg of gravel’.
Note: This class is not the same as IfcMaterial; the former can typically represent the type of bulk materials such as sand, gravels, nails and so on (note these can be instantiated from IfcProduct as well depending on their uses in the system) used in a construction process. The latter is about physical materials used in a physical building element typically with detailed positioning (e.g. offset) and layering information.
The association of an actual material with an IfcConstructionMaterialResource is handled by IfcRelAssociatesMaterial.
Quantities for an IfcConstructionMaterialResource are defined through IfcRelDefinesByProperty and use IfcElementQuantity.

IfcRelAssociates is objectified relationship between a material definition and elements or element types to which this material definition applies. The material definition can be: A single material, a material list, e.g. for composite elements, a material layer set, for layered elements with an indication of the layering direction and individual layer thicknesses. The IfcRelAssociatesMaterial relationship is a special type of the IfcRelAssociates relationship. It can be applied to subtypes of IfcElement and subtypes of IfcElementType.

IfcClassification (9)
An IfcClassification is used for the arrangement of objects into a class or category according to a common purpose or their possession of common characteristics. IfcClassification identifies the classification system or source from which a classification notation is derived. In order to formalize a general classification mechanism for the instances of IfcObject or IfcPropertyDefinition, IfcRelAssociatesClassification can be used.

New Entity Type Definitions, Page 4

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/3	Version	V-1	Status	Draft
Relationships	IfcConstructionResource, IfcMaterial, IfcClassification			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

New Entity Type Definitions:

IfcResourceCostItem (10)
An IfcResourceCostItem is an amount of money or value that affects a cost or financial value of a construction resource. It describes the resource context in a form that enables it to be used to formalize the cost value or price of a resource. IfcResourceCostItem brings together value and currency concepts available through the IfcCostResource schema. The value of a resource is directly connected with IfcResourceQuantitySet. The multiplication process of IfcResourceCostItem and IfcResourceQuantitySet gives the value of the resource. The unit value should be defined within IfcResourceCostItem.

EXAMPLE: The Unit Values can be:

- 1 Concrete Worker 1 Hour working price.....
- 1 m³ of Concrete Gravel price.....
- 1 Excavator (20 tones) 1 hour working price
- 1 kg of Nail price etc.

The unit values are accepted as general descriptive values, in order to describe quantities.

IfcResourceCostCalculation (11)
An IfcResourceCostCalculation is used to formalize necessary calculations in order to multiply IfcResourceCostItem and IfcResourceQuantitySet instances.

IfcResourceQuantitySet (12)
The IfcResourceQuantitySet, is an entity that holds a single quantity measure value, together with a semantic definition of the usage for the measure value.

EXAMPLE: A resource, like concrete worker which is required to produce concrete, has to be formalized based on the questions like; how many concrete workers are required and how long these workers have to work to form 1 m³ of concrete (there is a direct connection of IfcResourceCostItem).

- 1 m³ of C25 Concrete Production:
Requirements: Concrete Worker, Number of Conc. Workers, Working Time
(When it is examined for existing catalog structures or companies databases, these requirement details are generally established based on the UseCase Applications).
For 1 m³ of C25 Concrete Production, we assume that we need:
1,5 Concrete Worker for 20 minutes, (This should be given and embedded within IfcConstructionResource subtypes based on the external references).
1,5 Concrete Worker x 20 minutes = 30 man, minutes is derived,
(The calculation is done via IfcResourceQuantityCalculation). This is illustrated under IfcResourceQuantitySet.

Note: IfcPhysicalSimpleQuantity can not be used due to existing relationship definitions (IfcRelDefinesByProperties) which are given under IfcConstructionResource subtypes.

New Entity Type Definitions, Page 5

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/4	Version	V-1	Status	Draft
Relationships	IfcConstructionResource, IfcMaterial, IfcClassification			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
New Entity Type Definitions:					
IfcResourceQuantityLength (13)					
A physical quantity, <i>IfcResourceQuantityLength</i> , defines a derived length measure to provide a resources's physical property. It is normally derived from the resource quantity set of the resource under the specific measure rules given by a method of measurement. Note: The existing <i>IfcQuantityLength</i> entity is defined under <i>IfcElementQuantity</i> which helps to obtain length measure especially for <i>IfcBuildingElements</i> . In <i>IfcResourceQuantityLength</i> the properties are defined based on the specific measure rules for the resources.					
EXAMPLE: Parking Lines Construction Requirements: Paint, Length of the Line, Painter. The length of the painted line is required for cost info. and depends on the method of measurement use.					
IfcResourceQuantityArea (14)					
A physical quantity, <i>IfcResourceQuantityArea</i> , defines a derived area measured to provide the resources's physical property. It is normally derived from the resource quantity set of the resource under the specific measure rules given by a method of measurement. Note: The existing <i>IfcQuantityArea</i> entity is defined under <i>IfcElementQuantity</i> which helps to obtain area measure especially for <i>IfcBuildingElements</i> . In <i>IfcResourceQuantityArea</i> the properties are defined based on the specific measure rules for the resources.					
EXAMPLE: Wall Painting Construction Requirements: Paint, Painting Area, Painter. The area of the painted area is required for cost info. and depends on the method of the measurement use.					
IfcResourceQuantityVolume (15)					
A physical quantity, <i>IfcResourceQuantityVolume</i> , defines a derived volume measure to provide a resource's physical property. It is normally derived from the resource quantity set of the resource under the specific measure rules given by a method of measurement. Note: The existing <i>IfcQuantityVolume</i> entity is defined under <i>IfcElementQuantity</i> which helps to obtain volume measurements especially for <i>IfcBuildingElements</i> . In <i>IfcResourceQuantityVolume</i> the properties are defined based on the specific measurement rules of the resources.					
EXAMPLE: Brick Wall Construction Requirements: Bricks, Wall Volume, Wall Worker. The volume of the wall is required for cost info. and depends on the method of the measurement use.					

New Entity Type Definitions, Page 6

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/5	Version	V-1	Status	Draft
Relationships	IfcConstructionResource, IfcMaterial, IfcClassification			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
New Entity Type Definitions:					
IfcResourceQuantityCount (16)					
<p>A physical quantity, <i>IfcResourceQuantityCount</i>, defines a derived count measure to provide a resource's physical property. It is normally derived from the resource quantity set of the resource under the specific measure rules given by a method of measurement.</p> <p>Note: The existing <i>IfcQuantityCount</i> entity is defined under <i>IfcElementQuantity</i> which helps to obtain count measure especially for <i>IfcBuildingElements</i>.</p> <p>In <i>IfcResourceQuantityCount</i> the properties are defined based on the specific measure rules for the resources.</p> <p>EXAMPLE: 1 m³ of C25 Concrete Production:</p> <p>Requirements: Concrete Worker, Number of Concrete Workers, Cement etc.</p> <p>The number of Concrete Worker is required for cost info. and depends on the method of the measurement use.</p>					
IfcResourceQuantityWeight (17)					
<p>A physical quantity, <i>IfcResourceQuantityWeight</i>, defines a derived weight measure to provide a resource's physical property. It is normally derived from the physical properties of the resource under the specific measure rules given by a method of measurement.</p> <p>Note: The existing <i>IfcQuantityWeight</i> entity is defined under <i>IfcElementQuantity</i> which helps to obtain a weight measure especially for <i>IfcBuildingElements</i>.</p> <p>In <i>IfcResourceQuantityWeight</i> the properties are defined based on the specific measure rules of the resources.</p> <p>EXAMPLE: 1 m³ of C25 Concrete Production:</p> <p>Requirements: Concrete Worker, Cement, Sand, Gravel etc.</p> <p>The weight of Cement, Sand, Gravel is required for cost info. and depends on the method of the measurement use.</p>					
IfcResourceQuantityTime (18)					
<p>An element quantity, <i>IfcResourceQuantityTime</i>, defines a time measure to provide a property of time related to an element. It is normally given by the recipe information of the element under the specific measure rules given by a method of measurement.</p> <p>Note: The existing <i>IfcQuantityTime</i> entity is defined under <i>IfcElementQuantity</i> which helps to obtain time measure.</p> <p>In <i>IfcResourceQuantityTime</i> the properties are defined based on the specific measure rules for the resources.</p> <p>EXAMPLE: 1 m³ of C25 Concrete Production:</p> <p>Requirements: Concrete Worker, Concrete Workers, Working Time.</p> <p>The time period of Concrete Workers is required for cost info. and depends on the method of the measurement use.</p>					

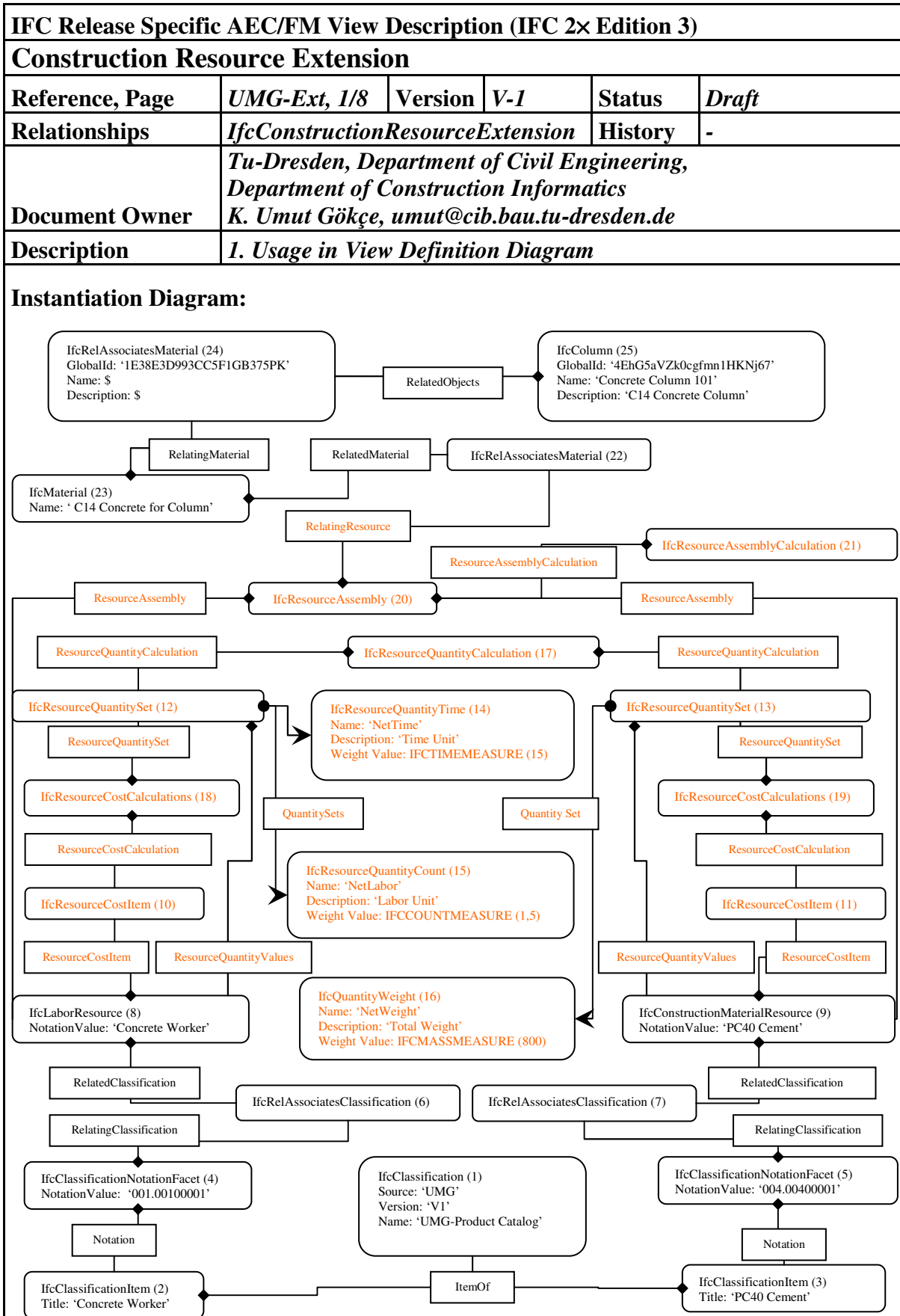
New Entity Type Definitions, Page 7

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/6	Version	V-1	Status	Draft
Relationships	IfcConstructionResource, IfcMaterial, IfcClassification			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
New Entity Type Definitions:					
IfcResourceQuantityCalculation (19)					
An IfcResourceQuantityCalculation is used to formalize necessary calculations in order to multiply IfcResourceQuantitySet instances.					
IfcResourceAssembly (20)					
A container class that represents complex resource assemblies aggregated from several resources.					
In IfcResourceAssembly, properties are defined based on the specific combination rules of the resources.					
Note: The existing IfcElementAssembly entity is defined under IfcElement which helps to combine complex element assemblies especially for IfcBuildingElements.					
EXAMPLE: 1 m ³ of C25 Concrete assemblies such as:					
Concrete Worker, Cement, Sand, Gravel, Vibrator etc. can be combined via IfcResourceAssembly entity.					
Note: The association of an actual material with an IfcResourceAssembly should be handled by IfcRelAssociatesMaterial. (New connection within a new and existing entity.)					
IfcResourceAssemblyCalculation (21)					
An IfcResourceAssemblyCalculation is used to formalize necessary calculations in order to add resources within each other. Therefore the required compositions can be obtained.					

Detailed Entity Type Definitions, Page 8

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/7	Version	V-1	Status	Draft
Relationships	IfcConstructionResource, IfcMaterial, IfcClassification			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
DetailedEntityTypeDefintion In order to formalize a composition structure which supports cost information, new entities as IfcResourceCostItem, IfcResourceCostCalculations, IfcResourceQuantitySet IfcResourceQuantityCalculation, IfcResourceAssembly, IfcResourceAssmbyCalculations, IfcResourceQuantityLength, IfcResourceQuantityArea, IfcResourceQuantityVolume, IfcResourceQuantityCount, IfcResourceQuantityWeight, IfcResourceQuantityTime and new relations between these and existing entities are structured. In this context, the new entities are settled as subtypes of IfcConstructionResource class. The existing resource entities as IfcCrewResource, IfcLaborResource IfcSubcontractResource, IfcConstructionProductResource, IfcConstructionEquipmentResource, IfcConstructionMaterialResource are directly connected with IfcResourceCostItem which obtains cost value relating to these resources. IfcResourceCostCalculations is used to calculate (multiply) related resource cost values with quantities to obtain cost value per quantities. The IfcResourceQuantitySet is directly connected with the existing resource entities. This provides to get quantity structures of the envisaged resource. The subtypes of IfcResourceQuantitySet as IfcResourceQuantity Time, IfcResourceQuantityCount etc. give the quantity value of the resource. Based on the specific requirements which come from resource representations, there is a need to multiply these within each other. The IfcResourceQuantityCalculation obtains this calculation via multiplying the related quantity values. IfcResourceAssembly collects all these resources which are required to form compositions (material analysis). These resource’s costs have to be added to each other to realize the cost value of the composition such as concrete. These can be supported via IfcResourceAssemblyCalculation. All these resource information can be derived from a classification structure via IfcRelAssociatesAssociation and established composition can be directly attached with IfcMaterial through IfcRelAssociatesMaterial which than can be directly connected to a IfcBuildingElement					

Instantiation Diagram, Page 9



Instantiation Diagram Definition, Page 10

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Construction Resource Extension					
Reference, Page	UMG-Ext, 1/9	Version	V-1	Status	Draft
Relationships	IfcConstructionResourceExtension			History	--
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Department of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram Instantiation Definition: An instantiation diagram illustrates an object (column) with its basic material information (definition) which includes basic resources with their quantity and cost data. Instantiation Details: In this instantiation diagram, a column instance (25) is instantiated to illustrate its material information which is composed of basic resources. This is connected to related material <i>IfcMaterial</i> (23) through an objectified relationship of <i>IfcRelAssociatesMaterial</i> (24). The <i>IfcResourceAssembly</i> (20) is connected through a new relating resource relationship to instances of <i>IfcMaterial</i> via <i>IfcRelAssociatesMaterial</i> (22). The proposed type <i>IfcResourceAssemblyCalculation</i> (21) supports assembly requirements and connected to <i>IfcResourceAssembly</i> (20) through <i>ResourceAssemblyCalculation</i> . The envisaged resource information are connected with classification codes as classification notation facets (4), (5) through <i>IfcRelAssociatesClassification</i> (6), (7). The notation facets are associated with classification system (<i>IfcClassification</i> (1)) through classification items as <i>IfcClassificationItem</i> (2), (3) which have the titles as ‘Concrete Worker’ and ‘PC40 Cement’. The resources as <i>IfcLaborResource</i> (8) and <i>IfcConstructionMaterialResource</i> (9) are connected with new <i>IfcResourceQuantitySet</i> (12), (13) which illustrate quantity sets such as <i>IfcResourceQuantityTime</i> (16), <i>IfcResourceQuantityCount</i> (17) and <i>IfcQuantityWeight</i> (18). This provides the ability to see each resource quantity. But in order to formulate these in terms of multiplying the required quantity sets by each other based on the specific resource structures, there is a requirement for a new entity as <i>IfcResourceQuantityCalculation</i> (17). This may be used to obtain necessary calculations. To get cost information, a new type such as <i>IfcResourceCostItem</i> (10), (11) is suggested. To structure the cost data based on the quantities, there is need a formulation entity such as <i>IfcResourceCostCalculations</i> (19) which multiplies the cost information and quantity sets. All these resources should be assembled to reach a material analysis such as concrete. In this case a new entity is offered as <i>IfcResourceAssembly</i> (20) and connected to <i>IfcMaterial</i> (23) through a type of <i>IfcRelAssociatesMaterial</i> (22).				

In this context with the new entity definitions and with the new relations suggested within the IFC Construction Resource Extension Concept, the cost information exchange is constituted, which is required for the Design & Build and Lump-sum Procurement Systems.

Moreover data exchange structures are examined briefly in the following paragraphs.

7.6.5 Data Exchange Structures

It is important to convert/define the product catalog information elements as IFC product data. However, the established views do not define in detail a standard data access interface for product catalogs.

Currently, IFC data is exchanged via two formats. These are:

- STEP Physical File Format (SPF), ISO 10303-21:1994 and,
- The ifcXML format, which is based on XML schema definition of the IFC Product data model, ISO10303-2x (Liebich 2001).

Actually, there are two ways to exchange product catalog data:

- Via an exchange file which is produced by the product catalog system and then imported by the using application.
- Via an on-line data access interface, which is provided by the product catalog system and with which the using applications directly connect to and access the product information.

There are also technologies for the implementation of interfaces for the catalog systems and applications to communicate over the internet as it was envisaged. However none of them are identified as standard by the IFC specification.

Alternatives technologies for the Internet-based product catalogs are as follows (ProIT 2005):

- Http-calls from an application to the product catalog server and as a response the server returns information as an XML-document (for example in ifcXML format), which is then parsed by the receiving application.
- Web services technology for exchanging product catalog object information as XML-documents that the receiving end needs to parse through.
- Web services technology as an object-based interface (SOAP, RPC), where the interface provides the applications with accessible product catalog objects and their properties.

Another consideration for product catalog information exchange is a new approach (Nour et.al 2004) which establishes a link between objects in the IFC model from one side and their technical and commercial attributes for the manufacturer and supplier from the other side. This system uses electronic product catalogs based on the concept of Object Information Packs.

7.6.6 IFC View for Architectural Design to Quantity Take-off

The main aim to formalize this view is to transfer the building product model data produced within the design phase by CAD applications as input for quantity take-off performed by ERP systems according to the IT Management Design Process.

In order to formalize BOQ in IT Management BOQ Process, there is a transformation need as such. The proposed quantity information is not concerned in the view information but it is the outcome of the definition itself. The envisaged view is defined to provide exchange of information which is a basic input for the production of project quantity information.

As it is implied within IT Management Design Process, the project dimensional data should be identified from/as 3D shapes (ITMDP_{F_8}), in order to constitute quantity take-offs regarding the identified building objects. The 3D dimensional data composed of 3D-shape representations of building objects with their length, width and height. This helps to identify spaces and building elements. The quantity information which is derived from 3D dimensional data describes the quantity of the building objects and spaces. In some cases it addresses the same construction type which is summarized from objects of the same type.

The exposed view does not define any management or responsibility issues. These items have already defined within process definitions in the previous chapters.

According to established ceEPC models two parties which are the main users of this data view, are examined as: the architect of the design office (based on Design & Build Procurement System) or quantity surveyor of the bidding department (based on Lump-sum or Unit Price Procurement Systems) who produces the building product data model using a 3D model-based architectural CAD-application and the bidding engineer of the bidding department who is the responsible for the bidding preparation based on quantity take-off and cost estimations.

In order to implement an IFC view for Architectural Design to Quantity Take-off in this approach, the statements are structured below:

- Design tools in terms of CAD systems should produce a building element model.
- CAD systems should write out the building product model into the data exchange application forms and exchange format in order to be used by interface structures.
- An interface structure between CAD-ERP systems should read the building product model information from the data exchange application form and exchange format of CAD system into the internal data of the quantity take-off application of ERP system.
- Both CAD and ERP structures should have a common view of the building element, building type class information i.e. use a common classification for building types which are examined in Product Catalog View. This class information can also be used to identify the properties of the product. Moreover it can be used to identify building elements according to data which is derived from external digital product catalogs.

7.6.7 Information Requirement

Based on the requirement analysis of the CAD structures, process definitions and IFC specification, the main information is constituted as: the project, the site and building, the building storey, spaces and their type of information (space type, space use), building elements, production resources and material analysis and their type of information, 3D-shape of spaces and building elements (geometry/dimensional data), location information of spaces and building elements. Besides, this all building objects should be uniquely identified

(Production Unit IDs) to obtain a general product modeling principle. The main purpose is to identify the building objects including the building element types, 3D shapes of the objects, their location and entities in this context.

A project should be composed of basic identifiers such as: name, identifier, the 3D-coordinate system, which defines the exact location and orientation. These are generally addressed within project specifications and drawings and used initially in the process definitions. The common measurement units which can be derived from product catalogs are also used in that level. Moreover a site/plot is needed for the data exchange implementation, in the data exchange structure. The site area can be derived from 3D-shape in this regard. To derive volume and area information from 3D-shape and to use it as a container object for the building stories which are essential for our approach, buildings can be accepted as the main part of the view information content. Building storey which conveys the spaces and building elements is also an essential part of the view. It includes the 3D-shape from which the building storey volume and area can be derived. The space information should include space type (classification item) and 3D shape of a space.

The main important information that our structure needs to implement interoperability between the envisaged systems are the building elements. The view information content is composed of different building elements in this context. The information for building elements should include their building element type which is represented by production resources and material analysis, 3D-shape (geometry/dimensional data), and the location.

The envisaged model is constituted according to requirements of the proposed product catalog formalizations. By using the 3D shape of building elements which determines dimensional data and which is an input for quantity take-off, cost information for BOQ can be derived by combining is data with building element type information. Building element type information is accepted as one of the key information aspects for BOQ information. By using this information with the building element type information, the quantity information produced by the CAD systems and the cost information produced by product catalogs can be attached to corresponding construction product structure. Thereby the required quantity data which is derived from dimensional data with its product attributes can be possessed.

7.6.8 IFC View Implementation for Architectural Design to Quantity Take-off

The proposed view information content is realized according to envisaged software integration requirements. The implementation of view is formalized based on IFC 2x3 Addendum 1 release specification. The constituted software integration structure supports data exchange formalizations by showing interactions between functions and resources. Later these are mapped with IFC Classes as given in **Table 7.11**.

In order to establish a view comprising building elements, quantity take-offs and production resource prices process resource attributes have to be defined. To prove this, the proposed data exchange view which includes the project, site, building, stories, spaces and production resource information is defined based on IFC formalization needs. Moreover they have to be identified with their IDs and with their 3D-shapes based on dimensional data. Additionally

because Building contains Stories and Stories contains spaces and production units, the building has to have a container for Stories and Stories has to have a container for spaces and production units. Space has to be defined with its type of space and where it is located within a storey. Building elements have to be identified with their building element type and where they located within stories and sections also. These information contents are structured based on the ITMP requirements as illustrated in **Table 7.10**. The formulation which is given in Figure 7.12 will be applied in this section too. Each ceEPC function reference 1 or many (1:n) ITMP resources are related with the product catalogs.

Table 7.10 ITMP Functions and Resources Referencing IFC Classes

ITMP Functions where left Resources are Input	ITMP Resources Referencing IFC Classes in the Context of the Architectural Design
ITMDPf_i, i=1-11 ITMBPf_j, i=1-13, 21,22,23,24	<i>Project ID</i>
	<i>Project</i>
	<i>Site</i>
	<i>Building</i>
	<i>Storey</i>
	<i>Space, Space Shape</i>
	<i>Project Containment Structure</i>
	<i>Building Elements</i>
	<i>Building Element Types</i>
	<i>Building Element Shapes</i>
	<i>Building Classification</i>
	<i>Product IDs</i>
	<i>Production Resources</i>
	<i>Material Analysis</i>
	<i>Compositions</i>
	<i>Material Properties</i>
	<i>Classification</i>
	<i>Grouping</i>
	<i>Production Resource Shapes</i>
	<i>Material Analysis Shapes</i>
	<i>Compositions Shape</i>
	<i>Logical Location of Production Resources</i>
	<i>Logical Location of Material Analyses</i>
	<i>Logical Location of Compositions</i>
	<i>Properties of Production Resources</i>
	<i>Properties of Material Analysis</i>
	<i>Properties of Compositions</i>

Table 7.11 Mappings of ITMP Resources into IFC Classes

ITMP Resources as Collected in Table 7.10	IFC Classes Referenced by the ITMP Resources
Project ID	* IfcRoot
Project	* IfcSpatialStructureElement
Site	* IfcSpatialStructureElement, IfcSite
Building	* IfcSpatialStructureElement, IfcBuilding
Storey	* IfcSpatialStructureElement, IfcStorey
Space	* IfcSpatialStructureElement, IfcSpace
Space Shape	* IfcShapeRepresentation, IfcSweptAreaSolid, IfcExtrudedAreaSolid * IfcGeometricRepresentationItem, IfcTopologicalRepresentation * IfcRepresentationMap
Project Containment Structure	* IfcRelContainedInSpatialStructure
Building Elements	* IfcBuildingElement, IfcDistributionElement, * IfcComponentElement, IfcTransportElement, * IfcFurnishingElement
Building Element Types	* IfcBuildingElementType, IfcDistributionElementType * IfcComponentElementType, IfcTransportElementType * IfcFurnishingElementType
Building Element Shapes	* IfcShapeRepresentation, IfcSweptAreaSolid, IfcExtrudedAreaSolid * IfcGeometricRepresentationItem, IfcTopologicalRepresentation * IfcRepresentationMap
Building Classification	* IfcClassification
Product IDs	* IfcRoot
Production Resources, Material Analysis	* IfcMaterial * IfcConstructionResource
Compositions	* IfcBuildingElement, IfcBuildingElementType * IfcDistributionElement, IfcDistributionElementType * IfcComponentElement, IfcComponentElementType * IfcTransportElement, IfcTransportElementType * IfcFurnishingElement, IfcFurnishingElementType
Classification	* IfcClassification
Grouping	* IfcGroup
Production Res. Shapes	* IfcProductDefinitionShape
Material Analysis Shapes	* IfcProductDefinitionShape
Compositions Shape	* IfcProductDefinitionShape
Log. Location of Prod R.	* IfcRelContainedInSpatialStructure
Log. Location of Mat. A.	* IfcRelContainedInSpatialStructure
Log. Location of Comp.	* IfcRelContainedInSpatialStructure
Properties of Prod. Res.	* IfcPropertSet, IfcProperty
Properties of Mat. Anal.	* IfcPropertSet, IfcProperty
Properties of Comp.	* IfcPropertSet, IfcProperty

ITMP resources for architectural design, which are structured in Table 7.10 are used as primary keys to formulate related IFC classes in Table 7.11 after examination of IFC model. Each ITMP resource is using 1 or many (1:n) IFC classes.

7.6.9 IFC Concepts for Architectural Design to Quantity Take-off

IFC Concepts for Architectural Design to Quantity Take-off are constituted as given in **Table 7.12**. Each IFC Concept is using 1 or many (1:n) IFC Classes in its constitution i.e in Type Object Concept. Also IFC Classes can be represented in 1 or many (1:m) concepts to support different demands i.e. IfcClassification. The detailed IFC Concepts and Instance Diagrams are given in Appendix C.

Table 7.12 IFC Concepts for Architectural Design to Quantity Take-off View

IFC Classes Referenced by the ITMP Resources in Table 7.11	IFC Concepts for Architectural Design to Quantity Take-off View	IFC View
* IfcRoot	* <i>Identification</i>	IFC View for Architectural Design to Quantity Take-off is the Sum of 20 Concepts
* IfcSpatialStructureElement, IfcSite, IfcBuilding, IfcStorey, IfcSpace * IfcRelContainedInSpatialStructure	* <i>Spatial Element</i>	
* IfcShapeRepresentation, IfcProduct Definition Shape	* <i>Shape Representation</i>	
* IfcBoundingBox,	* <i>Bounding Box</i>	
* IfcSweptAreaSolid,	* <i>Swept Area Solid</i>	
* IfcGeometricRepresentationItem,	* <i>Geometric Representation</i>	
* IfcTopologicalRepresentation,	* <i>Topological Representation</i>	
* IfcRepresentation Map	* <i>Representation Map</i>	
* IfcBuildingElement	* <i>Building Element</i>	
* IfcDistributionElement	* <i>Distribution Element</i>	
* IfcComponentElement	* <i>Component Element</i>	
* IfcTransportElement	* <i>Transport Element</i>	
* IfcFurnishingElement	* <i>Furnishing Element</i>	
* IfcBuildingElementType, IfcDistributionElementType, IfcComponentElementType, IfcTransportElementType, IfcFurnishingElementType	* <i>Type Object</i>	
* IfcClassification (<i>arrangement of an object into a class</i>)	* <i>Classification Concept</i>	
* IfcClassification (<i>to assign a classification notation to objects</i>)	* <i>Construction Type Classification</i>	
* IfcMaterial	* <i>Material</i>	
* IfcConstructionResource	* <i>Construction Resource Extension</i>	
* IfcGroup	* <i>Group</i>	
* IfcPropertySet, IfcProperty	* <i>Properties</i>	

7.7 IFC View for IT Management BOQ Process

The building product model which is produced by CAD applications and the product catalog information which can be used for cost estimations are the major inputs of the suggested IT Management BOQ Process. According to information derived from CAD and Product Catalogs in this phase, a bill of quantities can be realized within the ERP systems.

Although BOQ information can be implemented according to inputs, such as production resources, material analysis, quantity take-offs, there is a need to identify relevant items such as space, building elements to specify a general level exchange of BOQ information.

7.7.1 IFC View for Exchange of BOQ information

The main aim in formalizing this view is to form BOQ information by transferring quantity and cost information as input for the activity which utilizes these information for cost estimation, bidding and as well for planning purposes. This is done by exchanging building elements related to quantity and cost information on a general level. This information is used not only for the Bidding Preparation phase but also for the Planning & Construction, the Evaluation and the Feedback phases in the envisaged model.

The main elements of BOQ information exchange are defined as: (1) the Identity of the BOQ objects (e.g. production resources, material analysis and compositions) (2) The classification of BOQ objects, (3) The quantities and the quantity units of the BOQ objects, (4) The grouping of the quantity information, (5) Location of the quantity information, (6) Cost information of the BOQ objects (cost of production resources, material analysis, building elements). (7) The classification of BOQ objects' cost information, (8) the grouping of BOQ objects' cost information and (9) Property information.

In this 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 is formalized using the ceEPC model. According to ceEPC, two parties can be identified the architect of the design office (based on Design & Build Procurement System) or quantity surveyor of the bidding department (based on Lump-sum or Unit Price Procurement Systems) who produces the quantity take-off information, and the bidding engineer of the bidding department who is the responsible for the BOQ preparation based on quantity take-offs and cost of production resources.

In order to implement the view for exchange of BOQ information two approaches can be chosen (ProIT 2005):

- 1 The BOQ information can be exchanged via an attachment to individual building elements and space objects. In this approach the BOQ information derived from the 3D-shape of a building element is attached to an object, which the receiving application can use without exchanging the 3D geometry information. In this approach the building product model and objects with the attached quantity information can be exchanged.

- 2 The BOQ information can be exchanged by summarizing each building element type. No individual objects, space building elements are transferred in this case.

In our approach from the process point of view, specific quantity information of building elements which are composed of production resources and material analysis are exchanged within CAD and ERP systems (ITMDP_{F_11}). Later these quantity take-offs are rearranged within ERP system (ITMBP_{F_21}) and sent to BOQ folder (ITMBP_{F_22}). In order to form BOQ lists production resource1 and material analysis1 (which are rearranged according to market prices) are sent to BOQ folder (ITMBP_{F_23, F_24}) and used for calculation of the bid.

According to proposed general level of data exchange, the main statements are formalized as:

1. In order to implement 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 Product Catalogs, CAD and ERP systems should use common formats such as Production ID's for 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 this BOQ information from this representation form into its representation structures.

7.7.2 Information Structure

There are two items, which should be considered in this context: (1) Individual items for BOQ information exchange such as individual building elements and space, (2) Sum of individual items such as types of building elements and space types according to intended use of classification.

To formalize BOQ information, there is a need to organize BOQ objects into groups. These are organized based on the different aspects such as building elements, the location of the quantity information based on building sections, price of the production resources and material analysis.

All building elements have dimensional structures which are shown as length, area, volumes and in order to define these dimensional entities there is a need to identify these items via quantity units. In order to use BOQ information for software integration, the additional dimension cost information is added to building elements which are composed of production resources and material analysis. The production resources and material analysis are classified and grouped in order to obtain the exact cost of building elements.

When a BOQ is 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 examined as building storey, the building sections and spaces. Depending on the envisaged interoperability structure, there is a need to attach the characteristic property information to individual quantity and cost information units. In order to attach production resources and material analysis, the proposed 3 layered catalog structure is used.

7.7.3 IFC View Implementation for Exchange of BOQ Information

The proposed IFC View for Exchange of BOQ Information content is constituted based on the IFC 2x3 Addendum 1 release specification. The content is constructed based on the combination and sum of individual items and represented as building total items. Building total items, for BOQ information exchange comprises quantity information and cost information based on the space and building elements and their related types as given in **Table 7.13** below. Each ceEPC function refers to 1 or many (1:n) ITMP resources.

Table 7.13 ITMP Functions and Resources Referencing IFC Classes

ITMP Functions where left Resources are Input	ITMP Resources Referencing IFC Classes in the Context of the Exchange of BOQ
ITMDPf_i, i=1-7,9,10,11 ITMBPf_j, J=2-24	Project ID
	Project
	Site
	Building
	Storey
	Space
	Project Containment Structure
	Building Elements
	Building Element Types
	Building Classification
	Product IDs
	Production Resources
	Material Analysis
	Compositions
	Material Properties
	Classification
	Grouping
	Logical Location of Production Resources
	Logical Location of Material Analysis
	Logical Location of Compositions
	Special Properties of Production Resources
	Special Properties of Material Analysis
	Special Properties of Compositions
	Quantities
	Measurement Unit
	Production Resource Prices
	Material Analysis Prices
	Composition Prices

ITMP resources for BOQ which are structured in Table 7.13 are used to formulate related IFC classes in **Table 7.14**. Each ITMP resource is using 1 or many (1:n) IFC classes.

Table 7.14 Mapping of ITMP Resources into IFC Classes

ITMP Resources as Collected in Table 7.13	IFC Classes Referenced by the ITMP Resources
Project ID	* IfcRoot
Project	* IfcSpatialStructureElement
Site	* IfcSpatialStructureElement, IfcSite
Building	* IfcSpatialStructureElement, IfcBuilding
Storey	* IfcSpatialStructureElement, IfcStorey
Space	* IfcSpatialStructureElement, IfcSpace
Project Containment Structure	* IfcRelContainedInSpatialStructure
Building Elements	* IfcBuildingElement, IfcDistributionElement, * IfcComponentElement, IfcTransportElement, * IfcFurnishingElement
Building Element Types	* IfcBuildingElementType, IfcDistributionElementType, * IfcComponentElementType, IfcTransportElementType, * IfcFurnishingElementType
Building Classification	* IfcClassification
Product IDs	* IfcRoot
Production Resources, Material Analysis	* IfcMaterial, * IfcConstructionResource
Compositions	* IfcBuildingElement, IfcBuildingElementType * IfcDistributionElement, IfcDistributionElementType * IfcComponentElement, IfcComponentElementType * IfcTransportElement, IfcTransportElementType * IfcFurnishingElement, IfcFurnishingElementType
Classification	* IfcClassification
Grouping	* IfcGroup
Logical Location of Prod. Res.	* IfcRelContainedInSpatialStructure
Logical Location of Mat. Anal.	* IfcRelContainedInSpatialStructure
Logical Location of Compositions	* IfcRelContainedInSpatialStructure
Special Properties of Prod. Res.	* IfcPropertySet, IfcProperty
Special Properties of Mat. Anal.	* IfcPropertySet, IfcProperty
Special Prop. of Compositions	* IfcPropertySet, IfcProperty
Quantities	* IfcElementQuantity, IfcPhysicalQuantity
Measurement Unit	* IfcSimplePhysicalQuantity
Production Resource Prices Material Analysis Prices Composition Prices	* IfcCostValue * IfcCostSchedule * IfcCostItem

7.7.4 IFC Concepts

In order to develop an IFC View for Exchange of BOQ Information, the collected IFC Classes referenced from ITMP resources in Table 7.13 are used to form the concepts which are listed in Table 7.14. Each IFC Concept is using 1 or many (1: n) IFC Classes in its constitution i.e in Type Object Concept. On the other hand IFC Classes can be represented in 1 or many (1: m) concepts i.e. IfcClassification. According to the proposed catalog structure, the supporting instance diagrams provide a basis and facilitate understanding. The detailed IFC Concepts and Instance Diagrams are given in Appendix C.

Table 7.15 IFC Concepts for the Exchange of BOQ Information View

IFC Classes Referenced by the ITMP Resources in Table 7.13	IFC Concepts for the Exchange of BOQ Information View	IFC View
* IfcRoot	* <i>Identification</i>	IFC View for Exchange of BOQ Information is the Sum of 16 Concepts
* IfcSpatialStructureElement, IfcSite, IfcBuilding, IfcStorey, IfcSpace, * IfcRelContainedInSpatialStructure	* <i>Spatial Element</i>	
* IfcBuildingElement,	* <i>Building Element</i>	
* IfcDistributionElement,	* <i>Distribution Element</i>	
* IfcComponentElement,	* <i>Furnishing Element</i>	
* IfcTransportElement,	* <i>Component Element</i>	
* IfcFurnishingElementType	* <i>Transport Element</i>	
* IfcBuildingElementType, IfcDistributionElementType, IfcComponentElementType, IfcTransportElementType, IfcFurnishingElementType	* <i>Type Object Concept</i>	
* IfcClassification	* <i>Classification</i>	
* IfcClassification	* <i>Construction Type Classification</i>	
* IfcMaterial	* <i>Material Concept</i>	
* IfcConstructionResource * IfcElementQuantity * IfcPhysicalQuantity * IfcSimplePhysicalQunatity	* <i>Construction Resource Extension</i>	
* IfcGroup	* <i>Group</i>	
* IfcPropertySet, IfcProperty	* <i>Properties</i>	
* IfcCostValue	* <i>Cost</i>	
* IfcCostSchedule, IfcCostItem	* <i>Cost Item and Cost Schedule</i>	

7.8 Summary and Conclusions

In this chapter, three IFC Views based on the requirements of IT Management Processes (ITMP) were outlined. The main aim in formalizing these views is to construct a process oriented information modeling methodology and to enable handling of various types of information in a standardized way.

To provide this, ITMP defined in the ceEPC model, is used as a baseline and the defined functions and resources which are relevant to IFC Views, are examined. Subsequently mappings between these resources and IFC objects are obtained. Whenever model subsets need to be applied, IFC Concepts and IFC Instance Diagrams are defined based on the IFC View Definition Format of the IAI. The details in this context are provided in Chapter 8.

Because, exchanging of cost data is a priority in this research, for the product catalogs (1) a three leveled structure and (2) an extension to “IfcConstructionResource” Concept, which includes new IFC Classes and new object relations are suggested. These provide the exchange of building element cost information based on the production resources and the material analysis.

Furthermore to validate the established structure, required subsets are formalized in GMSD in the next chapter. Runtime use of the IFC data is then provided via a specialized GMSD client which enables proper extraction of the specific IFC instances, in this regard.

CHAPTER 8: FORMALIZATION OF THE IFC VIEWS AND VALIDATION

This chapter is structured in 2 parts. In the first part IFC View formalization principles are presented by defining a conceptual schema. In order to define IFC Model View Definitions, the structure of IFC Concepts and IFC Instance Diagrams are examined in detail. Moreover a brief introduction of the General Model Subset Definition schema, View Edit and modified IFC View Definition Format are given. In the second part in order to validate the proposed methodology, IFC Concepts for product catalogs which are formalized within IFC View Definition Format are used. The implementation can be represented in two slightly distinct instantiations according to the requirements of the Procurement Systems. The validation will be carried out by comparing the outcomes of the 3D full model of the selected example and our proposed View. In the first case for the Unit Price system the desired results are obtained. The validation results are alphanumeric. For a supporting 3D visual cross check the IFC View for Product Catalogs was extended by the geometric concepts. However, due to the IFC extension need for Design & Build and Lump-sum Procurement systems as envisaged in Chapter 7 and because the necessary IFC Classes and relations has not already implemented in software tools, the comparison for Design & Build and Lump-sum Procurement systems have not been possible in the thesis.

8.1 Introduction

The most considerable problem with regard to data access to the shared repository is the amount of necessary data. In principle, the amount of necessary data can range from individual attributes to full models, but for practical purposes the most important part is the support of partial, domain-specific model views (Weise et al. 2003).

The partial models of the whole structure facilitate better understanding of domain applications by reducing the quantity of the exchanged data and by supporting well-defined domain views by simplifying the data management.

Therefore modeling partial structures is the main precedence to understanding whole models.

In this context the following partial models (IFC Views) based on the IT Management Processes are developed:

- 1 IT Mng. Design Process
 - IFC View for Product Catalog,
 - IFC View for Arch. Design to Quantity Take-off
- 2 IT Mng. BOQ Process
 - IFC View for Exchange of BOQ information

In order to represent these models, concepts are formalized according to IFC View Definition Format of the IAI.

However, as the objective is to propose an integrated framework and show how IFC suits into it rather than develop a specific IFC extension model for CPM, IFC View for Product Catalog partial model was chosen to validate the framework.

In order to provide this, the product catalog view is implemented with the generalized model subset definition schema (GMSD) (Weise et al. 2003) which contains rules for dynamic run-time filtering, and a dedicated service, performing the actual view extraction for the specifically referenced Views.

In this context, IFC objects are used as much as possible, with some needed extensions (see Section 7.6.4) for CPM purposes.

8.2 Related Work

The suggestions dealing with partial models have been proposed in COMBINE 2 (Augenbroe 1995b, Lockely & Augenbroe 2000). A repository called integrated data model (IDM) was used to derive subsets of information. In order to model needed subsets a sub schema approach which uses the same modeling language was suggested. Also to minimize data on the instance level additional restrictions were applied. Although it can be accepted as a sufficient approach, it doesn't comprise well dynamic (ad-hoc) view specification. Also it is not reliable enough to support IFC applications which directly operate on the IFC model schema.

The work related to GMSD is the Partial Model Query Language (PMQL) which was developed by Yoshinobu Adachi (Adachi 2002). PMQL borrowed many concepts from SQL. It is capable of using SQL statements and is in fact strongly optimized for implementations with underlying relational databases. The language was specifically designed to support client/server interactions, providing straight-forward language bindings for SOAP and XML. However, PMQL normally requires many request-response cycles to retrieve the information for a specific view. It does not contain dedicated constructs for explicit view specification and has more problems with path expressions, nested queries and inheritance hierarchies.

IFC is composed of a layered structure, based on inheritance, and partitioning into a set of schemas. However, this fixed configuration has not yet supported work with partial model data. Instead, for the implementation of the IFC model additional view definitions are introduced to address work tasks, e.g. coordination of design activities using the so called coordination view (Steinmann 2006). The aim is to obtain a basis for certifying IFC applications by supporting all quality criteria so that it can be said that it is fully available for realization and for use to certify applications. But despite this, the view definitions e.g. for structural engineering, HVAC design, is still barely structured due to the lack of tool support.

This can be changed by switching to a more structured way of defining views, as suggested in the BLIS project (Heitanen 2002). BLIS was set-up based on concepts which are introduced and allowed to start with the high level classes, such as wall, beam etc., which are then detailed step by step to reach low level classes. Subsequently, in this approach a view is defined in two ways: (1) generally, by using an engineering ontology representing the content of the targeted product data model, and (2) specifically, by mapping the general view to an

existing release of the product data model e.g. IFC2x2. The set of diagrams and form sheets are used to improve comprehensibility and maintenance. However, these definitions are not directly applicable as data queries.

As it was envisaged in the previous chapter, the ProIT project provides the basis for IFC view definitions (ProIT 2004). The IDM project developed a principal methodology for the creation of partial model views and their binding to process through so called functional parts (Wix 2005), which also show similarities with our process based configuration. Moreover there are initiatives which require a considerable effort to obtain generic criteria such as maintenance to for allow future refinements and human readability.

In order to formalize IFC views implementation agreements have been documented. In such agreements the use of objects and their attributes are defined by choosing the predefined types.

8.3 Conceptual Schema

Generically, there are two levels for defining the model subset conceptually:

- 1 Class level, restricting product model data to a generic view that is appropriate for a certain type of work tasks,
- 2 Instance level, restricting a generic view to product model data needed for a specific work task.

In this research, to formalize model subsets in terms of view definitions GMSD is used on class level.

In order to validate the structure, IFC View for Product Catalogs' Concepts are constituted. These are then brought together within GMSD to represent the whole Product Catalog subset.

Two solutions are provided for Product Catalog structure based on the Procurement Systems to support cost information exchange in Chapter 7.

In Unit Price Procurement System the compositions which are established within the product catalog are formalized directly by using envisaged Concepts (see section 7.6.3) with respect to existing product catalog prices and material analysis formalizations.

However, for Design & Build and Lump-sum procurement systems, there is a need to form production resources and material analysis according to project needs and market prices.

Based on the examinations of the IFC 2x3 (Addendum 1 Release), the necessary classes could not be observed. Therefore to represent the required material analysis based on the production resources the IFC 2x3 models are extended with new classes and new relations (see section 7.6.4). In this context the existing IFC classes are used as much possible but some special issues (explained within the Construction Resource Extension Concept) required for the implementations, *IfcConstructionResource* class is extended with new classes such as: *IfcResourceCostItem*, *IfcResourceCostCalculations* etc. and with new relations.

The detailed definitions are illustrated in the following paragraphs.

8.3.1 Generalized Model Subset Definition Schema (GMSD)

GMSD is a schema which allows a neutral definition format for different type of data exchange (for practical purposes) and client/server implementations and has a capability to specify generic views as well as specifically needed model subsets. The schema itself is composed of two separate subparts, obtaining functions for (1) the object selection and (2) the generic view definition.

The main idea is to select the required high level object instances which are then operated by a predefined generic view, picking up all required data related to these object instances. In the first part the selection of object instances are fulfilled by using a set theory as a baseline.

Also a large set of functions is provided to select object instances by value, class type and references. In contrast, the second part is intended for post-processing of the selected data in accordance with a predefined generic view.

According to Weise et al. (2003), it can be used to:

- Arrange object instances by their class type or reduce their data content on attribute level.
- Sever references to unneeded objects in order to create a consistent data set without external, possibly unmanaged references.
- Generalize objects to super types, to lower the complexity of the resultant model subset.
- Extend or reduce object selections by including/excluding referenced objects in accordance with some specified criteria.

The definition of generic views in our approach follows the concept of choosing a default handler for all class types and attributes based on functions/resources which are formalized within process definitions.

This approach provides a reduction in time and formalizes views, and results in rather compact data queries. The structure of sub views providing to specify handling of referenced object instances is more important. It not only helps to manage view definitions but also allows for differentiating the handling of object types by considering their use, i.e. the references to high level instances.

More details about GMSD schema can be found in Weise et al. (2003) in this context.

8.3.2 View Definition

The GMSD schema provides view definitions by using an editor called ViewEdit which was developed by Weise (2003) to interactively define generic views.

The GUI is divided in three parts as:

- 1 An inheritance graph and an alphabetical order which shows entity types (classes) and attributes (features) based on EXPRESS-based product data model in a layered (tree) structure.
- 2 Tree view which is composed of high level classes detailed in the second part by handling attributes which comprise sub-views for the handling of referenced object instances thereby deepening the first part.
- 3 A settings panel which forms various properties for the item selected in the view definition panel which is composed of a set of check and select boxes.

In this context a sample representation is illustrated in **Figure 8.1** below.

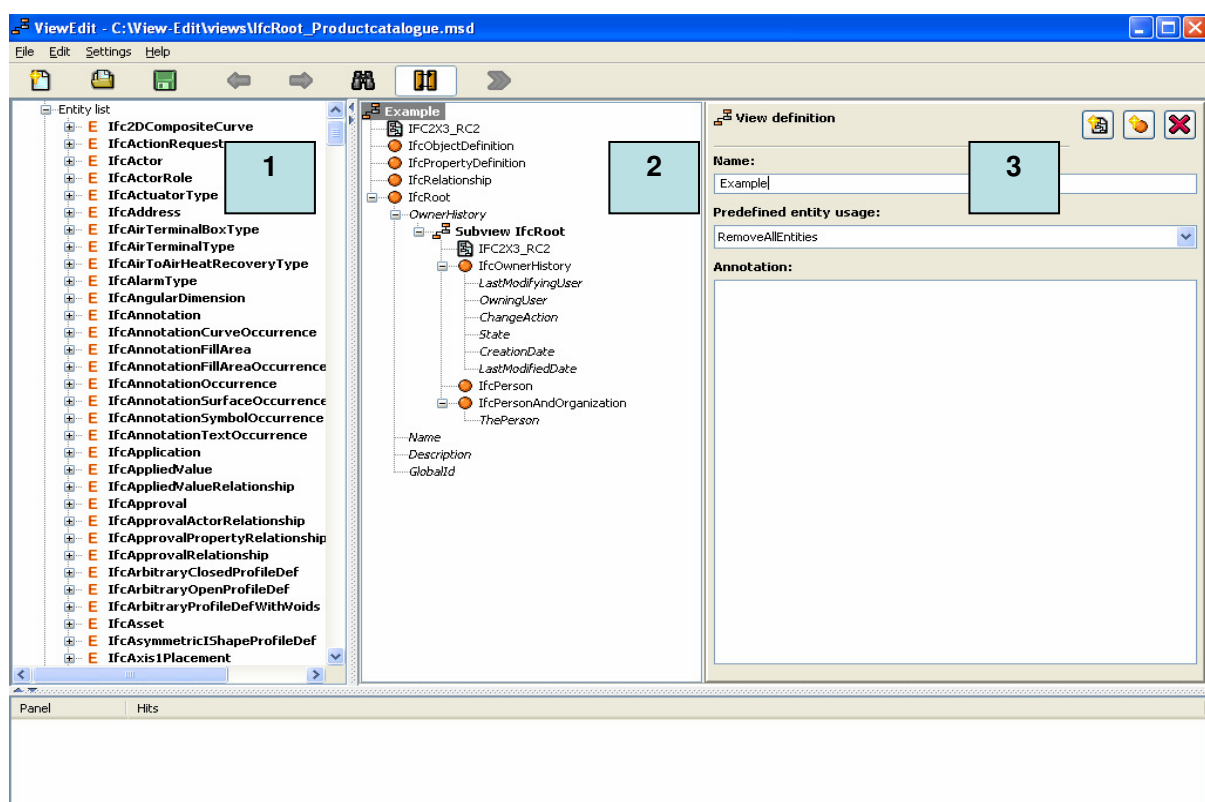


Figure 8.1 Screenshot of ViewEdit

8.4 IFC Model View Definition Format

In order to facilitate view definitions within GMSD, the IFC Model View Definition Format which was proposed by Hietanen (2006) is used as a baseline.

According to Hietanen, the IFC Model View Definition Format provides extensive use of two generic ideas which are

- (1) Definitions and
- (2) Configurations.

Definitions examine a range of possibilities and configurations represent these possibilities` used in a specific case. Each IFC Model View Definition is a configuration of the IFC Model Specification. They define a subset of the IFC Model and add new definitions, called agreements, to it.

The IFC View Definition Format is divided into two main parts namely:

- (1) IFC release independent and
- (2) IFC release specific.

The IFC release independent part defines concepts that are used in the data exchange in generic terms.

The IFC release specific part is a binding of the generic concepts into a specific IFC release. It defines how the IFC Model Specification is used for exchanging the required data.

Both parts are illustrated in documents and diagrams. Documents represent the idea of the view and the concepts which are used in these views. The same concepts can be used in different views. For instance, the same Grouping concept is used in all envisaged views in our approach.

However, the documents address an unconnected collection of concepts. In this case Diagrams are used for defining the relationships between the concepts in the context of a specific view. For instance, Construction Type Classification Concept diagram illustrates construction type classifications and their connection to objects based on IFC 2x3.

8.4.1 Process of creating IFC Model View Definitions based on ceEPC Model

In order to formalize IFC Model View Definitions, the information resources which address IFC objects should come from exchange requirements.

According to IFC Model View Definition Format (2006), the first detailed definition should be the IFC release independent part, consisting of the required concepts and their relationships. It is important to study existing concepts and to re-use them whenever possible. Also the structure of existing definitions (patterns) should be re-used as much as possible.

When the generic definition is done, the next step is to define the binding to a specific IFC release. This task requires strong involvement from the implementers, because this binding defines the necessary implementers' agreements. Also in this stage re-using existing concepts and patterns is very important.

When the IFC binding is done the definition can be implemented in software. In parallel the definition can be proposed to the IAI and the review process for making it official can begin, once a definition is accepted as a candidate, certification for it can be organized.

In our approach, exchange requirements are formalized based on the established information resources which represent the required information. In order to formalize the transition between exchange requirements to IFC Model View Definitions, the CPM information resources defined in ceEPC model are examined with regard to IFC partial views to find out the commonalities between organizational and resource entities.

An information resource defines one or several partial IFC views. An IFC Partial View contains one to several IFC Classes. Usually classes are represented in a network of classes. These networks are called IFC Concepts in our case. IFC Concepts are defined as a standard one page description of the new IFC Model View Definition. An IFC View comprises several IFC concepts which define the complete set of IFC classes as envisaged in Chapter 7.

The proposed IFC Model View Definitions cannot become official before it is implemented in software and the implementations certified. The GMSD is used to formalize the proposed views in order to show subset content. From the outcome of the envisaged structure, the first results are shown with the use of IFC viewers.

8.4.2 Concepts

The aim in forming a concept is to provide a clear definition and reuse ideas and software code. In IFC Model View Definition Format, Concepts are realized in two formalizations as: (1) Generic Concepts and (2) IFC Binding Concepts.

Generic Concepts are illustrated in three parts as

- 1 Variable Concept which is achieved by creating a diagram to which other concepts are connected i.e. wall in architectural design to quantity take-off.
- 2 Group Concept which provides structure for the generic diagrams by grouping together static concepts and/or other group concepts i.e. window properties.
- 3 Static Concept which remains the same in all scenarios in which they are used i.e. object ID.

IFC Binding Concepts are formed from:

- 1 Variable Concept which implements a generic variable concept with the same name, i.e. 'door' is 'door'.
- 2 Adapter Concepts which are reusable parts of IFC Model specification that connect static concepts to a variable concept i.e. classification assignment.
- 3 Static Concept which implements one or more generic static concepts i.e. object ID.

8.4.3 Documentation

Basically there are four types of descriptions which are given within IFC Model View Definition Format (Hietanen 2006). They are:

- Generic AEC/FM View Description
- IFC Release Specific AEC/FM View Description
- Generic AEC/FM Concept Description
- IFC Release Specific Concept Description

Generic AEC/FM View Description

The purpose of the high level description (Generic AEC/FM View Description) is to provide a quick overview of the ideas of the view.

IFC Release Specific AEC/FM View Description

The aim of high level description of an IFC binding of a view (IFC Release Specific AEC/FM View Description) is to document any general decisions that are made in the binding.

Generic AEC/FM Concept Description

The purpose of the Generic AEC/FM Concept Description is to document the idea of the concept independent from any data exchange format.

IFC Release Specific Concept Description

The IFC binding definition (IFC Release Specific Concept Description) of a concept documents how the concept must be implemented using a specific IFC release.

In our approach, in order to formalize IFC Concepts for GMSD use, the IFC Release Specific Concept description is used. Due to requirement analysis, the examination is done based on information resources which are also addressed by Generic and IFC Release Specific View descriptions. However these and Generic AEC/FM Concept definitions are not taken further into account. From this stand point the necessary implementations which also support GMSD requirements are constituted, i.e. definitions of diagrams in EXPRESS-G Language.

The established template and description structure is given in **Figure 8.2** and in **Figure 8.3**.

IFC Release Specific Concept Description (<IFC Release field>)					
<Title field>					
Reference	<Reference field>	Version	<Version field>	Status	<Status field>
Relationships					
History					
Authors	<Author field>				
Document Owner	<Company field>				
Usage in view definition diagram					
Instantiation diagram					
Implementation agreements					
This document uses the official IAI View Definition Format version 1.0.7. The content of this document has to be certified by the IAI before becoming part of an Official IAI View Definition.					

**Figure 8.2 Template for IFC release specific concept definition,
(IFC Model View Def. 2006)**

Field	Description
<IFC Release>	The IFC release for which the binding is defined
<Tile>	The name of the concept
Reference	The reference number of the concept
Relationships	Relations to other definitions * Implements: the generic concept implemented by the IFC binding * Extends: the adapter concept a concept is based on
Version	the sequential version number of the concept
Status	The status of the concept. Sample, Draft, Proposal, Candidate, Official or Deprecated
History	Any history specific to the IFC binding
Document Owner	The person and organization responsible for maintaining the document. Should contain some contact information, e.g. Email address
Description	<p>The 'Usage in View Definition Diagram' defines the place of the concept in diagrams</p> <p>The 'Instantiation Diagram' shows the IFC objects that need to be instantiated for the concept and any requirements on the attribute values. Instantiation diagrams may be freely commented and may contain clarifying diagrams. Instantiation diagrams from other concepts may be inserted and further specified.</p> <p>There is no official format for instance diagrams.</p> <p>The 'Implementation agreements' are the official agreements made regarding the implementation. Most of them will already be shown in the instantiation diagram, but this is the official list used in certification.</p>

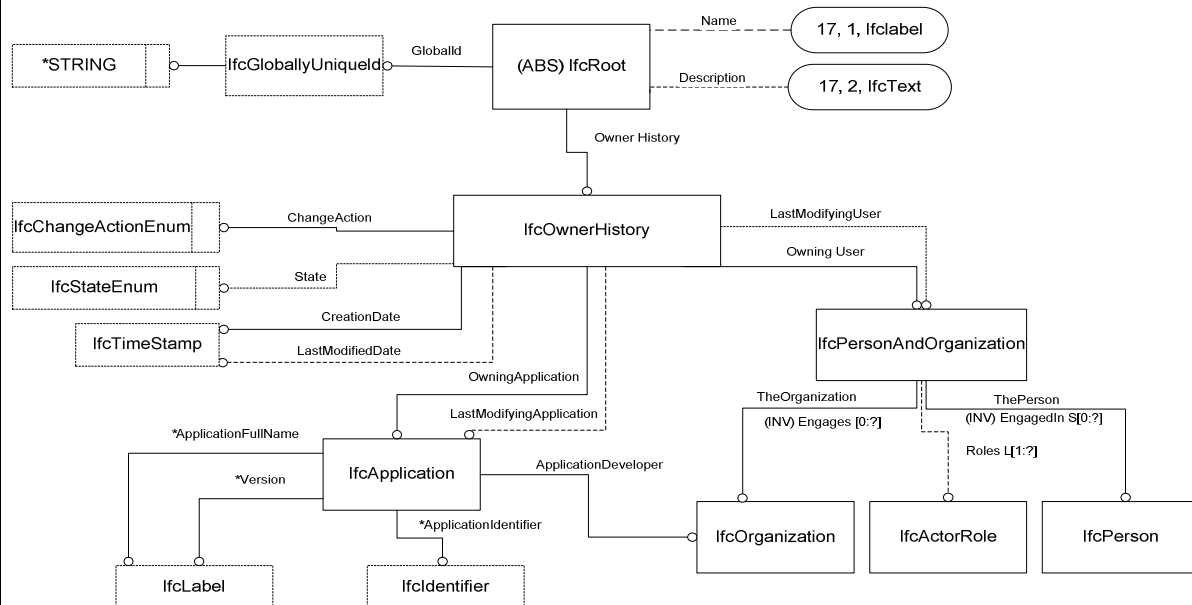
Figure 8.3 IFC release specific concept description (IFC Model View Definition 2006)

Based on the given templates the related Concepts are formalized as given in the followings.

IFC Identity Description Part 1 (EXPRESS-G Definition)

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Identity					
Reference, Page	UMG-1, 1	Version	V-1	Status	Draft
Relationships	IfcRoot			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition.

This concept is formalized in order to show how objects are identified and how ownership of objects is assigned according to IFC 2x3.

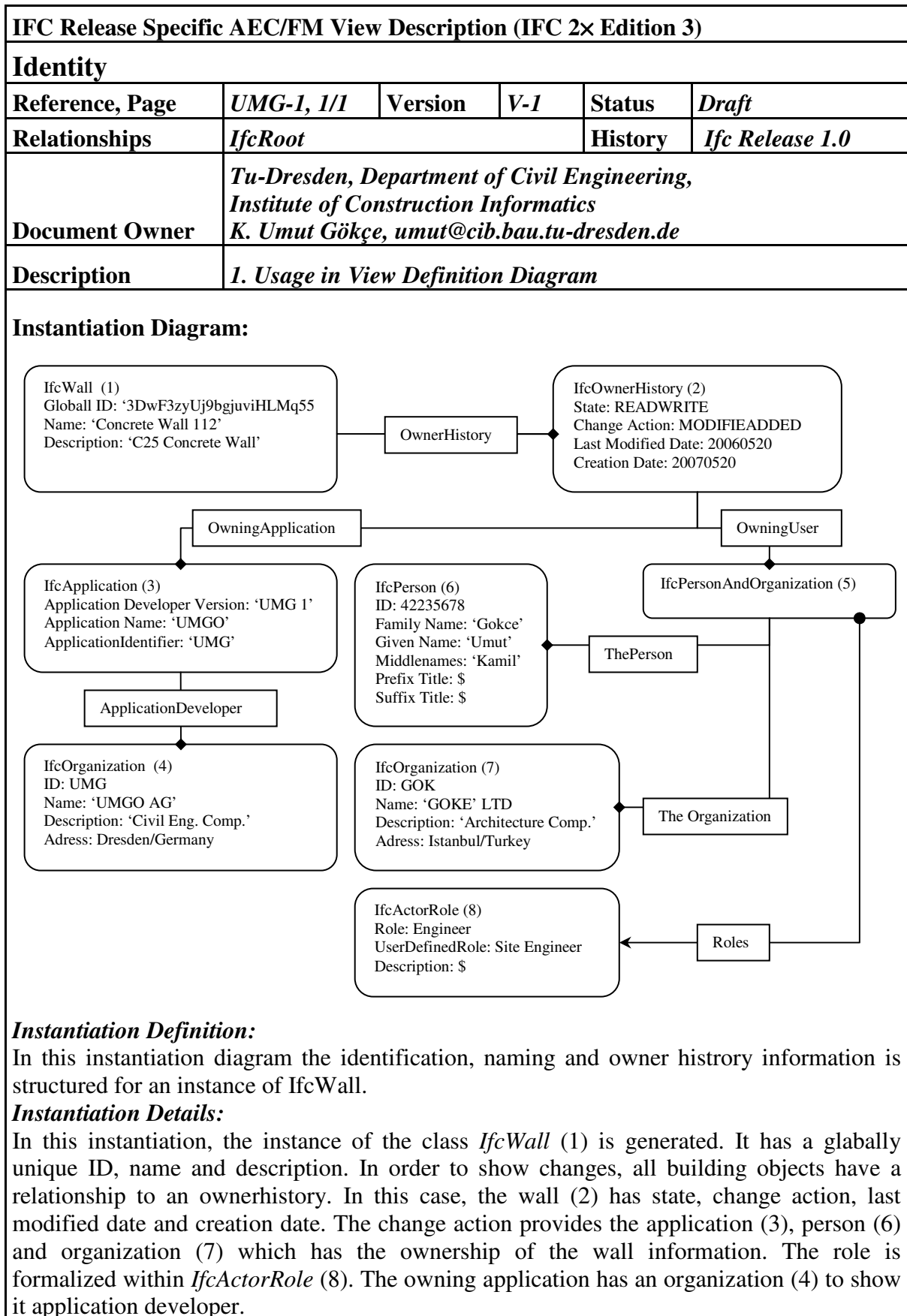
Entity Type Definition (*Definition from IAD*):

The *IfcRoot* is the most abstract root class for all IFC entity definitions that roots in the kernel or in subsequent layers of the IFC object model. It is therefore the common supertype of all IFC entities, beside those defined in an IFC resource schema. All entities that are subtypes of *IfcRoot* can be used independently, whereas resource schema entities, that are not subtypes of *IfcRoot*, are not supposed to be independent entities. The *IfcRoot* assigns the globally unique ID, and the ownership and history information to the entity. In addition it may provide a name and a description about the concepts.

Entity Type Detailed Definition:

Instantiated IFC model objects are uniquely identified by the *GlobalID* attribute which is maintained by every instance of subtypes of *IfcRoot*. For the additional naming and descriptions, *Name* and *Description* attributes are also structured in this context. The *IfcOwnerHistory* entity provides recent changes providing the state of the instance, the name and organization of the user, the creation and last modification time, the date and time of the instance etc.

IFC Identity Description Part 2 (Instantiation Diagram Definition)



8.5 Validation of the IFC View for Product Catalogs based on the Unit Price Procurement System

In the Unit Price Procurement System, the structure can be constituted based on the Concepts as illustrated in **Table 7.9**, (excluding the Construction Resource Extension Concept).

In this procurement system, the IFC 2x3 Specification can be used directly by possessing the proposed compositions structure. The existing catalog information i.e. production resources, material analysis and the related prices are realized within the proposed catalog structure initially. Subsequently these are used directly for building element mappings as it was envisaged in Chapter 7. In order to derive related subsets GMSD is used in this regard. The concept formalizations can be found in Appendix C.

8.5.1 Product Catalog View Definition with GMSD

The ViewEdit can be used to control the proposed IFC Views. The established IFC Concepts facilitate to complete envisaged Views by selecting object instances. Basically there are two levels to select object instances according to Weise: (1) by choosing a product model version, (2) by selecting individual object instances of the product model version.

Since the selection of object instances requires adapted user interfaces depending on the semantics of the underlying product data model, highly specialized clients are needed to apply generic views on the more precise level of individual object instances (Weise et al. 2003).

In our case, the object instances are identified based on the ceEPC Model. The information resources which are structured within process sequences are used as the basic objects. These are then mapped to partial IFC Views and later IFC Classes which address form related Concepts.

In this context, IFC View for Product Catalog is formalized with the use of ViewEdit by bringing together the envisaged concepts. Later, the outcome (see **Figure 8.4**) is used within an IFC Viewer to validate the obtained view by eye inspection.

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION('Generated by SpfGenerator', '2:1');
FILE_NAME('IFCROOT_PRODUCTCATALOGUE.MSD', '2007-03-20T14:55:47', ('M.Weise'), ('TU-Dresden'), 'Plugin: SpfGenerator (Version 0.5, January 2007)', 'EXPRESS-It', '');
FILE_SCHEMA('GMSD_V09');
ENDSEC;
DATA;
#1=FEATURESELECTION('LastModifiedDate', .USEFEATURE., '', $);
#2=ENTITYVIEWDEFINITION('IFC2X3_RC2.Ifcrelationship', .USEENTITYANDREMOVEALLFEATURES., '', $, .T., $);
#3=FEATURESELECTION('description', .USEFEATURE., '', $);
#4=FEATURESELECTION('Name', .USEFEATURE., '', $);
#5=FEATURESELECTION('GlobalId', .USEFEATURE., '', $);
#6=FEATURESELECTION('IfcPerson', .USEFEATURE., '', $);
#7=FEATURESELECTION('IfcPersonAndOrganization', .USEENTITYANDREMOVEALLFEATURES., '', $, .F., (#11));
#8=FEATURESELECTION('OwnerHistory', .USEFEATURE., '', $);
#9=FEATURESELECTION('State', .USEFEATURE., '', $);
#10=FEATURESELECTION('ChangeAction', .USEFEATURE., '', $);
#11=FEATURESELECTION('LastModifyingUser', .USEFEATURE., '', $);
#12=FEATURESELECTION('CreationDate', .USEFEATURE., '', $);
#13=ENTITYVIEWDEFINITION('IFC2X3_RC2.Ifcpersonhistory', .USEENTITYANDREMOVEALLFEATURES., '', $, .F., (#1, #13, #14, #15, #16, #17));
#14=ENTITYVIEWDEFINITION('IFC2X3_RC2.Ifcperson', .USEENTITYANDREMOVEALLFEATURES., '', $, .F., $);
#15=VIEWDEFINITION('Subview IfcRoot', '', ('IFC2X3_RC2'), .REMOVEALLENTITIES., (#10, #12, #18), .T., .F.);
#16=FEATURESELECTION('OwnerHistory', .USEFEATURE., '', $);
#17=ENTITYVIEWDEFINITION('IFC2X3_RC2.Ifcperson', .USEENTITYANDREMOVEALLFEATURES., '', $, .F., (#5, #6, #7, #8));
#18=ENTITYVIEWDEFINITION('IFC2X3_RC2.Ifcperson', .USEENTITYANDREMOVEALLFEATURES., '', $, .T., $);
#19=ENTITYVIEWDEFINITION('IFC2X3_RC2.Ifcperson', .USEENTITYANDREMOVEALLFEATURES., '', $, .T., $);
#20=VIEWDEFINITION('Example', '', ('IFC2X3_RC2'), .REMOVEALLENTITIES., (#4, #2, #19, #20), .T., .T.);
ENDSEC;
END-ISO-10303-21;
```

Figure 8.4 IFC View for Product Catalogs Outcome
(Only first 20 Lines of the Data Section are shown)

8.5.2 IFC Viewer

Beside commercial software packages there is also a number of free tools that support IFC i.e. IFC Viewer to visualize an IFC model, often in conjunction with showing the project structure and the properties of objects, Text Browser to show the original IFC file for debugging, Converter to convert project data from/to other file formats, and Syntax Checker to check the formal validity of IFC files (IAI 2007).

In our approach, DDS IFC Viewer which allows the opening of IFC files and viewing of the model in 2D or 3D on screen is used. It also supports navigation through the IFC model by object, space and system, and viewing of the detailed parameters of any object, including its associated property sets. It is also possible to switch off the display of objects or change their transparency, to allow viewing of the details of the model more clearly (DDS 2007).

8.5.3 Validation

Using a 3D Model (Building Sample) from the IAI Web-site (IAI 2007) the formalized concepts for the IFC View for Product Catalogs are validated. The outcome of the concepts which is represented with ViewEdit is embedded/used with the help of Client-Server in the 3D model to control whether the required data (IFC View) can be extracted from the 3D Model.

Based on this:

- 1 The outcome of the IFC View for Product Catalogs in ViewEdit is embedded in 3D model via Client-Server.
- 2 The selected original file of the 3D model which includes classes such as IfcBoundBox, IfcRelContainedInSpatialStructure, IfcSpace etc., has 4595 Kb and the derived IFC View for Product Catalogs which use classes like IfcMaterial, IfcBuildingElement, IfcGroup, etc. (see Table 7.9) to provide only Product Catalog data has only 560 Kb. In this context the subset of the 3D full model is provided. The result is determined as 'Positive'.
- 3 In order to control/check whether all required elements are represented within the DDS Viewer based on the Product Catalogs, 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 3D 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.
- 4 Due to the absence of Geometrical Representation the 2D/3D shape of the sample building couldn't be seen in the DDS IFC Viewer when the concepts of IFC View for Product Catalogs are applied. In order to provide an eye inspection tool using DDS IFC Viewer, additional six Concepts are formalized to realize 2D/3D representation:
 - Bounding Box,

- Swept Area Solid,
 - Geometric Representation Item,
 - Representation Map
 - Spatial Element
 - Topographical Representation Item
- 5 The new concepts are added to Product Catalog View in ViewEdit.
 - 6 The outcome is embedded in 3D model (in DDS IFC Viewer) via Client-Server. The file is representing 4595 Kb and the view for product catalog including shape representation concepts has 3464 Kb. The result is determined as 'positive'.
 - 7 The outcome is used within IFC Viewer, due to new formalization of the view the Geometrical representation of the sample building which also supports IFC2x3 specification can be seen as illustrated in **Figure 8.5**.

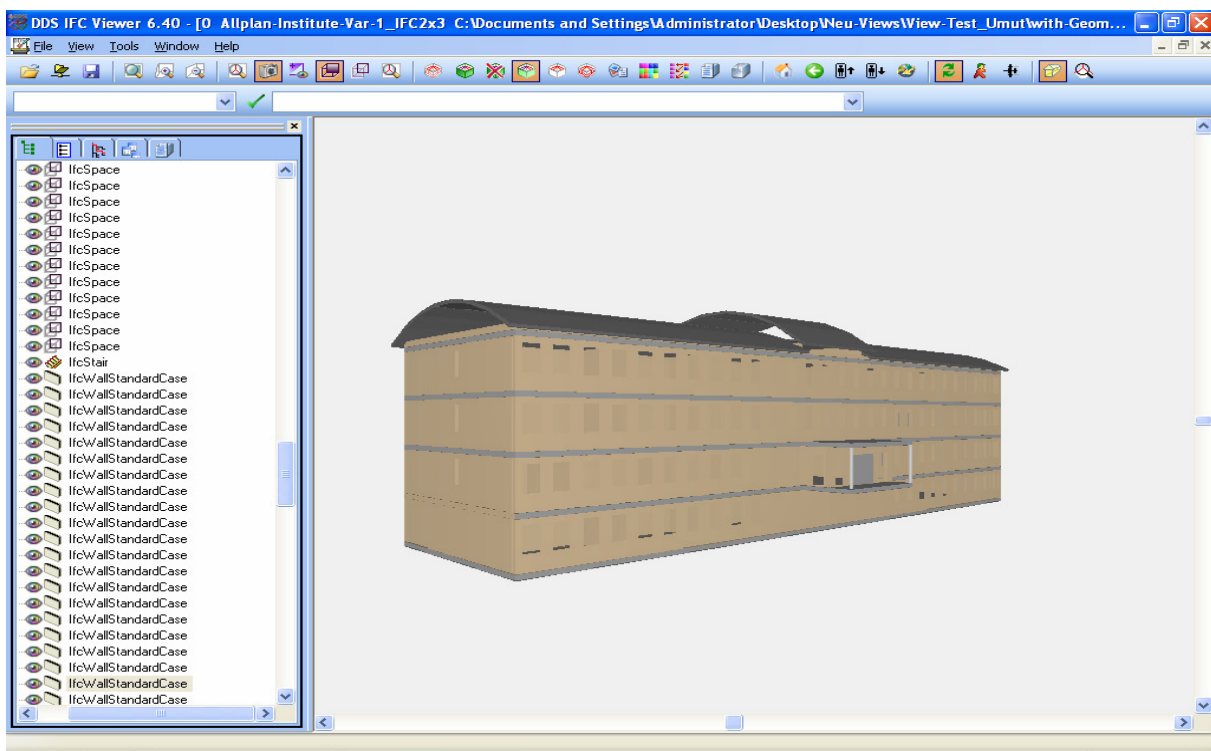


Figure 8.5 IFC View for Product Catalog View Edit Representation

8.6 Summary and Conclusions

In this chapter the principle formalizations of the IFC Views, in terms of a new structured approach for tackling of partial models and the validation of the IFC View for Product Catalogs were represented.

In order to define generic level specifications for the exchange of required information, IFC Model View Definition Format and GMSD were presented briefly.

In this context, the envisaged views can be constituted by bringing related concepts based on the IFC Model View Definition Format. This enables definition of views in a clear manner, suitable for standardization. However in order to support GMSD, the formalizations have to be based on EXPRESS-G language.

In our case the Product Catalog View has been chosen as a sample view and it tried to be formed on class level based on IFC Concepts, by using GMSD. This approach enables concentration on process logic by shielding from unnecessary information. Moreover it reduces the exchange data by guaranting consistency of the envisaged model subsets.

The presented IFC View for Product Catalogs has been proven to work with GMSD, clearly demonstrating the IFC compatibility. Nevertheless, further research is required to extend the capabilities for defining IFC views by allowing more sophisticated conditions for picking up related object instances and more flexible treatment of references.

Improper use of Views is currently handled with the help of the requesting client application supervising the selection of object instances. This is additionally restrained by invariant object identifiers enabling the handling of changed model subsets. It worked fine in all test examples but we should also have possibilities to check client requests on the server side, without external help. The second mentioned issue mentioned requires the enhancement of the subview definition. This is currently limited to handling referenced object instances by static specifications on class level only. More flexible extending/cutting of references dynamically, depending on the actual state can enable more precise view definitions with even fewer user interactions.

CHAPTER 9: CONCLUSIONS

This chapter provides a summarized evaluation of the developed concepts and discusses to what extent the problems have been solved. Moreover the open problems are outlined and a Web-based framework is suggested for future research.

9.1 The Summary of the Objectives and the Thesis Content

In the preceding chapters the individual components of the proposed computer integrated CPM Model were separately presented. In this chapter, contribution of the thesis is stated based on the main objectives which were given in Section 1.4.

- 1) To generalize and formally describe construction project management processes so that interoperability over a broad spectrum of applications is facilitated.
- Research in the area of integrated CPM processes has been the subject of many studies. The results show that the common approaches can provide high-level operability and consistency within the process. Hence the actions of all process resources can be treated by means of their generic commitment to high-level models. Moreover their generic formalizations depend on the generic interpretation of the domain data. The lossless and incremental formalizations can therefore be supported and lead to the desired results. However, before possessing presumed structures, data conflicts and related redundancies had to be taken into account. This requires persistent definition of the information resources and their relations in the process.

In our approach, in order to formalize generic CPM processes several steps have been provided. Based on the elaboration of ‘state of the art’ by means of examining the relevant project management processes, the construction management phases, the procedural definitions regarding to ISO, and the selected research projects which developed integration approaches namely ToCEE, iCSS and ISTforCEE, the basics were analyzed in detail in Chapter 2. The representations of the product and the process models were examined in Chapter 3, and the two convenient function modeling methodology namely IDEFØ and ARIS have been chosen to model our generic CPM approach.

In order to realize interoperability over a broad spectrum, the application domains and their interactions within the construction management phases were provided in Chapter 4, and named as ‘Construction Management Phases for Software Interoperability’, (CMPSI). The related phases are represented with IDEFØ function modeling methodology based on Construction General Life-cycle Model Phases and Process Formalization Principles. Hence the generic data which can be used to obtain object-oriented data structures can be supported. In order to clearly define CPM aspects and to narrow the scope of the thesis, the Bidding Preparation Phase of the CMPSI was chosen. Furthermore Bidding Preparations provide different types of data which can be used in the following phases of the CPM.

However managing and coordination of the work requires not only the domain specific data representations but moreover requires models which show interactions between different information resources within the process. In this context ISO9001:2000 Quality Management (QM) System Procedures were formalized for the existing real-world process specifications for the CPM in Chapter 4.

For the definition of a generic bidding preparation model, the ARIS Business Process Modeling Methodology was used. Although CPMSI was formalized with IDEFØ, it shows limitations when long and interconnected resource definitions are required. In this context ARIS-eEPC Model has been chosen. eEPC provides a holistic consideration of the functions, events, and resources. However to represent complete interoperability between different domains and to support mapping between interrelated data, the eEPC model was extended and named as a complemented-eEPC (ceEPC) model in Chapter 5.

The core CPM model for bidding preparations was formalized in Chapter 5 and named Organizational Management Process (OMP). It represents different views in its constitution. They are provided by a Life-cycle approach for the OMP. The OMP brings together (1) set of interrelated processes defined by the QM System, (2) application methods determined by the type of the procurement system, (3) the organizational data, and (4) the software integration requirements predefined by the CMPSI. The aim of this approach is to coordinate the different type of views to become an integrated information model for CPM. The set of interrelated processes are structured in such a way that one of the processes takes the role of the main process whereas the others are supporting processes. For the bidding preparation phase, the main process is the bidding preparation process which is supported by 7 further processes.

- 2) To develop a common formalized information model for construction project management based on the schema of the IFC standard, the necessary integration of product and process, cost and management data is provided.
- The information model for the CPM can be tackled by defining of relevant information resources which are then used within an object-oriented paradigm.

However to represent a generic information model it is required refined process approaches which shows application domain interactions. Therefore IT Management Processes which were also used for IFC Views' implementation were realized by deriving them from the OMP in Chapter 5. ITMP was formalized in three forms as (1) IT Management Design Process, (2) IT Management BOQ process and, (3) IT Management Scheduling Process. Each process represents the integration of domains regarding the design, the resource planning and the scheduling. These processes are then led to provide an information model based on the schema of the IFC which would fulfill our second objective. One another issue which has to be taken into consideration is the mapping structure between CMPSI, OMP and ITMP. In order to support information completeness between different but complementary aspects, a mapping model was provided in Chapter 5. The relevancy was controlled by defining scenarios for the procurement system dependent process aspects.

In our approach the IFC model has chosen to fulfill generality. In order to provide integration between different views regarding the application domains, IFC Views were

developed based on the ITMP in Chapter 7. ITMP were then used to provide the related views from which the refined data was constituted which would increase integration efficiency. In this context, three views namely (1) IFC View for Product Catalogs, (2) IFC View for Architectural Design to Quantity Take-off, related with the IT Management Design Process and, (3) IFC View for Exchange of Bill of Quantity (BOQ) information regarding to IT Management BOQ Process were developed. The mapping between process information resources and IFC classes were provided by partial IFC Views which contain one or several IFC Classes. Later these classes are brought together in a network of classes namely in IFC Concepts. Therefore the defined information resources' (within ITMP) mapping to IFC objects/classes were constituted. This approach leads to the development of an integration methodology to existing domain applications.

In order to realize the interoperability methodology between the different application domains, IFC Views, the related IFC Concepts and IFC Instance Diagrams were developed according to the IFC View Definition Format given in Chapter 8. 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 and not in XML as suggested by the IAI.

In this context IFC View for Product Catalogs was chosen. Moreover to provide exchange of cost information in our approach (1) a three leveled product catalog structure and (2) an extension to IFCs are suggested. The IFC Concept namely "Construction Resource Extensions" is realized with the suggested new IFC classes and the new object relations to existing classes.

Developed concepts were possessed to form the IFC View for Product Catalogs in GMSD. This was realized with ViewEdit which was given in Chapter 8. The validation has been made based on an alphanumerical comparison by eye checking of (1) the STEP physical file SPF on the alphanumerical basis and (2) the 3D model which was established from the catalog views by adding the geometrical concepts.

The expected result was observed, the size of the SPF was considerably reduced in the order of about 10. It should be mentioned that the validation for the Design & Build and the Lump-sum Procurement Systems was not possible because the suggested extension of IFCs need first to be implemented by the software companies.

9.2 Fulfillment of Basic Requirements to the Computer Integrated CPM Approach and Discussions

In order to realize a Computer Integrated CPM model, a methodology which is composed of several steps has been provided in the thesis.

The Construction General Lifecycle Model definitions were considered generically to formalize the CPM phases in this context. The model proposed by the AIA was used. The representations were structured according to the period of time between the lifecycle transition points as proposed by Gielingh (1988a), which can be named as phases.

In this approach the expressed phases designates a temporal period before a transition and suggests the primary activities during that period, whereas the PMI defines the building lifecycle according to its project management knowledge areas from a general perspective.

When these phases are examined in detail, the information representation of the bidding preparations seem different from the other phases, however it comprises all the data which is needed in the following phases of a construction project and used by the project participants with further developments, for instance the pre-work program which is provided in Bidding Preparation Phase can be improved to become a general work program for the Construction Phase. Thereby the bidding preparation activities would lead the project participants to decisions for the further steps. However the definition of the information and use of it between different application domains is not enough to reflect different aspects, moreover there is a need to realize data interactions between the related participants by defining the related processes.

In order to solve this problem, the procedural models can be used by describing the CPM processes that operate on the building information throughout the building's lifecycle. Thereby each phase can be described according to its general information processing activities with the human intervention and the types of data used.

ISO 9001:2000 Quality Management (QM) System was examined to address procedural representations. However QM comprises general definitions and there is a need to define the main procedures according to the application areas. In this context the required procedural model was possessed from CPM point of view. These procedures represent departmental definitions/processes for CPM purposes. However due to comprising complex processes, in terms of different departments' involvements in the bidding preparations, a need arose to define these procedures in a holistic process approach.

A serious impediment to the use of multiple processes has been the information preparation required to apply them. In this context the Procurement Systems (Contracts) should be checked whether the expressed processes suit them or not. In this regard, five main procurement systems were examined in detail. The requirements used represent a generic model in the following steps.

There is a need for generic models which combine different views in one structure. This will ensure that departments' are involved in defining processes based on QM System, software integration requirements based on the CMPSI, the organizational data in terms of actors' interactions and the procurement application's methods. This was achieved with a life-cycle model for processes which combines different views in one constitution.

However the representation of the model required a methodology to support a holistic approach. Initially, it was attempted to solve this problem by UML activity diagrams and then by ARIS-eEPC Model. The reason to use eEPC instead of UML can be expressed as; the eEPC comprises more aspects than UML activity diagrams such as a detailed description of process resources used for each function. However the eEPC is imprecise, when the resources are analyzed for IFC Classes. Therefore there is a need for an extension of eEPC with a new classification structure. Therefore eEPC was extended with a notation and named as complemented-eEPC (ceEPC) model. Thereby the process sequence and the related resources were provided.

Based on this, the OMP as a core process which represents different views in its constitution was structured with ceEPC model. Thereby the formalization of the bidding preparation process which comprises different perspectives was accomplished. Subsequently the ITMP was derived from the OMP. The ITMP represents domain application sequence of the involved resources. Although the CMPSI represents software domain applications and the basic data regarding to phase definitions, to reflect different views, it could only be provided by covering all resources. This was realized within the ITMP. The ITMP was structured into three parts to provide the partial IFC Views. Thereby the process (information) resources can be clearly realized to identify the related IFC Classes to reach IFC Views.

The IFC Views are the subsets of the IFC model which provide the sub-defined data formalizations. In this context, for each defined ITMP information resource, the relevant IFC Classes and relevant relationships are identified. These classes are embedded in a network of classes. These are defined as IFC Concepts which define the complete set of IFC classes required. IFC Concepts represent the IFC objects, the attributes and the object relations based on the information resources. Therefore the generic process data can be specified and represented as the IFC product data which lead to a standard approach.

The IFC Concepts were constituted based on the IFC View Definition Format. Moreover the existing XML IFC View Definition Format was extended to EXPRESS-G in order to facilitate to model the IFC Views for GSMD.

One of the most important concepts of this research can be accepted as defining and formalizing of additional cost data based on the material analysis for the IFC Model. According to examination of the IFC 2x3 specification and requirement analysis, the existing IFC class and object representations do not support the cost data in a level of detail which is expected in construction jobsite applications. In order to provide this, a (1) three leveled product catalog structure and (2) an extension to IFCs are provided. IFC Concept namely 'Construction Resource Extensions' is realized with new classes and with new relations.

On that basis, the formalized IFC Concepts were brought together in GSMD to represent domain applications in the example of IFC View for Product Catalog. Thereby, the results could be validated. As it was envisaged, a comparison between a selected 3D model and developed IFC View for Product Catalog model was done and results were elaborated from Unit Price Procurement system point of view.

However due to new IFC classes, new relations were suggested for Design & Build and Lump-sum procurement systems for the cost data which are still to be implemented in the IFC model by the software companies, the comparison could not be carried in the context of the thesis.

9.3 Future Work

As it was envisaged in Figure 1.1, Chapter 1, the solution steps were provided to form a conceptual CPM approach. In this context, the envisaged methodology was examined in detail from different procurement systems perspective.

On that basis, further work that arises from open question of the thesis can be distinguished into two categories.

The first one comprises the improvement of the developed methodology for the other procurement systems such as BOT and Public Private Partnership (PPP).

The open questions remain:

- If the envisaged methodology can be used for BOT and PPP Procurement Systems?
- Are the suggested IFC extensions sufficient to formulate BOT and PPP Procurement Systems or further extensions needed?
- Is the QM system sufficient to formulate BOT and PPP Procurement Systems processes or another type of procedural model is required?

Moreover to reach sub-defined level of detailing, for different application areas such as facility management or optimized and sustainable building operations which may comprise different views and aspects in their constitutions, another question can be asked:

- Is the envisaged methodology sufficient to provide a standard approach for the different application areas?

The second aspect concerns the extension of the represented knowledge in a framework and to provide integration on operational level. In this context a web based integrated CPM framework can be proposed.

9.3.1 The Web based Integrated CPM Framework

The framework as shown schematically in **Figure 10.1** can be proposed as a future work. The developed operational framework for CPM comprised of 4 layers namely (1) Application, (2) TSD (3) Management Process and (4) WPA Layers.

Application Layer

The purpose of this layer is to support different types of added-value project activities, performed with the help of CAD, ERP and CPM applications. Typically, such applications are locally installed and used. The main target is to combine the construction site and project partners' databases, by allowing improved project/cost control, increased work efficiency and fast response to changes within the construction environment. They may provide some in-built interoperability but the basic input/output to/from them is achieved via the TSD Layer which is their gate way to the Web.

TSD Layer

This layer consists of a Transfer Module, a System Database and a Data Exchange Module.

The information obtained from the Application Layer is stored in the System Database. This information covers the identified outcomes of the CAD, ERP and CPM applications. 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 some convenient standard format (e.g. using ISO 10303-21 files and/or ifcXML). The stored database information is then processed by the Data Exchange Module which is the coordination module for the layers below, ensuring synchronous and asynchronous information flows in a coherent and standardized way.

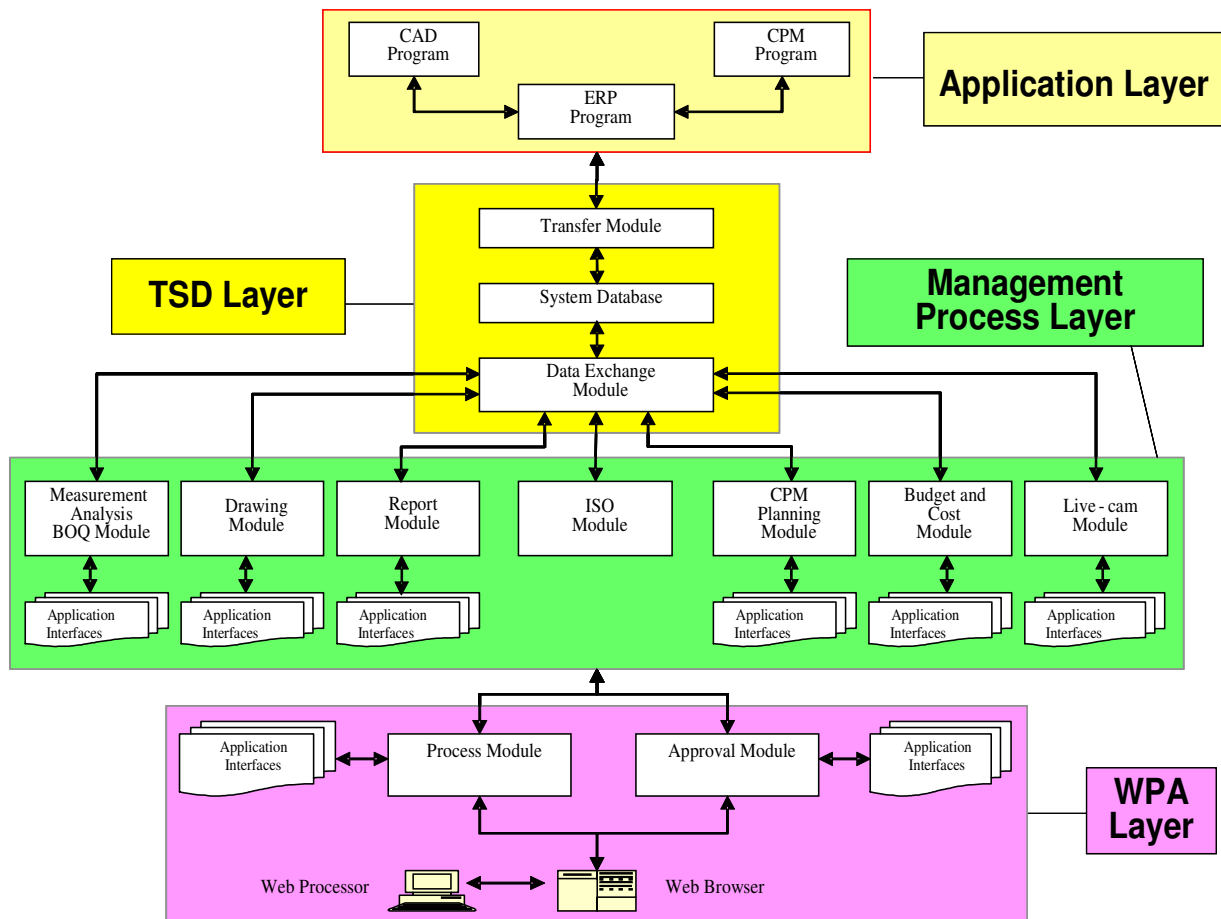


Figure 10.1 Suggested Integrated Web-based CPM

Management Process Layer

The Management Process Layer consists of different modules that can perform and be managed separately. Five of them shown in Figure 10.1, namely the Measurement/BOQ Analysis Module, the Drawing Module, the Reports Module, the CPM Planning Module, and the Budget and Cost Module are included and further processes 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 also enables the observation of the approval process within the partner organizations and within the applications. These are only examples of feasible modules and should not be an exhausted list.

WPA Layer

The WPA Layer provides 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 schema and on every step the information can be checked and approved by the responsible persons who are attained by the virtual project organization.

APPENDICES

This part includes three appendices comprising representation of Process Models and IFC Concepts which were given briefly within the preceding chapters.

APPENDIX A provides detailed representation of Organizational Management Process.

APPENDIX B presents detailed representation of IT Management Processes.

APPENDIX C contains detailed IFC Concepts based on the envisaged IFC Views.

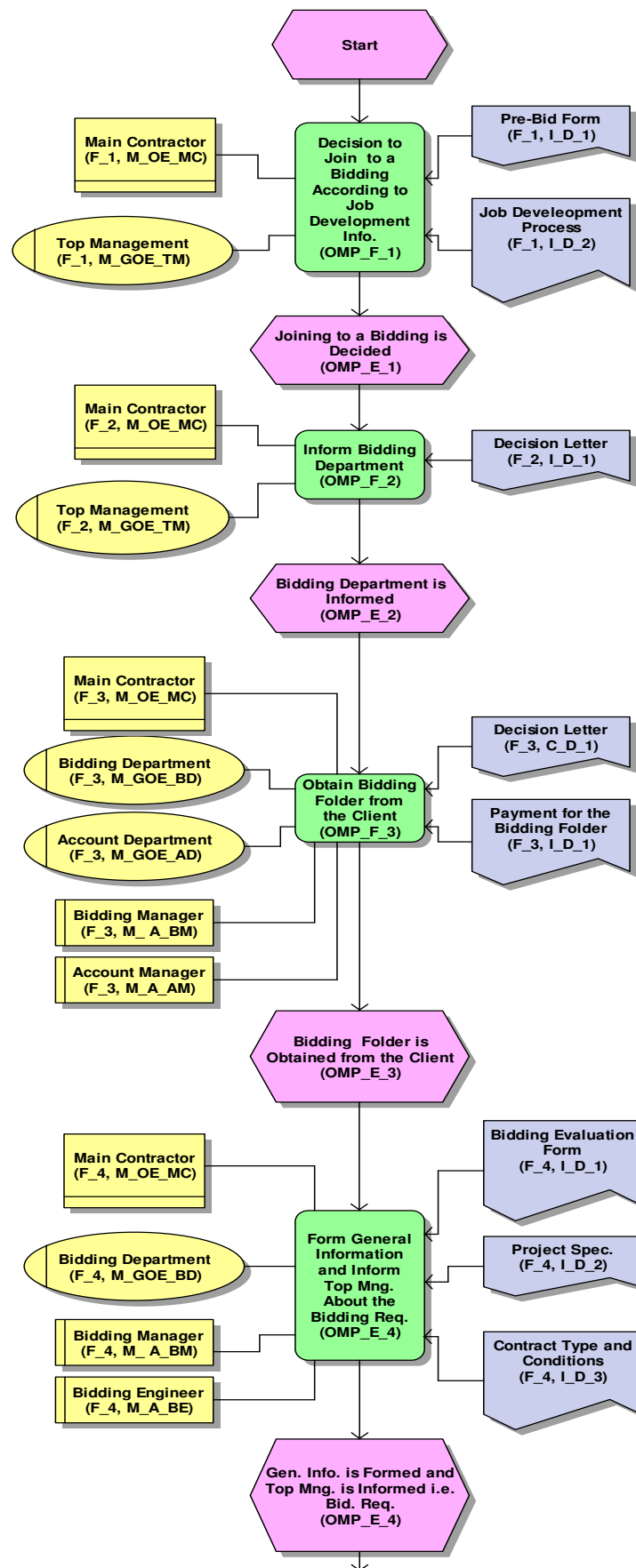
APPENDIX A: Organizational Management Process

This appendix presents the Organizational Management Process.

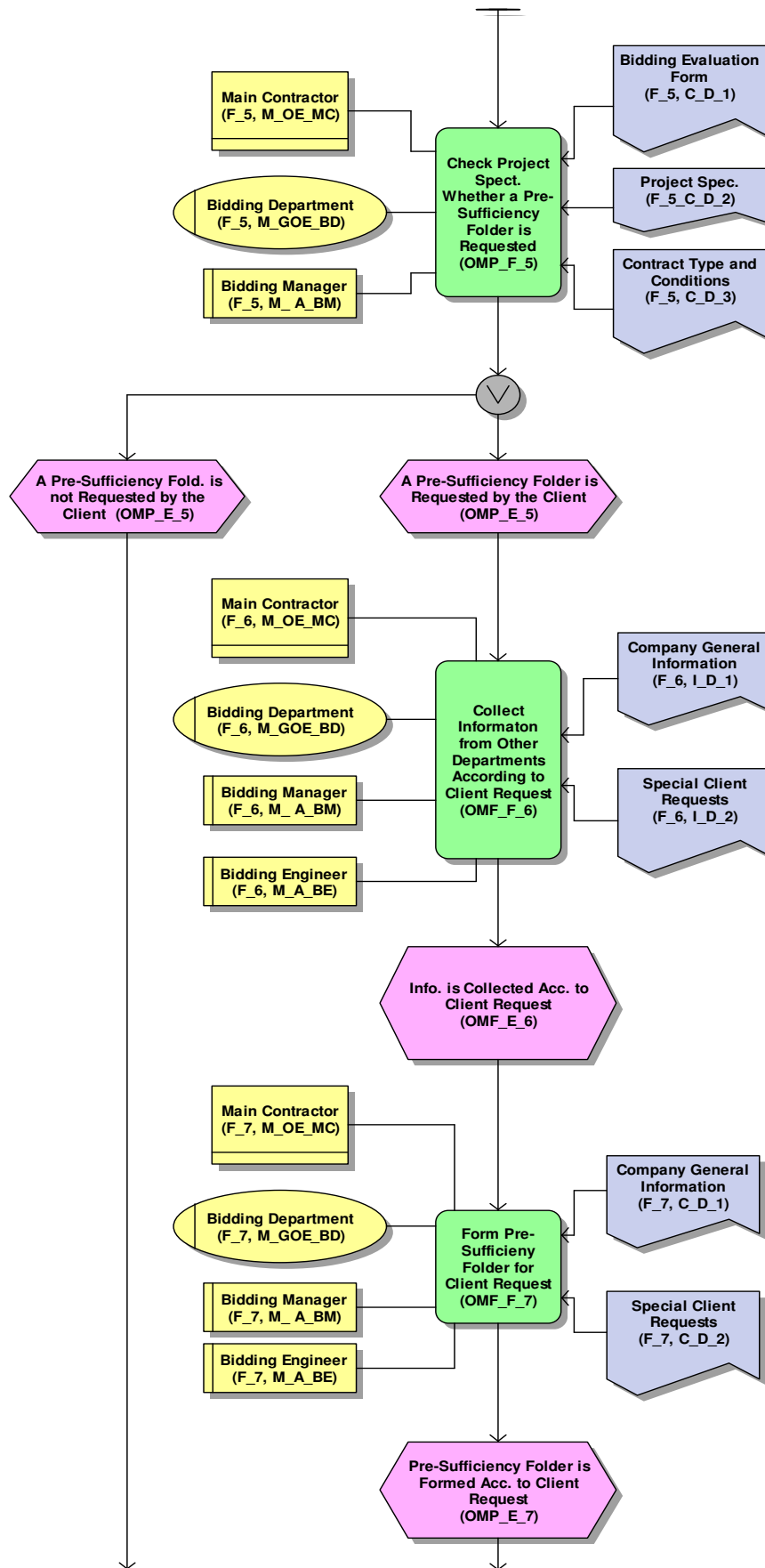
The structure is formed based on ceEPC which provides an integrated process formalization.

The intention is to facilitate understanding by matching the written format which was provided in Section 5.9, Chapter 5.

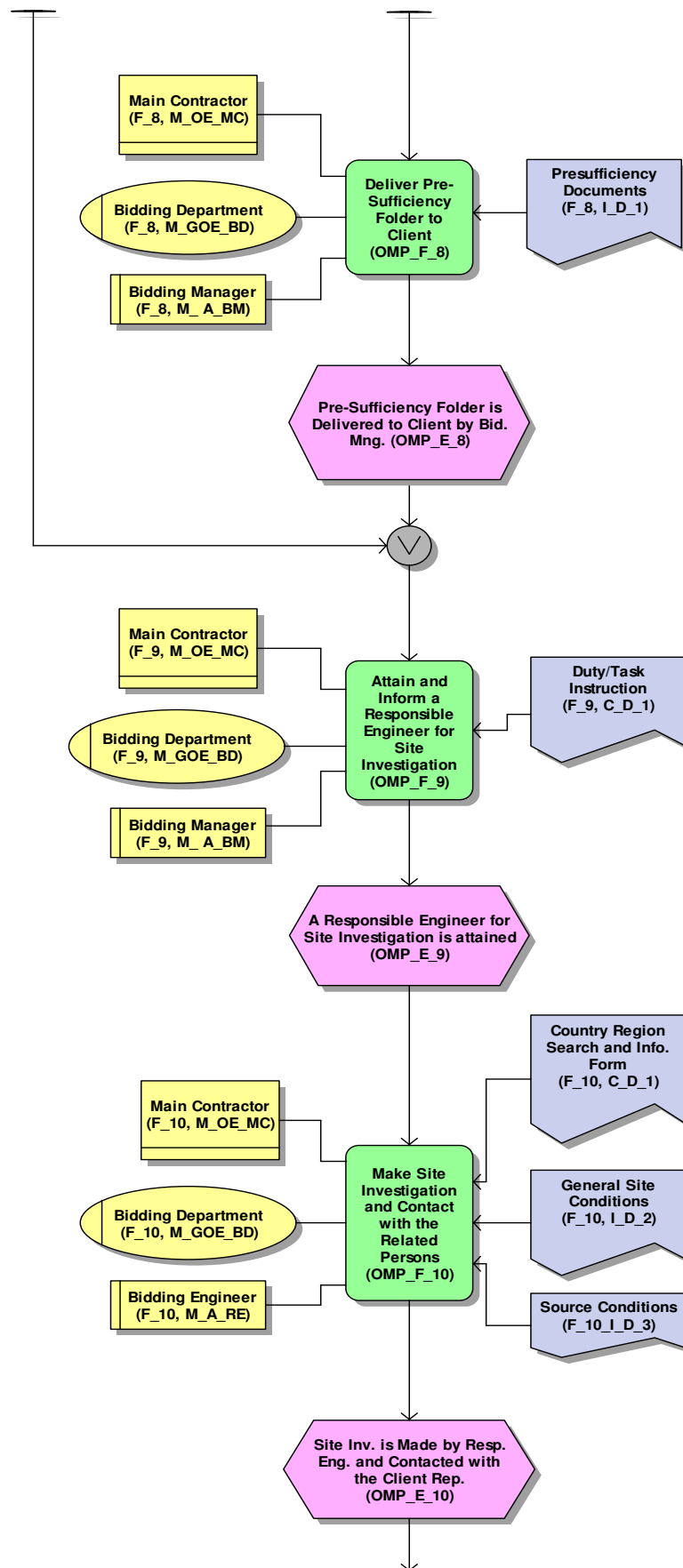
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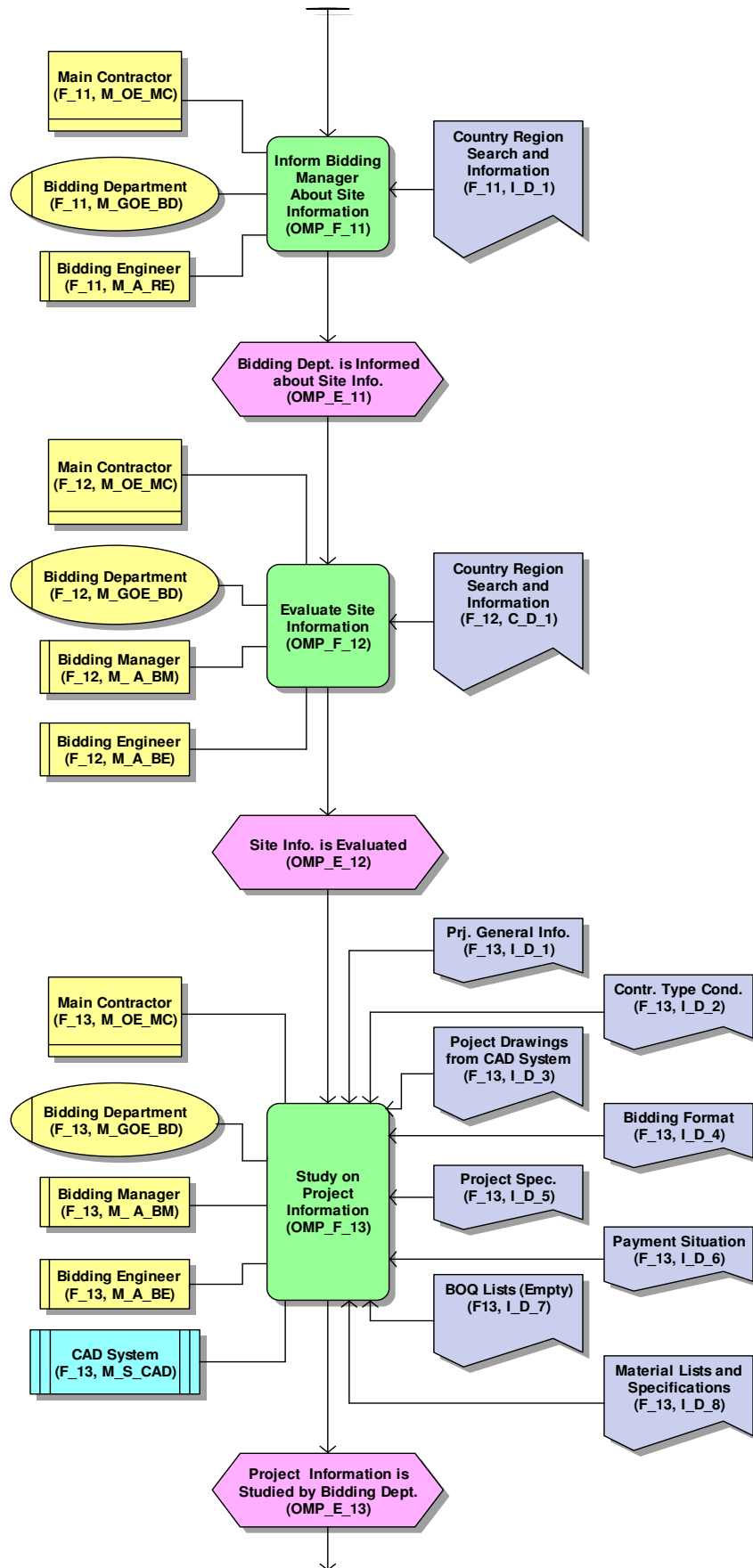
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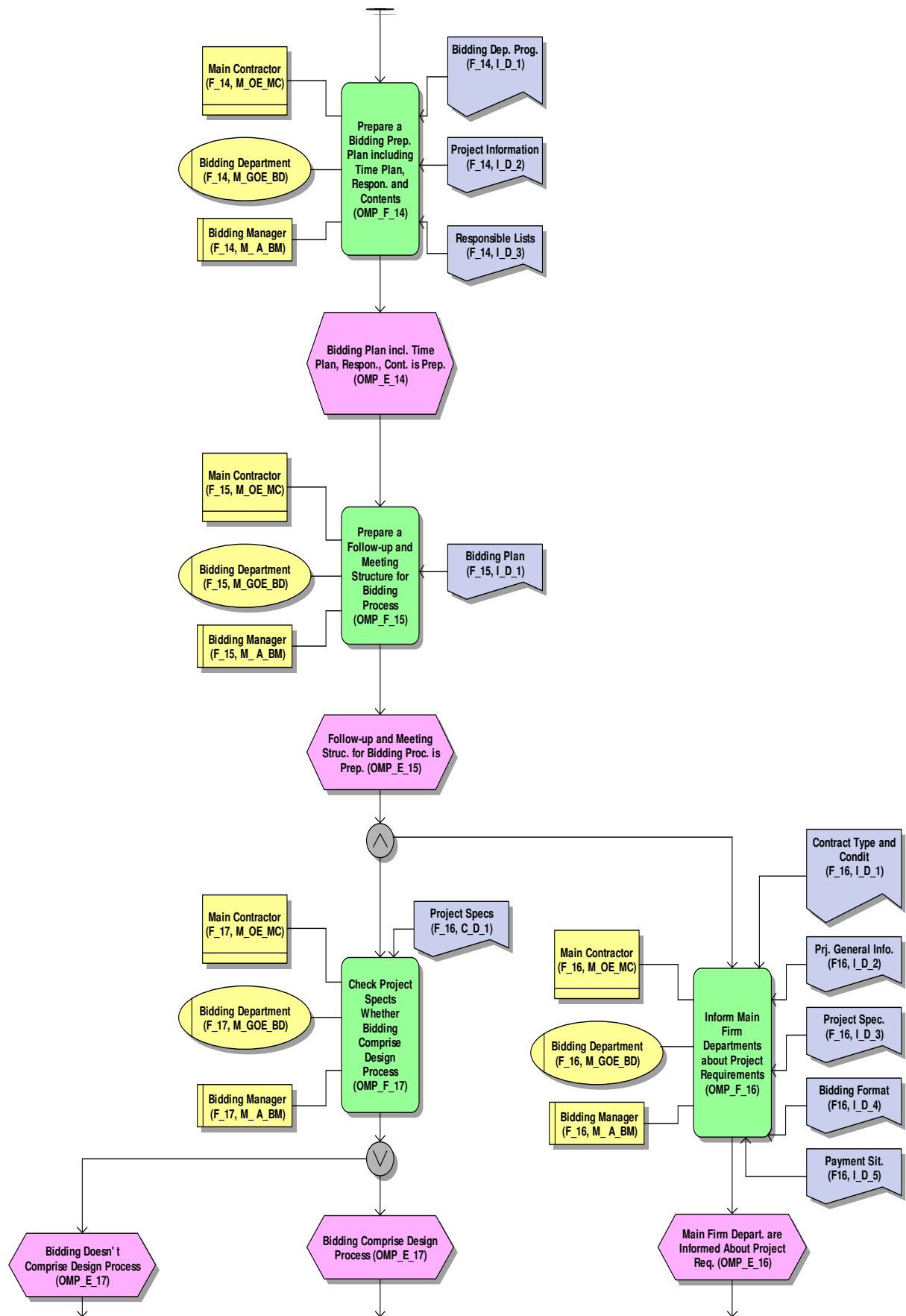
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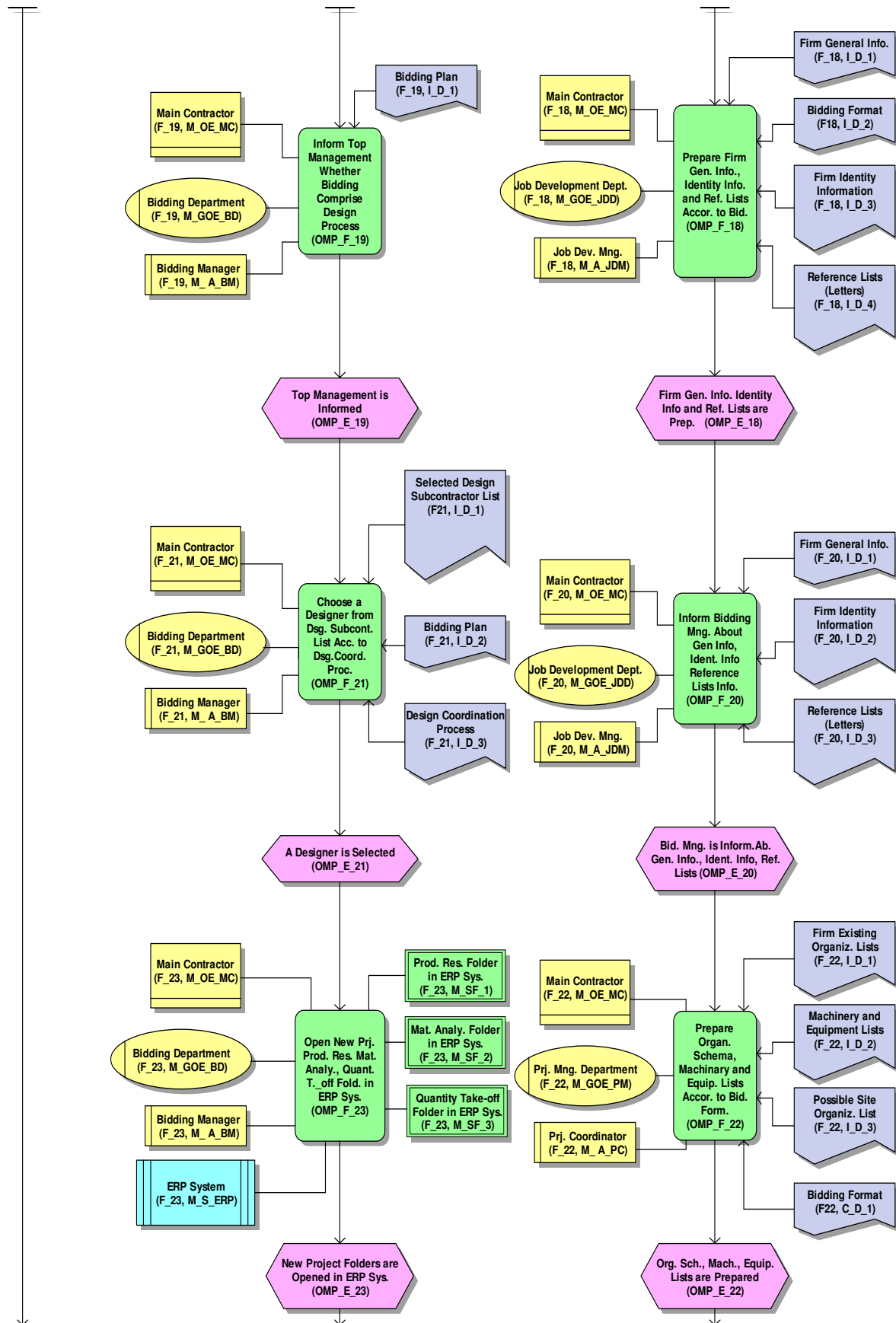
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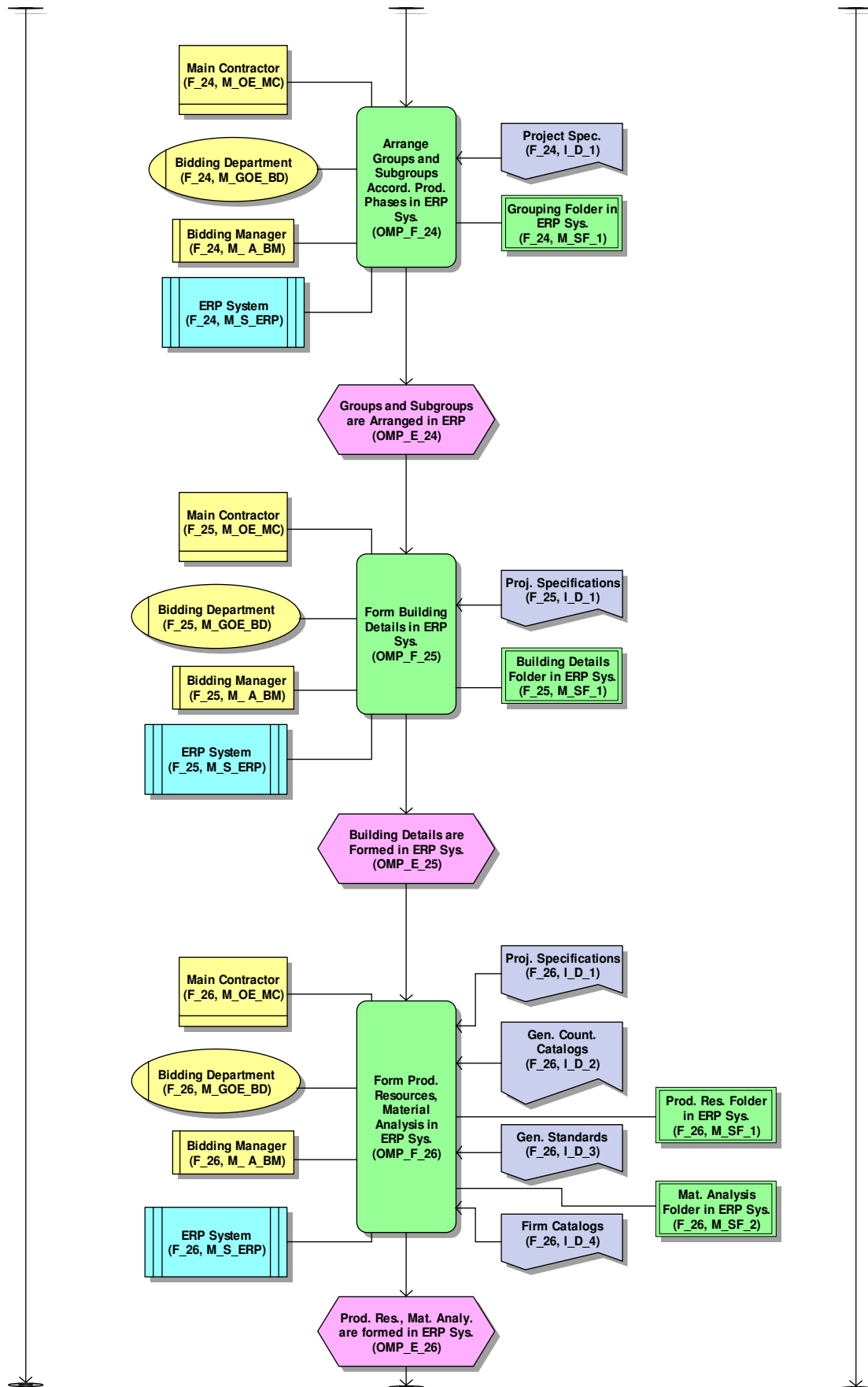
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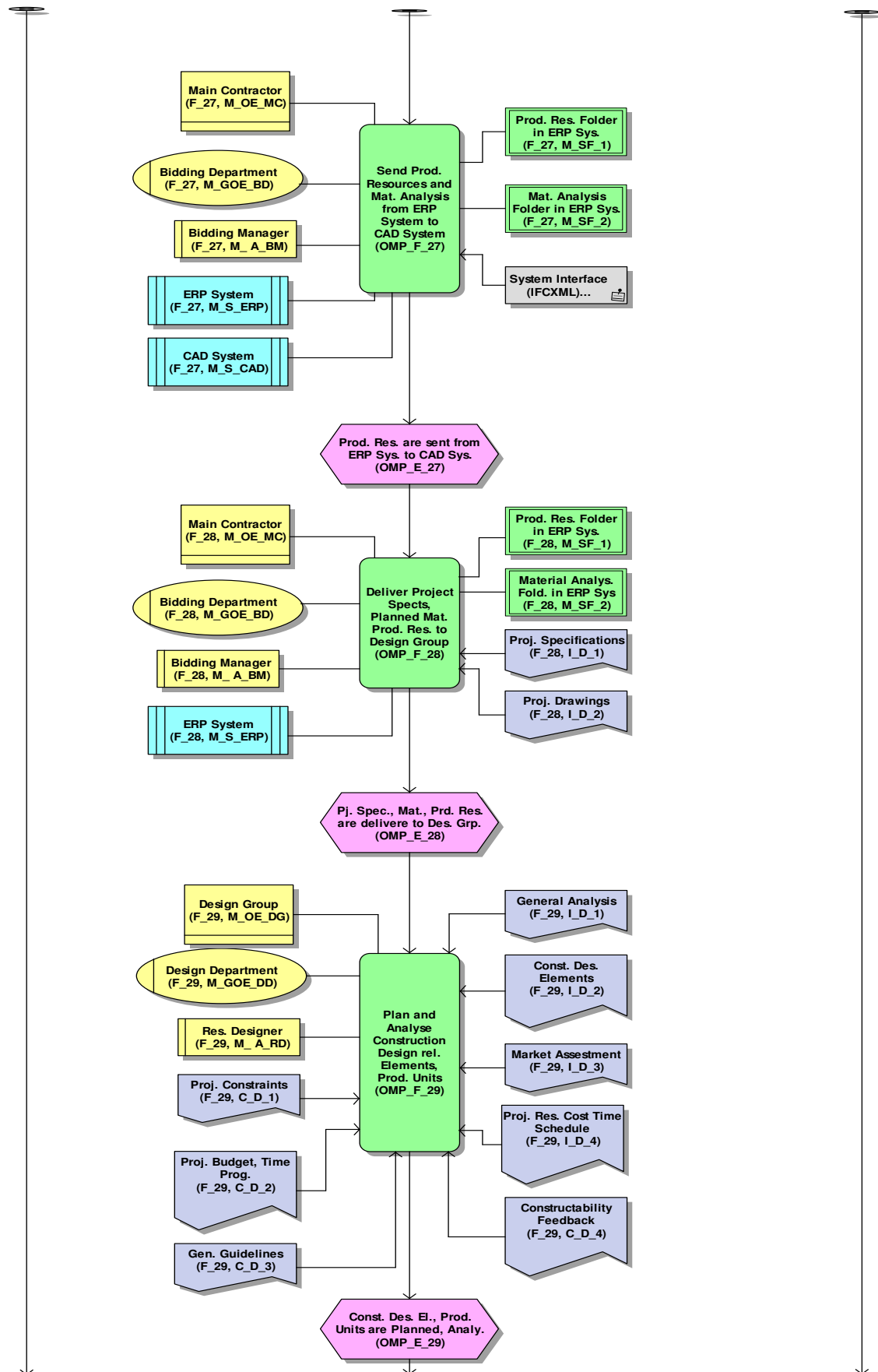
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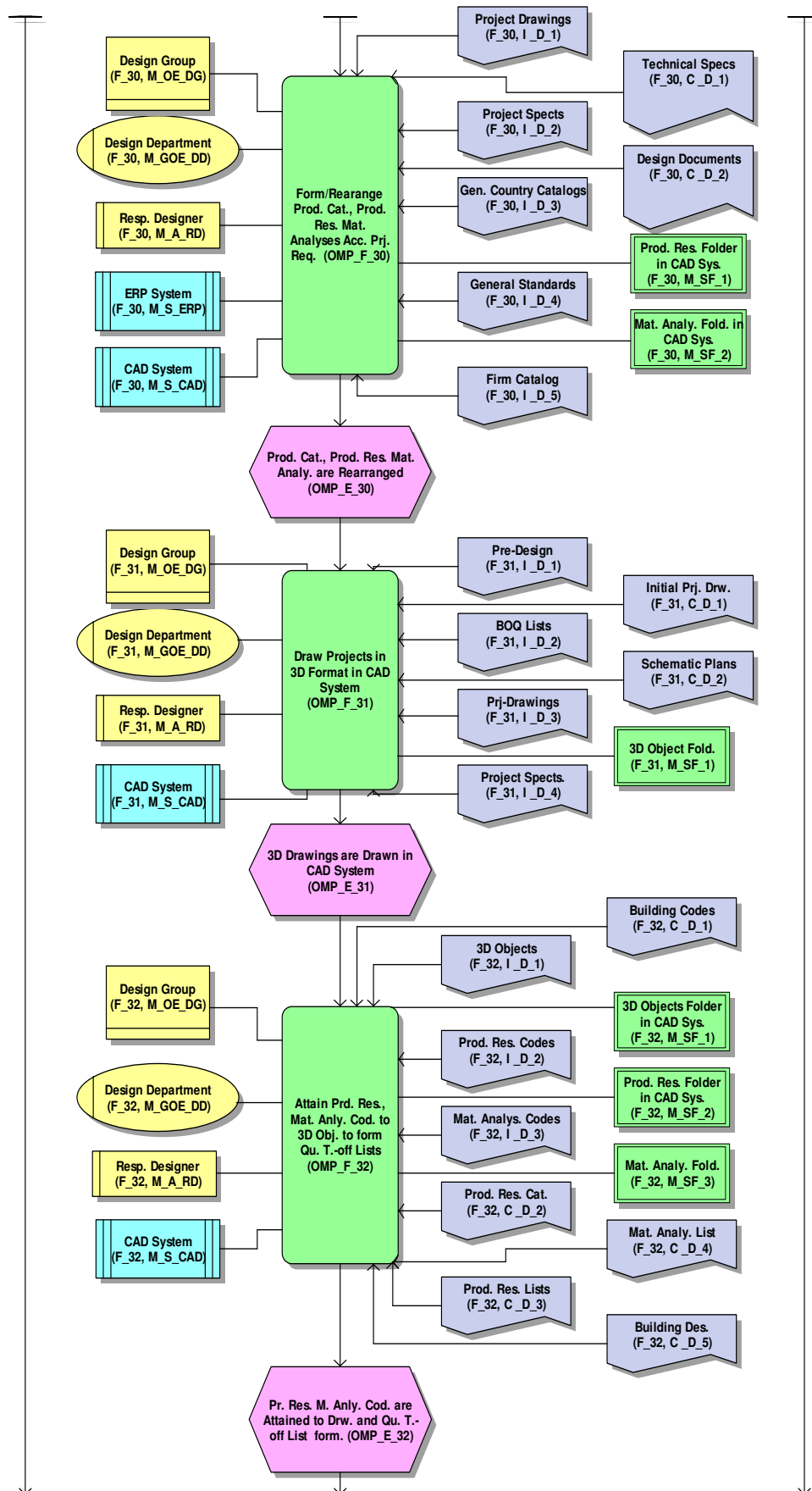
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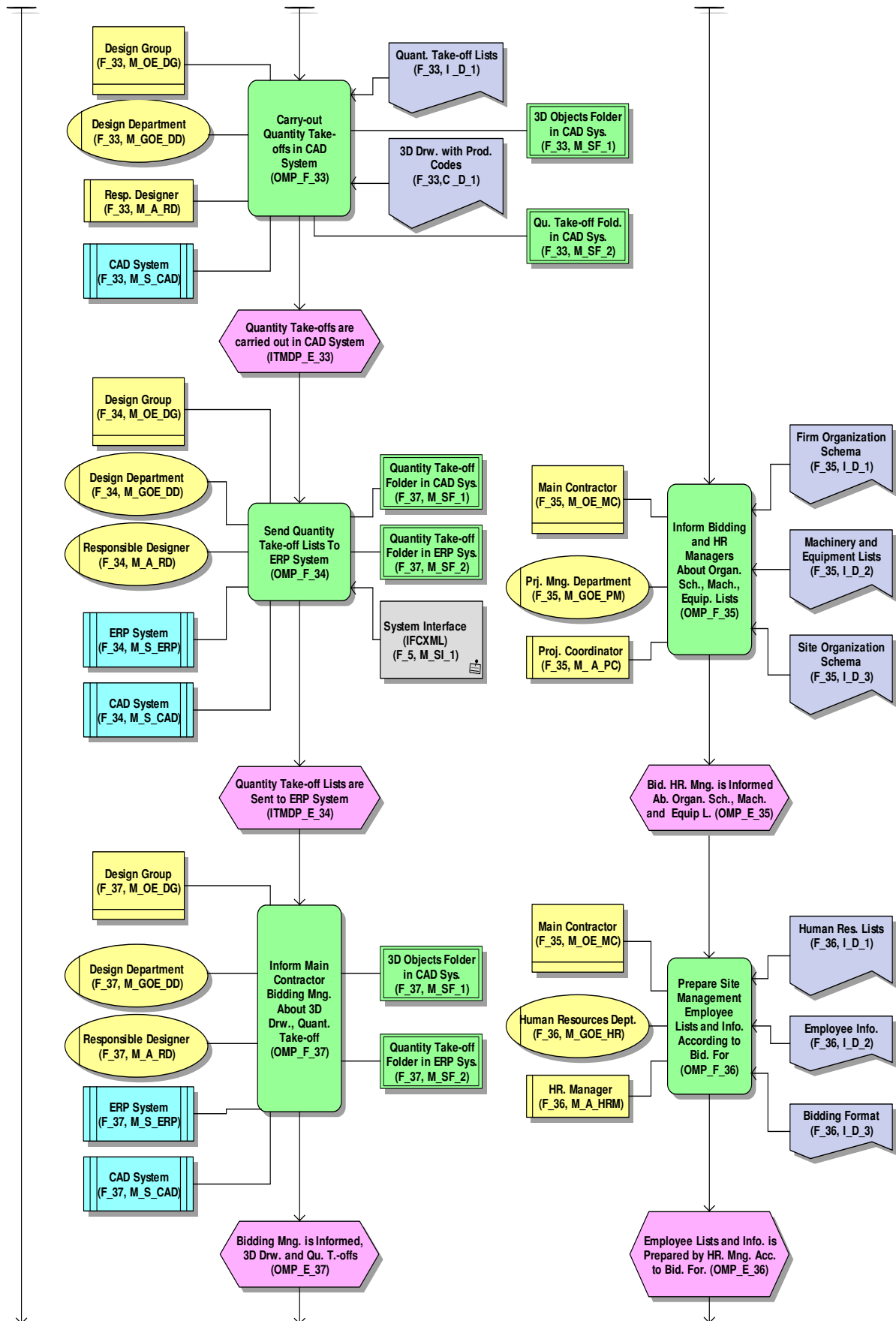
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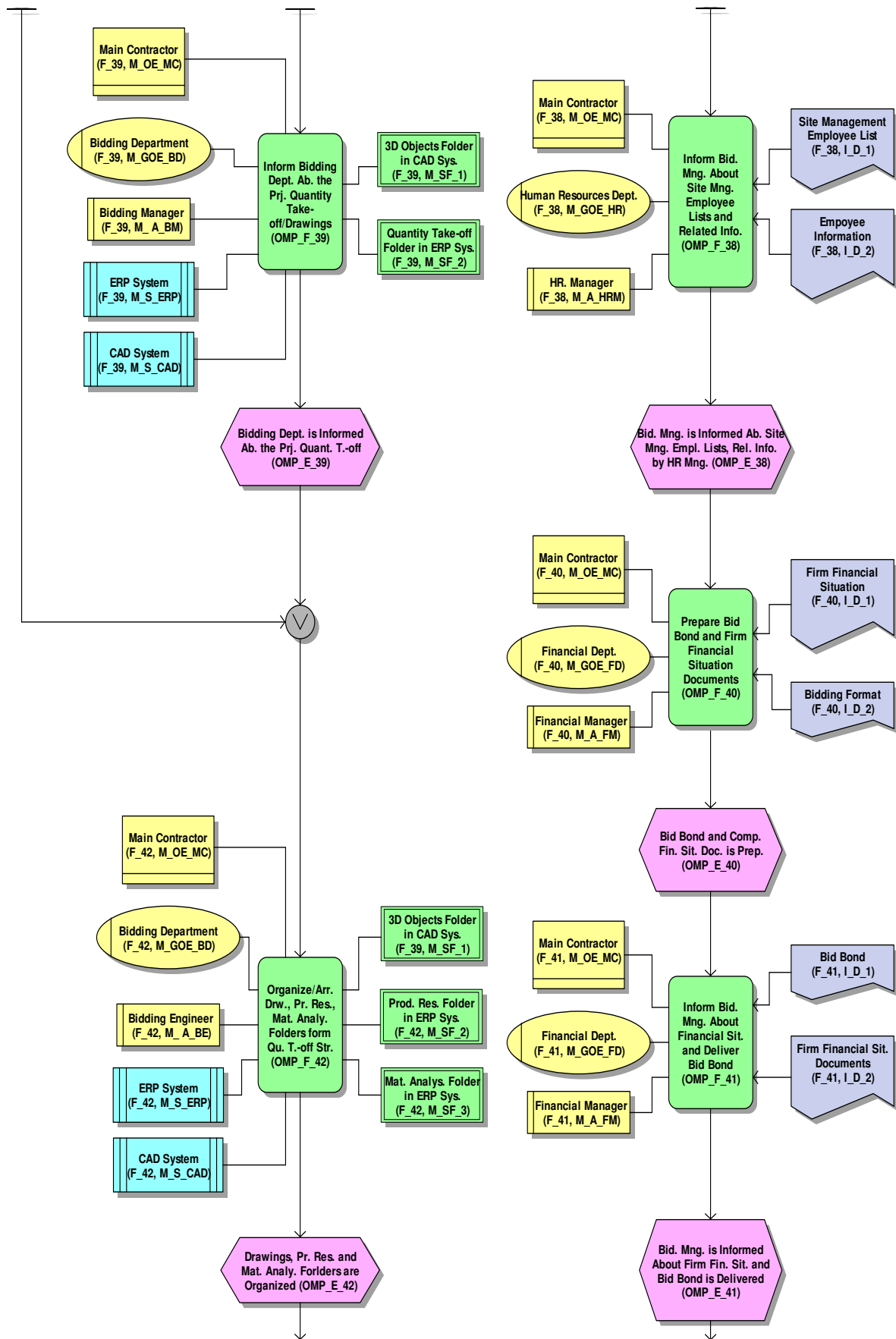
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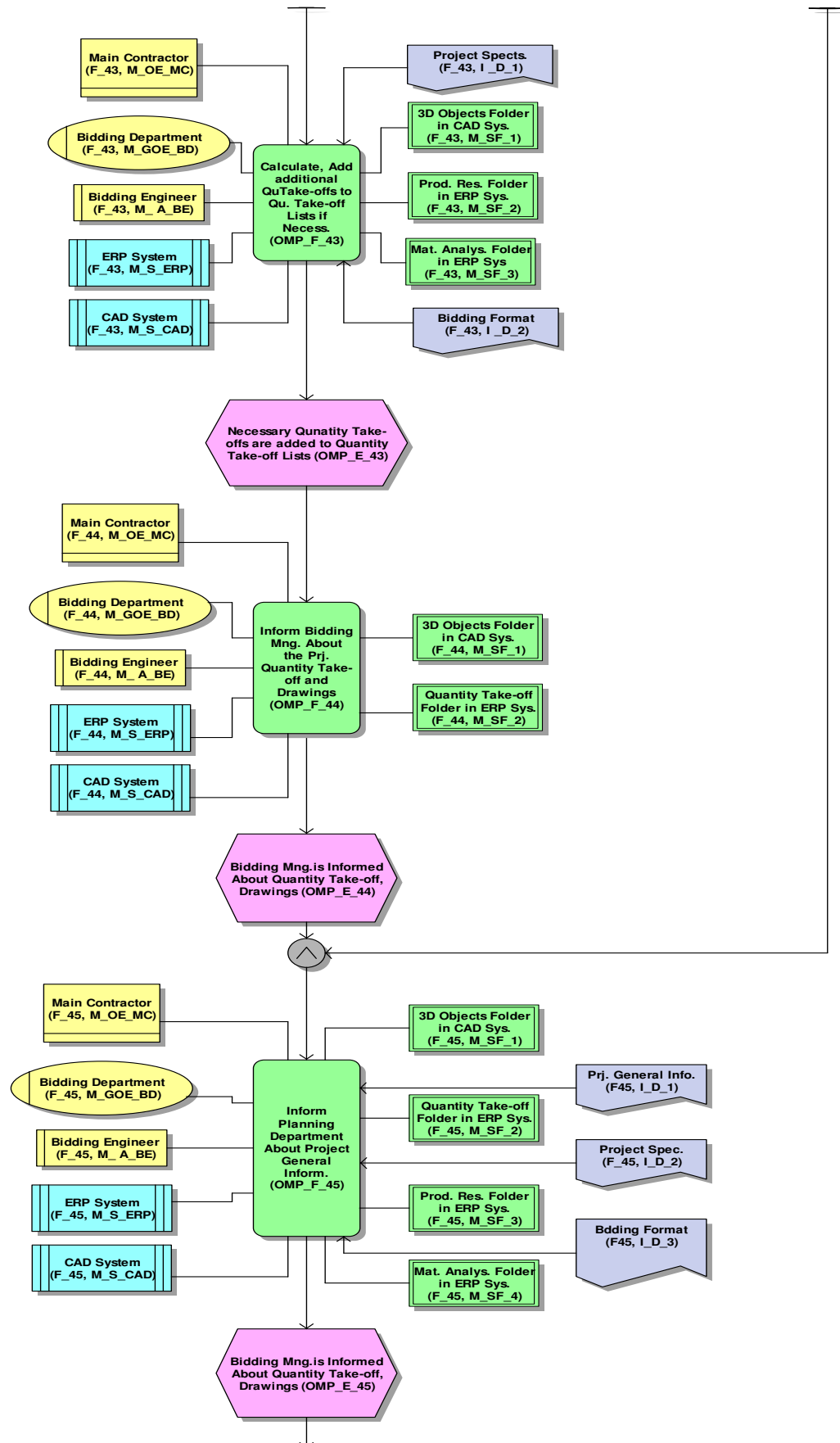
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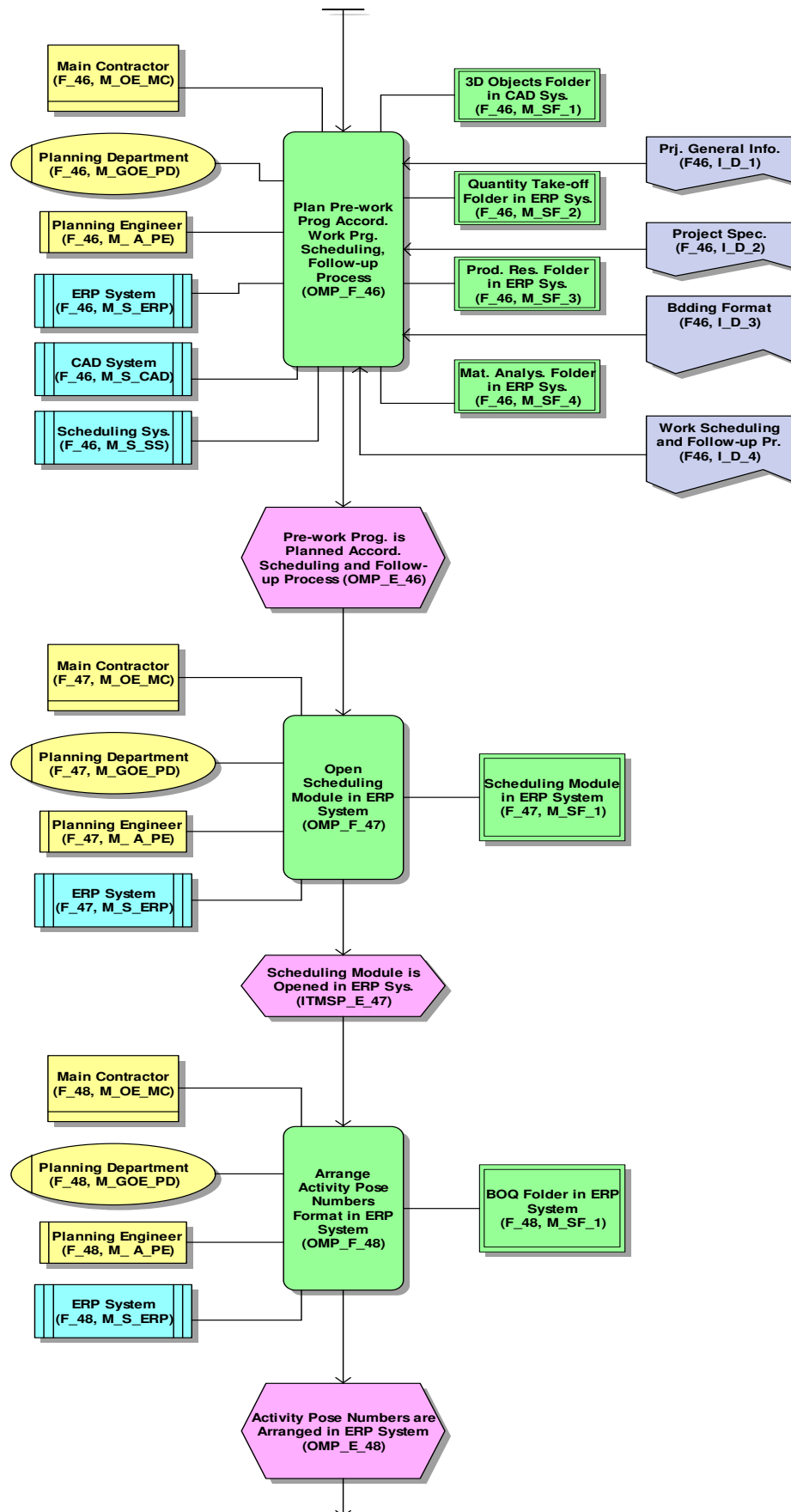
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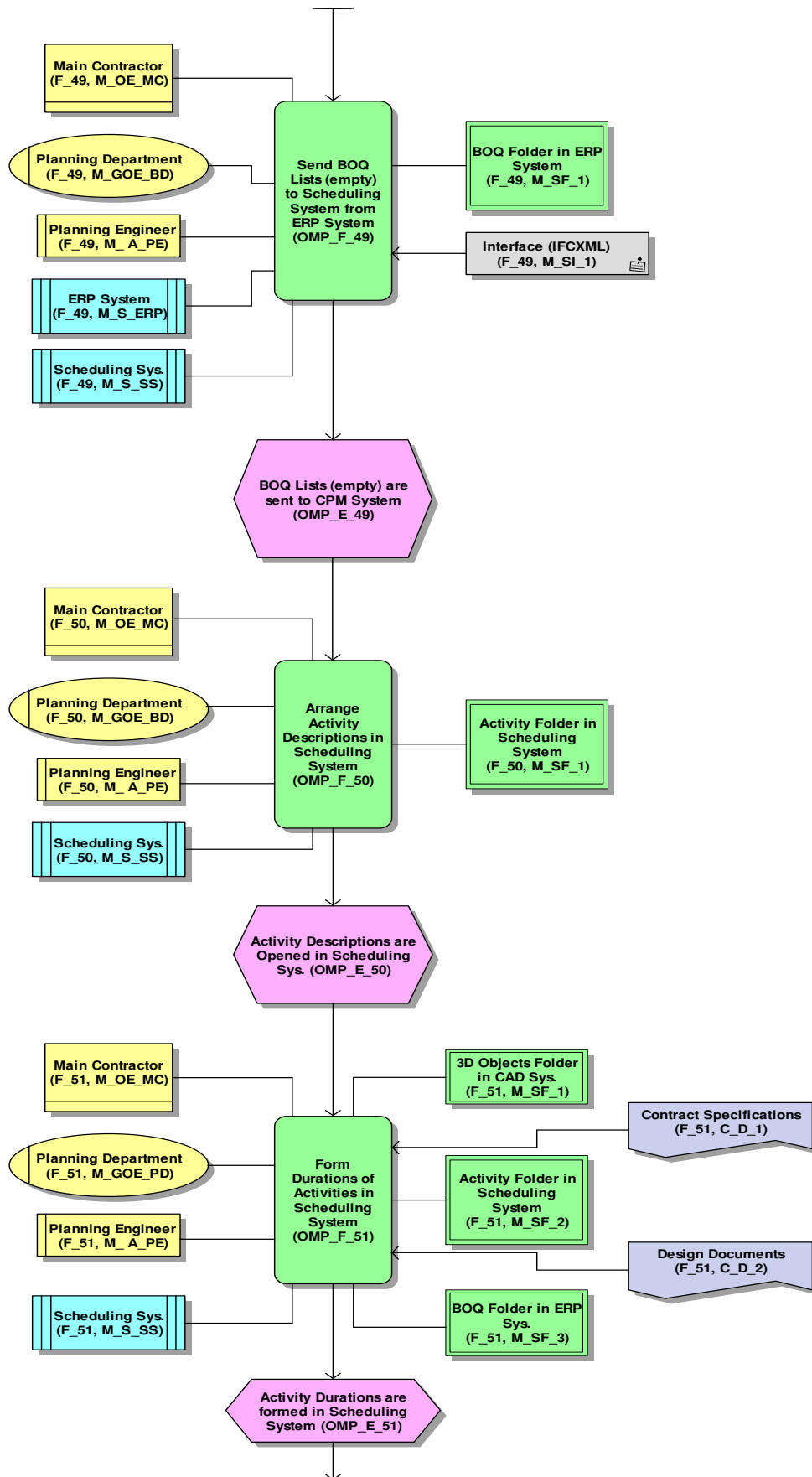
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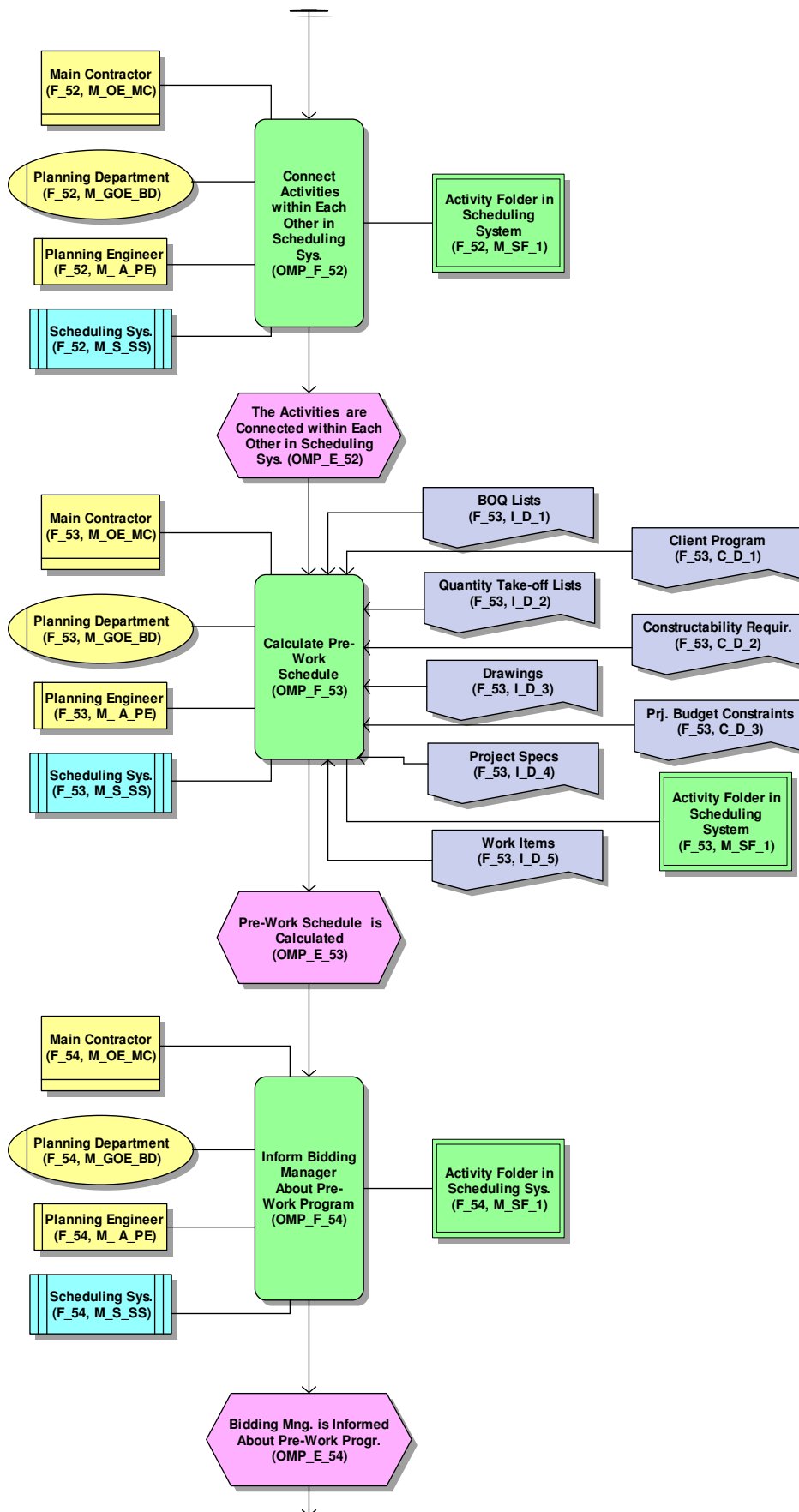
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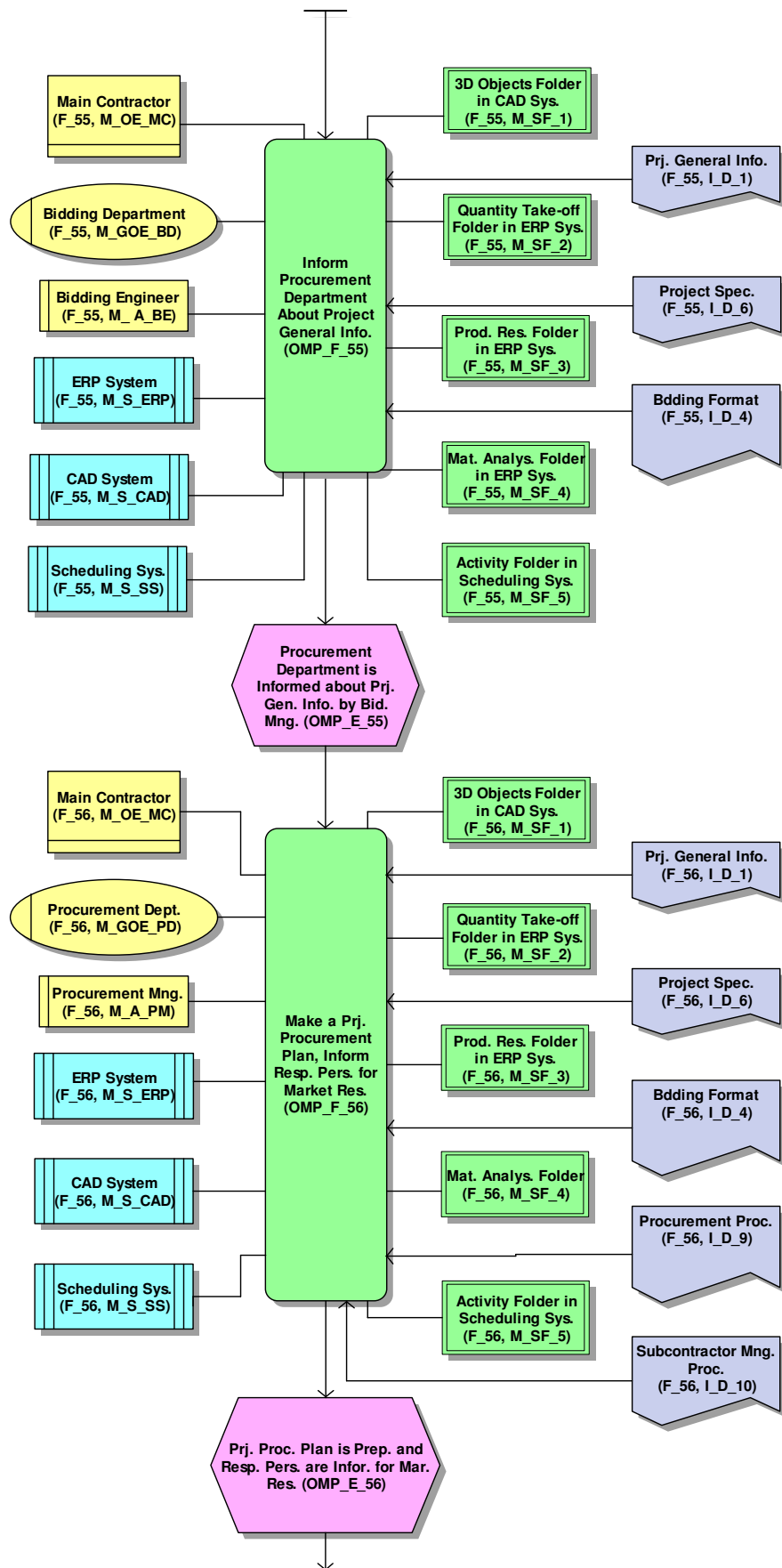
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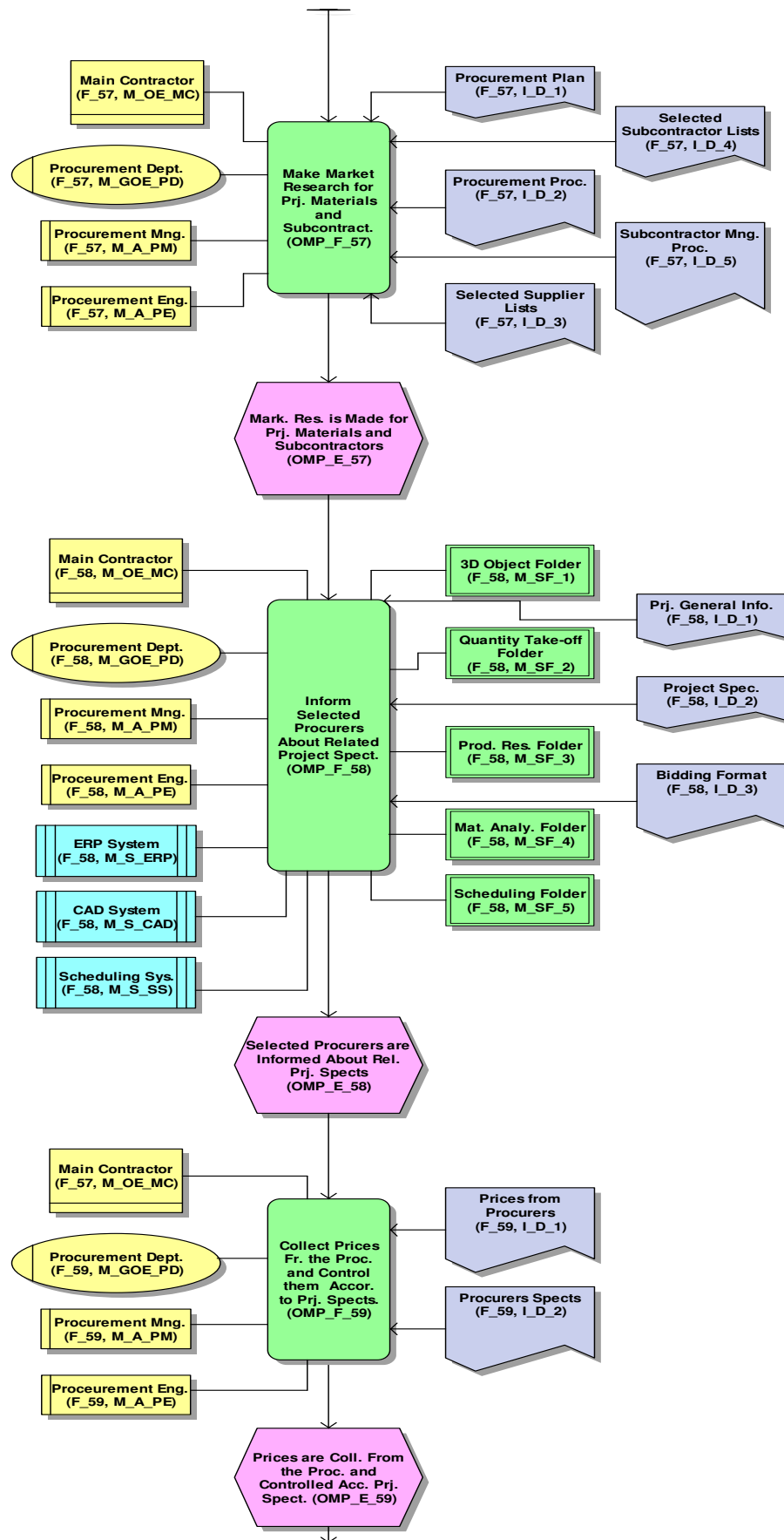
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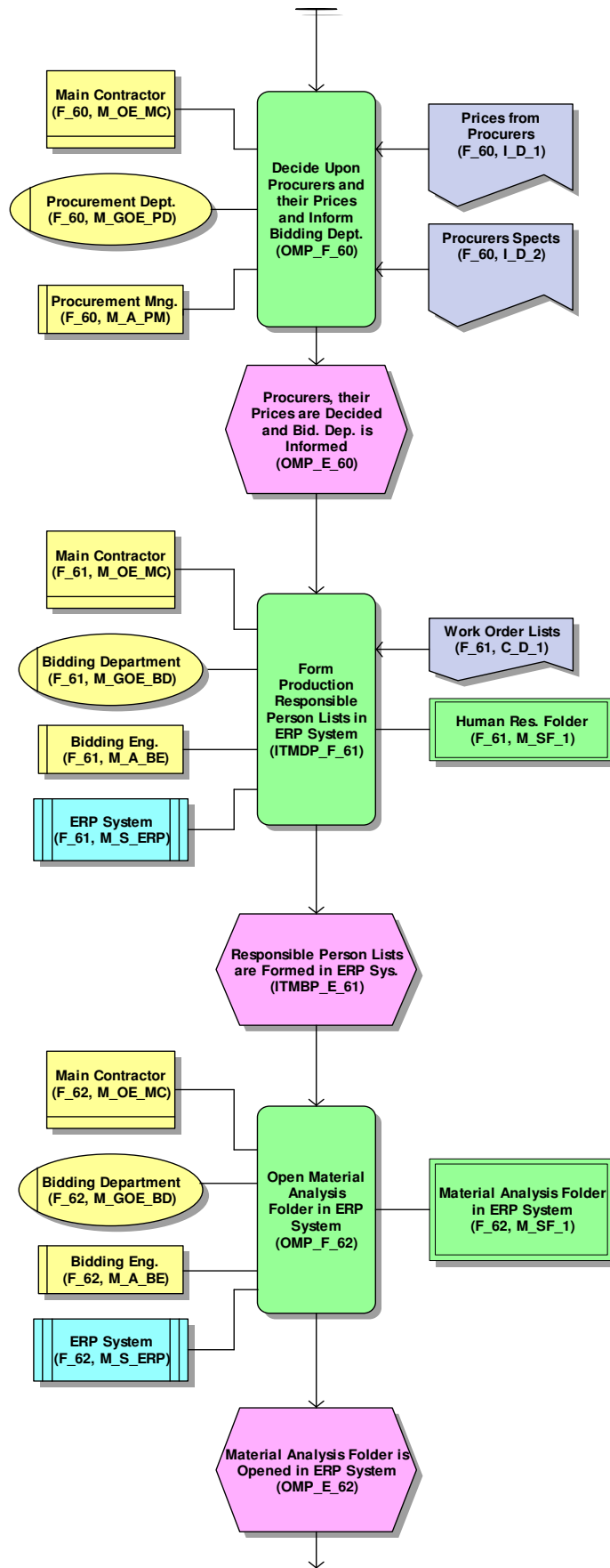
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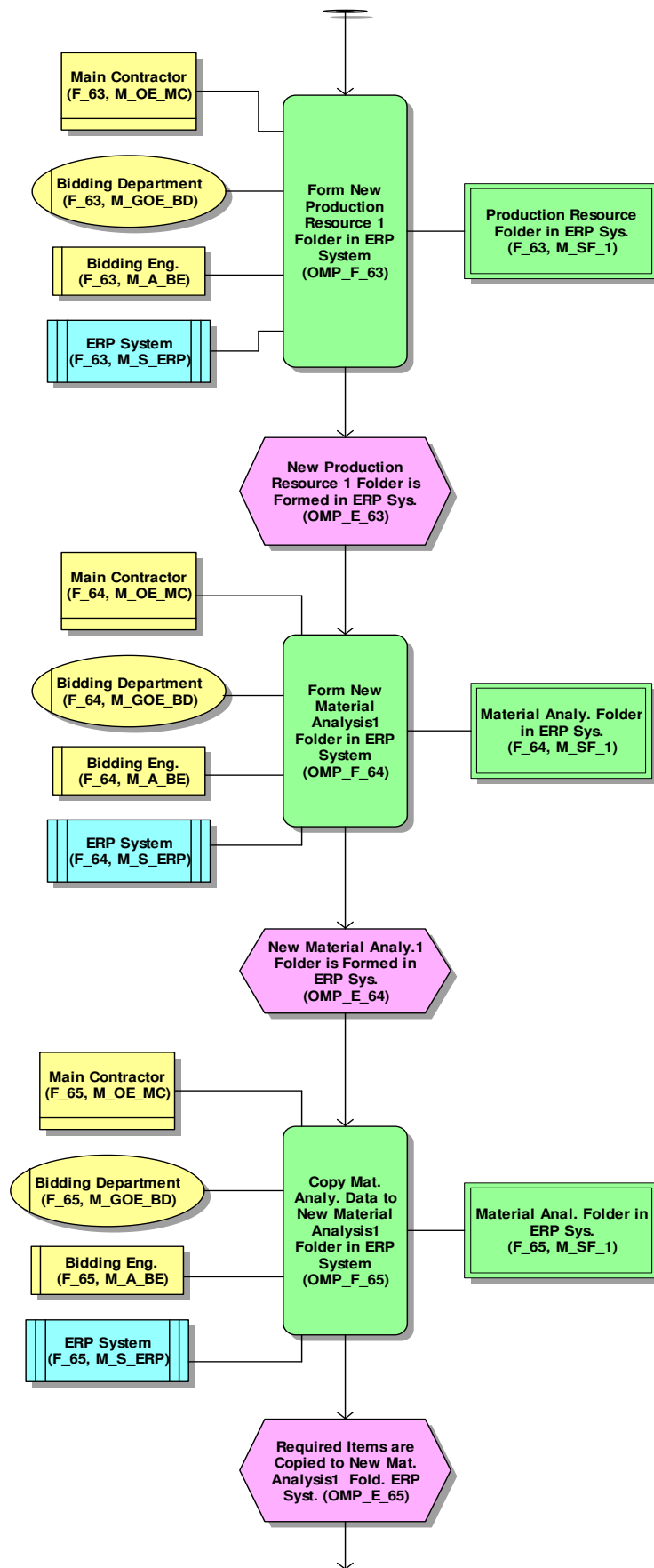


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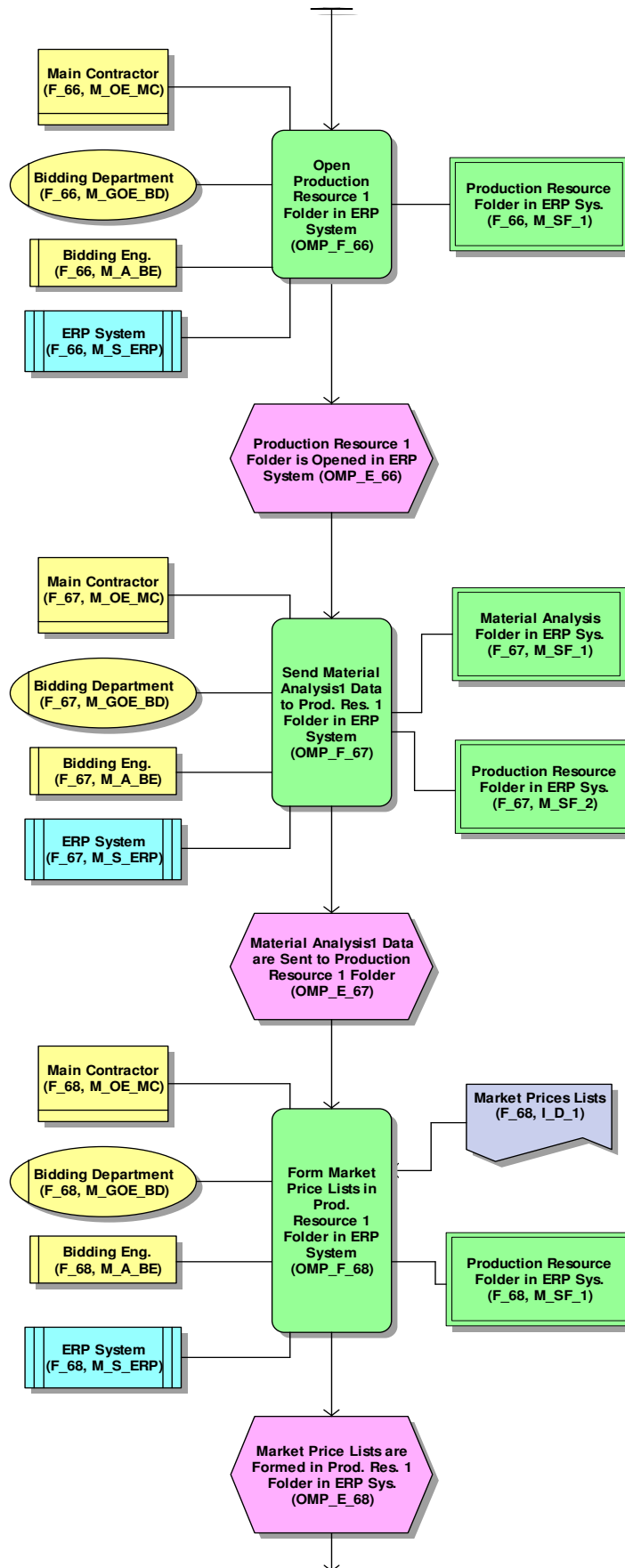


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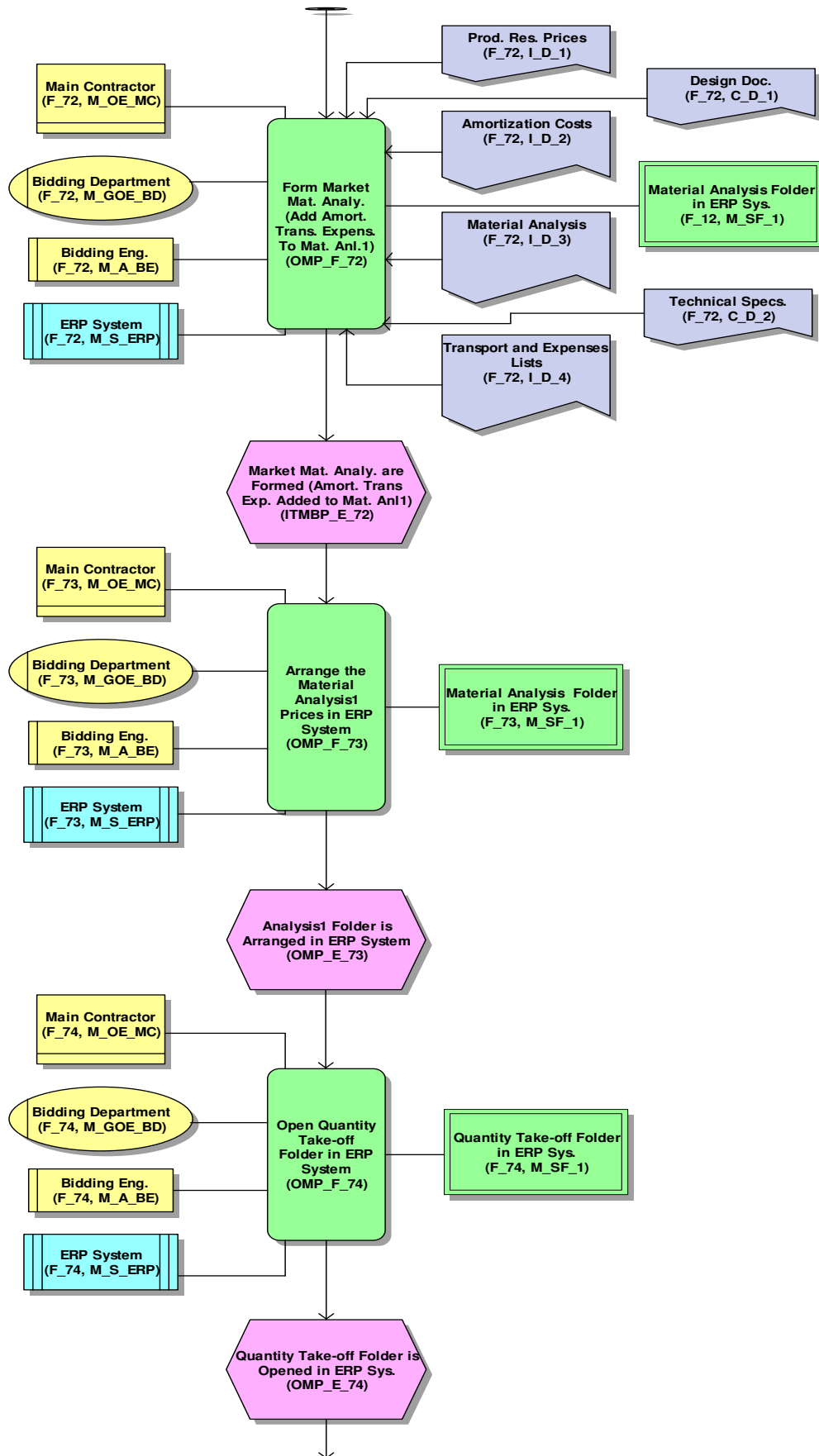


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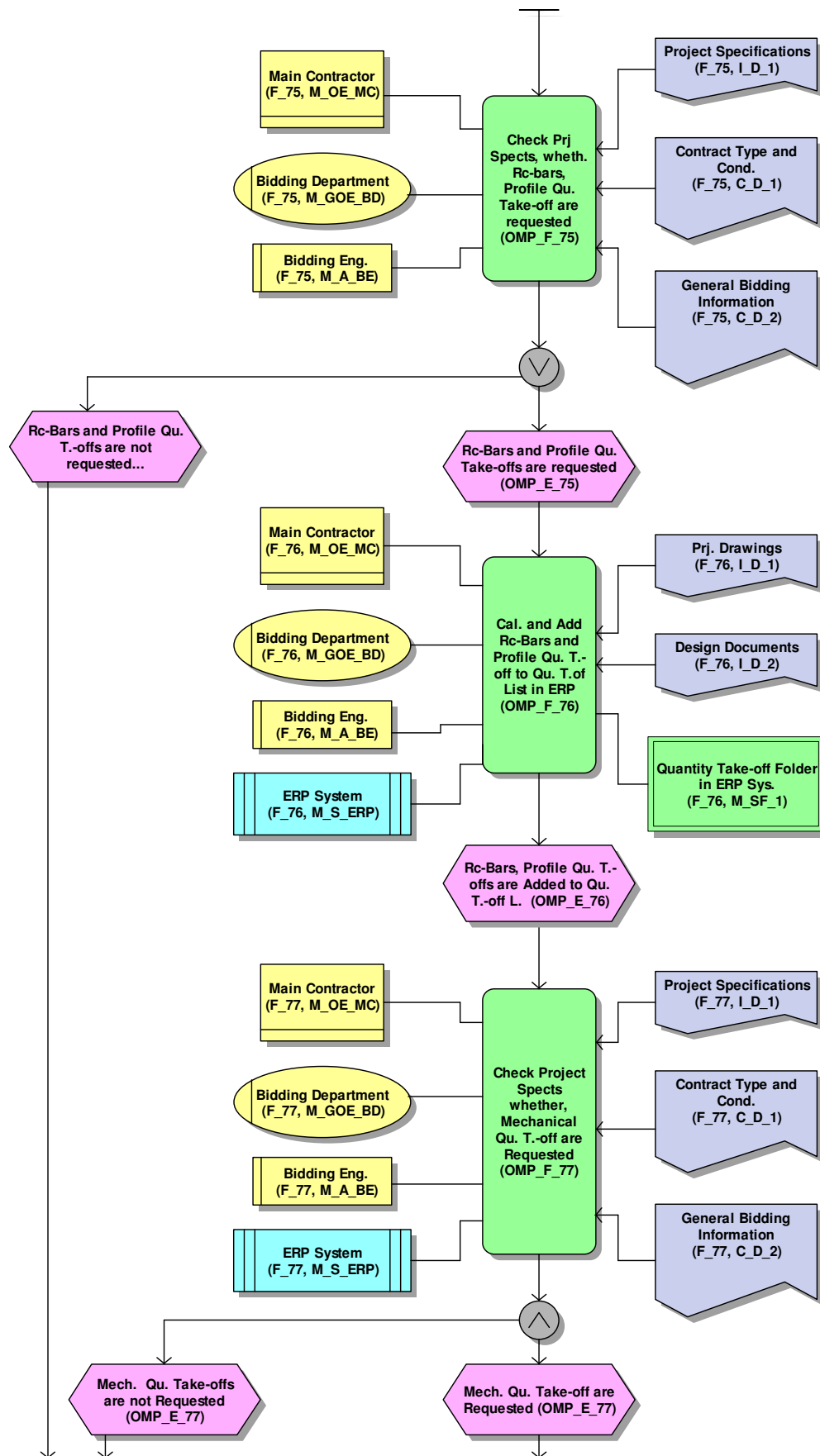
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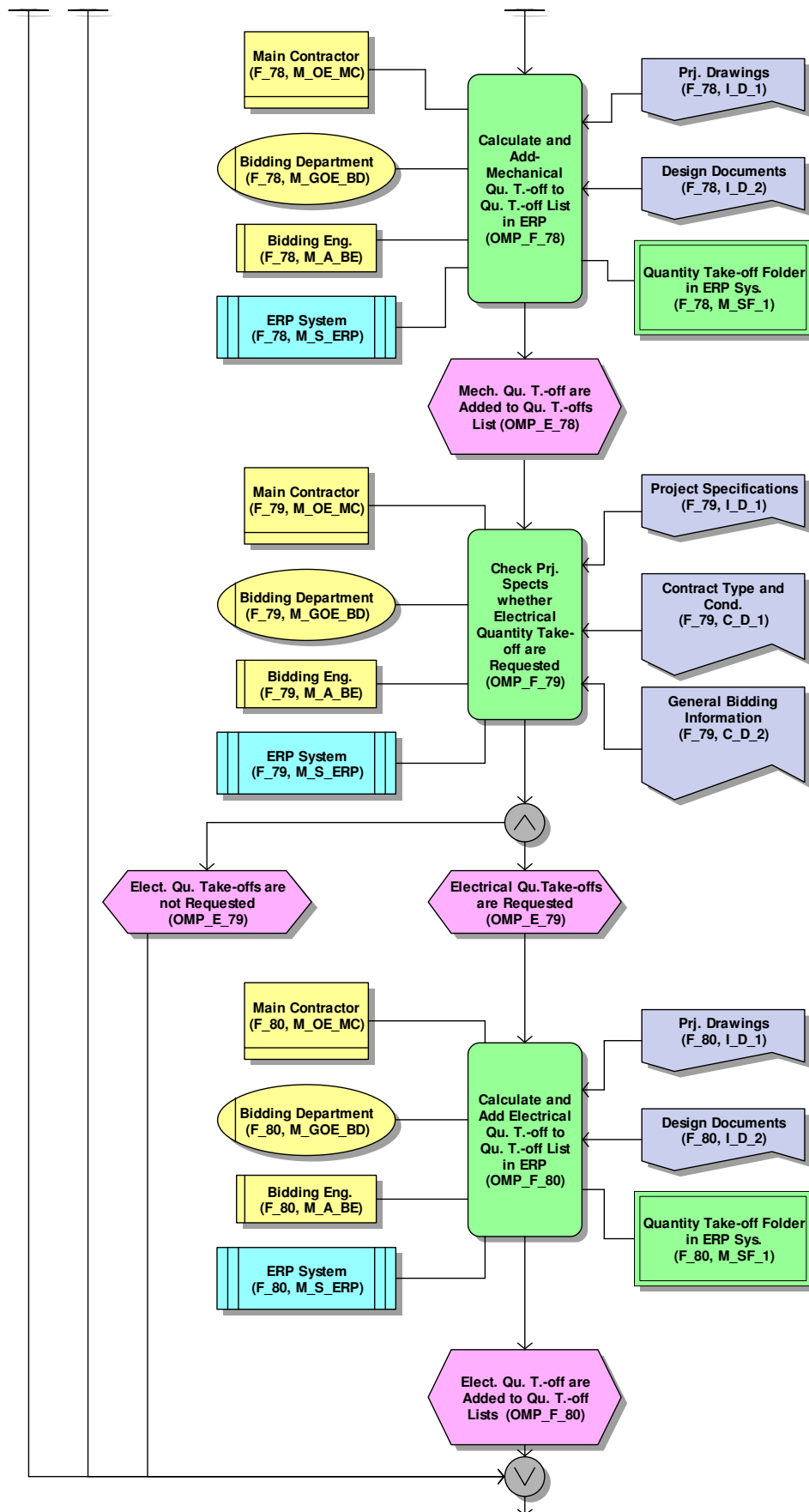
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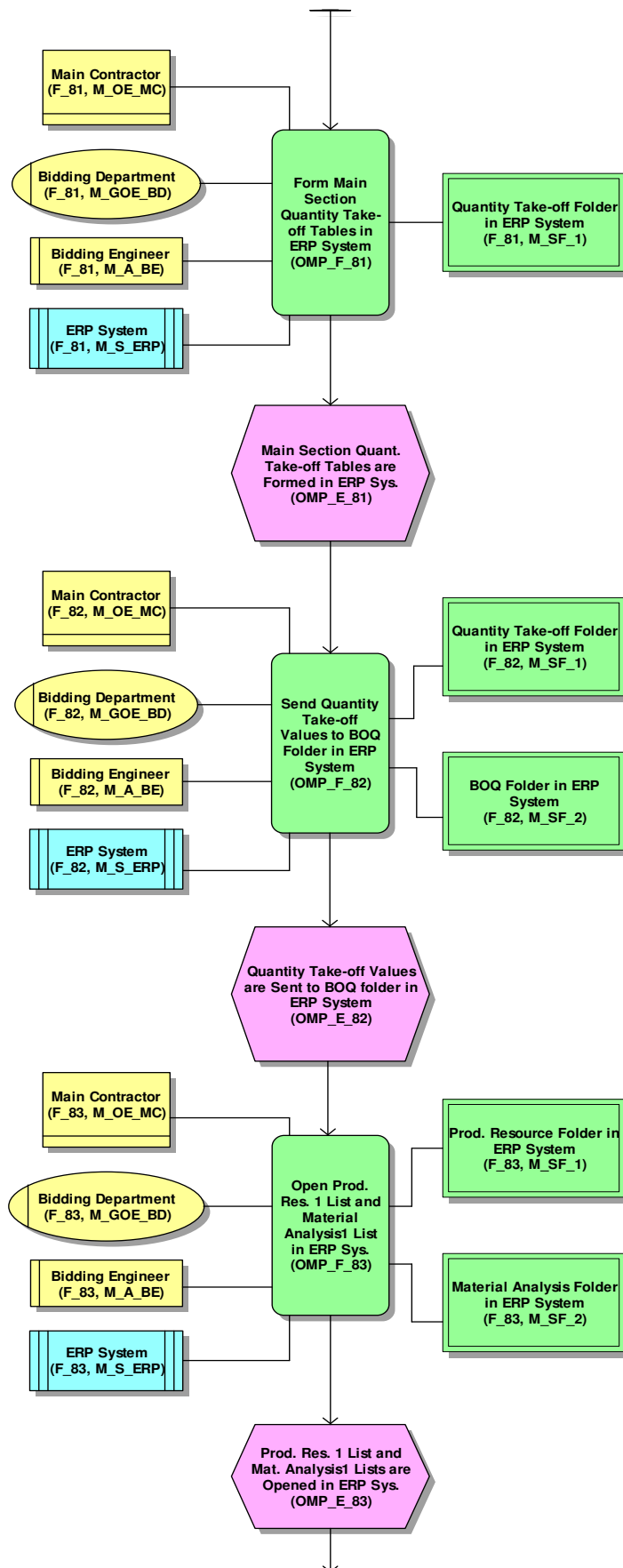
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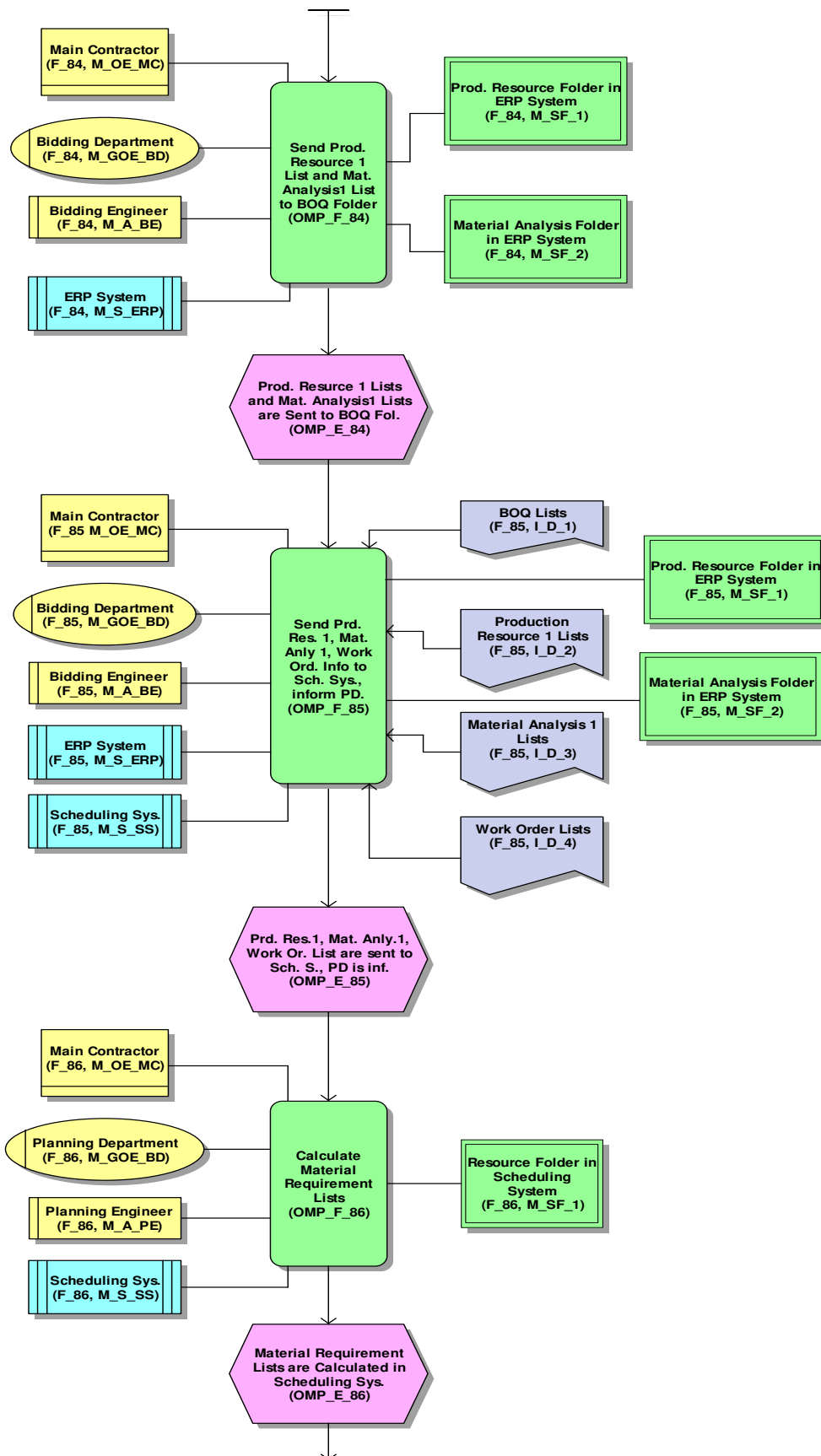
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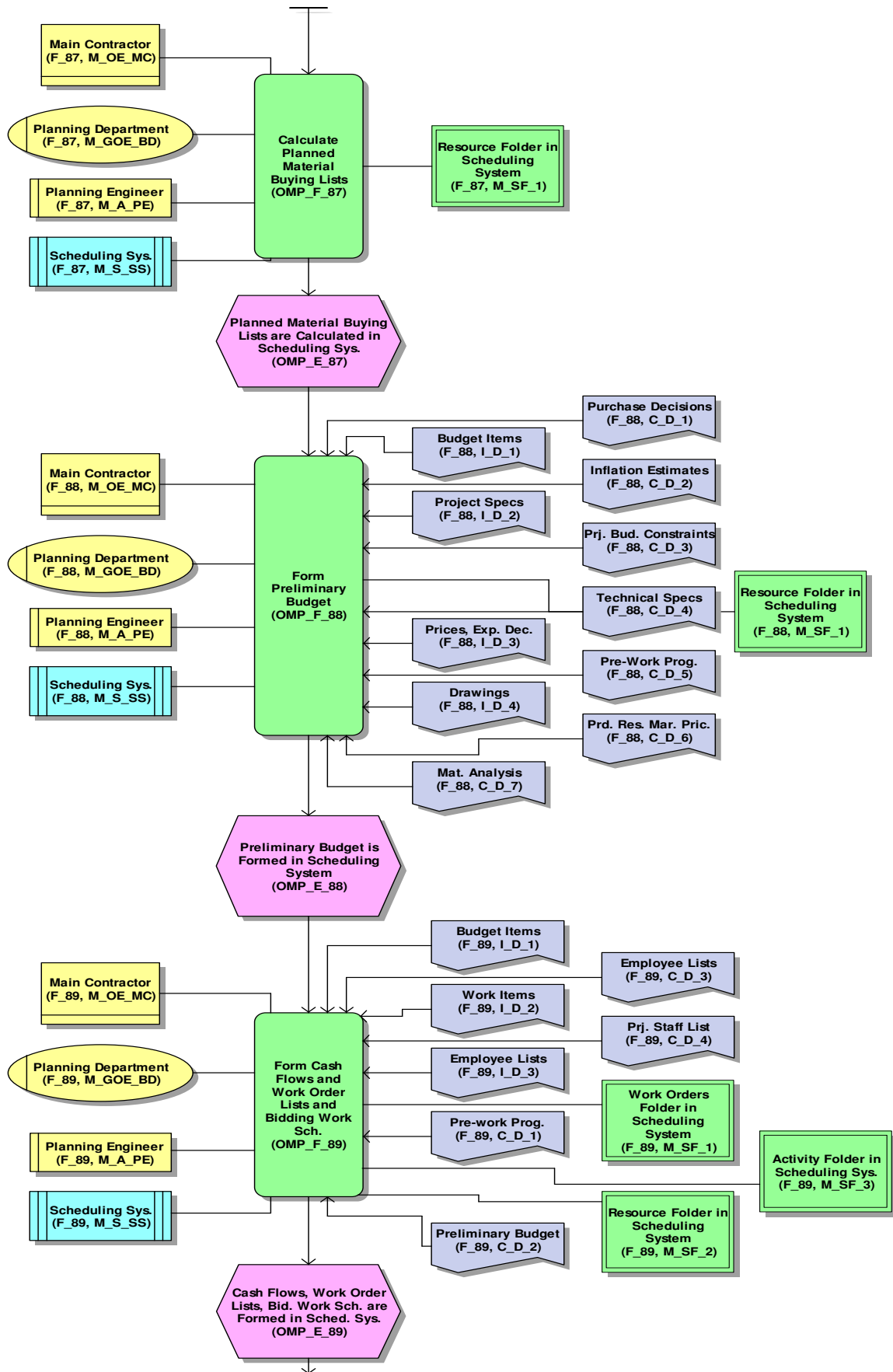
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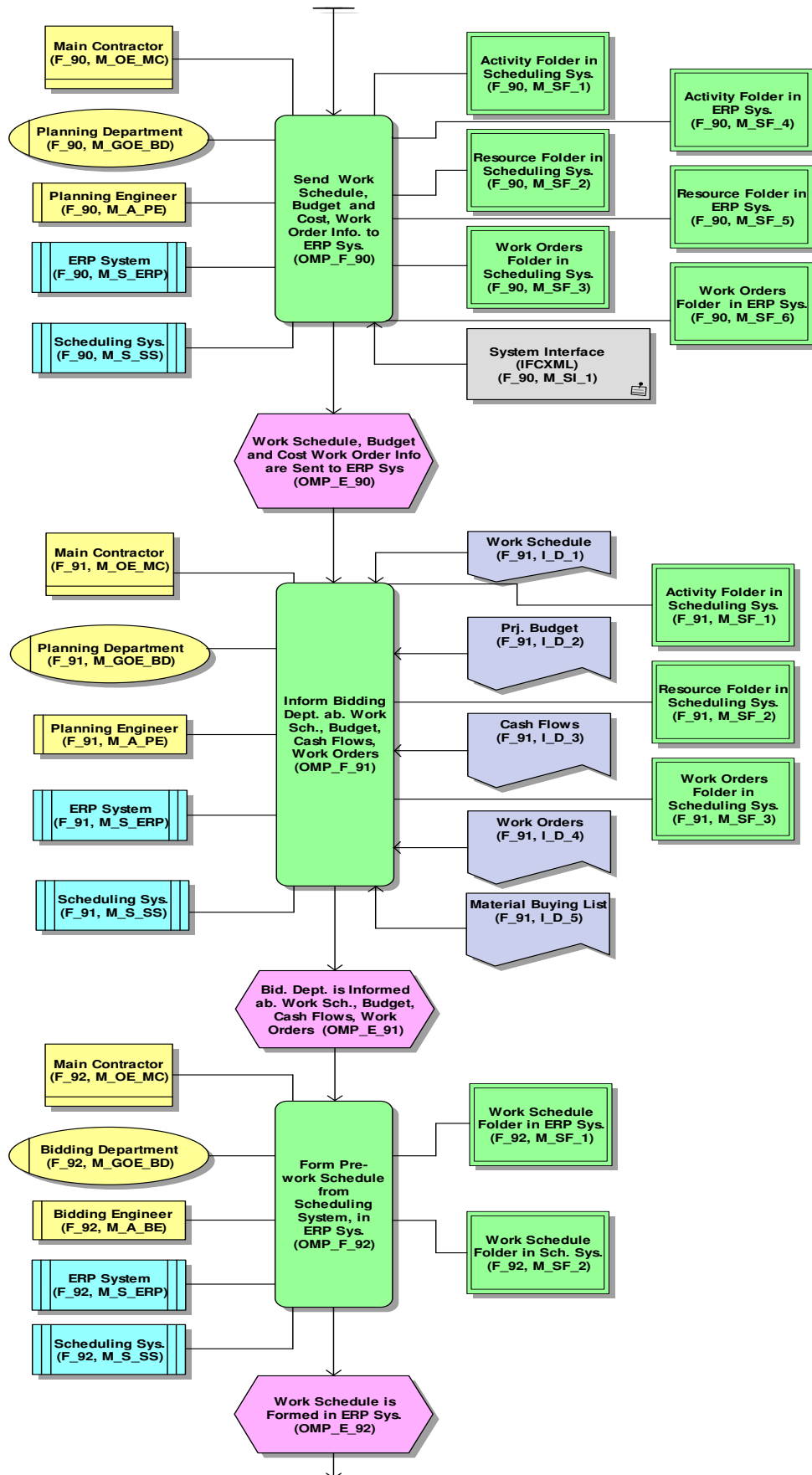
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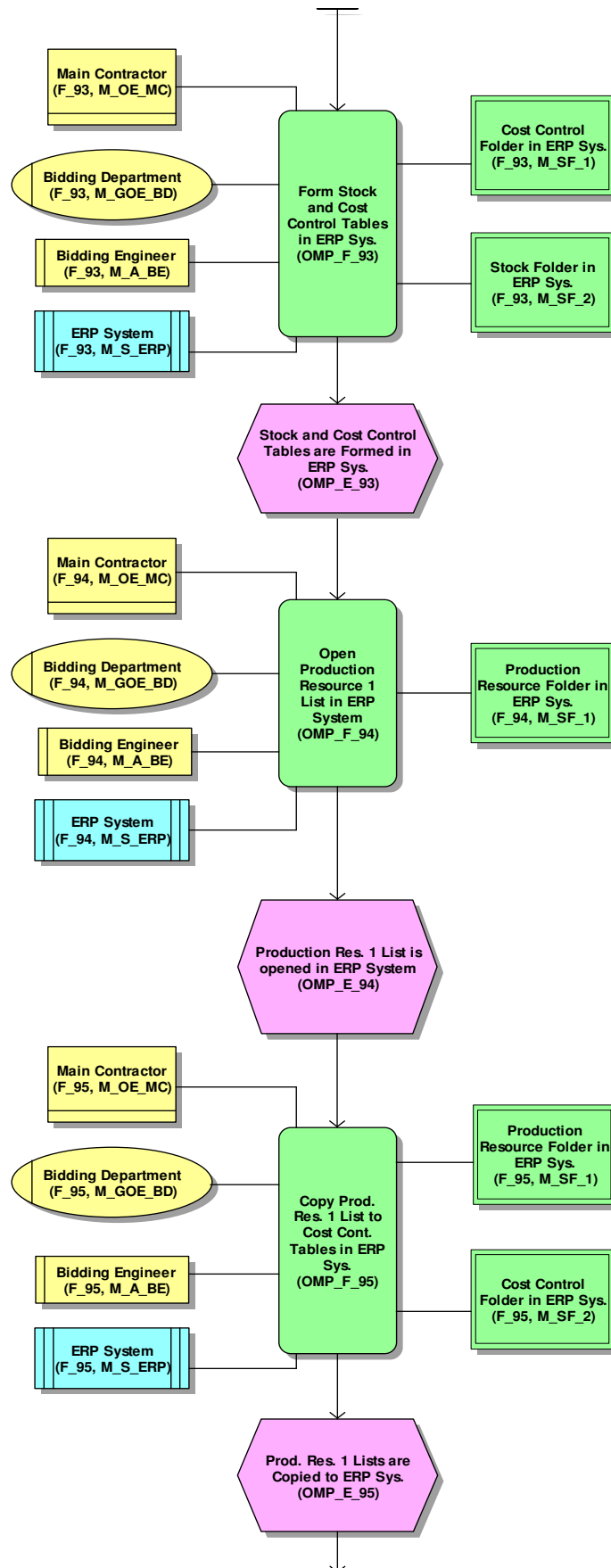
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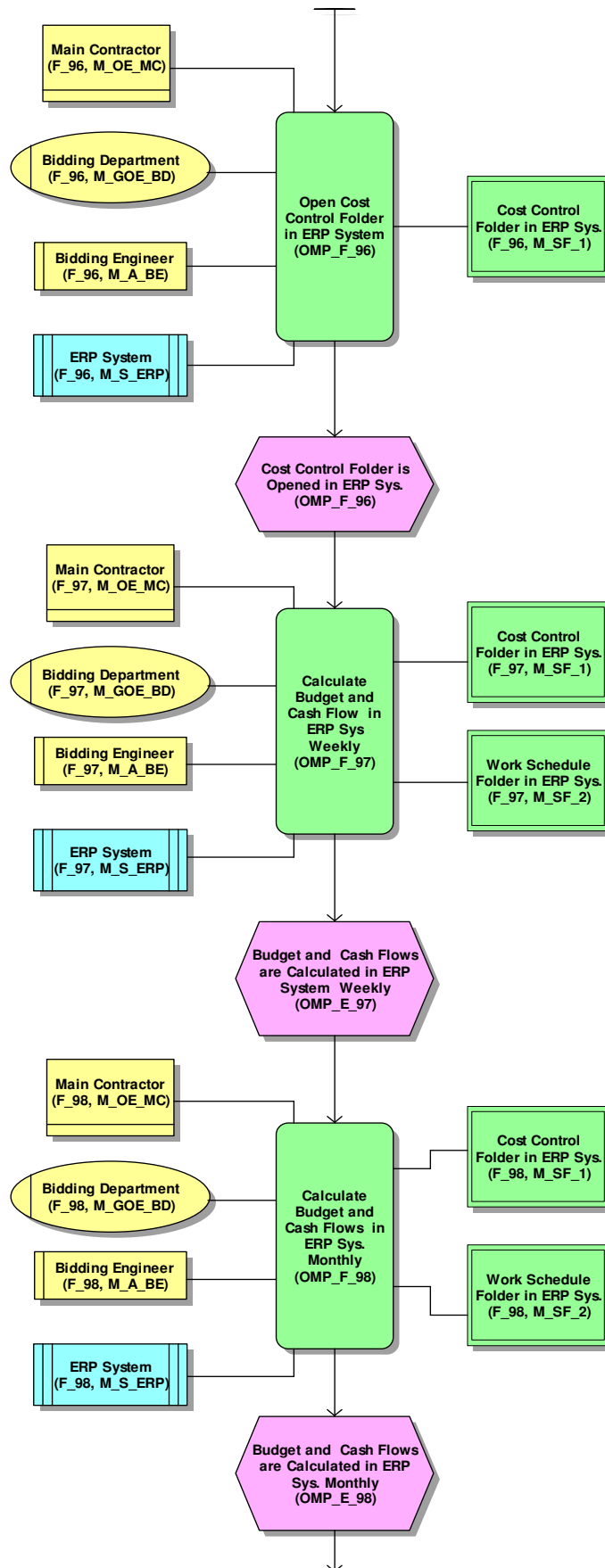
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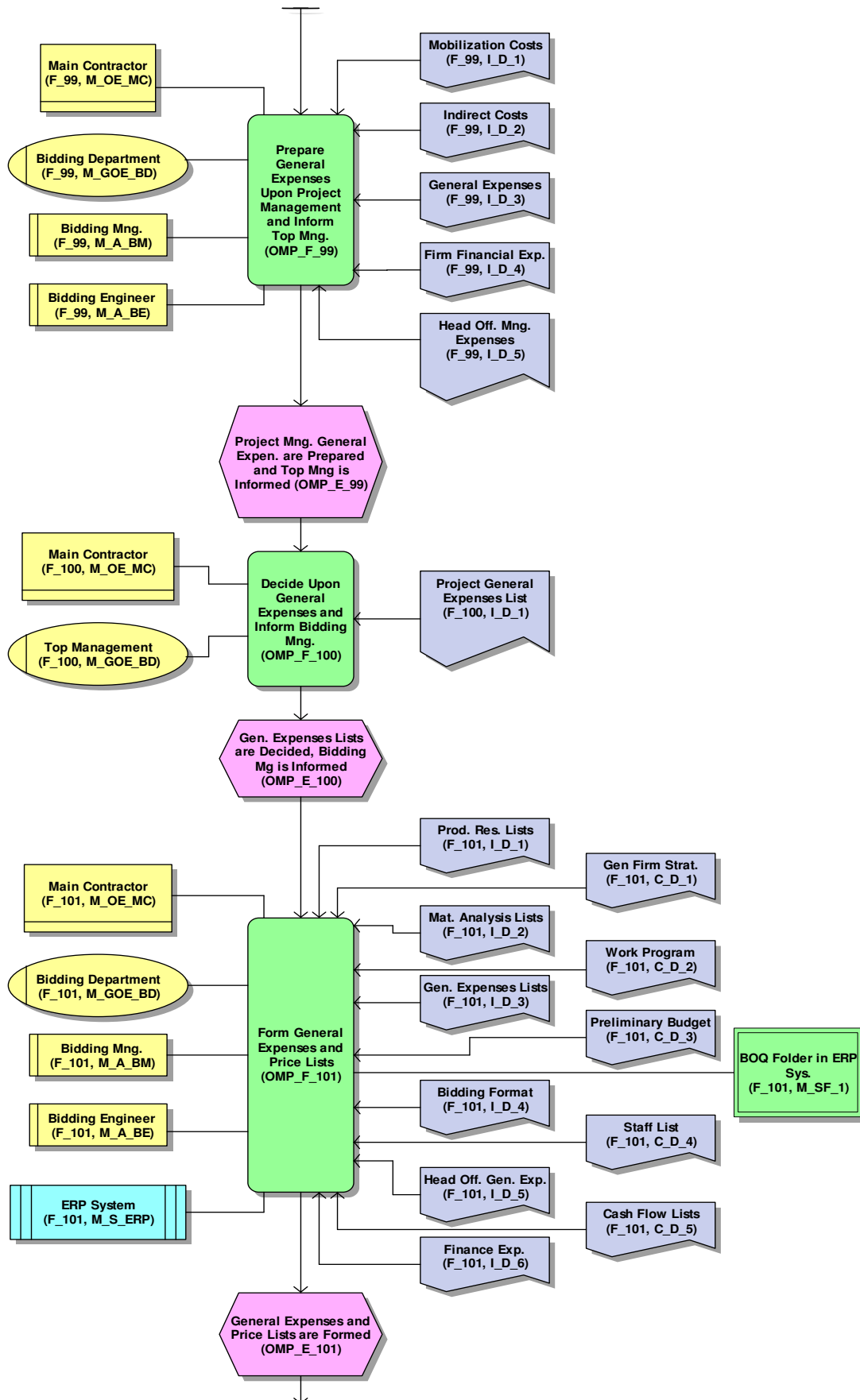
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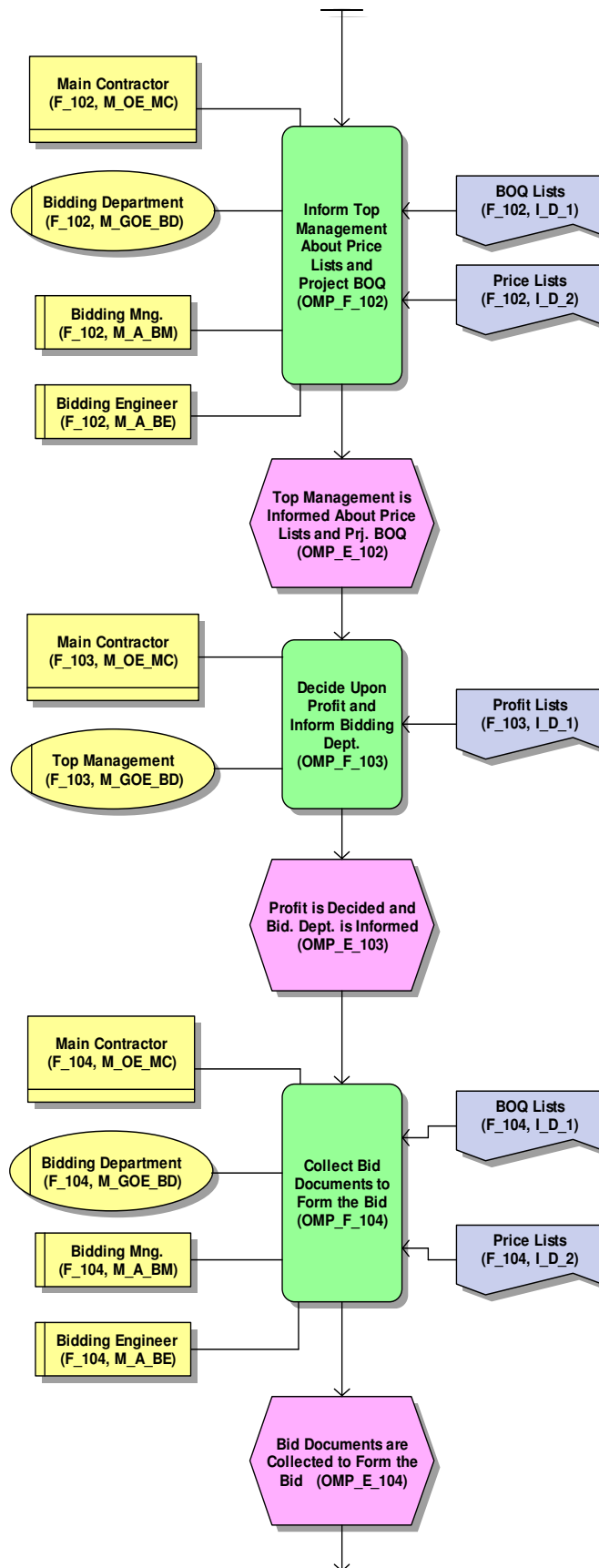
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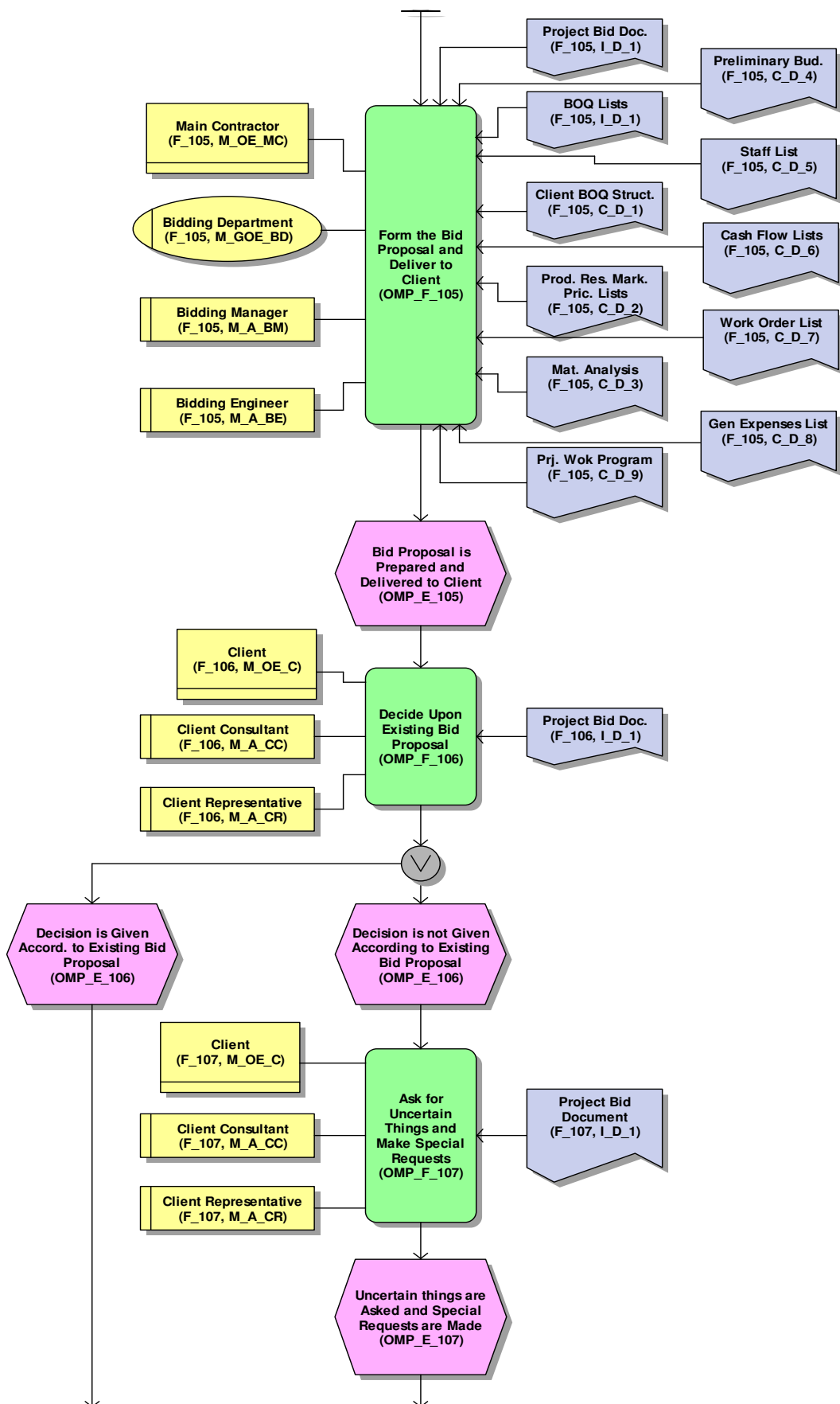
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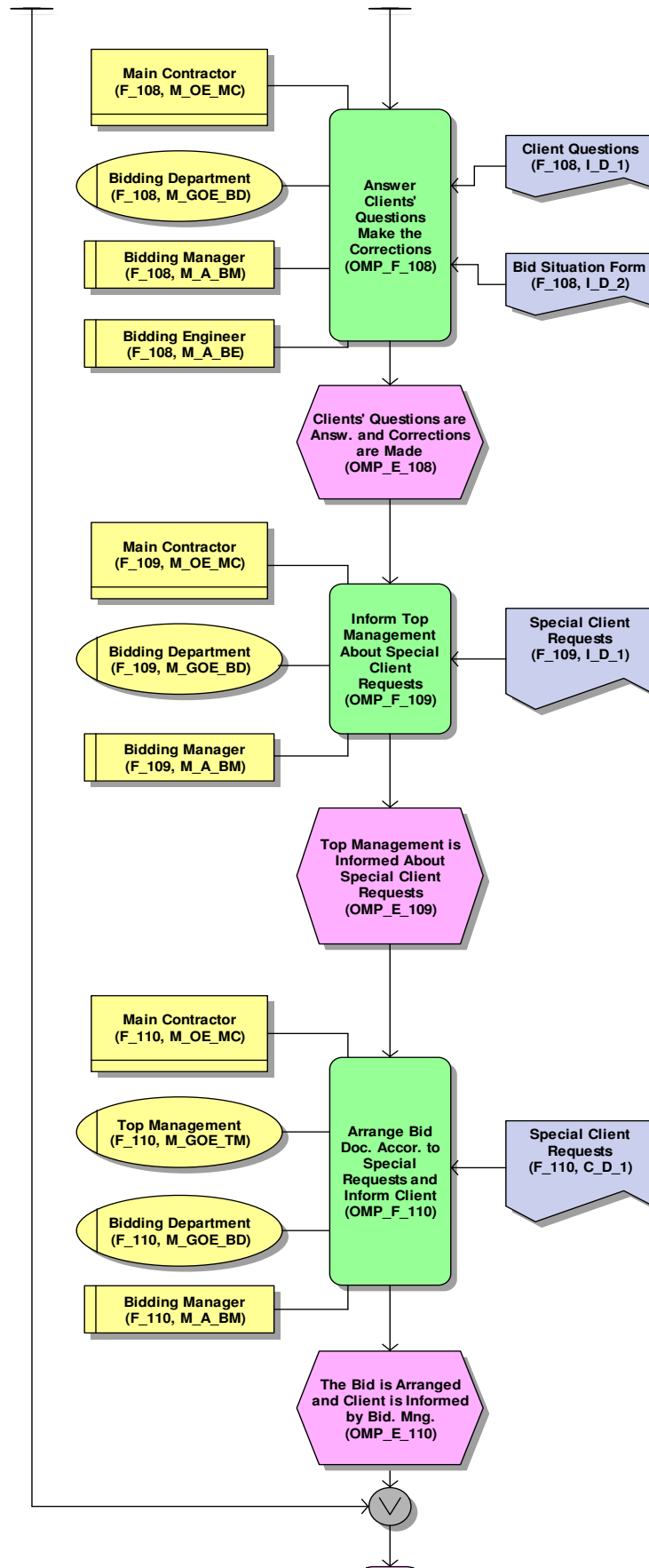
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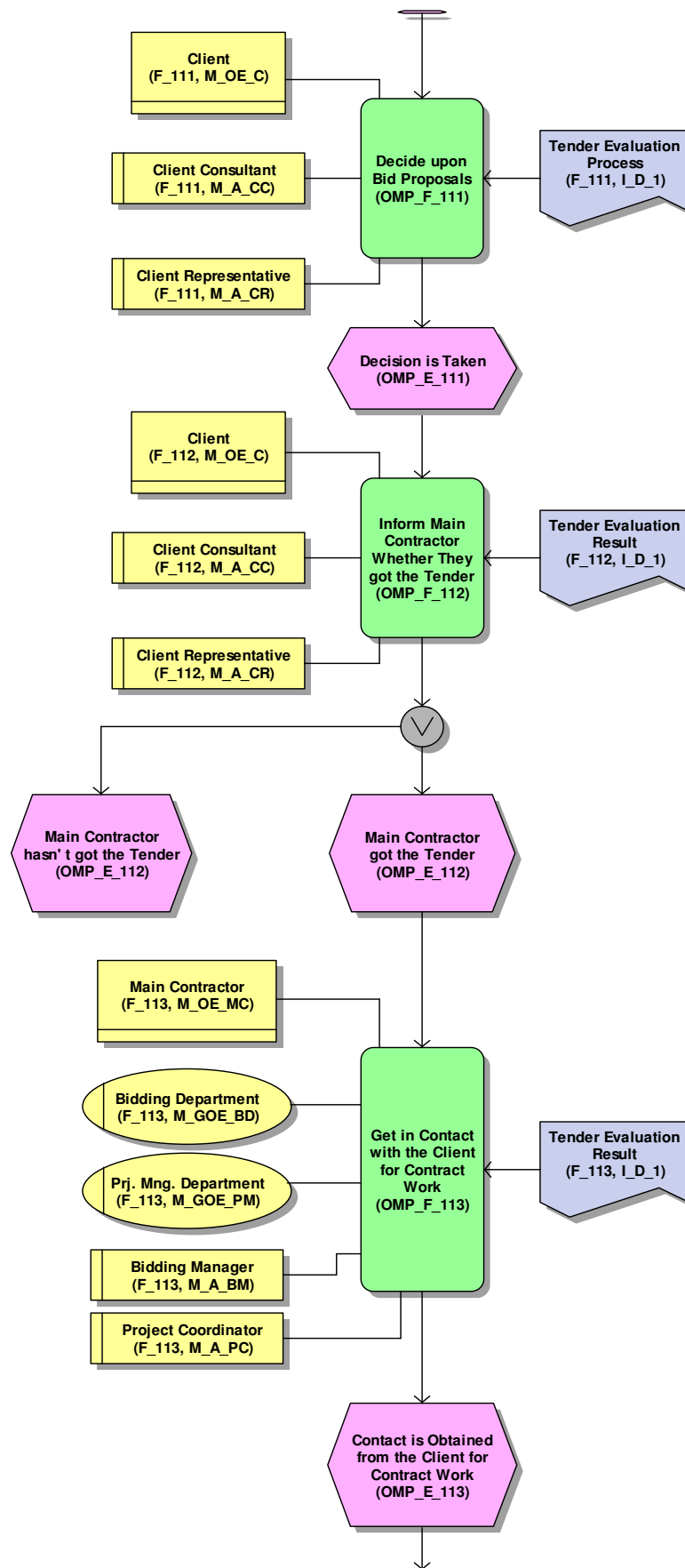
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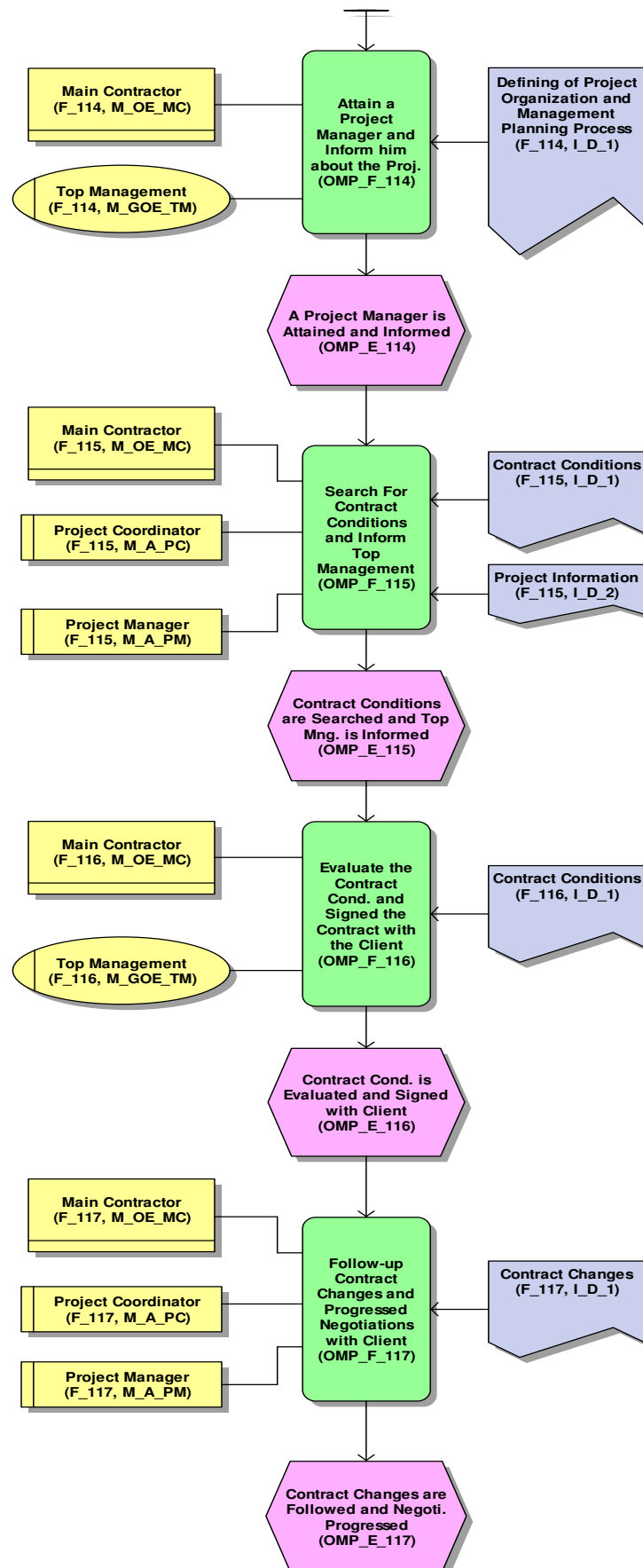
Organizational Management Process (OMP)



Organizational Management Process (OMP)



Organizational Management Process (OMP)



APPENDIX B: IT Management Processes

These appendixes present IT Management Processes (ITMP).

IT Management Processes are identified based on application systems integration. In order to represent application sequence of the IT tools, three sub-structured (in ceEPC) models are provided under:

APPENDIX B1

- **IT Management Design Process (ITMDP)**

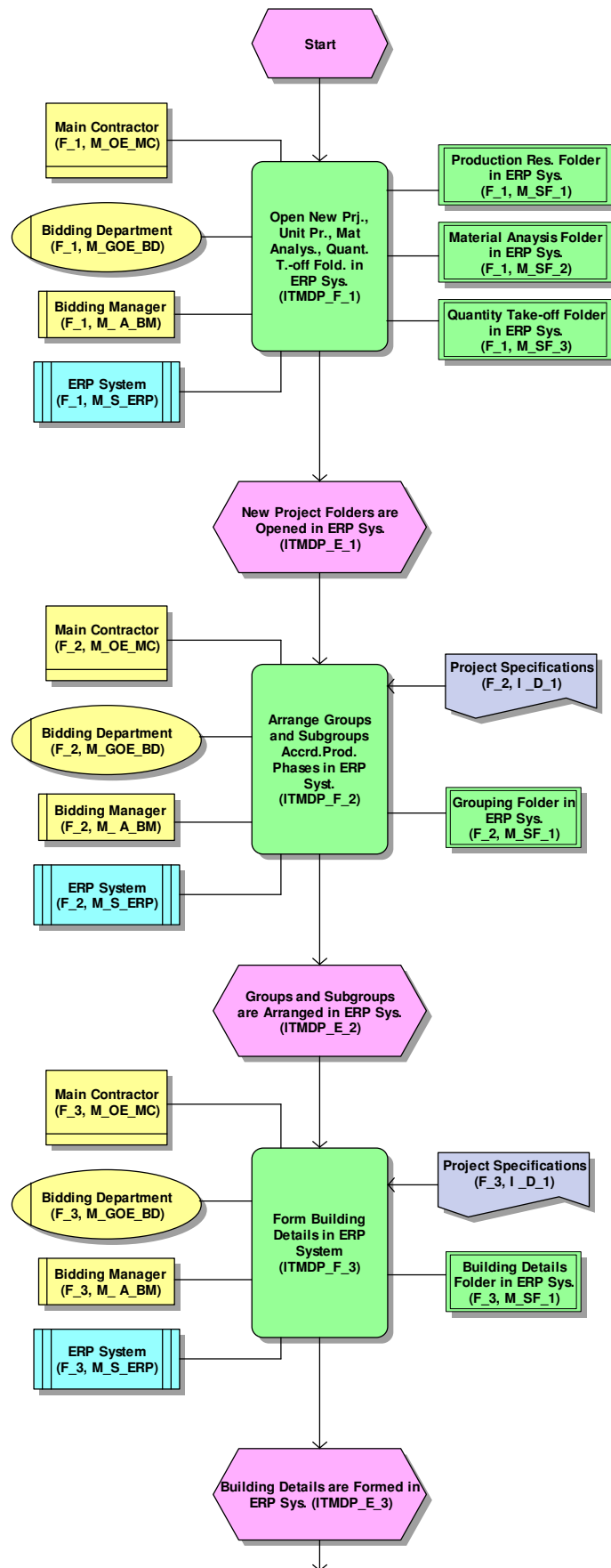
APPENDIX B2

- **IT Management BOQ Process (ITMBP)**

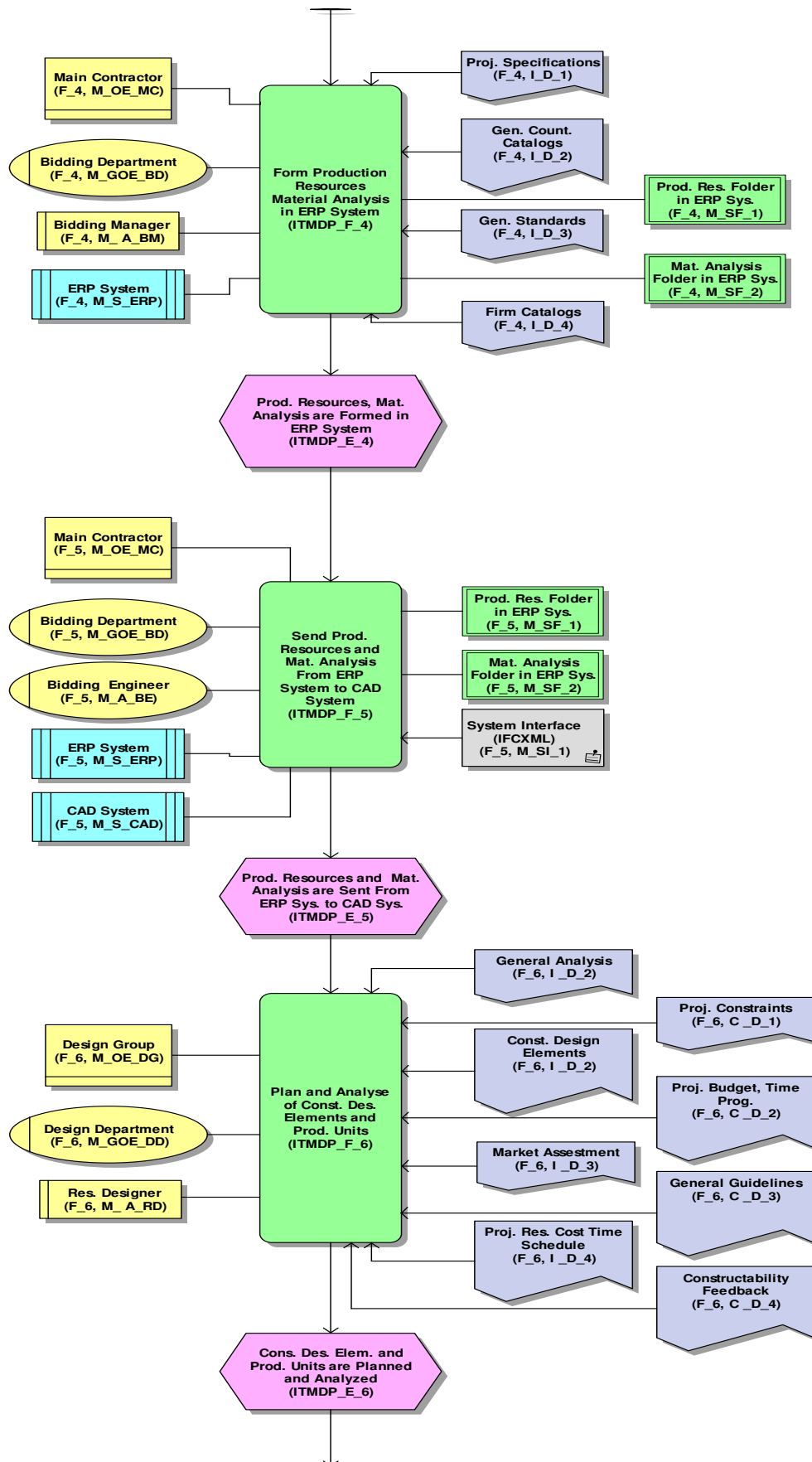
APPENDIX B3

- **IT Management Scheduling Process (ITMSP)**

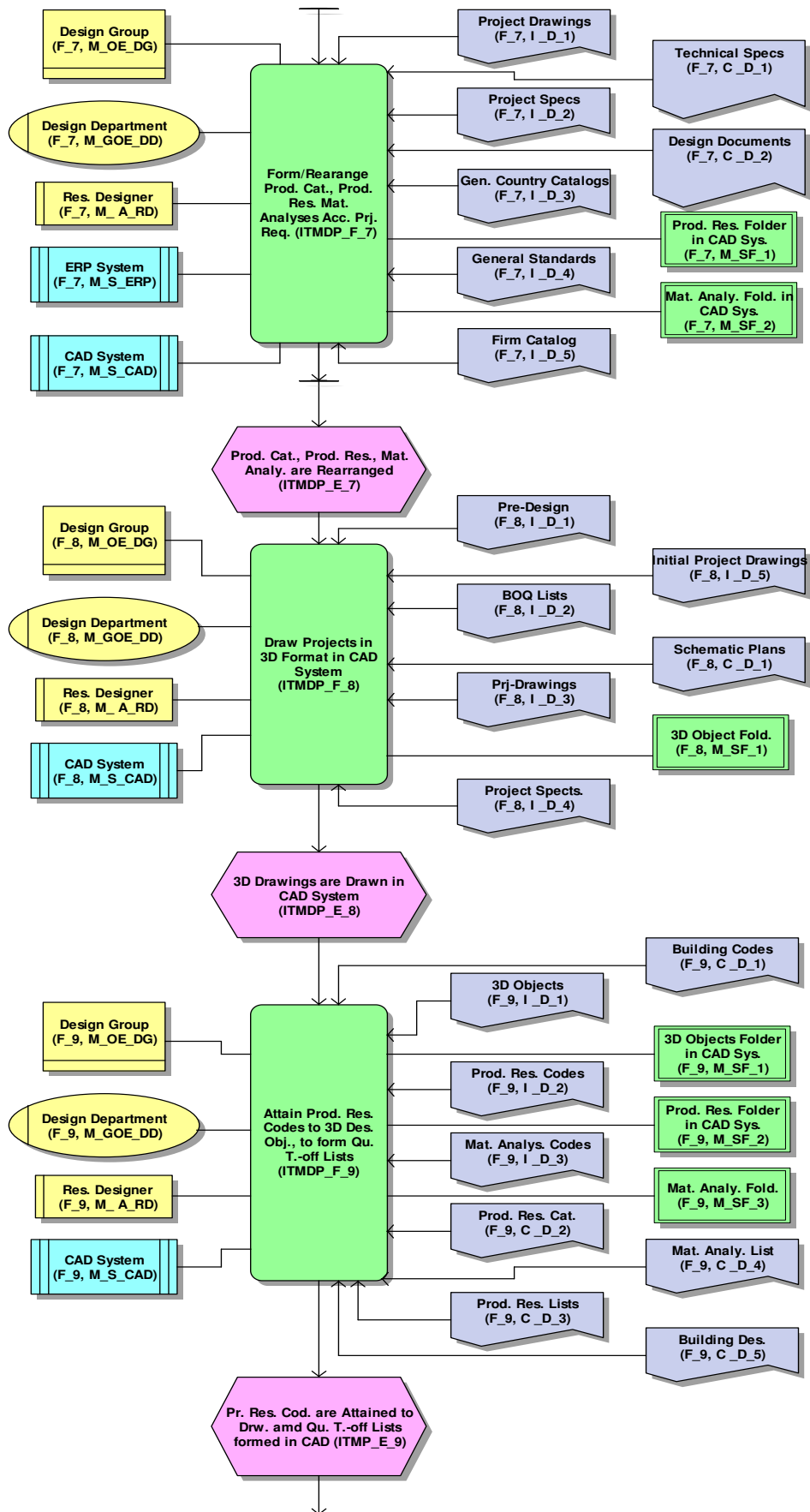
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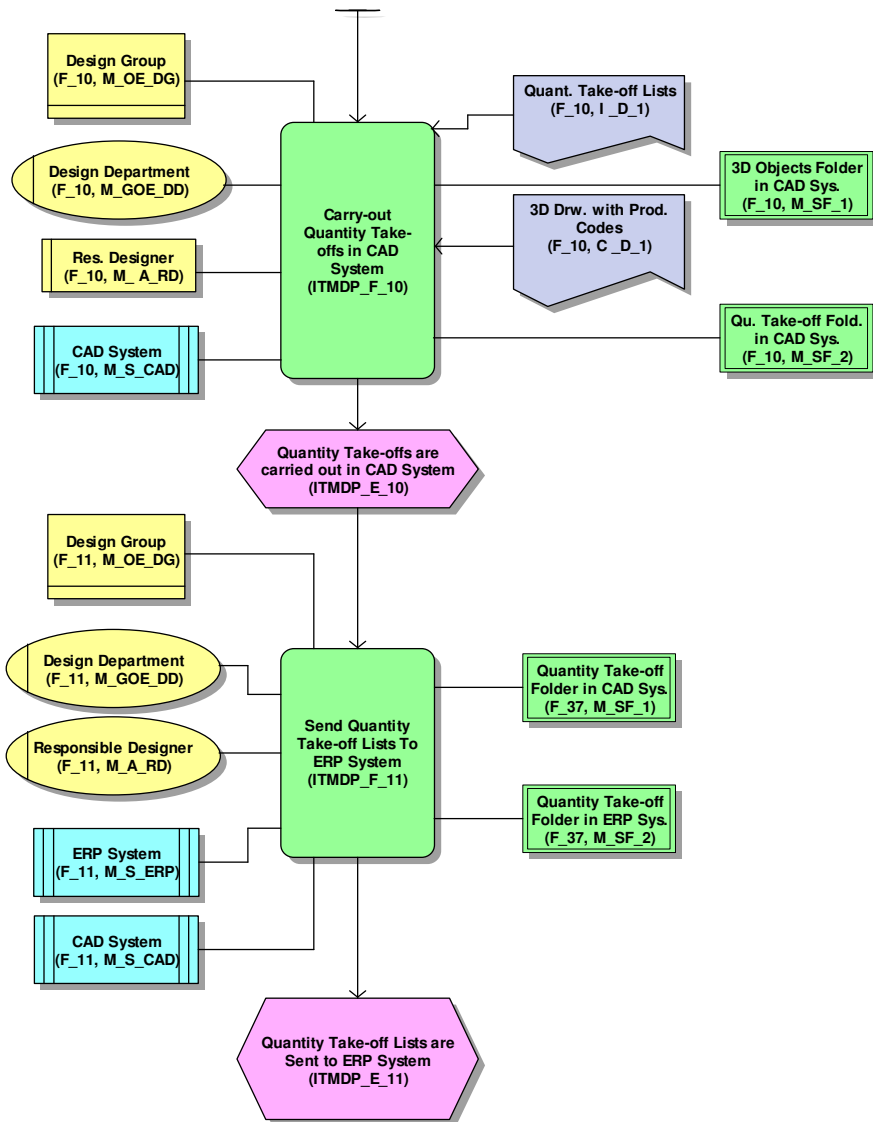
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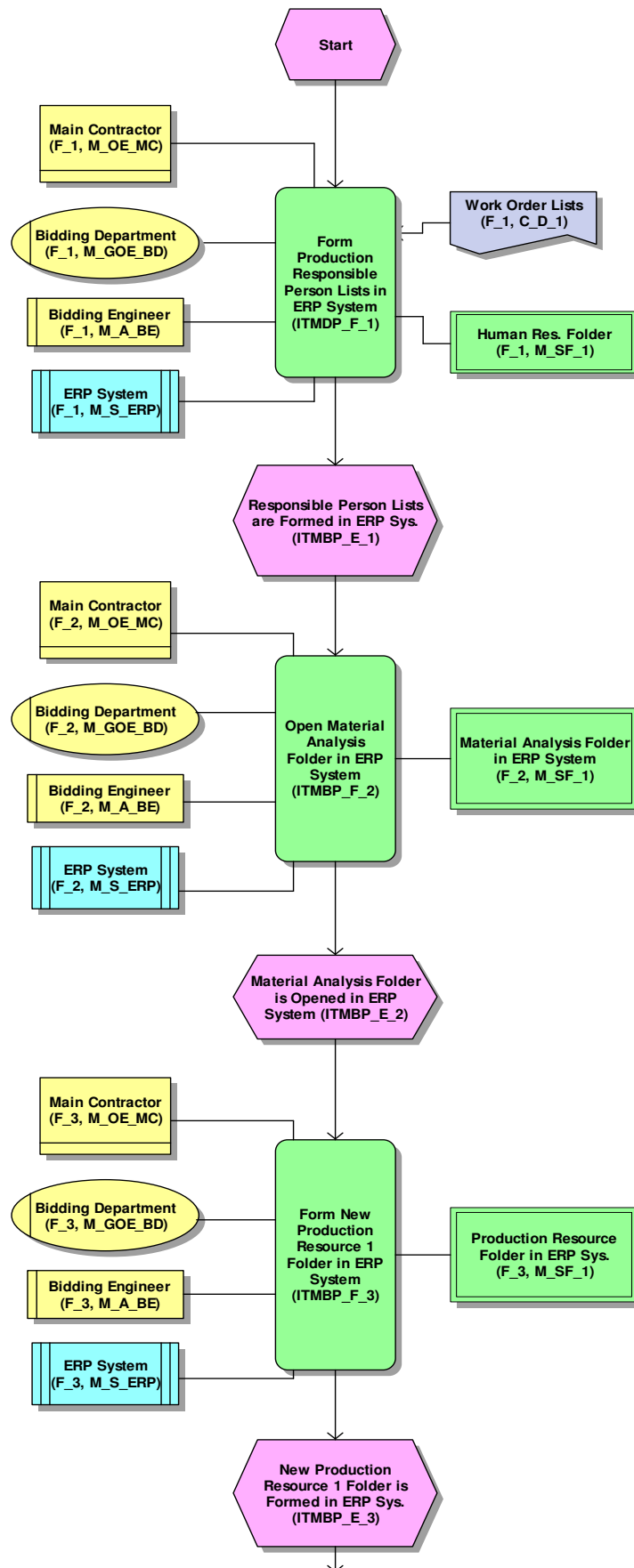
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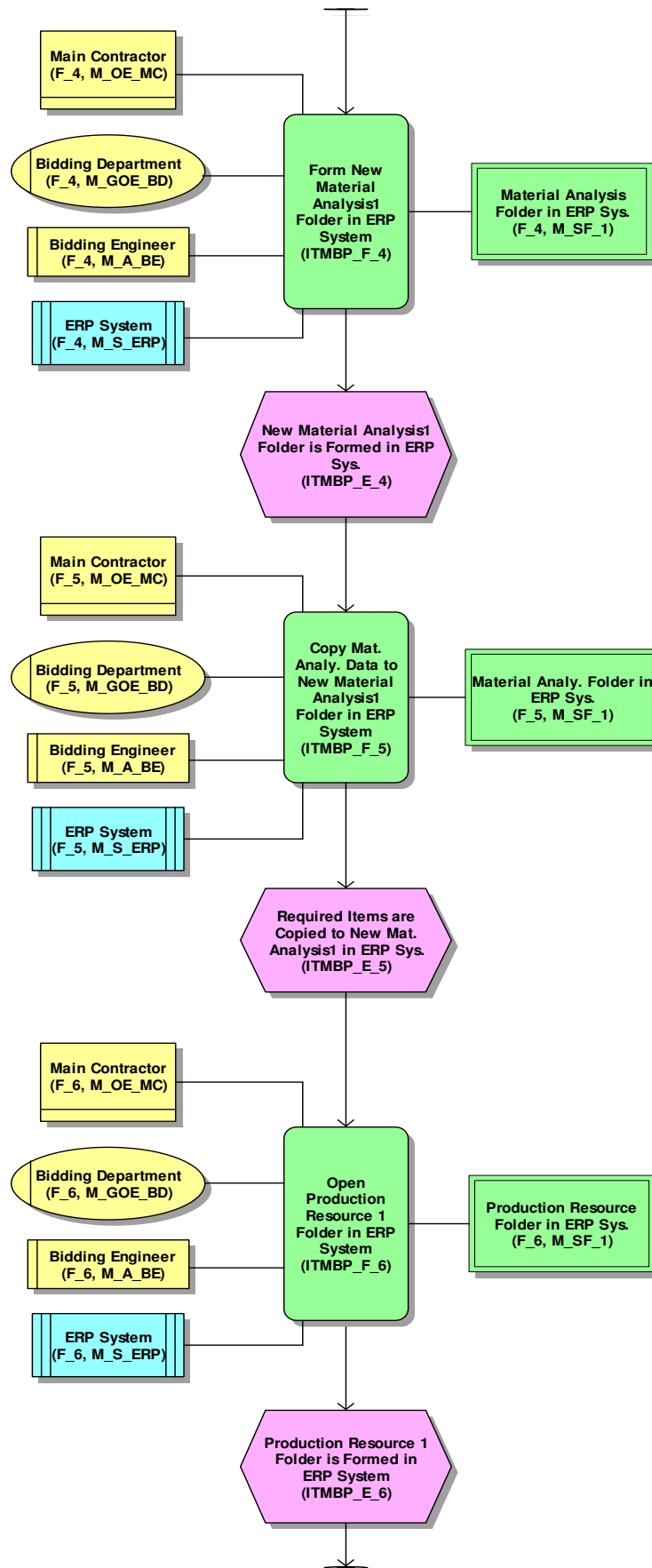
IT Management Design Process (ITMDP)



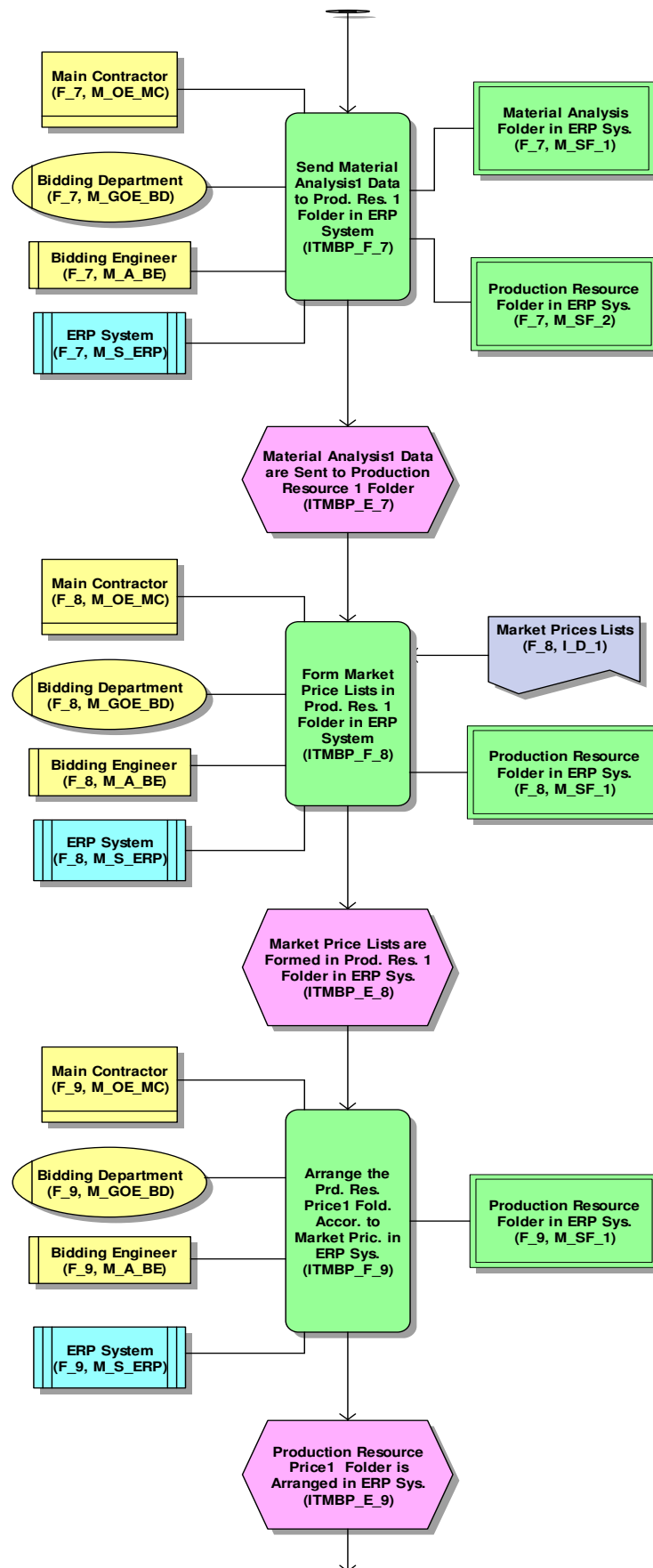
IT Management BOQ Process (ITMBP)



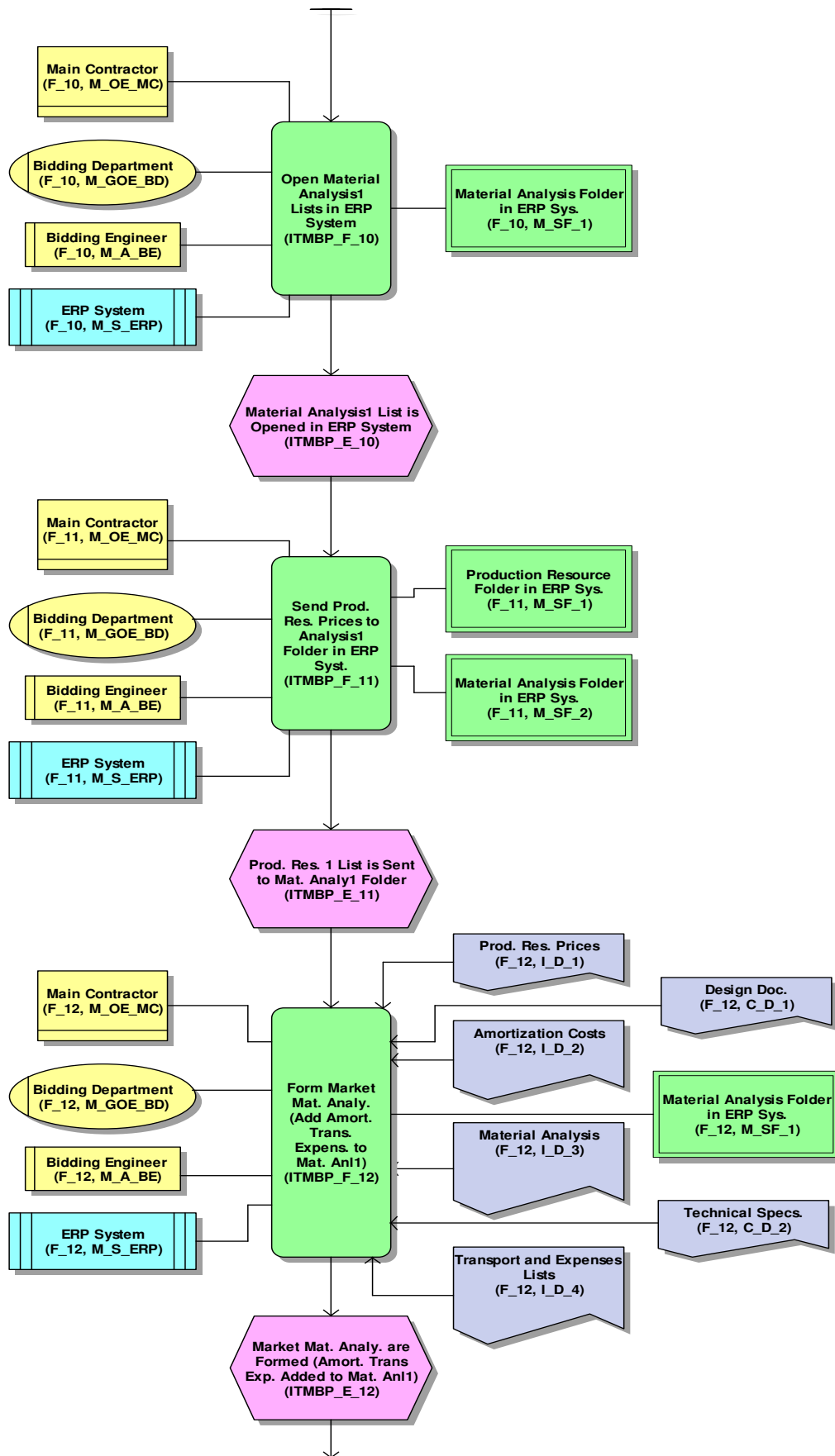
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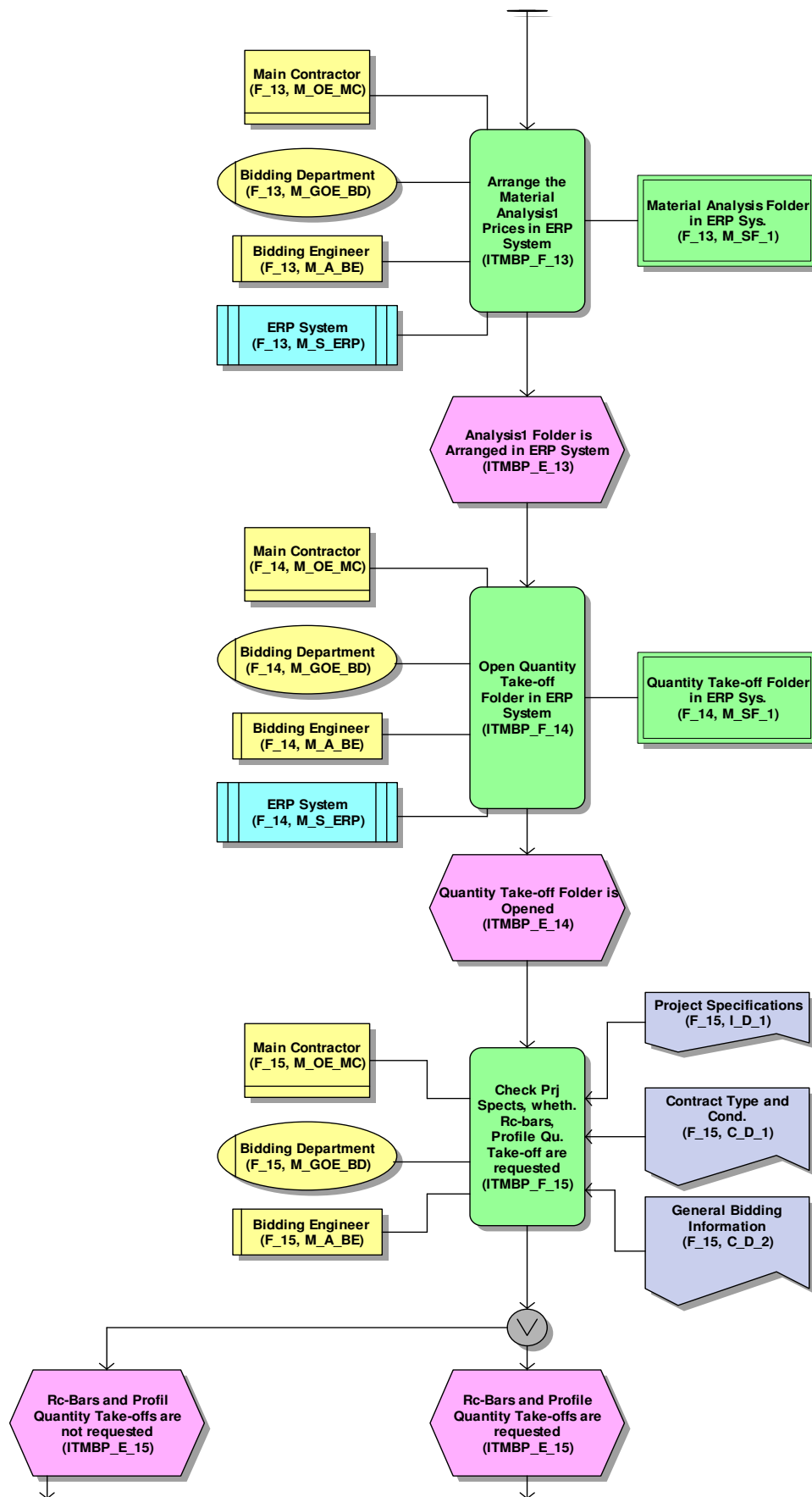
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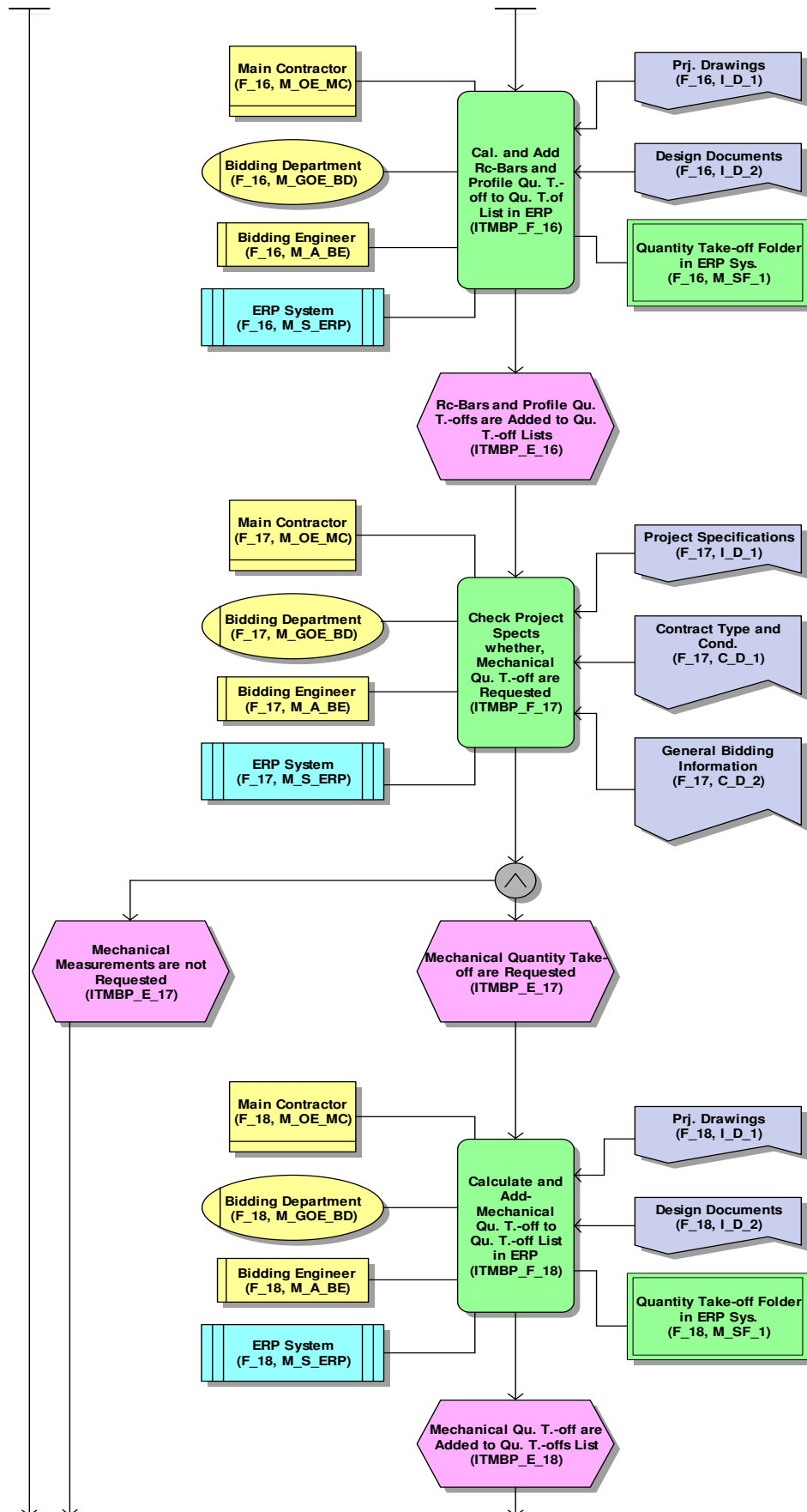
IT Management BOQ Process (ITMBP)



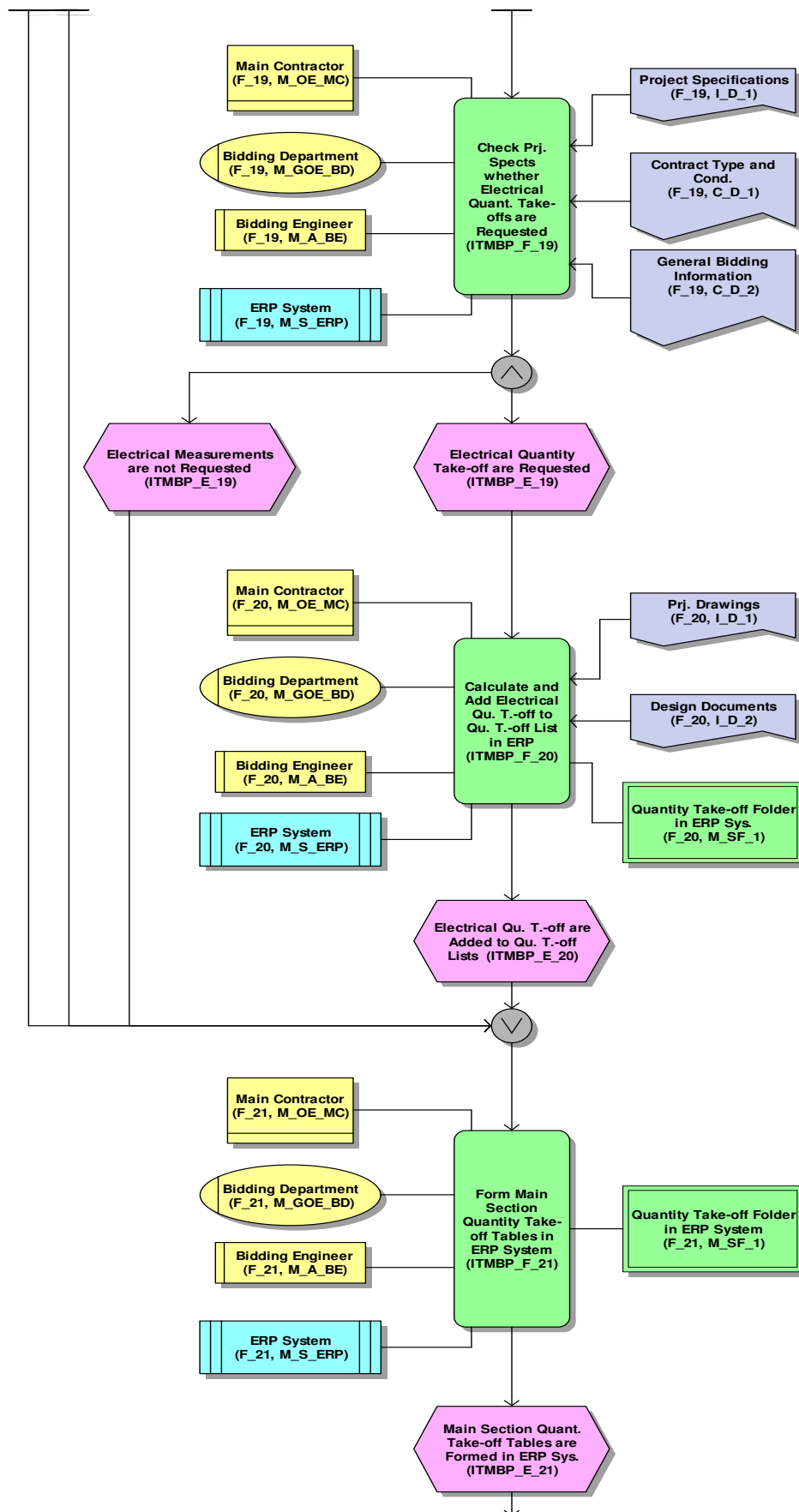
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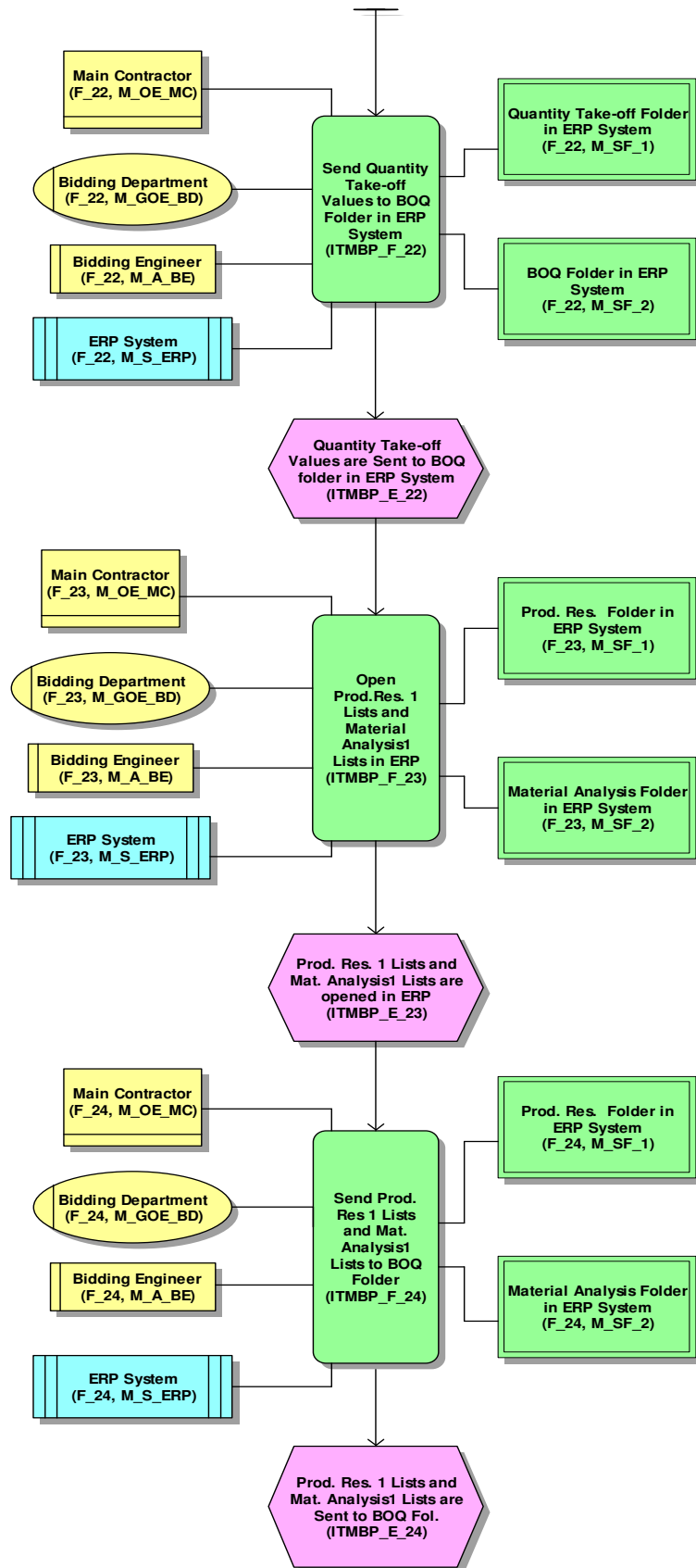
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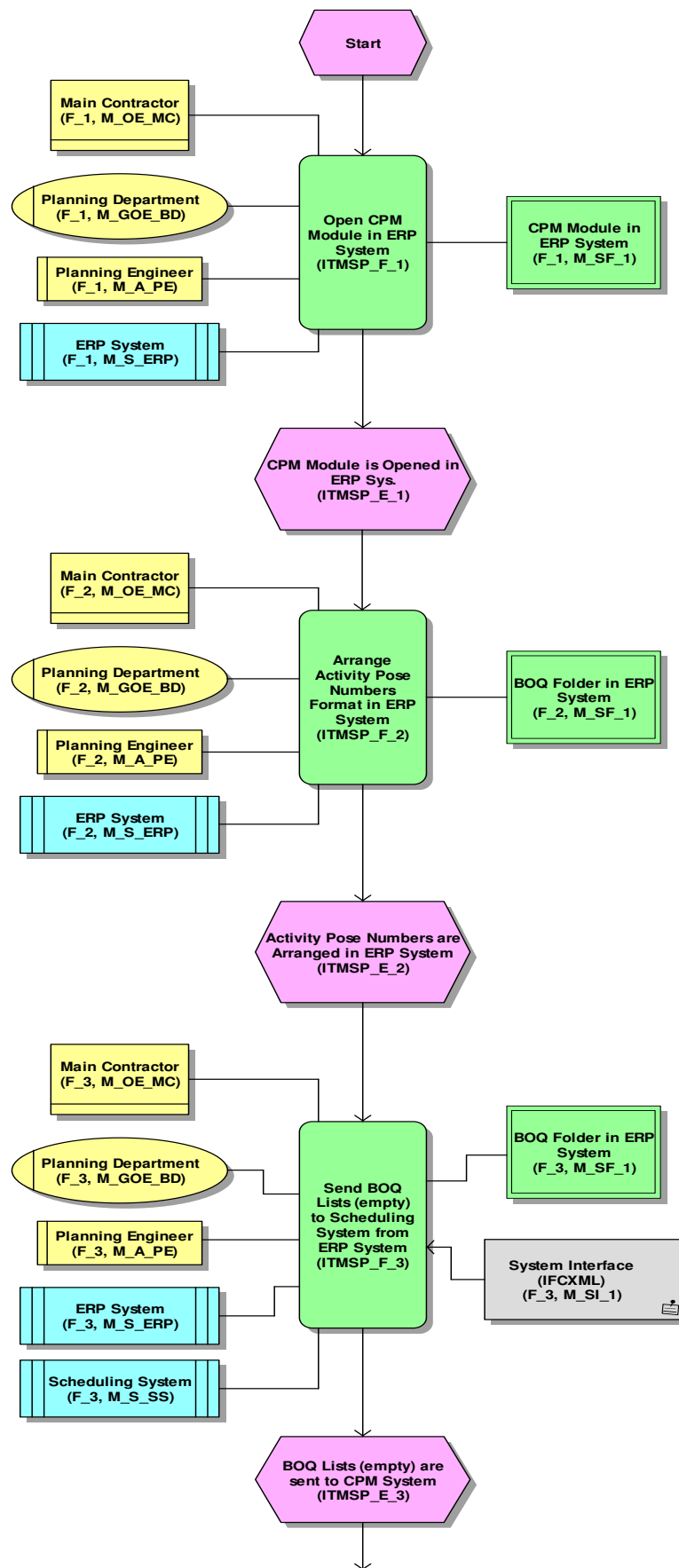
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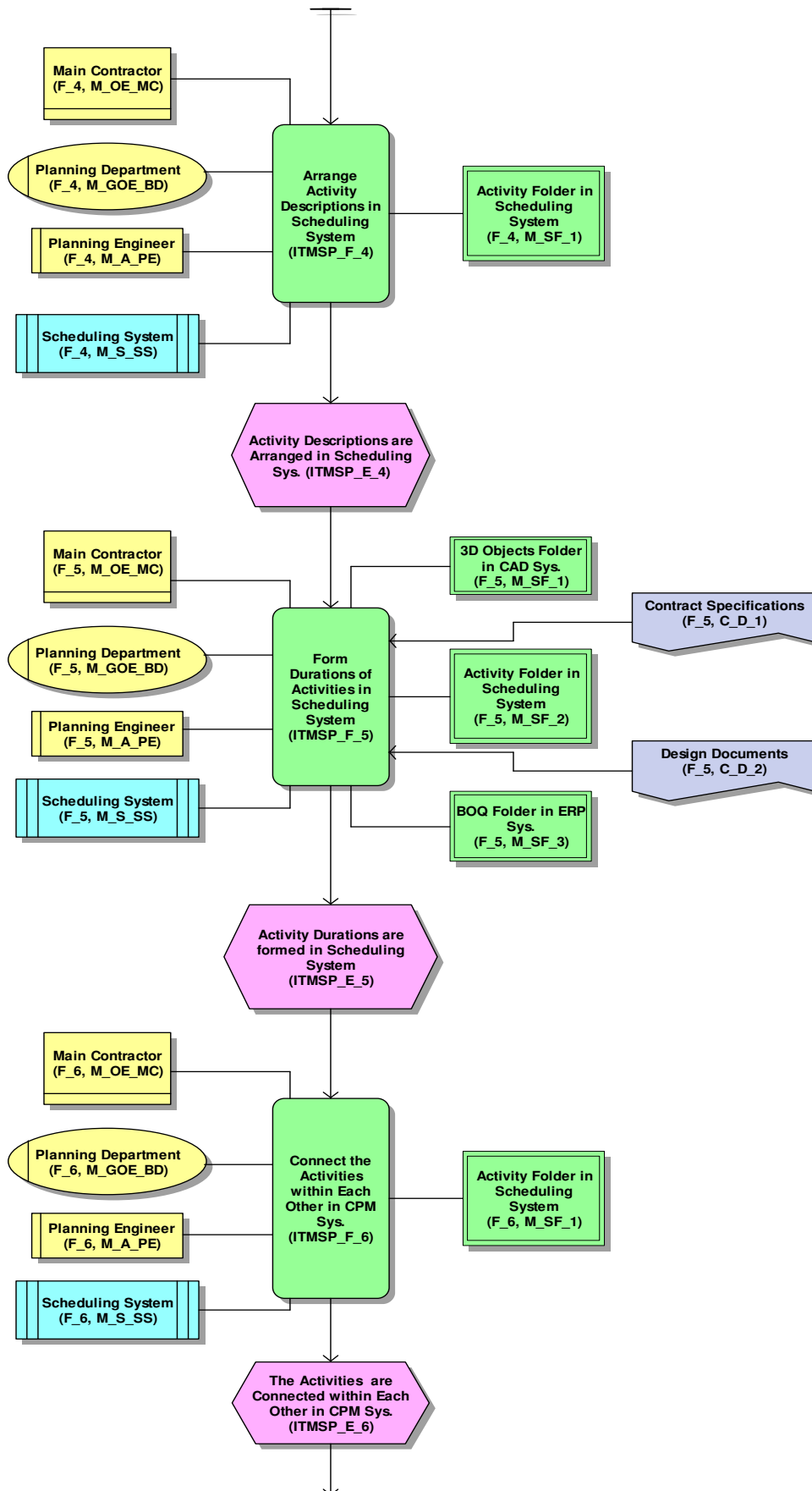
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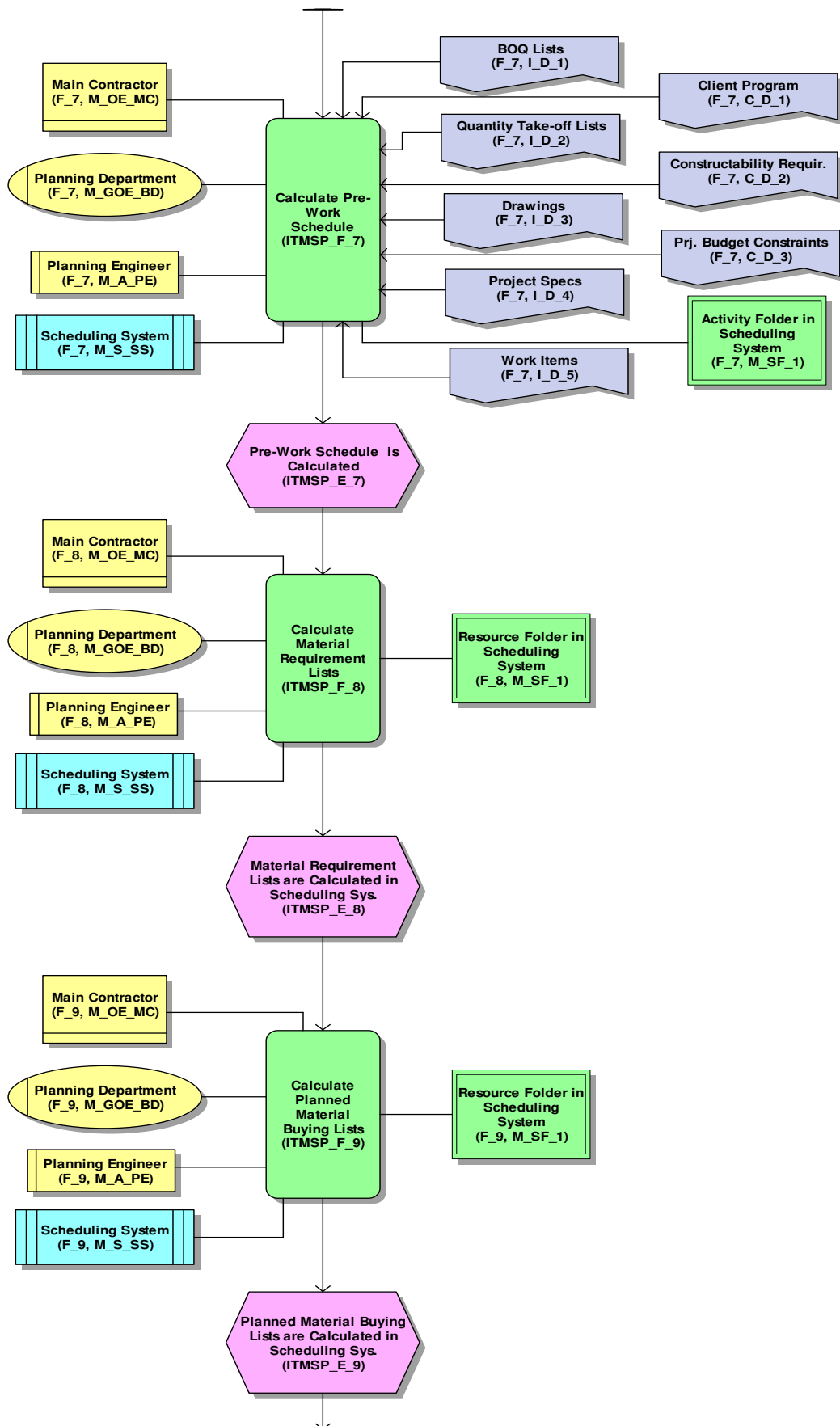
IT Management Scheduling Process (ITMSP)



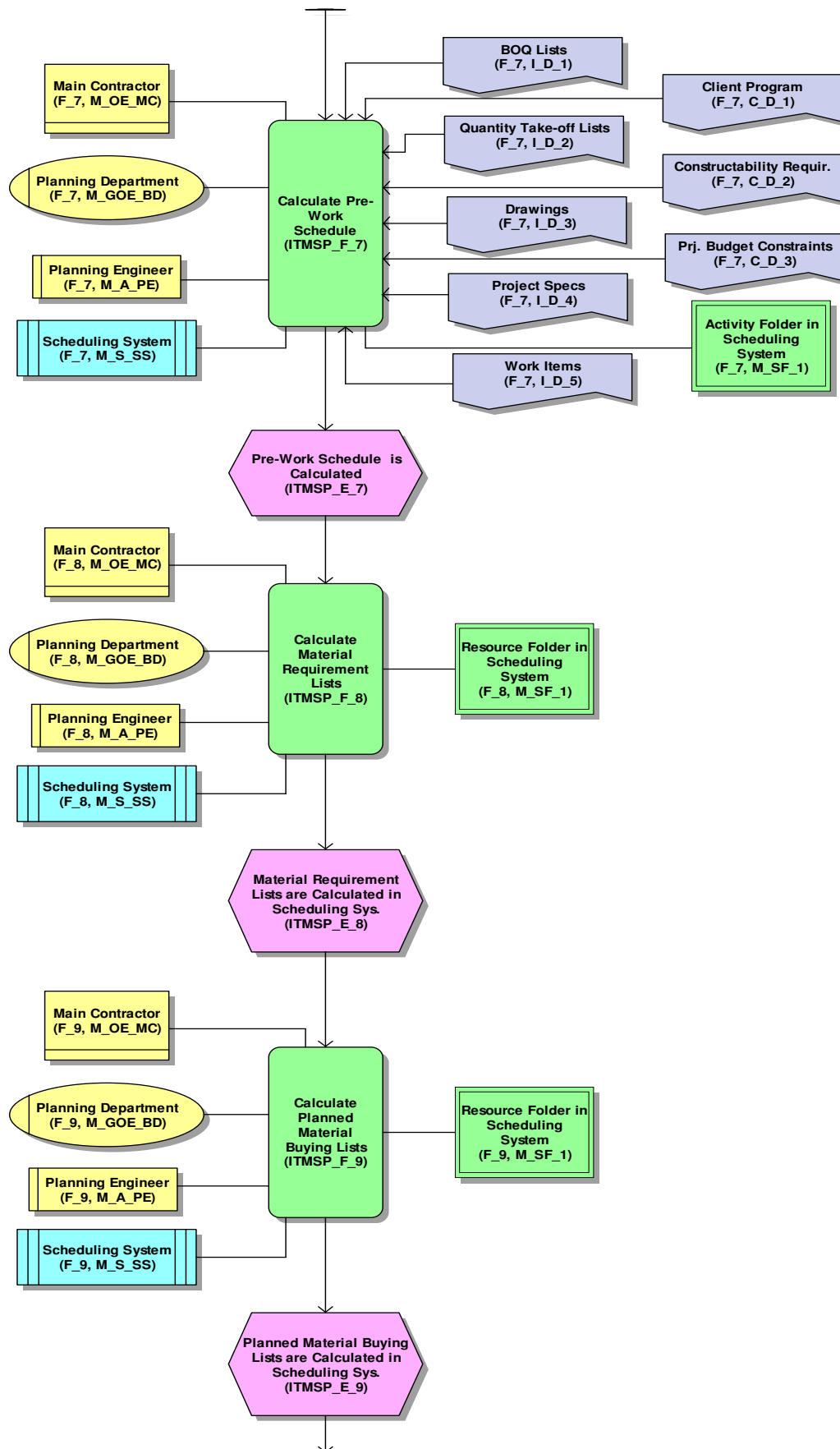
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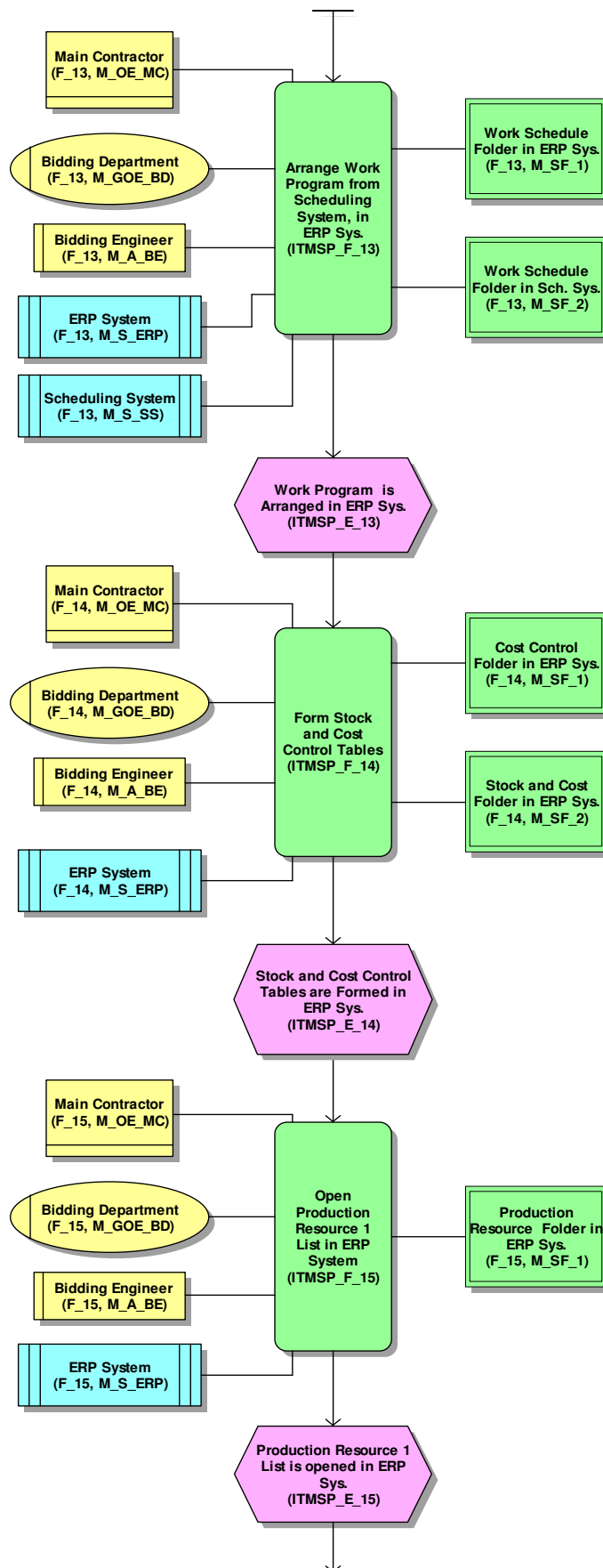
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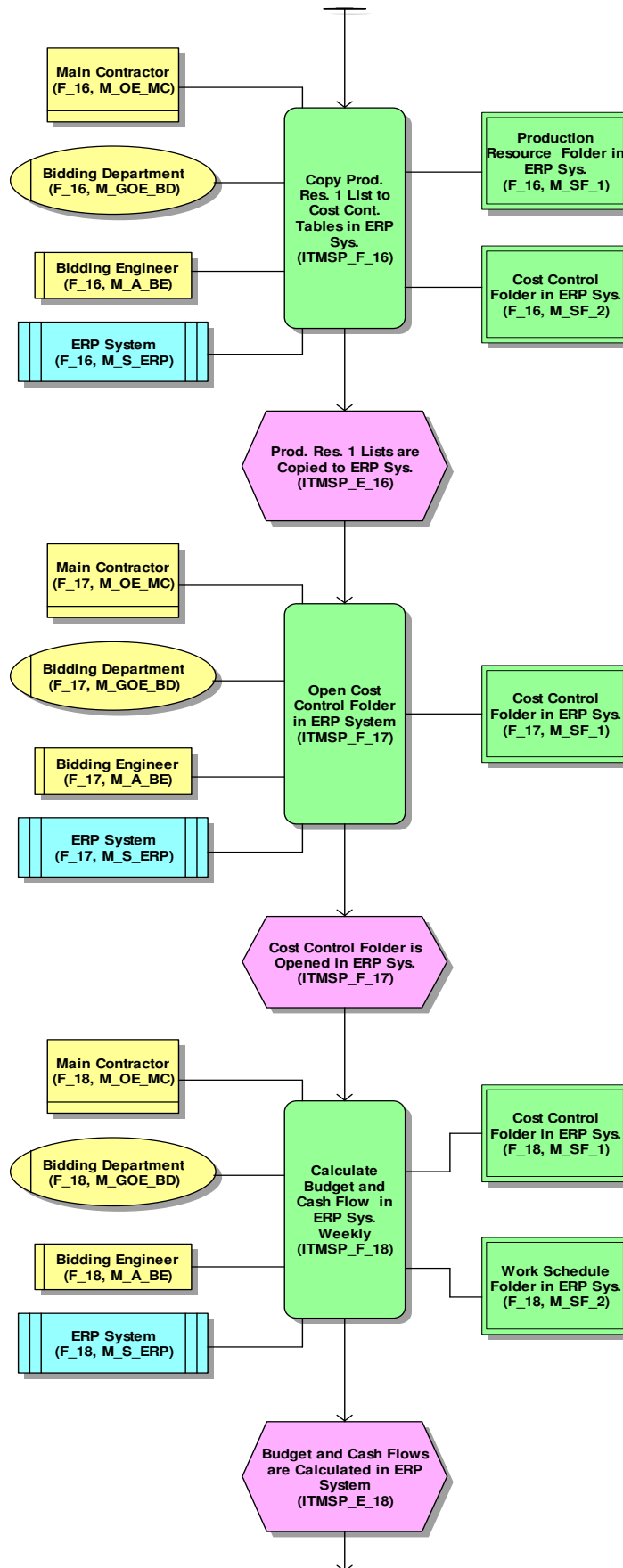
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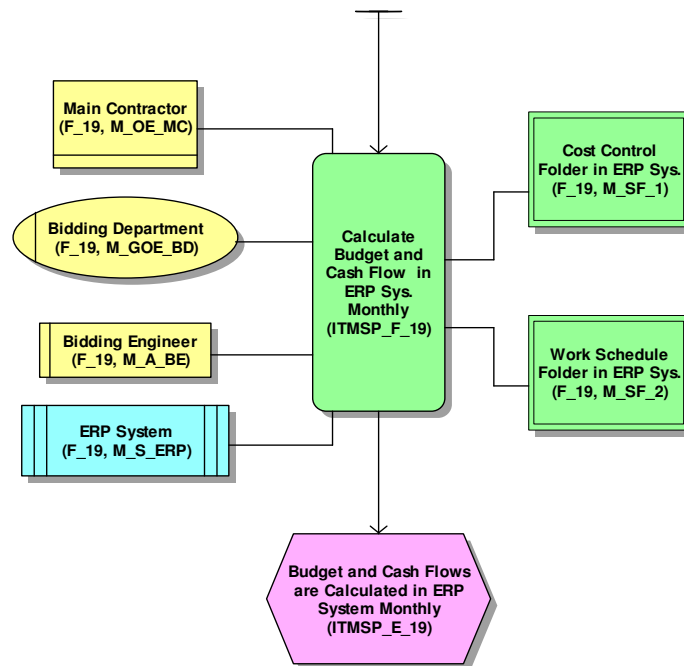
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IT Management Scheduling Process (ITMSP)



IT Management Scheduling Process (ITMSP)



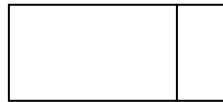
APPENDIX C: IFC Concepts

This appendix presents IFC Concepts for the IFC Views Implementation. The list below provides the references, name of the concept, their actual status and page numbers.

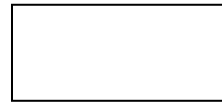
Reference	Name of the Concept	Status	Page Numbers
UMG-1	Identity	Draft	277-278
UMG-2	Group	Draft	279-280
UMG-3	Library	Draft	281-282
UMG-4	Document	Draft	283-285
UMG-5	Classification	Draft	286-289
UMG-6	Construction Type Classification	Draft	290-292
UMG-7	Properties	Draft	293-295
UMG-8	Material	Draft	296-299
UMG-9	Type Object	Draft	300-302
UMG-10	Cost	Draft	303-304
UMG-11	Cost Item and Cost Schedule	Draft	305-306
UMG-12	Building Element	Draft	307-310
UMG-13	Distribution Element	Draft	311-312
UMG-14	Furnishing Element	Draft	313-314
UMG-15	Transport Elements	Draft	315-316
UMG-16	Component Element	Draft	317-318
UMG-17	Reference Page-1	Draft	319
UMG-18	Reference Page-2	Draft	320
UMG-19	Reference Page-3	Draft	321
UMG-20	Reference Page-4	Draft	322
UMG-21	Reference Page-5	Draft	323
UMG-22	Building Element-Bounding Box	Draft	324-326
UMG-23	Building Element-Swept Area Solid	Draft	327-329
UMG-24	Building Element-Geometric Representation Item	Draft	330-331
UMG-25	Building Element-Representation Item	Draft	332-334
UMG-26	Building Element-Representation Map	Draft	335-338
UMG-27	Spatial Elements	Draft	339-342
UMG-28	Topological Representation Item	Draft	343-345

Guidelines

View Definition Diagrams: 'EXPRESS-G SYMBOLS'



Simple Data Type



Entity Type



Enumeration Type



Select Type



Defined Type



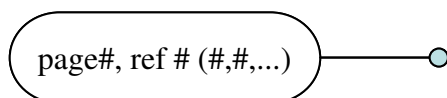
Super/Subtype Relationships



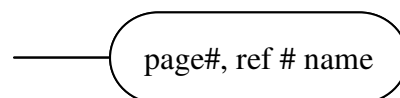
Attribute Relationship



Optional Attribute Relationship



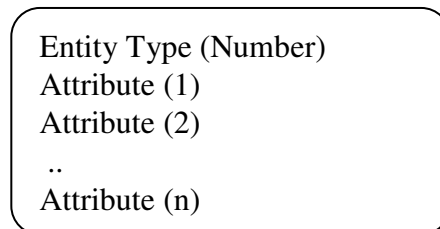
Reference to this page



Reference to another page

Guidelines

Instance Diagrams: 'NOTATIONS'



Instance Definition of Entity Type and its Attribute Values



Definition of Relationships between Instances



Definition of Aggregate Relationships between Instances

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Identity					
Reference, Page	UMG-1, 1	Version	V-1	Status	Draft
Relationships	IfcRoot			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):

```
graph TD
    ABS_IfcRoot["(ABS) IfcRoot"]
    IfcGloballyUniqueId["IfcGloballyUniqueId"]
    STRING["*STRING"]
    IfcChangeActionEnum["IfcChangeActionEnum"]
    IfcStateEnum["IfcStateEnum"]
    IfcTimeStamp["IfcTimeStamp"]
    IfcOwnerHistory["IfcOwnerHistory"]
    IfcPersonAndOrganization["IfcPersonAndOrganization"]
    IfcApplication["IfcApplication"]
    IfcLabel["IfcLabel"]
    IfcIdentifier["IfcIdentifier"]
    IfcOrganization["IfcOrganization"]
    IfcActorRole["IfcActorRole"]
    IfcPerson["IfcPerson"]

    ABS_IfcRoot -.->|Name| NameBox["17, 1, IfcLabel"]
    ABS_IfcRoot -.->|Description| DescriptionBox["17, 2, IfcText"]
    ABS_IfcRoot --> IfcGloballyUniqueId
    IfcGloballyUniqueId --> STRING
    ABS_IfcRoot -->|Owner History| IfcOwnerHistory
    IfcChangeActionEnum -->|ChangeAction| IfcOwnerHistory
    IfcStateEnum -->|State| IfcOwnerHistory
    IfcTimeStamp -->|CreationDate| IfcOwnerHistory
    IfcTimeStamp -->|LastModifiedDate| IfcOwnerHistory
    IfcOwnerHistory -->|Owning Application| IfcApplication
    IfcOwnerHistory -->|Last Modifying Application| IfcApplication
    IfcOwnerHistory -->|Last Modifying User| IfcPersonAndOrganization
    IfcOwnerHistory -->|Owning User| IfcPersonAndOrganization
    IfcApplication -->|*ApplicationFullName| IfcLabel
    IfcApplication -->|*Version| IfcLabel
    IfcApplication -->|*ApplicationIdentifier| IfcIdentifier
    IfcApplication -->|Application Developer| IfcOrganization
    IfcPersonAndOrganization -->|The Organization (INV Engages [0:?])| IfcOrganization
    IfcPersonAndOrganization -->|The Person (INV EngagedIn S[0:?])| IfcActorRole
    IfcActorRole -->|Roles L[1:?]| IfcPerson
```

Definition.

This concept is formalized in order to show how objects are identified and how ownership of objects is assigned according to IFC 2x3.

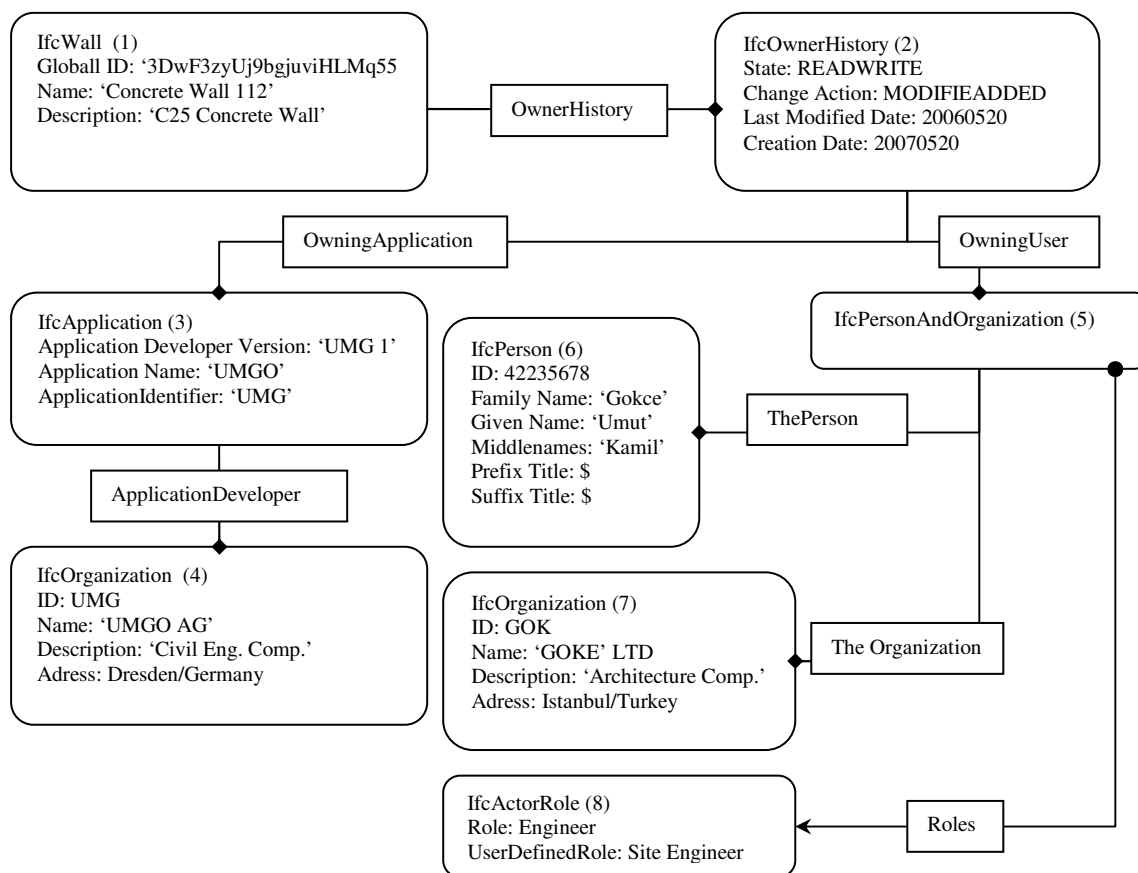
Entity Type Definition (Definition from IAI):

The *IfcRoot* is the most abstract and root class for all IFC entity definitions that roots in the kernel or in subsequent layers of the IFC object model. It is therefore the common supertype of all IFC entities, beside those defined in an IFC resource schema. All entities that are subtypes of *IfcRoot* can be used independently, whereas resource schema entities, that are not subtypes of *IfcRoot*, are not supposed to be independent entities. The *IfcRoot* assigns the globally unique ID, and the ownership and history information to the entity. In addition it may provide for a name and a description about the concepts.

Entity Type Detailed Definition:

To obtain instantiated IFC model objects, they are uniquely identified by the *GlobalId* attribute which is maintained by every instance of subtypes of *IfcRoot*. For the additional naming and descriptions, *Name* and *Description* attributes are also structured in this context. The *IfcOwnerHistory* entity provides recent changes providing by the state of the instance, the name and organization of the user, the creation and last modification time, the date and time of the instance etc.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Identity					
Reference, Page	UMG-1, 1/1	Version	V-1	Status	Draft
Relationships	IfcRoot			History	Ifc Release 1.0
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:**Instantiation Definition:**

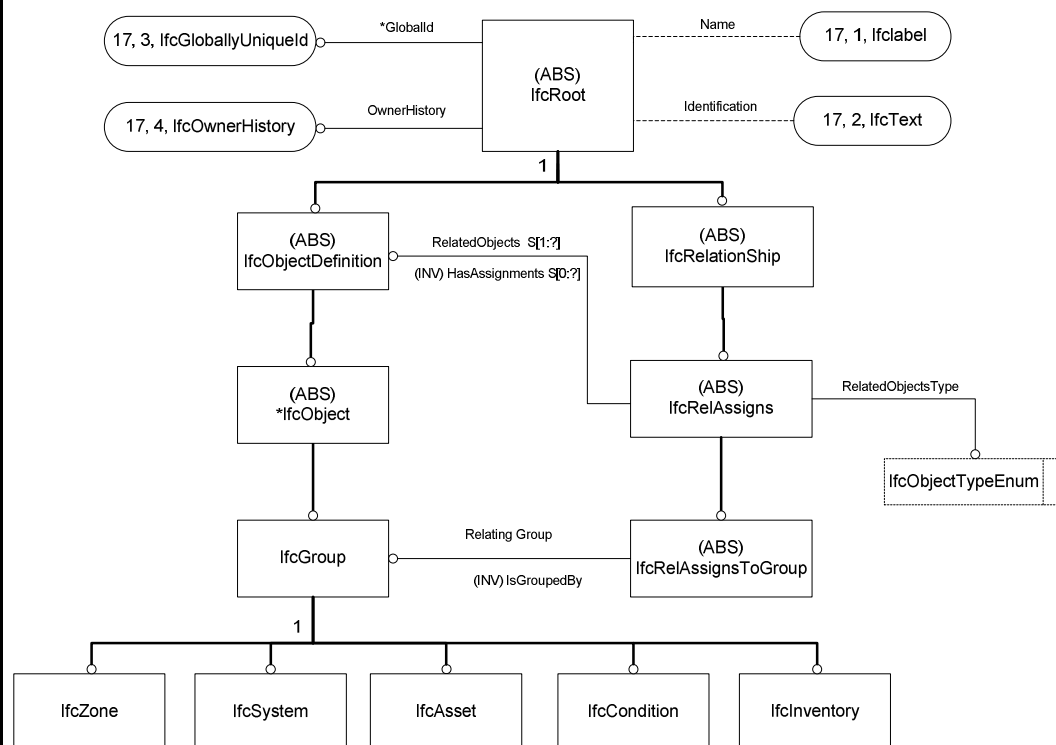
In this instantiation diagram the identification, naming and owner history information is structured for an instance of *IfcWall*.

Instantiation Details:

In this instantiation, the instance of the class *IfcWall* (1) is generated. It has a globally unique ID, name and description. In order to show changes, all building objects have a relationship to an owner history. In this case, the wall (2) has state, change action, last modified date and creation date. The change action provides the application (3), person (6) and organization (7) which have the ownership of the wall information. The role is formalized within *IfcActorRole* (8). The owning application has an organization (4) to show its application developer.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)
Group

Reference, Page	<i>UMG-2, 2</i>	Version	<i>V-1</i>	Status	<i>Draft</i>
Relationships	<i>IfcGroup</i>			History	<i>Ifc Release 1.0</i>
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

Usage in View Definition Diagram (EXPRESS G)

Definition:

This concept is formalized to define how objects are grouped together based on the IFC 2x3 specification.

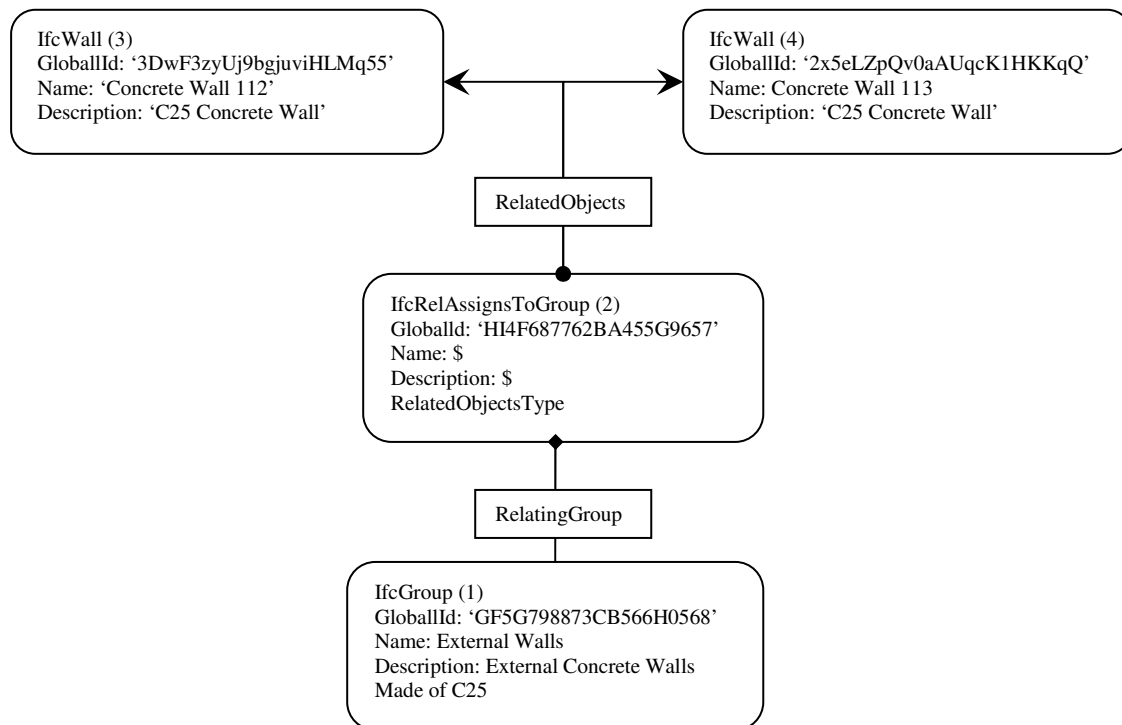
Entity Type Definition (Definition from IAI):

The *IfcGroup* is an generalization of any arbitrary group. A group is a logical collection of objects. It does not have its own position, nor can it hold its own shape representation. Therefore a group is an aggregation under some non-geometrical / topological grouping aspects.

Entity Type Detailed Definition:

In order to collect members of a system together, collecting objects according to different disciplines for different purposes such as procurement, establishment of hierarchical structures, etc., the grouping mechanism can be used as the instances of *IfcGroup* class. Group members can be attained using *IfcRelAssignsToGroup* instances in this context. A single object may be included in several groups, also a group may be part of an another group.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Group					
Reference, Page	UMG-2, 2/1	Version	V-1	Status	Draft
Relationships	IfcGroup			History	Ifc Release 1.0
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:**Instantiation Definition:**

This instantiation diagram is formalized in order to show how two concrete wall instances are assigned the group for external concrete walls.

Instantiation Details:

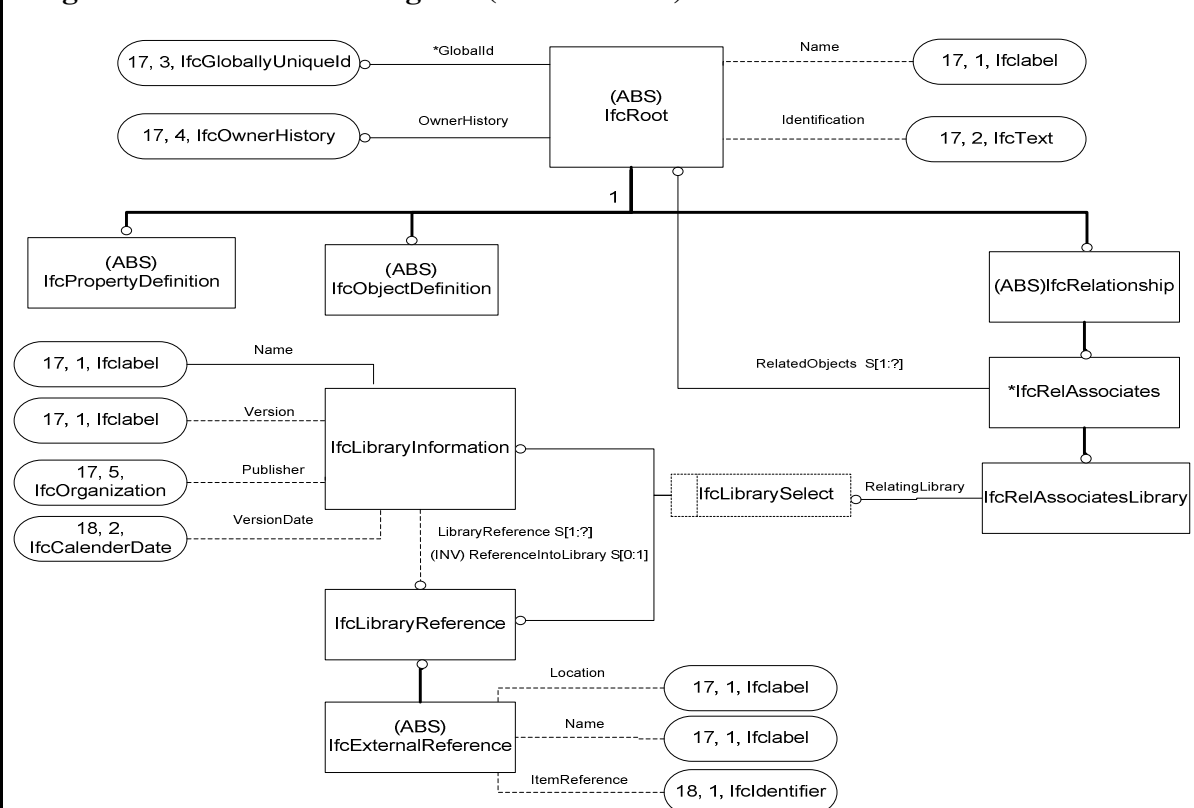
In this instantiation diagram two instances of *IfcWall* are assigned through a relationship (related objects), an instance of *IfcRelAssignsToGroup (2)*, to *IfcGroup (1)* instance. This *IfcGroup* instance (External Concrete Walls) is the collection of a type of a wall by which purpose is defined by the *IfcGroup*. Description as 'External Concrete Wall' identifies the attribute and used to attain this attribute to walls by using grouping mechanism.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Library

Reference, Page	UMG-3, 3	Version	V-1	Status	Draft
Relationships	IfcLibraryReference			History	Ifc Release 2.0 Restructured in 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Department of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show library information and how they are attached to objects according to the IFC 2x3 specification.

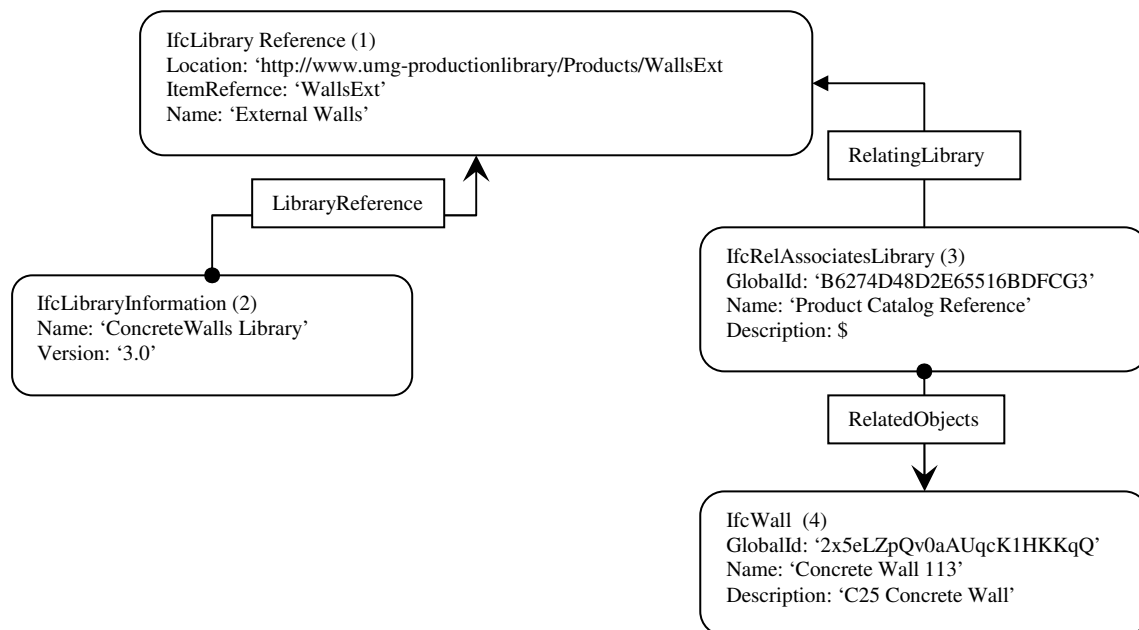
Entity Type Definition (Definition from IAI):

An *IfcLibraryReference* is a reference into a library of information by location (as an URL). It also provides an optional inherited *ItemReference* key to allow more specific references to library sections or tables, and the inherited *Name* attribute allows for a human interpretable identification of the library item. Also, general information on the external library can be given through *IfcLibraryInformation*, accessed by *ReferenceIntoLibrary*.

Entity Type Detailed Definition:

Library references can be connected with all instances of *IfcObject* or *IfcPropertyDefinitions* via *IfcRelAssociatesLibrary* instances. It can be done as a reference by using external references with *IfcLibraryReference* instances or directly to library information through instances of *IfcLibraryInformation*.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Library					
Reference, Page	UMG-3, 3/1	Version	V-1	Status	Draft
Relationships	IfcLibraryReference			History	Ifc Release 2.0 Restructured in 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Department of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:**Instantiation Definition:**

The instantiation example describes how a library reference with accompanying library information is associated with a discrete accessory.

Instantiation Details:

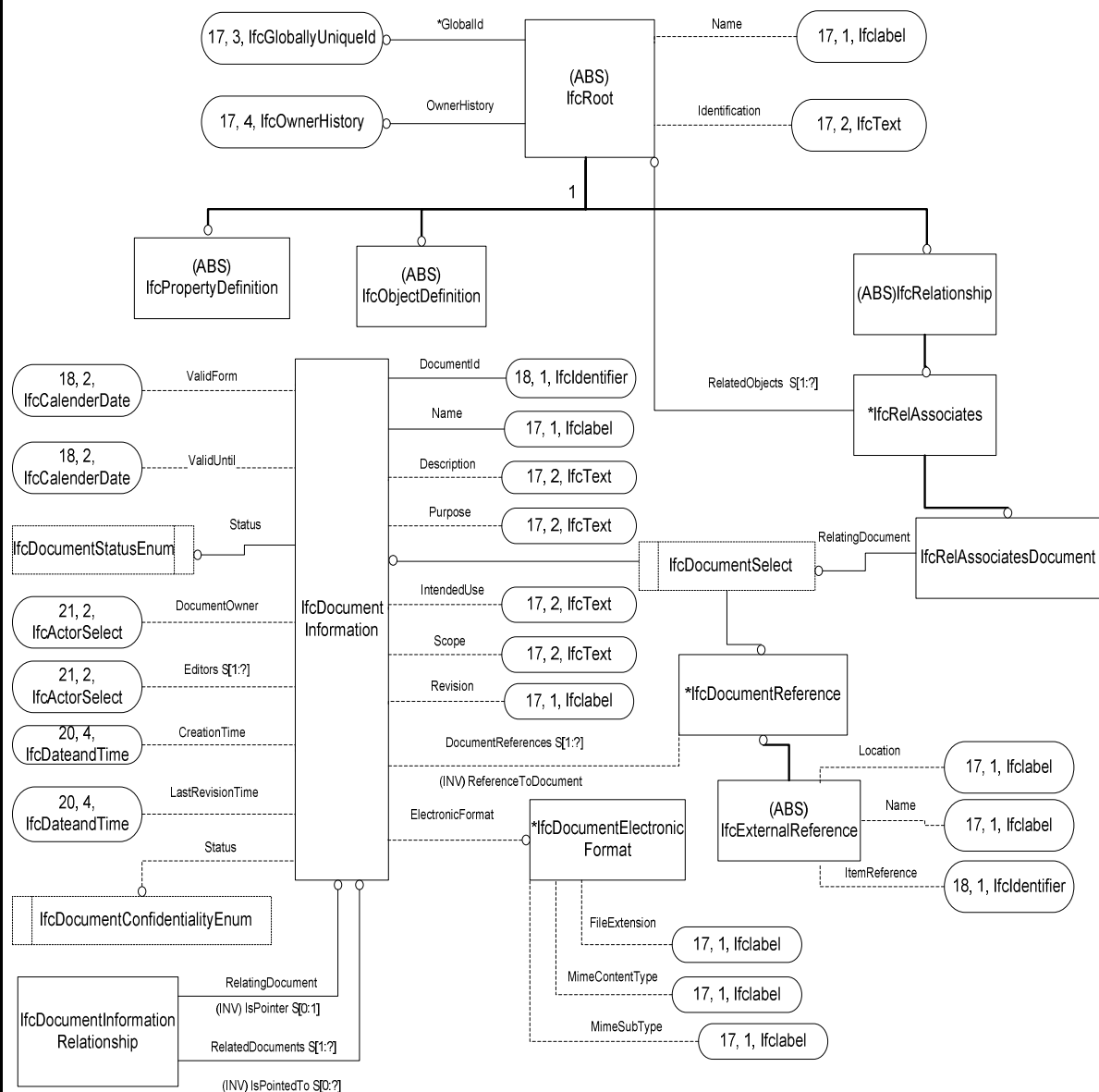
A concrete wall named 'Concrete Wall 113' (4) is connected with a library reference through a relationship (related objects) of instance of *IfcRelAssociatesLibrary*. The library reference consist of name, location, item reference information. Also additional information via *IfcLibraryInformation* is given through library reference. This library information indicates that the library reference is for a library named Concrete Walls Library.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Document

Reference, Page	UMG-4, 4	Version	V-1	Status	Draft
Relationships	IfcDocumentInformation			History	Ifc Release 2.0 Modified in IFC 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G)



Definition:

This concept is formalized to show document information and how they are attached to objects according to the IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Document					
Reference, Page	UMG-4, 4/1	Version	V-1	Status	Draft
Relationships	IfcDocumentInformation			History	Ifc Release 2.0 Modified in IFC 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI):</p> <p>An <i>IfcDocumentReference</i> is a reference to the location of a document. The reference is given by a system interpretable <i>Location</i> attribute (e.g., an URL string) or by a human readable location, where the document can be found, and an optional inherited internal reference <i>ItemReference</i>, which refers to a system interpretable position within the document. The optional inherited <i>Name</i> attribute is meant to have meaning for human readers. Optional document metadata can also be captured through reference to <i>IfcDocumentInformation</i>.</p> <p>Provides a lightweight capability that enables a document to be identified solely by reference to a name by which it is commonly known. The reference can also be used to point to document information for more detail as required. An <i>IfcDocumentInformation</i> captures "metadata" of an external document. The actual content of the document is not defined in IFC; instead, it can be found following the reference given to <i>IfcDocumentReference</i>.</p> <p>Entity Type Detailed Definition</p> <p>Library references can be connected with all instances of <i>IfcObject</i> or <i>IfcPropertyDefinition</i> instances through <i>IfcRelAssociatesDocument</i> instances. It can be done as using external references with instances of <i>IfcDocumentReference</i> or directly connecting to document information through instances of <i>IfcDocumentInformation</i>. As it seen from the definition <i>IfcDocumentInformation</i> contains numbers of attributes such as document ID, name, description etc. Also it may has a relation to other document information through instances of <i>IfcDocumentInformationRelationship</i> and to electronic format of the document through <i>IfcDocumentElectronicFormat</i>.</p>					

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Document					
Reference, Page	UMG-4, 4/2	Version	V-1	Status	Draft
Relationships	IfcDocumentInformation			History	Ifc Release 2.0 Modified in IFC 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:

```
graph TD
    subgraph "IfcDocumentReference (1)"
        D1["Location: 'Material Specifications WallSpec'  
ItemReference: 'WallSpec'  
Name 'WallSpec Specifications'"]
    end
    subgraph "IfcDocumentInformation (2)"
        D2["DocumentId: 'WallSpec'  
Name: 'WallSpec Specifications'  
Description: 'Wall Material Analysis Specifications'  
Purpose: $  
IntendedUse 'Production'  
Scope: $  
Revision: '3.0'  
Confidentiality: $  
Status: 'REVISION'"]
    end
    subgraph "IfcRelAssociatesDocument (3)"
        D3["GlobalId: 'B6274D48D2E655116BDFCG3'  
Name: 'Material Specifications Reference'  
Description: $"]
    end
    subgraph "IfcWall (4)"
        D4["GlobalId: '2x5eLZpQv0aAUqcK1HKKqQ'  
Name: 'Concrete Wall 113'  
Description: 'C25 Concrete Wall'"]
    end

    D2 -- DocumentReferences --> D1
    D3 -- RelatingDocument --> D1
    D3 -- RelatedObjects --> D4
```

The diagram illustrates the instantiation of a document reference. It shows four main entities: **IfcDocumentReference (1)**, **IfcDocumentInformation (2)**, **IfcRelAssociatesDocument (3)**, and **IfcWall (4)**. **IfcDocumentReference (1)** is linked to **IfcDocumentInformation (2)** via a **DocumentReferences** relationship and to **IfcRelAssociatesDocument (3)** via a **RelatingDocument** relationship. **IfcRelAssociatesDocument (3)** is further linked to **IfcWall (4)** via a **RelatedObjects** relationship. Each entity box contains its specific attributes, such as location, name, global ID, and description.

Instantiation Definition:
The instantiation example describes how a document reference with accompanying document information is associated with a discrete accessory.

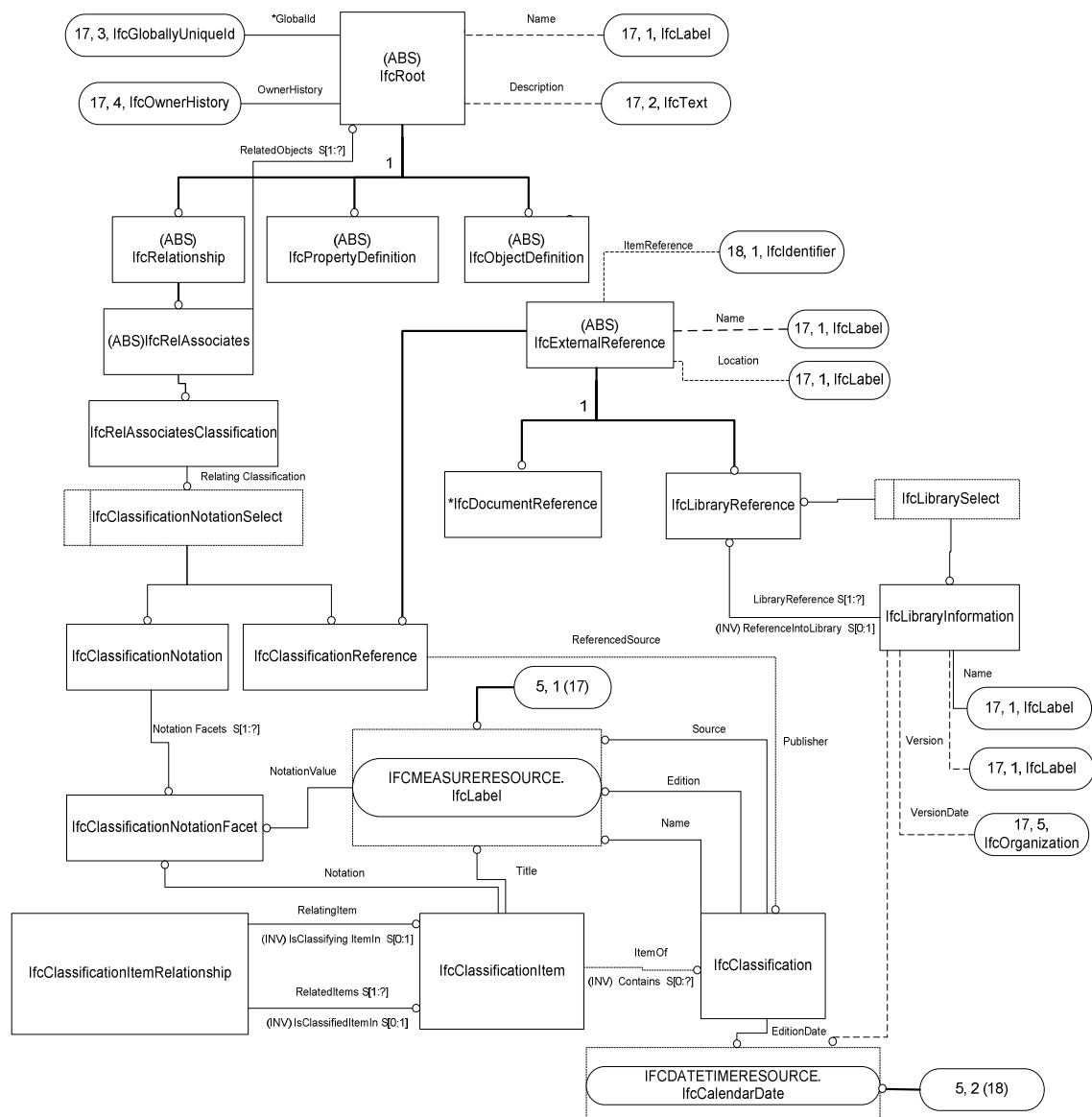
Instantiation Details:
A concrete wall named ‘Concrete Wall 113’ (4) is connected with a document reference through a relationship (related objects) of instance of *IfcRelAssociatesDocument*. The document reference consist of name, location, item reference information. Also additional information via *IfcDocumentInformation* instance is given through document reference. This document information indicates that the document reference is for a document named WallSpec Specifications.

IFC Release Specific AEC/FM View Description (IFC 2x3 Edition)

Classification

Reference, Page	<i>UMG-5, 5</i>	Version	<i>V-1</i>	Status	<i>Draft</i>
Relationships	<i>IfcClassification</i>			History	<i>Ifc Release 1.5 Modified in IFC 2x</i>
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

Usage View Definition Diagram (EXPRESS G):

**Definition:**

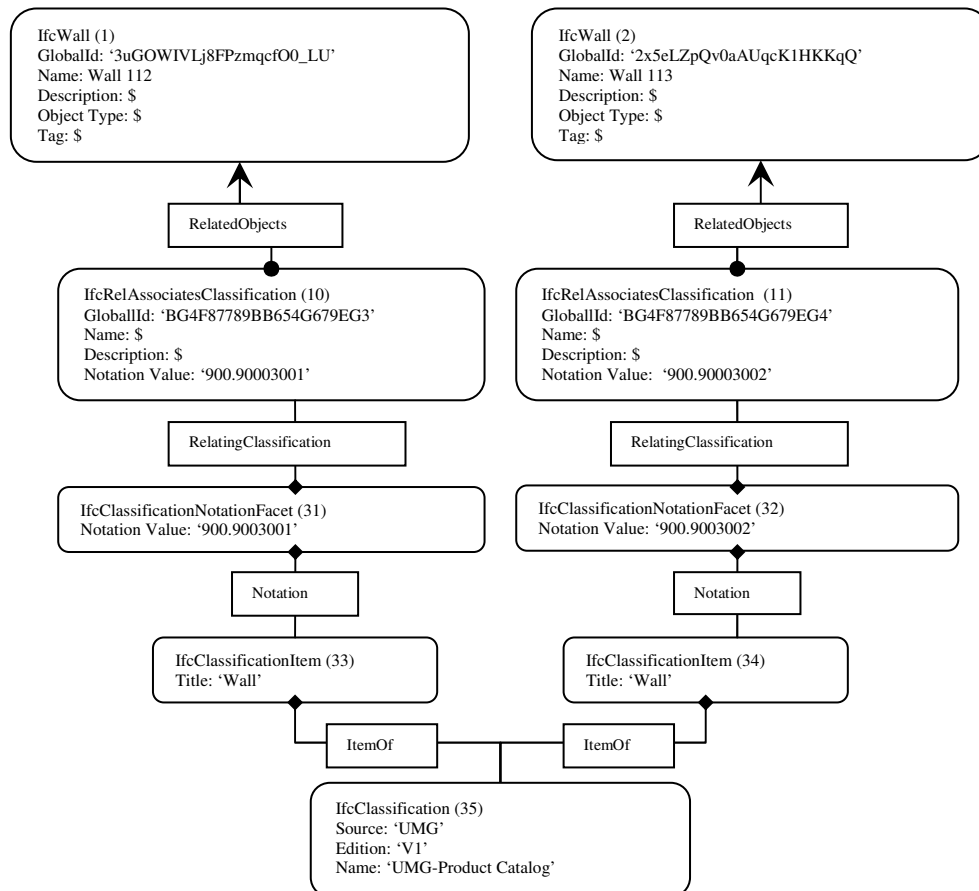
This concept is formalized in order to show classifications, their connections to objects and structure of classification hierarchy according to IFC 2x3 specifications.

IFC Release Specific AEC/FM View Description (IFC 2× Edition3)					
Classification					
Reference, Page	UMG-5, 5/1	Version	V-1	Status	Draft
Relationships	IfcClassification			History	Ifc Release 1.5 Modified in IFC2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI):</p> <p>An <i>IfcClassification</i> is used for the arrangement of objects into a class or category according to a common purpose or their possession of common characteristics. <i>IfcClassification</i> identifies the classification system or source from which a classification notation is derived. The objective is to minimize the number of <i>IfcClassification</i> objects contained within an IFC model. Ideally, each classification system or source used should have only one <i>IfcClassification</i> object. However, because multiple classification is allowed, there may be many <i>IfcClassification</i> objects used, each identifying a different classification system or source.</p> <p>Entity Type Detailed Definition:</p> <p>In order to formalize a general classification mechanism for the instances of <i>IfcObject</i> or <i>IfcPropertyDefinition</i>, <i>IfcRelAssociatesClassification</i> instances can be used. In this context, classification association can be done through a reference to the classification sytem using external references with insances of <i>IfcClassificationReference</i> or to a classification code through instances of <i>IfcClassificationNotation</i> with using of <i>IfcClassificationNotationFacet</i>.</p>					

IFC Release Specific AEC/FM View Description (IFC 2x3 Edition)					
Classification					
Reference, Page	UMG-5 5/2	Version	V-1	Status	Draft
Relationships	IfcClassification			History	Ifc Release 1.5 Modified in IFC2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

In order to show applicability of the suggested 3 leveled product catalog structure, we formalized two example instantiations diagrams which present to attach the classifications to objects.

Instantiation Diagram 1:



Instantiation Definition 1:

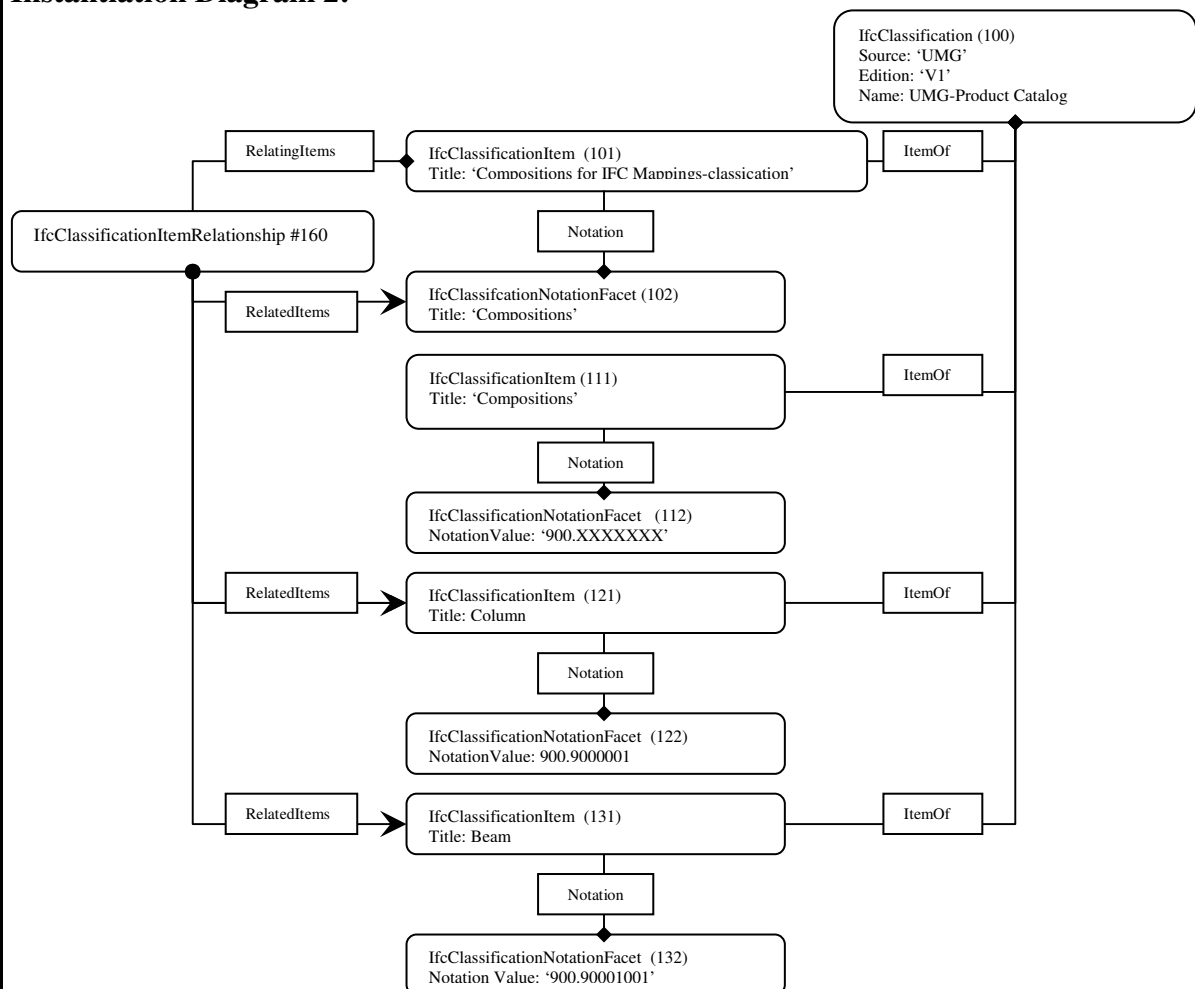
In instantiation diagram 1, two walls are represented with using of classification code.

Instantiation Details 1:

In this instantiation diagram two instances of *IfcWall* (1), (2) are connected with classification codes as classification notation facets (31), (32) through instance of *IfcRelAssociatesClassifications* (10), (11). The notation facets are associated with classification system through a classification items (33), (34) giving the name of the classification code as 'wall'.

IFC Release Specific AEC/FM View Description (IFC 2x3 Edition)					
Classification					
Reference, Page	UMG-5 5/3	Version	V-1	Status	Draft
Relationships	IfcClassification			History	Ifc Release 1.5 Modified in IFC2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram 2:



Instantiation Definition 2:

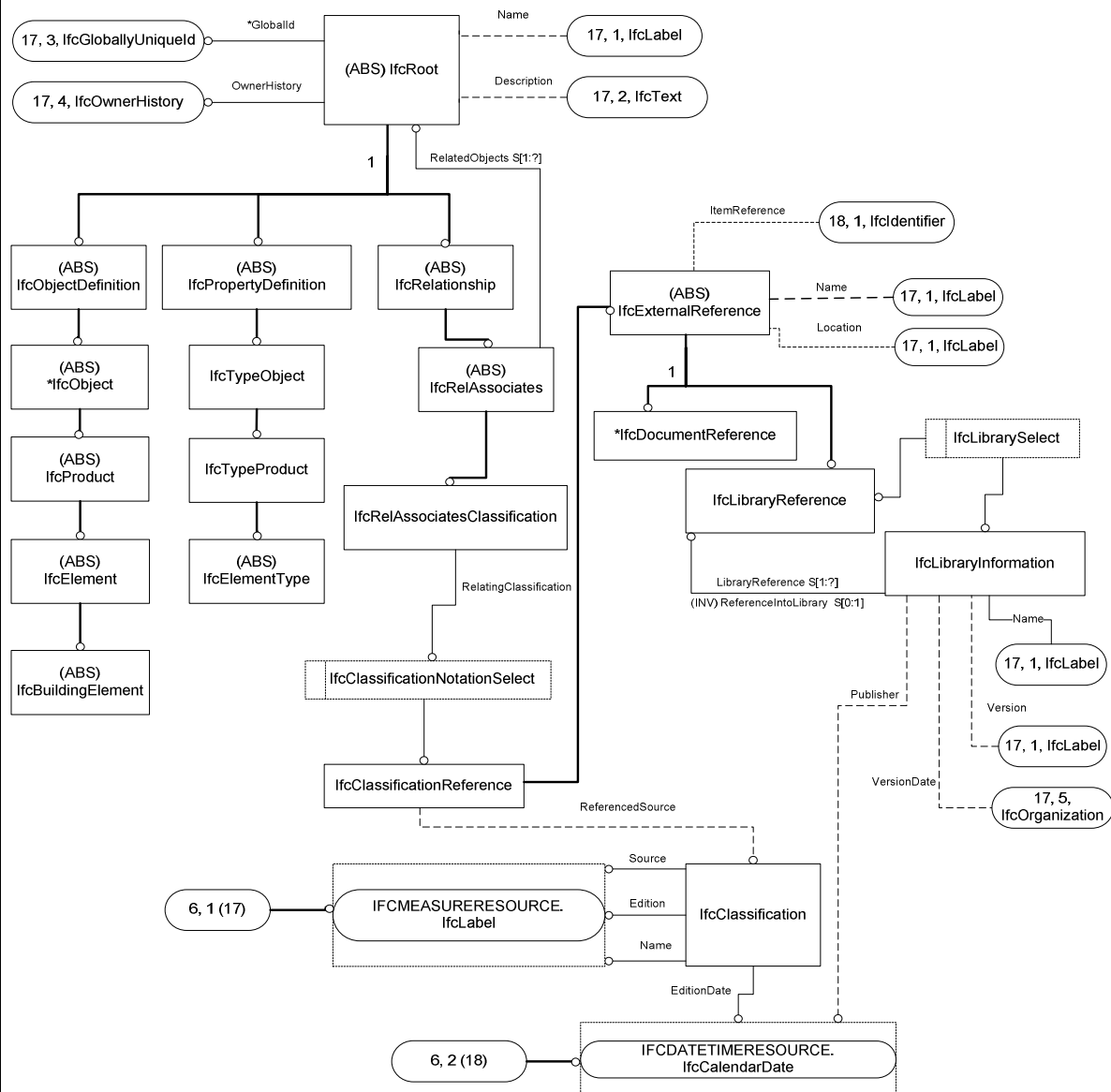
In instantiation diagram 2, building classification with its hierarchical structure is represented.

Instantiation Details 2:

The proposed product catalog structure 'UMG Product Catalog' as the instance of *IfcClassification* is represented with Column and Beam through the instances of *IfcClassificationItem* (121), (131). Each have a notation facet as '900.9000001' and '900.90001001' which represents their classification codes through the instance of *IfcClassificationNotationFacet* (122), (132).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Construction Type Classification					
Reference, Page	UMG-6, 6	Version	V-1	Status	Draft
Relationships	IfcClassification			History	Ifc Release 1.5 Modified in IFC 2x
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to illustrate construction type classifications and their connection to objects according to IFC 2x3 specifications.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Construction Type Classification					
Reference, Page	UMG-6, 6/1	Version	V-1	Status	Draft
Relationships	IfcClassification			History	Ifc Release 1.5 Modified in IFC 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI)

This objectified relationship (*IfcRelAssociatesClassification*) handles the assignment of a classification object (items of the select *IfcClassificationSelect*) to objects (subtypes of *IfcObject*).

The relationship is used to assign a classification notation or a classification reference to objects. A single notation can be applied to multiple objects. Depending on the type of the *RelatingClassification*, either a reference to a fully described classification system can be made, or just a reference using the classification code.

The inherited attribute *RelatedObjects* define the objects to which the classification is applied. The attribute *RelatingClassification* is the reference to a classification, applied to the object(s).

An *IfcClassificationReference* is a reference into a classification system or source (see *IfcClassification*). An optional inherited *ItemReference* key is also provided to allow more specific references to classification items (or tables) by type. The inherited *Name* attribute allows for a human interpretable designation of a classification notation (or code).

Classifications of an object may be referenced from an external source rather than being contained within the IFC model. This is done through the *IfcClassificationReference* class.

Entity Type Detailed Definition:

In order to set up a general classification mechanism for the instances of *IfcObject* or *IfcPropertyDefinition*, *IfcRelAssociatesClassification* instances can be used. This can provide to assign construction types to objects. The instance of *IfcClassificationReference* obtains classification association as a reference to the classification system using external references. The source can be identified via *IfcClassification* instance.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Construction Type Classification					
Reference, Page	UMG-6, 6/2	Version	V-1	Status	Draft
Relationships	IfcClassification			History	Ifc Release 1.5 Modified in IFC 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:

```
graph TD
    A["IfcRelAssociatesClassification (2)  
GlobalId: 0E29C3D664AB5F0GA256DG  
Name: 'UMG Classification'  
Description: $"]
    B["IfcWall (1)  
GlobalId: '3DwF3zyUj9bgjuviHLMq55'  
Name: 'Wall-1-1'  
Description: $  
Object Type: $  
Tag: $"]
    C["IfcClassificationReference (3)  
Location: 'UMG Ph.D. Thesis'  
ItemReference: '900.90003001'  
Name: 'Wall'"]
    D["IfcClassification (4)  
Source: 'UMG'  
Edition 'V1'  
Name 'UMG Classification'"]
    E["RelatedObjects"]
    F["RelatingClassification"]
    G["ReferencedSource"]

    A --> E
    E --> B
    A --> F
    F --> C
    C --> G
    G --> D
```

The diagram illustrates the instantiation of a construction type classification. It shows four main entities: *IfcRelAssociatesClassification* (2), *IfcWall* (1), *IfcClassificationReference* (3), and *IfcClassification* (4). *IfcRelAssociatesClassification* (2) is connected to *IfcWall* (1) via a *RelatedObjects* relationship. It is also connected to *IfcClassificationReference* (3) via a *RelatingClassification* relationship. *IfcClassificationReference* (3) is connected to *IfcClassification* (4) via a *ReferencedSource* relationship. The entities contain specific data such as GlobalId, Name, Description, Location, ItemReference, Source, and Edition.

Instantiation Definition:

In this instantiation diagram, a construction type information association to an object through a classification is illustrated.

Instantiation Details

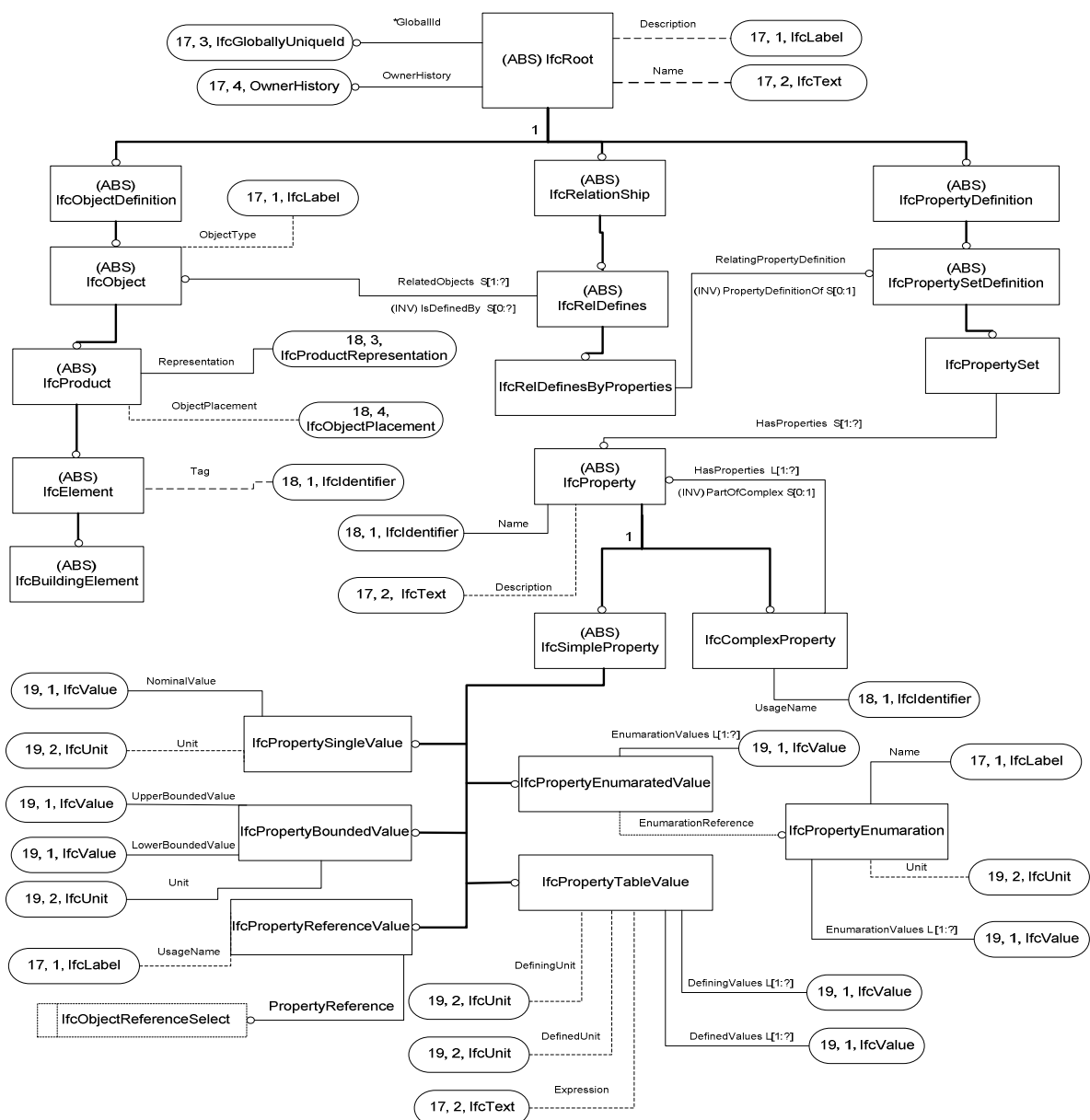
In this diagram, a wall (1) is connected to a classification code through an instance of *IfcRelAssociatesClassification* (2) as classification reference (3) with an item reference value '900.90003001'. *IfcRelAssociates* is used to possess classification. The referenced source is illustrated as instances of *IfcClassification* (4).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Properties

Reference, Page	UMG-7, 7	Version	V-1	Status	Draft
Relationships	IfcPropertySet			History	IfcRelease 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show how properties are attached to objects based on the IFC 2x3 specifications.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Properties					
Reference, Page	UMG-7, 7/1	Version	V-1	Status	Draft
Relationships	IfcPropertySet			History	IfcRelease 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI):</p> <p>The <i>IfcPropertySet</i> defines all dynamically extensible properties. The property set is a container class that holds properties within a property tree. These properties are interpreted according to their name attribute. Property sets, defining a particular type of object, can be assigned an object type (<i>IfcTypeObject</i>). Property sets are assigned to objects (<i>IfcObject</i>) through an objectified relationship (<i>IfcRelDefinedByProperties</i>). If the same set of properties applies to more than one object, it should be assigned by a single instance of <i>IfcRelDefinedByProperties</i> to a set of related objects. Those property sets are referred to as shared property sets. Instances of <i>IfcPropertySet</i> are used to assign named sets of individual properties (complex or single properties). Each individual property has a significant name string. Some property sets have predefined instructions on assigning those significant name, these are listed under "property sets" main menu item within this specification. The naming convention "Pset_Xxx" applies to those property sets and shall be used as the value to the <i>Name</i> attribute. In addition any user defined property set can be captured, those property sets shall have a <i>Name</i> value not including the "Pset_" prefix.</p> <p>Entity Type Detailed Definition:</p> <p>In order formalize object property characteristics, <i>IfcPropertySet</i> is used in this context. The seperate property information (instance of <i>IfcPropertyDefinition</i> subtypes) of <i>IfcObject</i> instances are illustrated through objectified relationship of type <i>IfcRelDefinesByProperties</i> which point to <i>IfcPropertySetDefinition</i> subtypes.</p>					

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Properties					
Reference, Page	UMG-7, 7/2	Version	V-1	Status	Draft
Relationships	IfcPropertySet			History	IfcRelease 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:

```
graph TD
    A["IfcRelDefinesByProperties (1)  
GlobalId: 'C52CFD937475D15C8D5G7'  
Name: 'Wall'  
Description: $"]
    B["IfcPropertySet (3)  
GlobalId: '237GFB7D51575038C1FB25'  
Name: 'Property Set Wall'  
Description: $"]
    C["IfcWall (2)  
GlobalId: '2x5eLZpQv0aAUqcK1HKKqQ'  
Name: 'Concrete Wall 113'  
Description: 'C25 Concrete Wall'"]
    D["IfcPropertySingleValue (4)  
Name: 'External'  
Description: $  
Nominal Value: IFCBOOLEAN .T."]
    E["IfcPropertySingleValue (5)  
Name: 'WaterResistance'  
Description: $  
Nominal Value: IFCLABEL 'WR101'"]

    A -- RelatingPropertyDefinition --> B
    A -- RelatedObjects --> C
    B -- HasProperties --> D
    B -- HasProperties --> E
```

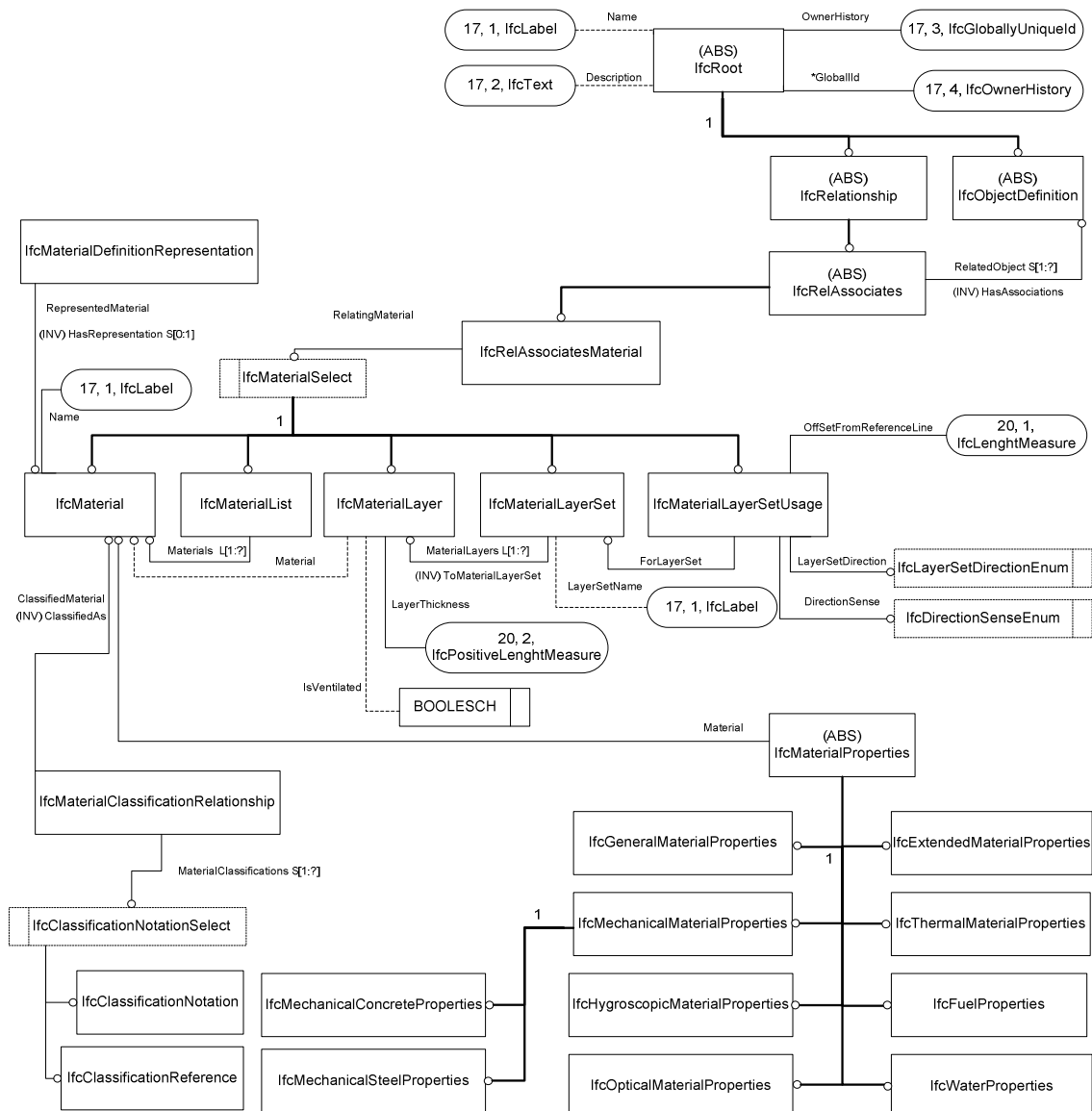
The diagram illustrates the instantiation of a concrete wall object (IfcWall 2) through a relationship (IfcRelDefinesByProperties 1) to a property set (IfcPropertySet 3). The property set defines two single value properties (IfcPropertySingleValue 4 and 5) for the wall.

Instantiation Definition:
This instantiation diagram shows how an object is assigned properties using a property set defined as a standard property set definition according to IFC 2x3 specification.

Instantiation Detailed Definition:
In this instantiation diagram the concrete wall 113 is an instance (2) of the *IfcWall* class. The additional properties are attained through objectified relationship to instance of the *IfcRelDefinesByProperties* (1). The property sets are established though property definition relation to instance of *IfcPropertySet* (3). The Property Set has two single value properties (4), (5) as External boolean type values and Waterresistence label type value ‘WR101’.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Material					
Reference, Page	<i>UMG-8, 8</i>	Version	<i>V-1</i>	Status	<i>Draft</i>
Relationships	<i>IfcMaterial</i>			History	<i>Ifc Release 2 Modified in IFC 2x</i>
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to define material information, according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Material					
Reference, Page	UMG-8, 8/1	Version	V-1	Status	Draft
Relationships	IfcMaterial			History	Ifc Release 2 Modified in IFC 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):
IfcRelAssociates is objectified relationship between a material definition and elements or element types to which this material definition applies. The material definition can be:
A single material
A material list, e.g. for composite elements
A material layer set, for layered elements with an indication of the layering direction and individual layer thicknesses
The *IfcRelAssociatesMaterial* relationship is a special type of the *IfcRelAssociates* relationship. It can be applied to subtypes of *IfcElement* and subtypes of *IfcElementType*.
The *IfcElement* has an inverse relation to its material definition by the *HasAssociations* attribute, inherited from *IfcObject*.
The *IfcElementType* has an inverse relation to its material definition by the *HasAssociations* attribute, inherited from *IfcPropertyDefinition*.
If there are several different material assignments to a single element (e.g. to give different materials to parts of the element) the inherited Name attribute may provide additional information about the element part to which the material applies. If both, the element occurrence (by an instance of *IfcElement*) and the element type (by an instance of *IfcElementType*, connected through *IfcRelDefinesByType*) have an associated material, then the material associated to the element occurrence overrides the material associated to the element type.

Entity Type Detailed Definition:
In order to formalize material information within IFC, the structure is constructed based on the material as (instances of *IfcMaterial*), the material lists as (instances of *IfcMaterialList*), the material layers as (instances of *IfcMaterialLayer*), the sets of materials as (instances of *IfcMaterialLayerSet*), the use of material layer sets as (instances of *IfcMaterialLayerSetUsage*).The material properties are used as to define basic material information with (*IfcMaterialProperties*). The classification is supported with the use of relation to classification via a (*IfcMaterialClassificationRelationship*).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Material					
Reference, Page	UMG-8, 8/2	Version	V-1	Status	Draft
Relationships	IfcMaterial			History	Ifc Release 2 Modified in IFC 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

In order to validate, 3 leveled product catalog structure, two instantiation diagrams which represent association of materials to objects are formalized.

Instantiation Diagram 1:

```
graph TD
    Wall1["IfcWall (1)  
GlobalId: '3DwF3zyUj9bgjuviHLMq55'  
Name: 'Concrete Wall 112'  
Description: C25 Concrete Wall"]
    Wall2["IfcWall (2)  
GlobalId: '2x5eLZpQv0aAUqcK1HKkqQ'  
Name: 'Concrete Wall 113'  
Description: C25 Concrete Wall"]
    RelatedObjects["RelatedObjects"]
    RelMat["IfcRelAssociatesMaterial (3)  
GlobalId: '1E38E3D993CC5F1GB375PK'  
Name: $  
Description: $"]
    RelatingMaterial["RelatingMaterial"]
    MatLayerSetUsage["IfcMaterialLayerSetUsage (4)  
LayerSetDirection: AXIS4  
Direction Sense : POSITIVE  
OffsetFromReferenceLine: 0.0"]
    ForLayerSet["ForLayerSet"]
    MatLayerSet["IfcMaterialLayerSet (5)  
Name:$"]
    MatLayer1["Material Layer"]
    MatLayer2["Material Layer"]
    MatLayer6["IfcMaterialLayer (6)  
Layer Thickness :200.0  
IsVentilated: F"]
    MatLayer7["IfcMaterialLayer (7)  
LayerThickness: 100.0  
IsVentilated: F"]
    Mat1["Material"]
    Mat2["Material"]
    IfcMat8["IfcMaterial (8)  
Name: 'C 25 Concrete'"]

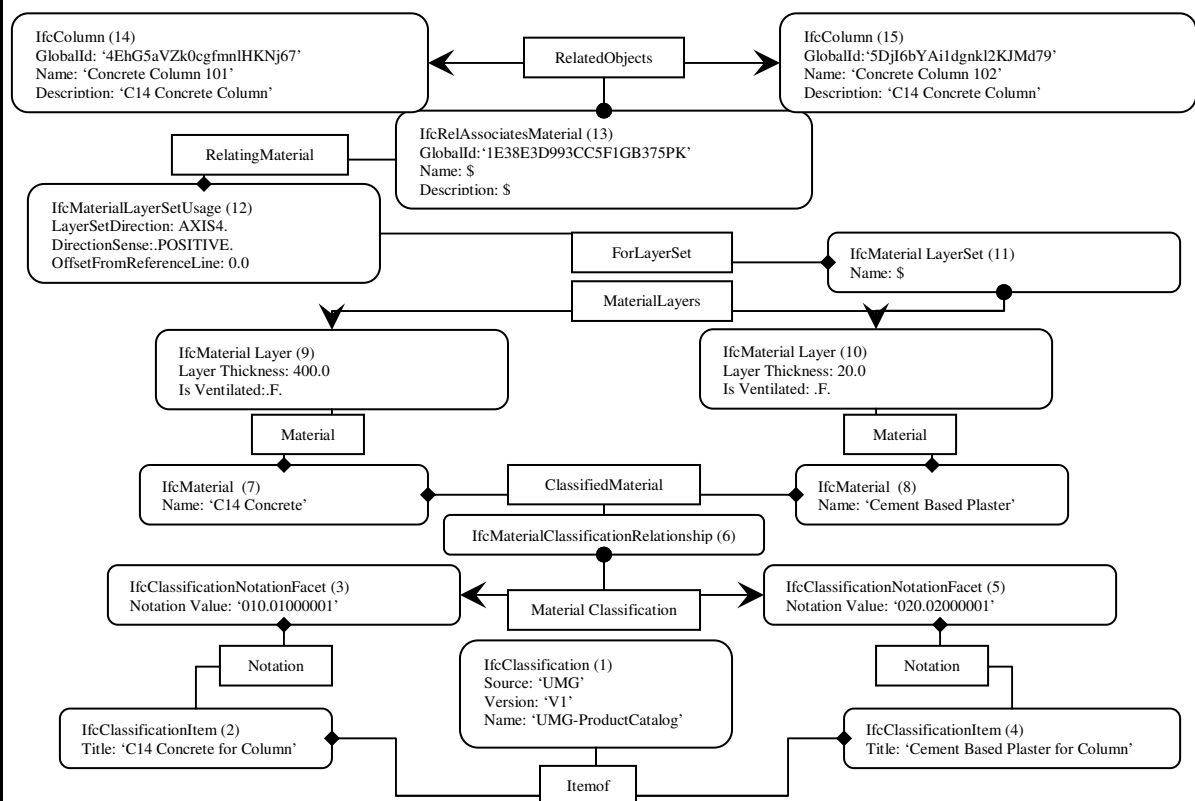
    Wall1 --> RelatedObjects
    Wall2 --> RelatedObjects
    RelatedObjects --> RelMat
    RelMat --> RelatingMaterial
    RelatingMaterial --> MatLayerSetUsage
    MatLayerSetUsage --> ForLayerSet
    ForLayerSet --> MatLayerSet
    MatLayerSet --> MatLayer1
    MatLayerSet --> MatLayer2
    MatLayer1 --> MatLayer6
    MatLayer2 --> MatLayer7
    MatLayer6 --> Mat1
    MatLayer7 --> Mat2
    Mat1 --> IfcMat8
    Mat2 --> IfcMat8
```

Instantiation Definition:
Instantiation diagram 1 illustrates two objects (walls) with their basic material information (definition).

Instantiation Details:
In this instantiation diagram, two wall instances (1), (2) are instantiated to illustrate their basic material definitions. These are connected to material layer sets through an objectified relationship of type *IfcRelAssociatesMaterial* (13). The type *IfcMaterialLayerSetUsage* (4) is used to define offset and direction information with their common material definition and connected through an objectified relationship to instances of *IfcWalls*. It identifies material layers (6), (7) with individual material layers through an instance of *IfcMaterialLayerSet* (5). Concrete instance (*IfcMaterial* (8)) is defined with its thicknesses subsequently.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)**Material**

Reference, Page	<i>UMG-8, 8/3</i>	Version	<i>V-1</i>	Status	<i>Draft</i>
Relationships	<i>IfcMaterial</i>			History	<i>Ifc Release 2 Modified in IFC 2x</i>
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

Instantiation Diagram 2:**Instantiation Definition:**

Instantiation diagram 2 illustrates two objects (columns), their basic material information with classification codes and material layers.

Instantiation Details:

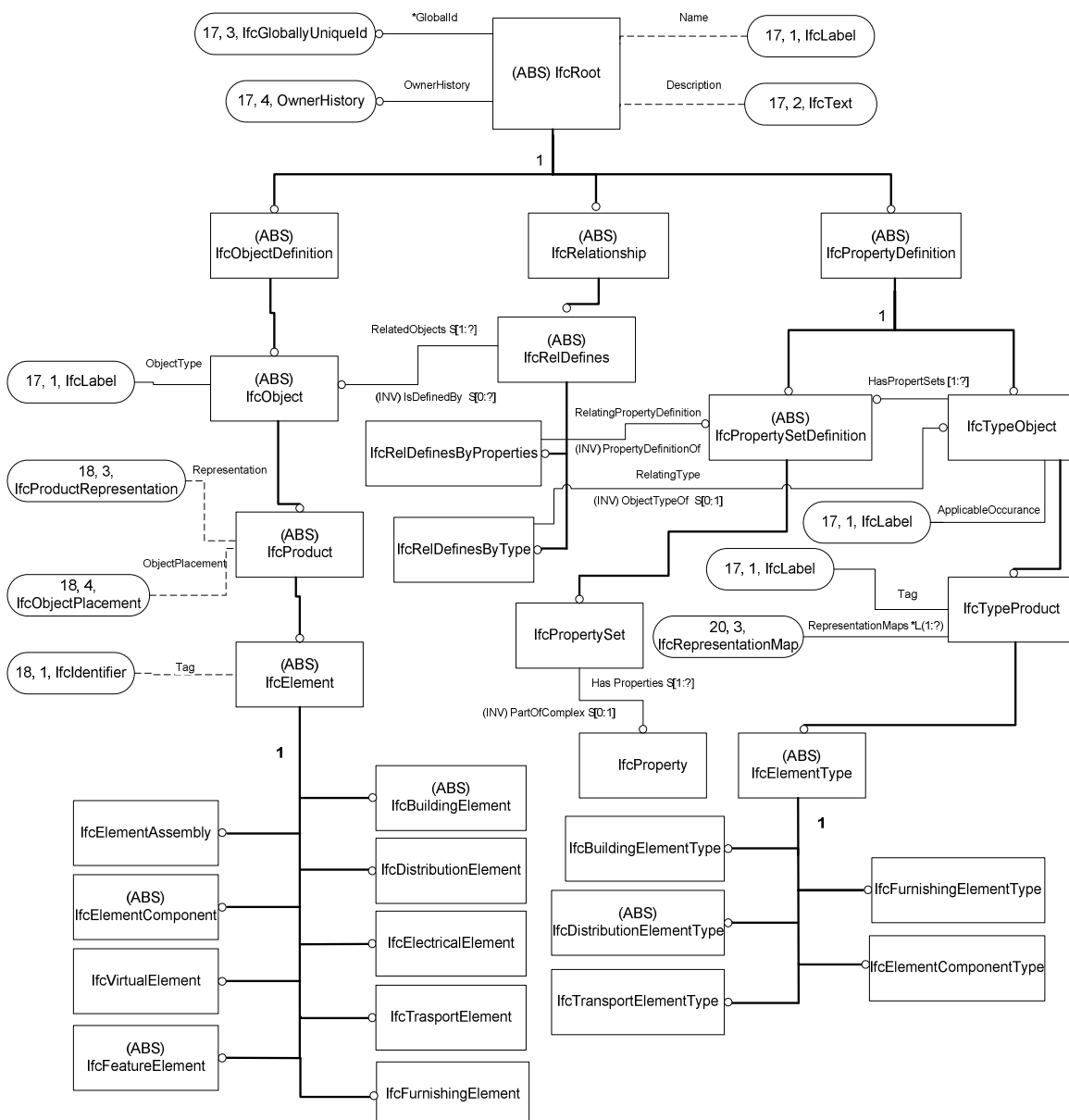
In this instantiation diagram, two wall instances (14), (15) are instantiated to illustrate their basic material definitions. These are connected to material layer sets through an objectified relationship of type *IfcRelAssociatesMaterial* (13). The type *IfcMaterialLayerSetUsage* (12) is used to define offset and direction information with their common material definition and connected through an objectified relationship to instances of *IfcColumns*. It identifies material layers (9), (10) through an instance of *IfcMaterialLayerSet* (11). Concrete instance (*IfcMaterial* (7)) and Plaster instance (*IfcMaterial* (8)) is defined with their thickness subsequently. These materials are connected with classification codes as classification notation facets (3), (5) through type of *IfcMaterialClassificationRelationship* (6). The notation facets are associated with classification system (1) through classification items (2), (4).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

TypeObject

Reference, Page	<i>UMG-9, 9</i>	Version	<i>V-1</i>	Status	<i>Draft</i>
Relationships	<i>IfcTypeObject</i>			History	<i>Ifc Release 2x</i>
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

Usage in View Definition Diagram (EXPRESS G):

**Definition:**

This concept is formalized in order to define type object and related objects according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
TypeObject					
Reference, Page	UMG-9, 9/1	Version	V-1	Status	Draft
Relationships	IfcTypeObject			History	Ifc Release 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):
The object type (*IfcTypeObject*) defines the specific information about a type. It refers to the specific level of the well recognized *generic - specific - occurrence* modeling paradigm. The object style is represented by a list of property set definitions, where the order in the list implies a decreasing generality. The list of property sets describes the available specific information about the object type. Thereby the object type is used to define the common properties of a certain type (or style) of an object that may be applied to multiple instances of the same type. The *IfcTypeObject* gets assigned to the individual object instances (the occurrences) via the *IfcRelDefinesByType* relationship. Object types may be exchanged without being already assigned to objects. An object type may have an indication of the library (or catalogue) from which its definition originates. This association is handled by the inherited *HasAssociations* relationship.

Entity Type Detailed Definition:
In order to formalize specific information about an object, classes as *IfcTypeObject* and its subtype *IfcTypeProduct* can be used. The location information and specific properties of an object can be illustrated via *IfcElement*, also common characteristics of an object are collected together in through instances of *IfcPropertySets*. The *IfcRelDefinesByType* relationship connects occurrences of objects. Representation of objects through their geometry is shown via *IfcRepresentationMap* in this context.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
TypeObject					
Reference, Page	UMG-9, 9/2	Version	V-1	Status	Draft
Relationships	IfcTypeObject			History	Ifc Release 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:

```
graph TD
    subgraph Objects
        B1["IfcBuildingElement (1)  
GlobalId: '4EzGavOk90hiuKLNAqt65'  
Name: 'Windows 110'  
Description: 'PVC Windows'"]
        B2["IfcBuildingElement (2)  
GlobalId: '3DwFzyUj9bgjuviHLMq55'  
Name: 'Windows 111'  
Description: 'PVC Windows'"]
        RT["IfcRelDefinesByType (3)  
GlobalId: 'GF47D0GD58BG5G2DCDCF78'  
Name: '$'  
Description: '$'"]
        BET["IfcBuildingElementType (4)  
GlobalId: 'G5CB66D38CB35BB801GC9D'  
Name: 'Windows'  
Description: 'PVC Windows'  
ApplicableOccurance: 'IfcWindow'"]
        PS["IfcPropertySet (5)  
GlobalId: 'E16DEB7CB9275369CC37E9'  
Name: 'Property Set Window'  
Description: '$'"]
        PSH1["IfcPropertySingleValue (6)  
Name: 'External'  
Description: '$'  
NominalValue: IFCBOOLEAN .T."]
        PSH2["IfcPropertySingleValue (7)  
Name: 'Color'  
NominalValue: IFCLABEL ('White')"]
        PSH3["IfcPropertySingleValue (8)  
Name: 'Style'  
NominalValue: IFCLABEL ('PVC-1221')"]
        PSH4["IfcPropertySingleValue (9)  
Name: 'NominalHeight'  
Description: '$'  
NominalValue: IFCPOSITIVELENGHTMEASURE (1600)"]
        PSH5["IfcPropertySingleValue (10)  
Name: 'NominalLenght'  
Description: '$'  
NominalValue: IFCPOSITIVELENGHTMEASURE (2000)"]
        PSH6["IfcPropertySingleValue (11)  
Name: 'NominalDepth'  
Description: '$'  
NominalValue: IFCPOSITIVELENGHTMEASURE (150)"]
    end

    B1 -- RelatedObjects --> B2
    RT --> B1
    RT --> B2
    RT -- RelatingType --> BET
    PS -- HasPropertySets --> BET
    PS -- HasProperties --> PSH1
    PS -- HasProperties --> PSH2
    PS -- HasProperties --> PSH3
    BET -- HasProperties --> PSH4
    BET -- HasProperties --> PSH5
    BET -- HasProperties --> PSH6
```

Instantiation Definition:

In this instantiation diagram, two windows occurrences which have common properties are illustrated through building element type object.

Instantiation Details:

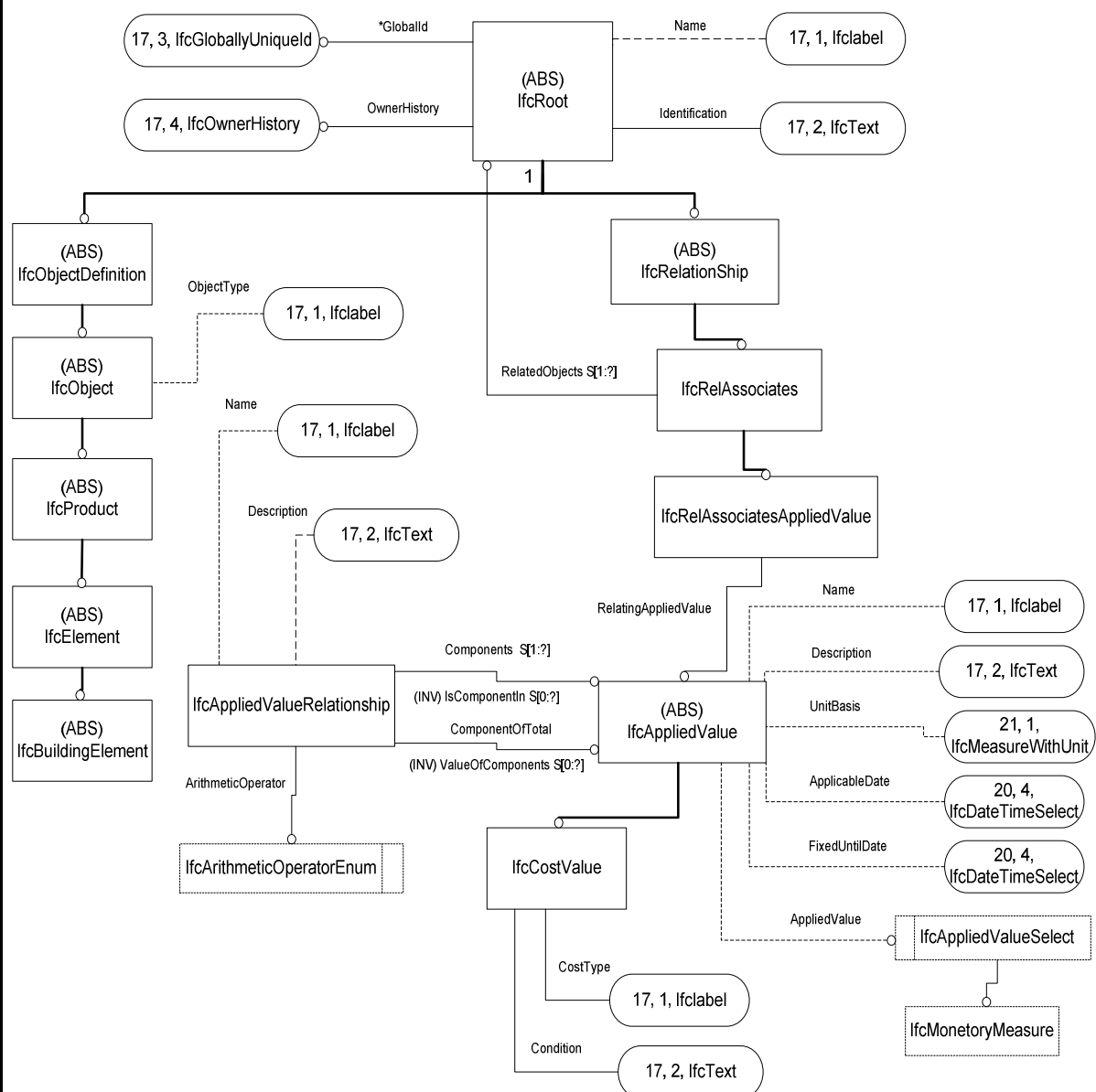
This intantiation diagram illustrates two windows, as two instances of *IfcBuildingElement* (1), (2). The connection of type object are set-up through an objectified relationship to instance of *IfcRelDefinesByType* (3). *IfcBuildingElementType* illustrates common properties with *IfcPropertySet* type named 'Property Set Window'. This formalized to illustrate type of *IfcPropertySingleValues* instances named 'External' (6), 'Color' (7), 'Style' (8), 'Nominal Height' (9), 'Nominal Lenght' (10), 'Nominal Depth' (11).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Cost

Reference, Page	UMG-10, 10	Version	V-1	Status	Draft
Relationships	IfcCostValue			History	Ifc Release 1
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show cost definition of cost value information and connection with the related objects according to IFC 2x3 Edition.

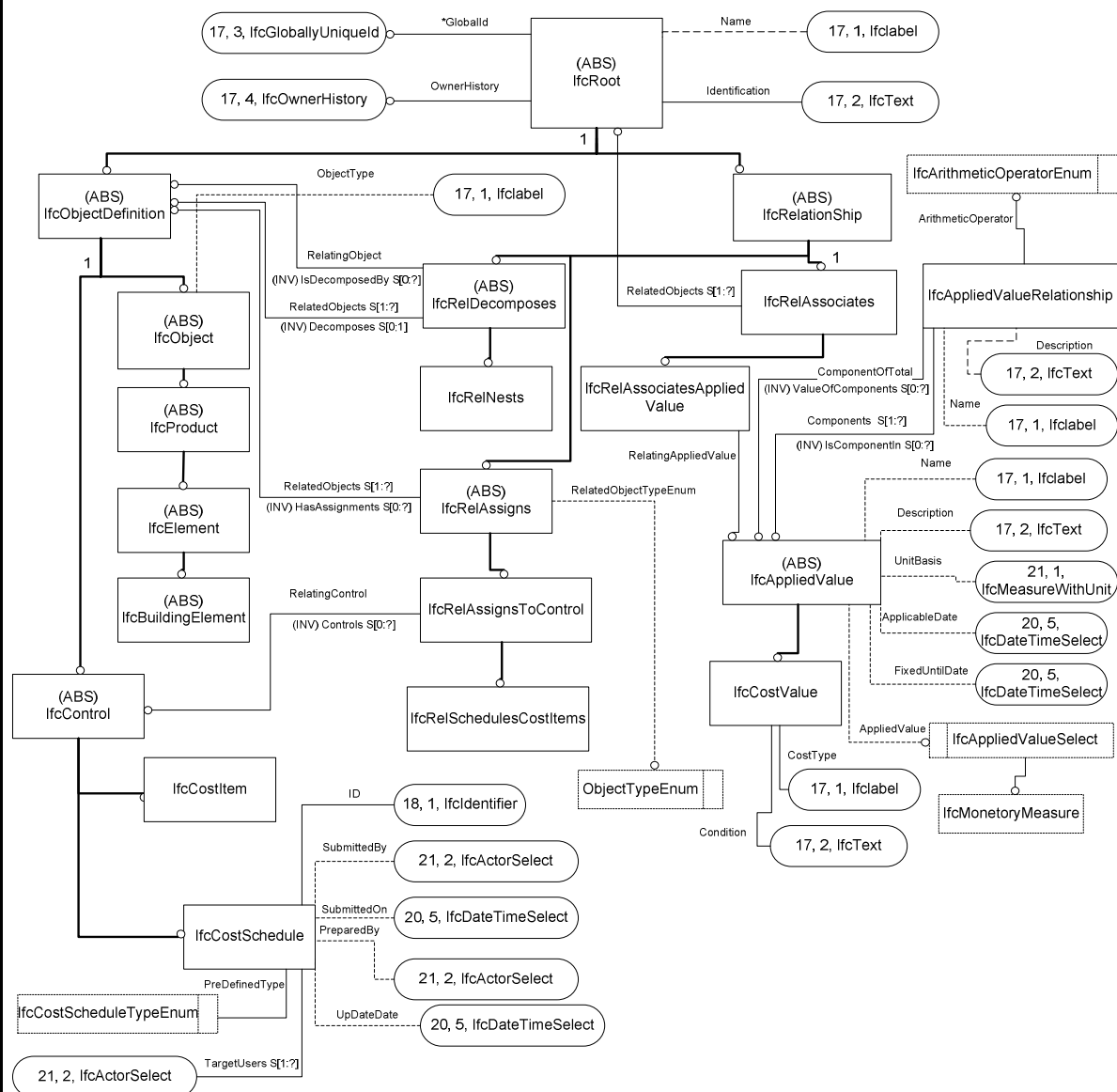
IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)																																						
Cost																																						
Reference, Page	UMG-10, 10/1	Version	V-1	Status	Draft																																	
Relationships	IfcCostValue			History	Ifc Release 1																																	
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de																																					
Description	1. Usage in View Definition Diagram																																					
<p>Entity Type Definition (Definition from IAI):</p> <p>An <i>IfcCostValue</i> is an amount of money or a value that affects an amount of money. Each instance of <i>IfcCostValue</i> may also have a cost type. There are many possible types of cost value that may be identified. Whilst there is a broad understanding of the meaning of names that may be assigned to different types of costs, there is no general standard for naming cost types nor are there any broadly defined classifications. To allow for any type of cost value, the <i>IfcLabel</i> datatype is assigned. The following defines some cost types that might be applied:</p> <table><tr><td>Annual rate of return</td><td>Lease</td><td>Replacement</td></tr><tr><td>Bonus</td><td>List price</td><td>Sale</td></tr><tr><td>Bulk purchase rebate</td><td>Maintenance</td><td>Small quantity surcharge</td></tr><tr><td>Contract</td><td>Material</td><td>Spares</td></tr><tr><td>Consultancy</td><td>Overhead</td><td>Storage</td></tr><tr><td>Delivery</td><td>Postage and packing</td><td>Sub-Contract</td></tr><tr><td>Estimated cost</td><td>Profit</td><td>Trade discount</td></tr><tr><td>Hire</td><td>Purchase</td><td>Transportation</td></tr><tr><td>Installation</td><td>Rental</td><td>Waste allowance</td></tr><tr><td>Interest rate</td><td>Repair</td><td>Whole life</td></tr><tr><td>Labor</td><td></td><td></td></tr></table> <p>In the absence of any well-defined standard, it is recommended that local agreements should be made to define allowable and understandable cost value types within a project or region.</p> <p>Entity Type Detailed Definition:</p> <p><i>IfcCostValue</i> class illustrates the cost value of an object. The cost value can be defined through a type of <i>IfcAppliedValue</i>. The cost breakdown hierarchies are shown through the type of <i>IfcAppliedValueRelationship</i>. In this case, cost values can be related with the <i>IfcObject</i> and <i>IfcPropertyDefinition</i> subtypes through an objectified relationship of <i>IfcRelAssociatesAppliedValue</i>.</p>						Annual rate of return	Lease	Replacement	Bonus	List price	Sale	Bulk purchase rebate	Maintenance	Small quantity surcharge	Contract	Material	Spares	Consultancy	Overhead	Storage	Delivery	Postage and packing	Sub-Contract	Estimated cost	Profit	Trade discount	Hire	Purchase	Transportation	Installation	Rental	Waste allowance	Interest rate	Repair	Whole life	Labor		
Annual rate of return	Lease	Replacement																																				
Bonus	List price	Sale																																				
Bulk purchase rebate	Maintenance	Small quantity surcharge																																				
Contract	Material	Spares																																				
Consultancy	Overhead	Storage																																				
Delivery	Postage and packing	Sub-Contract																																				
Estimated cost	Profit	Trade discount																																				
Hire	Purchase	Transportation																																				
Installation	Rental	Waste allowance																																				
Interest rate	Repair	Whole life																																				
Labor																																						

IFC Release Specific AEC/FM View Description (IFC 2x3 Edition)

Cost Item and Cost Schedule

Reference, Page	UMG-11, 11	Version	V-1	Status	Draft
Relationships	<i>IfcCostItem, IfcCostSchedule</i>			History	<i>Ifc Release 2.0 Modified in IFC 2x2</i>
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show cost definitions as cost items and relation to other objects according to IFC specification.

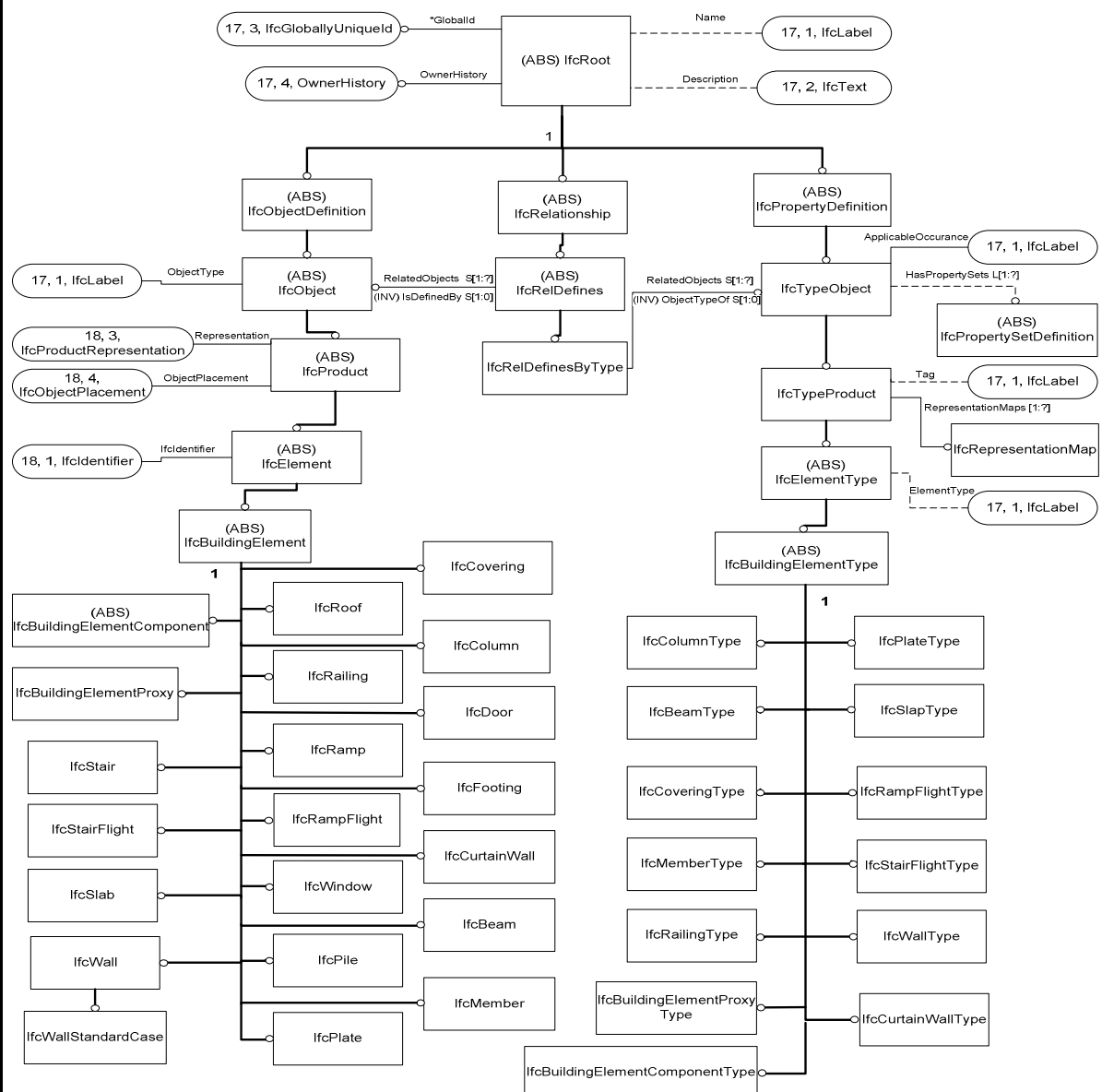
IFC Release Specific AEC/FM View Description (IFC 2x3 Edition)					
Cost Item and Cost Schedule					
Reference, Page	UMG-11, 11/1	Version	V-1	Status	Draft
Relationships	IfcCost Item, IfcCostSchedule			History	Ifc Release 2.0 Modified in IFC 2x2
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI):</p> <p>An <i>IfcCostItem</i> describes a cost or financial value together with descriptive information that describes its context in a form that enables it to be used within a cost schedule. An <i>IfcCostItem</i> can be used to represent the cost of goods and services, the execution of works by a process, lifecycle cost and much more.</p> <p><i>IfcCostItem</i> brings together the value and currency concepts available through the <i>IfcCostResource</i> schema with the identification, naming and descriptive powers that all non-resource entities in the model inherit from <i>IfcRoot</i>.</p> <p>Instances of <i>IfcCostItem</i> can be assigned to an <i>IfcCostSchedule</i> through the <i>IfcRelSchedulesCostItems</i> relationship class.</p> <p>Instances of <i>IfcCostItem</i> are used for cost estimates, budgets, etc., where a variety of identification codes are used extensively to identify the meaning of the cost. Examples include project phase codes, CSI codes, takeoff sequence numbers, cost accounts, etc. The IFC model allows for all classes that are ultimately subtypes of <i>IfcObject</i> to inherit the ability to have one or more instances of <i>IfcClassificationNotation</i> to be assigned. Where identification codes are required, the generic IFC classification facility should be used.</p> <p>An <i>IfcCostSchedule</i> brings together instances of <i>IfcCostItem</i> either for the purpose of identifying purely cost information as in an estimate for constructions costs, bill of quantities etc. or for including cost information within another presentation form such as an order (of whatever type)Use Definitions. An <i>IfcCostSchedule</i> is ultimately a subtype of <i>IfcRoot</i> and consequently inherits its identifying, naming and description attributes.</p> <p>In addition to the global unique identifier, an <i>IfcCostSchedule</i> may be assigned a specific local unique identifier.The name attribute may be used to give an overall title or name to the <i>IfcCostSchedule</i>.The description attribute may be used to provide further descriptive narrative. This may include specific comments that can be applied.An <i>IfcCostSchedule</i> may be assigned a status that determines its current level of development or agreement. In the case of an 'APPROVED' status, this should only be set after an approval has been given through the association of an instance of <i>IfcApproval</i>.</p> <p>An <i>IfcCostSchedule</i> may also be declared as being of a particular type. A number of predefined types are included through the <i>IfcCostScheduleTypeEnum</i> enumeration.</p> <p>Entity Type Detailed Definition:</p> <p>Basically, in order to describe a cost or financial value with its descriptive information in a form <i>IfcCostItem</i> class can be used. This enables to use this information within a schedule <i>IfcCostSchedule</i>. The relation cost items to their cost schedules are illustrated through <i>IfcRelSchedulesCostItems</i> relationships. The cost values <i>IfcCostValue</i> instances are connected with the cost items through <i>IfcRelAssociatesAppliedValue</i> relationship.</p>					

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Building Element

Reference, Page	UMG-12, 12	Version	V-1	Status	Draft
Relationships	IfcBuildingElement			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition:

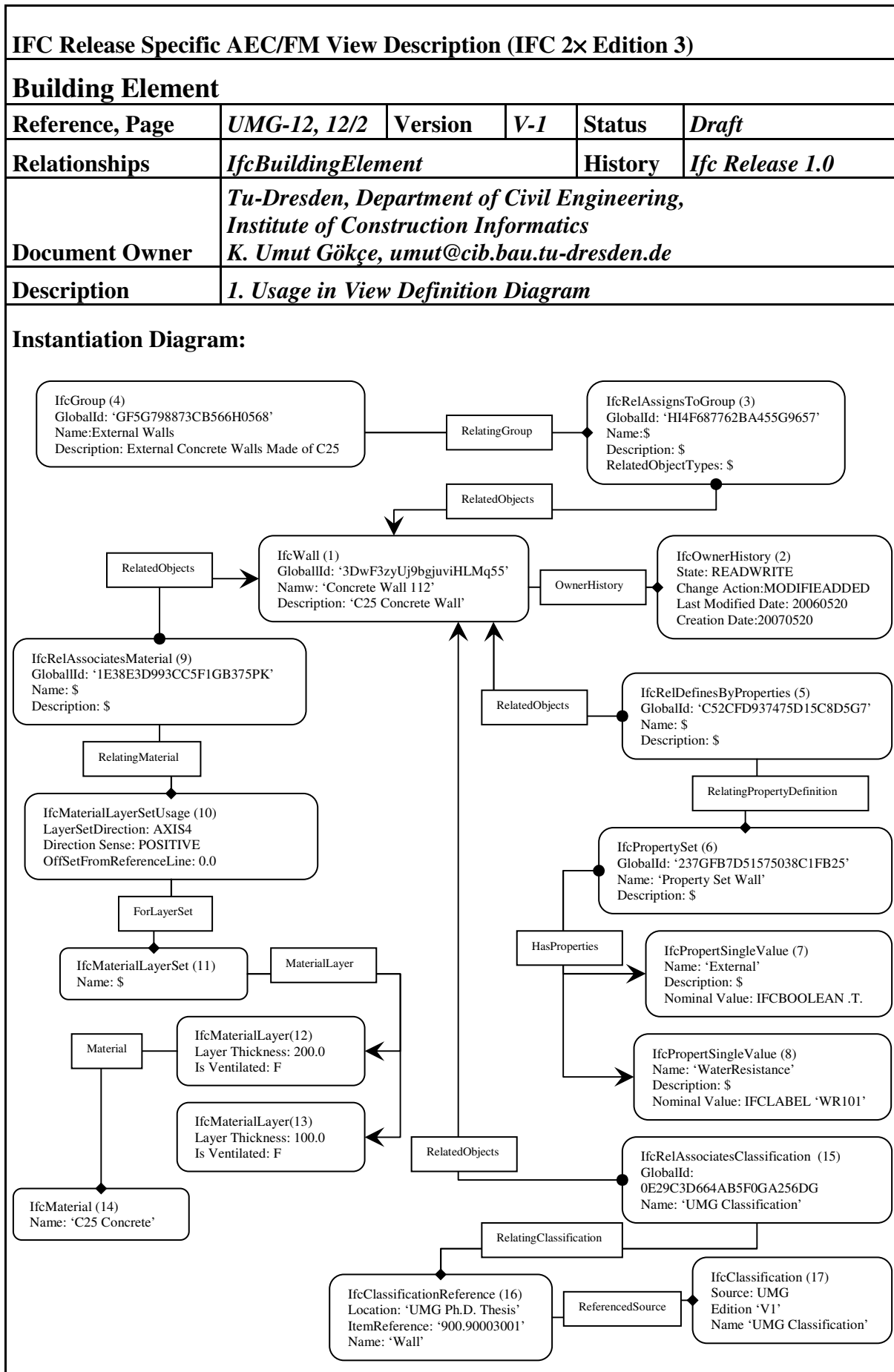
This concept is formalized in order to show building element structure and illustrates the relation of their type information according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element					
Reference, Page	UMG-12, 12/1	Version	V-1	Status	Draft
Relationships	IfcBuildingElement			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):
The building element comprises all elements that are primarily part of the construction of a building, i.e., its structural and space separating system. They are separated from other elements, since they are dealt with in separate AEC processes. The *IfcBuildingElement* utilizes the following capabilities mainly through inverse referenced to objectified relationships:

1. Grouping - being part of a logical group of objects
2. Classification - assigned reference to an external classification
3. Documentation - assigned reference to an external documentation
4. Type - reference to the product type information for the element occurrence
5. Properties - reference to all attached properties, including quantities
6. Cost control - reference to cost elements associated with this building element
7. Work processes - reference to work tasks, in which this building element is used
8. Aggregation - aggregated together with other elements to form an aggregate
9. Connection - connectivity to other elements, including the definition of the joint
10. Ports - information, whether the building element has ports for system connections
11. Realization - information, whether the building element is used to realize a connection
12. Assignment to spatial structure - hierarchical assignment to the right level within the spatial structure
13. Material - assignment of material used by this building element
14. Boundary - provision of space boundaries through this building element
15. Opening - information, whether the building element includes openings
16. Projection - information, whether the building element has projections
17. Filling - information whether the building element is used to fill openings.

Entity Type Detailed Definition:
In order to represent different type of building element objects *IfcBuildingElement* class can be used. To represent building elements type information, *IfcRelDefinesByType* class can be used through an objectified relationship. The similar type classes can be identified as the instances of *IfcBuildingElementType*.



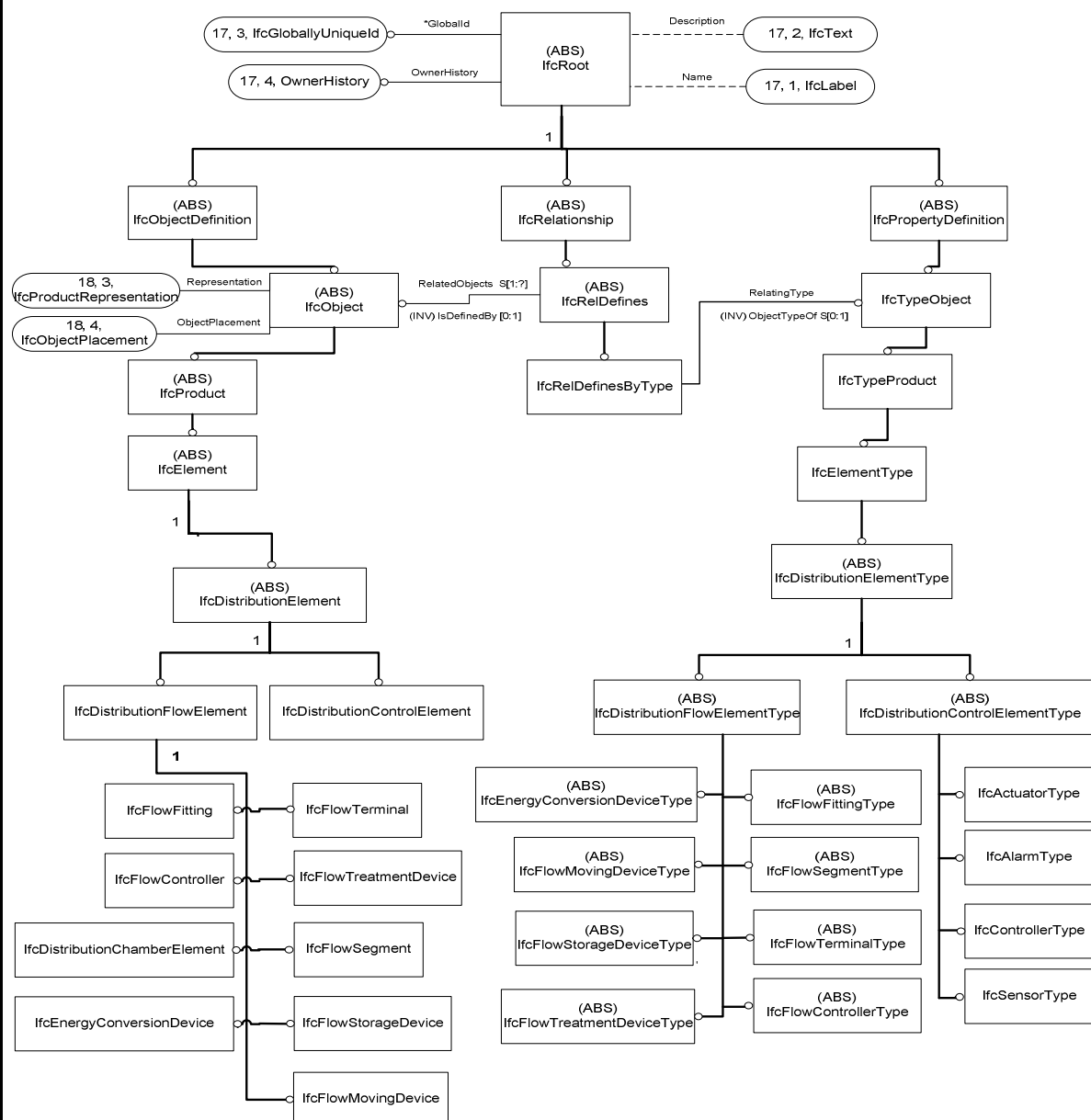
IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element					
Reference, Page	UMG-12, 12/3	Version	V-1	Status	Draft
Relationships	IfcBuildingElement			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Instantiation Definition: In this instantiation diagram, a typical building element with its occurrences are represented.</p> <p>Instantiation Details: In this instantiation, the instance of IfcWall (1) is generated with its related information. The wall is identified with additional classes as:</p> <ul style="list-style-type: none">• Owner History (2)• Grouping (3), (4)• Properties with property sets (5), (6), (7), (8)• Material information with material set. (9), (10), (11), (12), (13), (14)• Classification (15), (16), (17)					

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Distribution Element

Reference, Page	UMG-13, 13	Version	V-1	Status	Draft
Relationships	IfcDistributionElement			History	IfcRelease 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage View in Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show distribution elements structure and illustrates the relation of their type information according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Distribution Element					
Reference, Page	UMG-13, 13/1	Version	V-1	Status	Draft
Relationships	IfcDistributionElement			History	IfcRelease 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):

The distribution element IfcDistributionFlowElement defines occurrence elements of a distribution system that facilitate the distribution of energy or matter, such as air, water or power. The IfcDistributionFlowElement utilizes the following capabilities mainly through inverse references to objectified relationships:

- Grouping - being part of a logical group of objects
- Classification - assigned reference to an external classification
- Documentation - assigned reference to an external documentation
- Type - reference to the product type information for the element occurrence
- Properties - reference to all attached properties, including quantities
- Cost control - reference to cost elements associated with this distribution element
- Work processes - reference to work tasks, in which this distribution element participates
- Aggregation - aggregated together with other elements to form an aggregate
- Connection - connectivity to other elements, including the definition of the connection or joint.

The IfcDistributionFlowElement defines the occurrence of a distribution element within the spatial context of a project. The parameters that define the type of the distribution element and/or its shape are defined by the IfcDistributionFlowElementType subtypes, which is related by the inverse relationship IsDefinedBy pointing to IfcRelDefinesByType.

Entity Type Detailed Definition:

IfcDistributionElement class and its subtypes provide the hierarchy and different type of building services element objects. The IfcRelDefinesByType class associates type information to building services element through an objectified relationship. These classes are subtypes of IfcDistributionElementType.

These are defined as IfcDistributionFlowElement, IfcDistributionControlElement, IfcDistributionFlowElementType and IfcDistributionControlElementType classes.

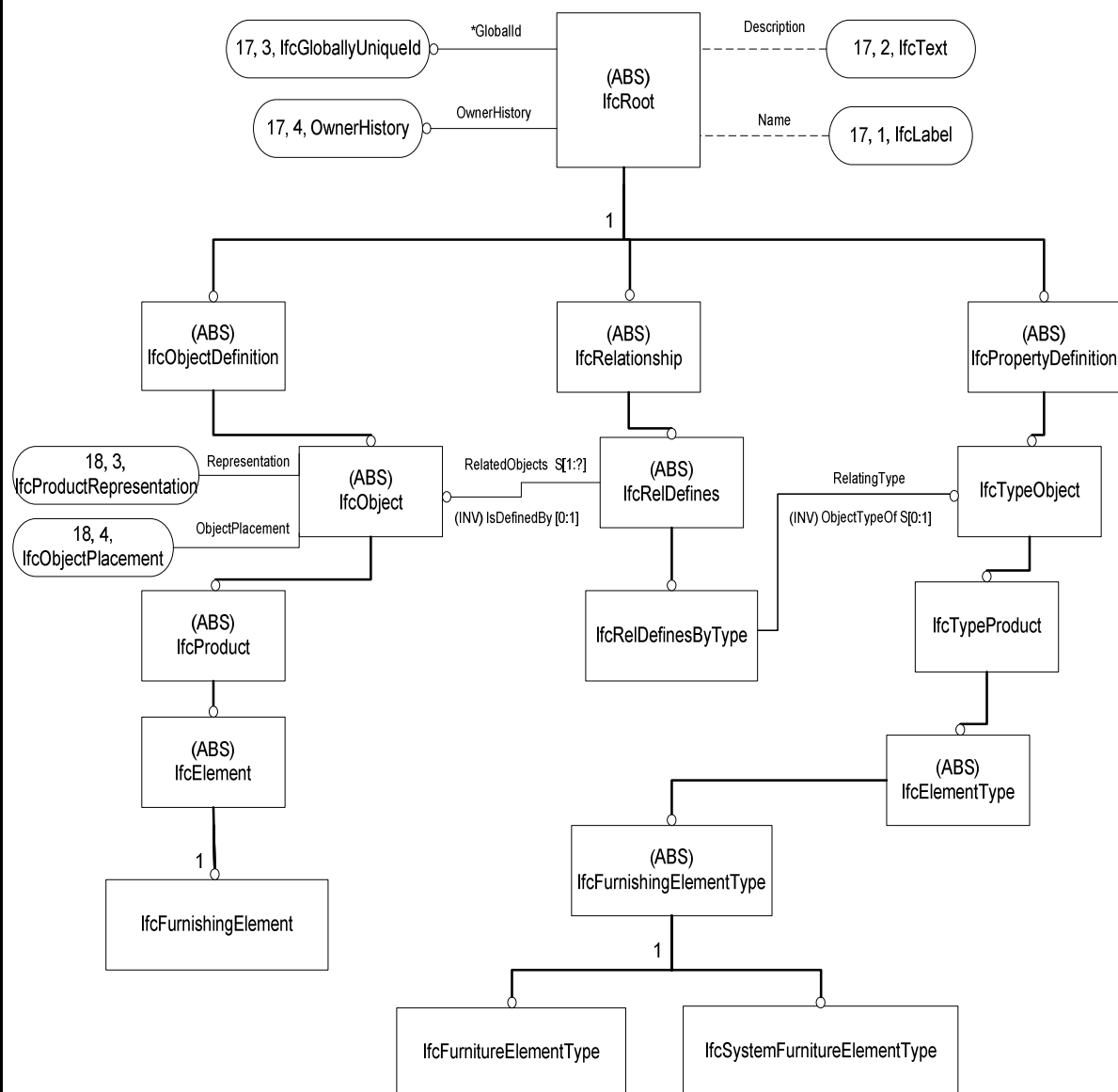
This concept does not include any instantiation diagram. The related instantiations are shown within Building Element Concept.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Furnishing Element

Reference, Page	UMG-14, 14	Version	V-1	Status	Draft
Relationships	IfcFurnishingElement			History	IfcRelease 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage View in Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show furnishing element structure and illustrates the relation of their type information according to IFC 2x3 specification.

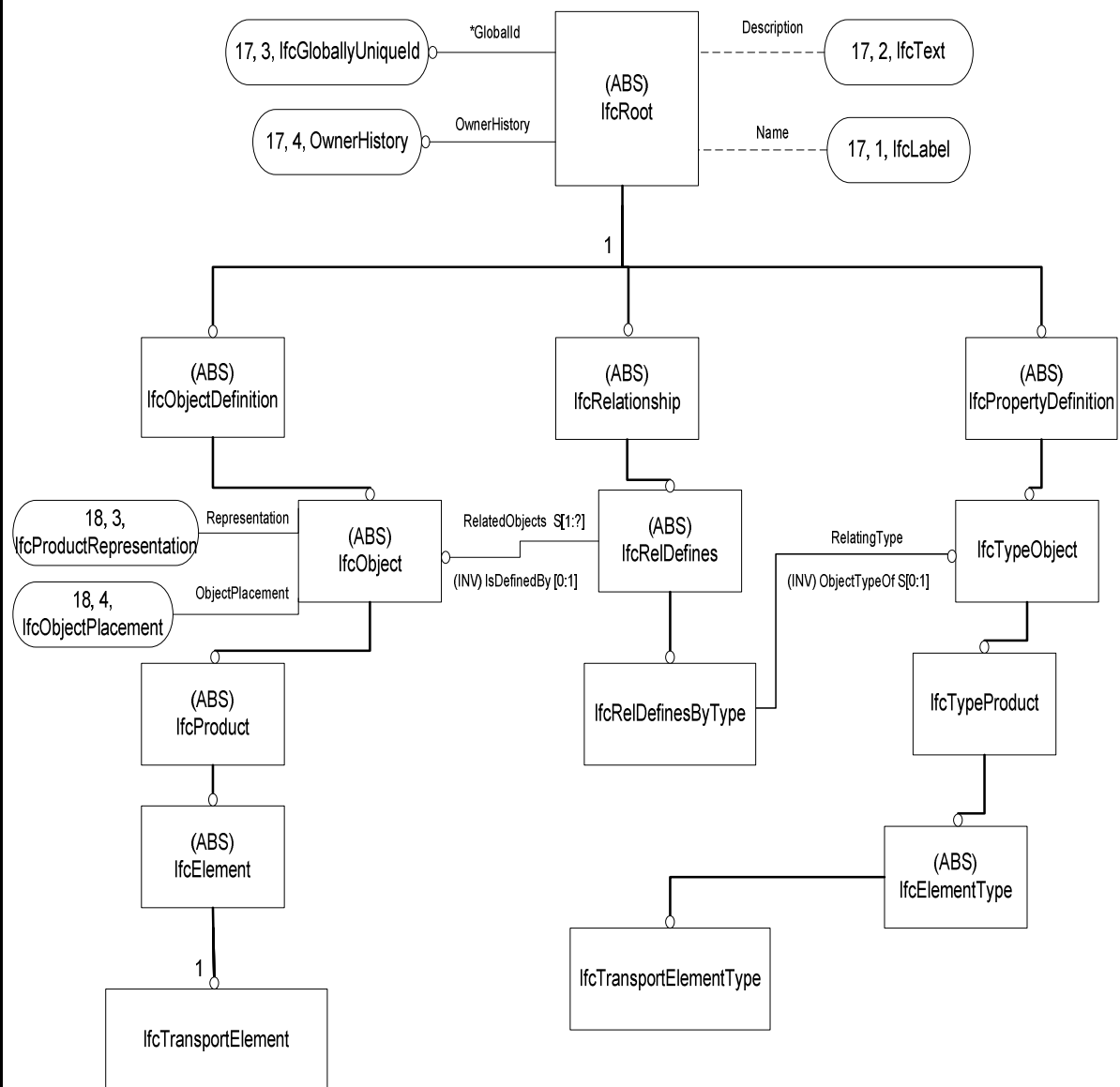
IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Furnishing Element					
Reference, Page	UMG-14, 14/1	Version	V-1	Status	Draft
Relationships	IfcFurnishingElement			History	IfcRelease 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI): Generalization of all furniture related objects. Furnishing objects are characterized as being pre-manufactured and assembled on-site, or manufactured on-site (built-in). Thus furnishing elements can either be movable, or not (as the built-ins). The element type (<i>IfcFurnishingElementType</i>) defines a list of commonly shared property set definitions of an element and an optional set of product representations. It is used to define an element specification (i.e. the specific product information, that is common to all occurrences of that product type). A furnishing element type is used to define the common properties of a certain type of a furnishing element that may be applied to many instances of that feature type to assign a specific style. Furnishing element types (or the instantiable subtypes) may be exchanged without being already assigned to occurrences. An <i>IfcFurnitureElementType</i> defines a particular type of item of furniture such as a table, desk, chair, filing cabinet etc.</p> <p>Entity Type Detailed Definition: <i>IfcFurnishingElement</i> class provides furniture related objects. The <i>IfcRelDefinesByType</i> class associates type information to furnishing element objects through an objectified relationship. In order to identify common properties of a certain type of a furnishing element <i>IfcFurnishingElementType</i> class as the subtype of <i>IfcElementType</i> class can be used. The subtypes as; <i>IfcFurnitureElementType</i> and <i>IfcFurnitureElementType</i> represent different type of items of furniture such as a table, desk etc. This concept does not include any instantiation diagram. The related instantiations are shown within Building Element Concept.</p>					

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Transport Elements

Reference, Page	UMG-15, 15	Version	V-1	Status	Draft
Relationships	IfcTransportElement			History	IfcRelease 2x
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Usage View in Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show transport element structure and illustrates the relation of their type information according to IFC 2x3 specification.

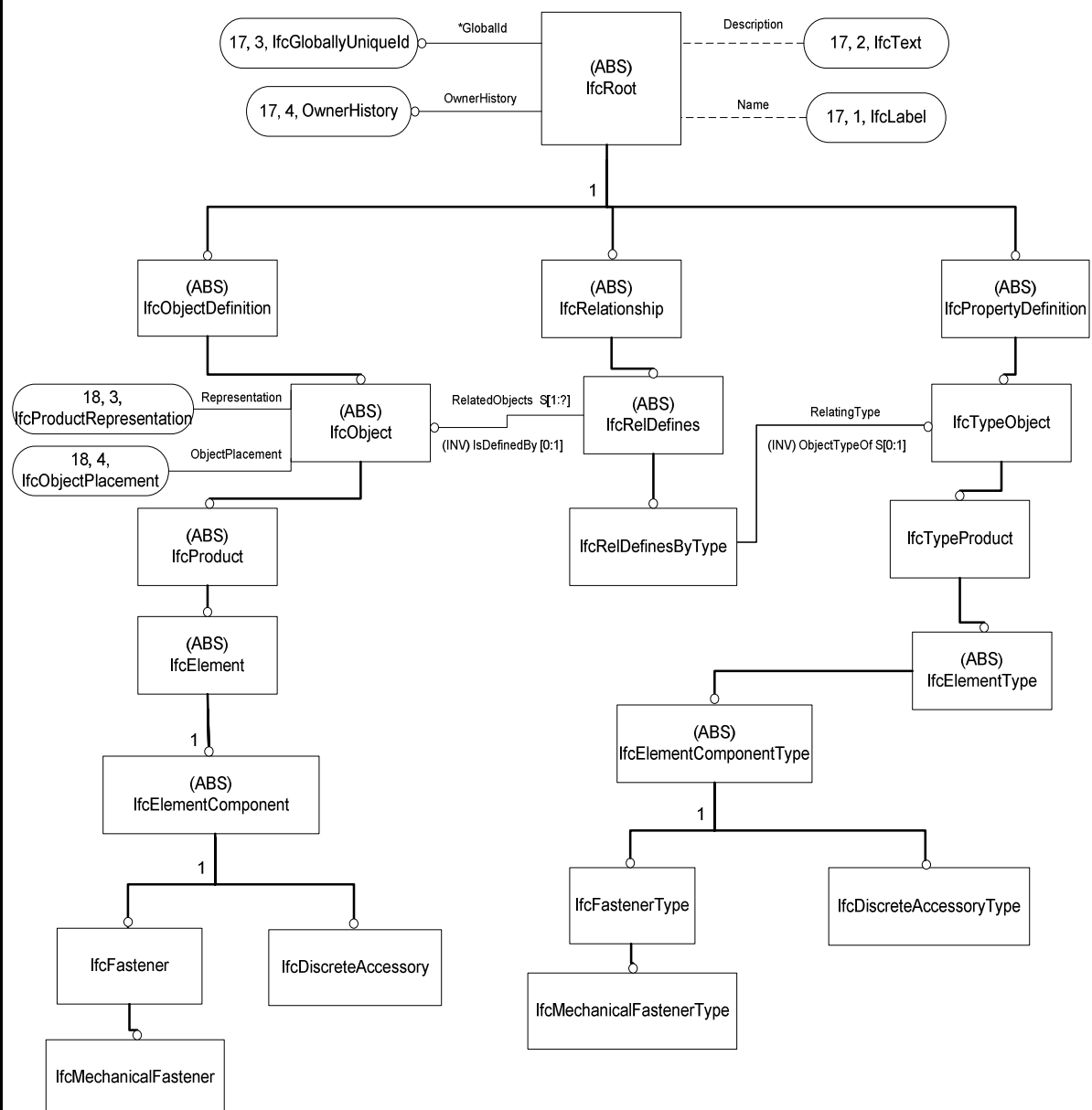
IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Transport Elements					
Reference, Page	UMG-15, 15/1	Version	V-1	Status	Draft
Relationships	IfcDistributionElement			History	IfcRelease 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI): Generalization of all transport related objects that move people, animals or goods within a building or building complex. The <i>IfcTransportElement</i> defines the occurrence of a covering type, that (if given) is expressed by the <i>IfcTransportElementType</i>. EXAMPLE: Transportation elements include elevator (lift), escalator, moving walkway, etc. The element type (<i>IfcTransportElementType</i>) defines a list of commonly shared property set definitions of an element and an optional set of product representations. It is used to define an element specification (i.e. the specific product information, that is common to all occurrences of that product type). A transport element type is used to define the common properties of a certain type of a transport element that may be applied to many instances of that type to assign a specific style. Transport element types (or the instantiable subtypes) may be exchanged without being already assigned to occurrences. The occurrences of the <i>IfcTransportElementType</i> are represented by instances of <i>IfcTransportElement</i> (or its subtypes).</p> <p>Entity Type Detailed Definition: The building elements are assigned their shape representation and location information through the inherited Representation and ObjectPlacement attributes. For type objects the common shape representation is given through the inherited RepresentationMaps attribute.</p>					

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Component Element

Reference, Page	UMG-16, 16	Version	V-1	Status	Draft
Relationships	IfcElementComponent			History	IfcRelease 2x2
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Usage View in Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show component elements structure and illustrates the relation of their type information according to IFC2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Component Element					
Reference, Page	UMG-16, 16/1	Version	V-1	Status	Draft
Relationships	IfcElementComponent			History	IfcRelease 2x2
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):

An element component is a representation for minor items included in, added to or connecting to or between elements, which usually are not of interest from the overall building structure viewpoint. However, these small parts may have vital and load carrying functions within the construction. These items do not provide any actual space boundaries. Typical examples of *IfcElementComponents* include different kinds of fasteners and various accessories.

The element type (*IfcElementComponentType*) represents the supertype for element types which define lists of commonly shared property set definitions of various small parts and accessories and an optional set of product representations. It is used to define a supporting element mainly within structural and building services domains (i.e. the specific type information common to all occurrences of that type).

Entity Type Detailed Definition:

IfcElementComponent class and its subtypes provides basic objects which are used to add or connect to or between elements. The *IfcRelDefinesByType* class associates element component type to element component’s information through an objectified relationship. In order to identify common properties of a certain type of a component element *IfcElementComponentType* class as the subtype of *IfcElementType* class can be used. The subtypes as: *IfcFastenerType*, *IfcDiscreteAccessoryType*, *IfcMechanicalFastenerType* represent different type of items of components.

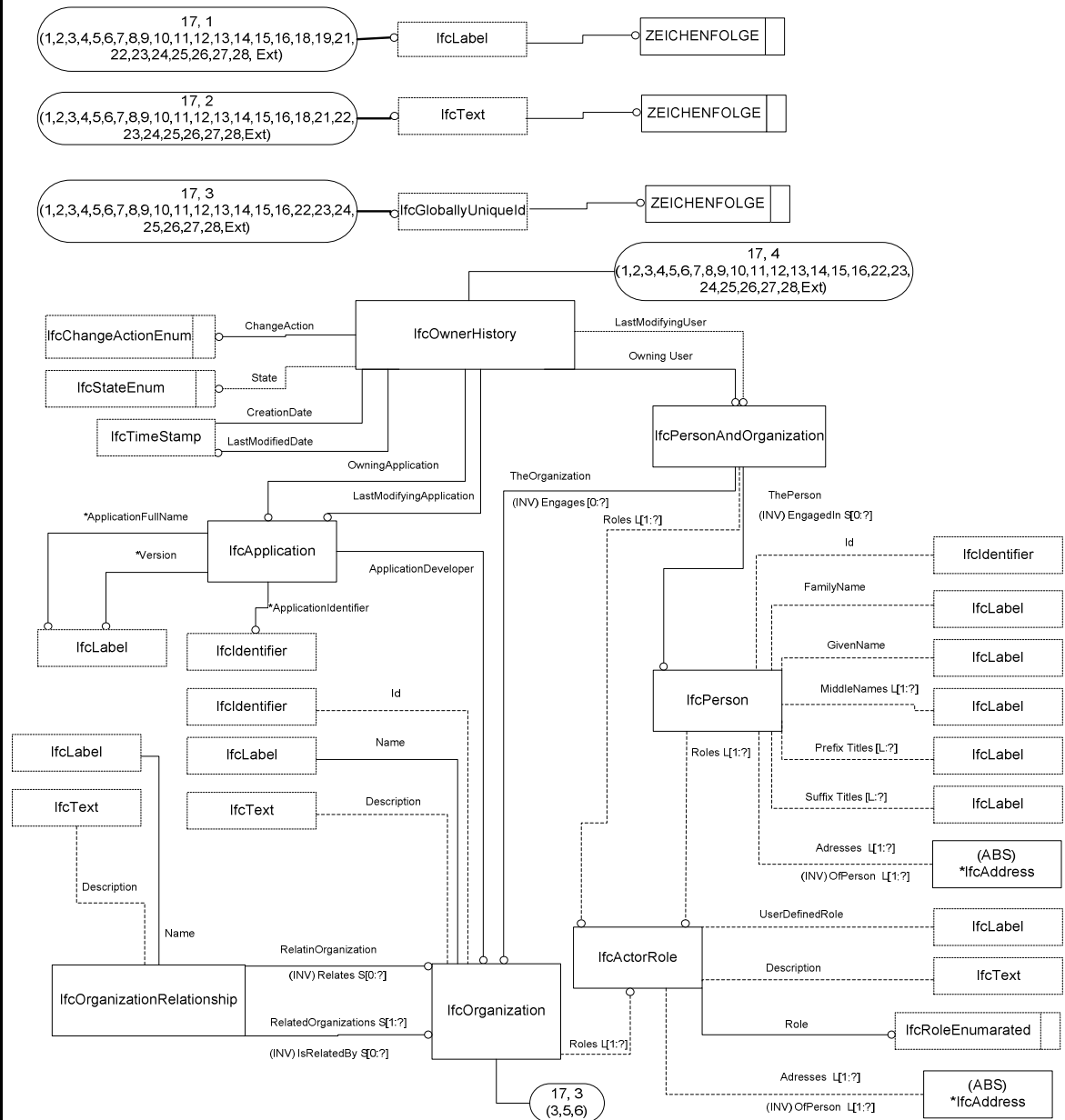
This concept does not include any instantiation diagram. The related instantiations are shown within Building Element Concept.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Reference Page-1

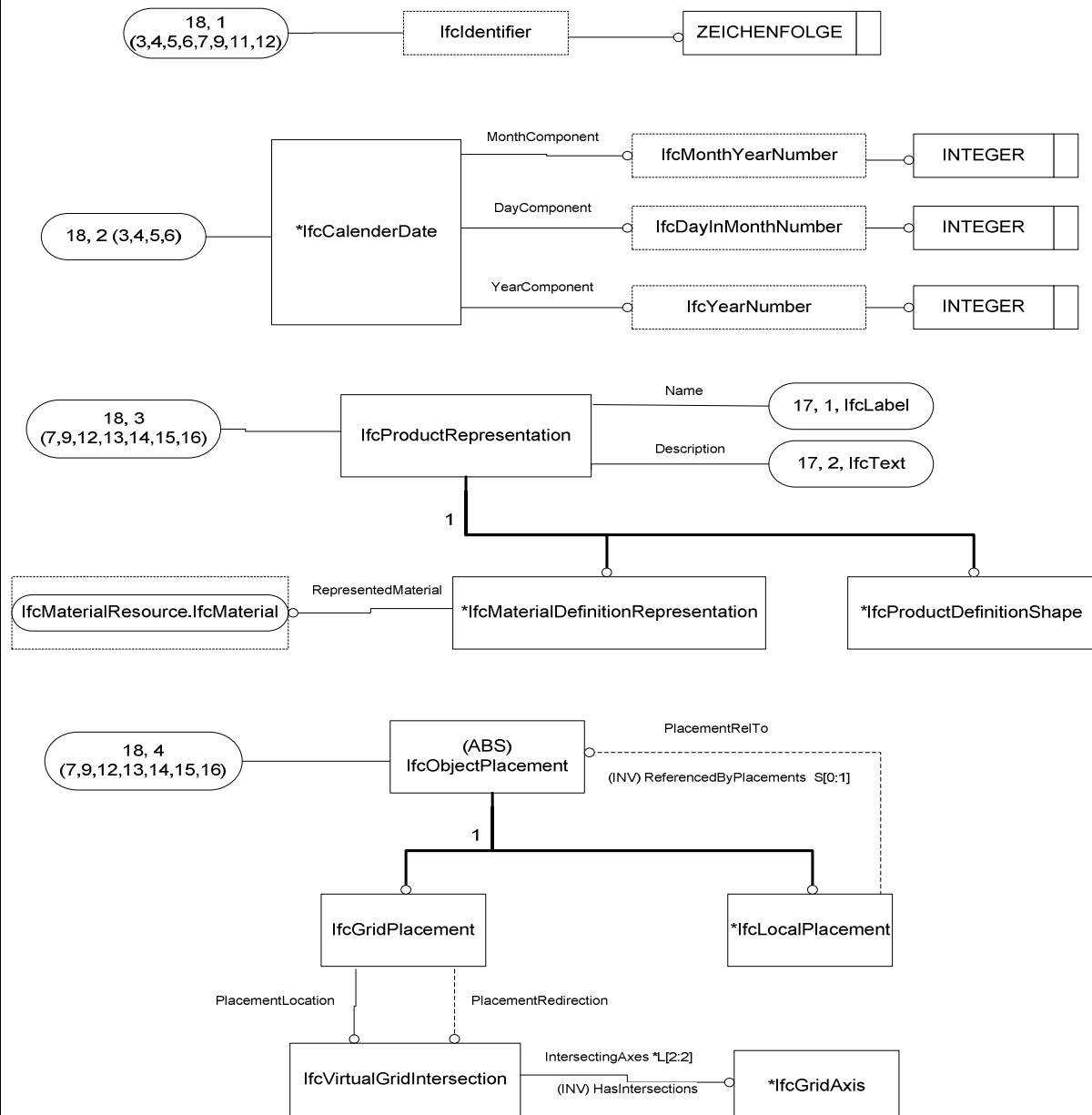
Reference, Page	UMG-17, 17	Version	V-1	Status	Draft
Relationships	IfcLabel, IfcText, IfcGloballyUniqueId, IfcOwnerHistory, IfcOrganization			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)**Reference Page-2**

Reference, Page	UMG-18, 18	Version	V-1	Status	Draft
Relationships	<i>IfcIdentifier, IfcCalenderDate, IfcProductRepresentation, IfcObjectPlacement</i>			History	--
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

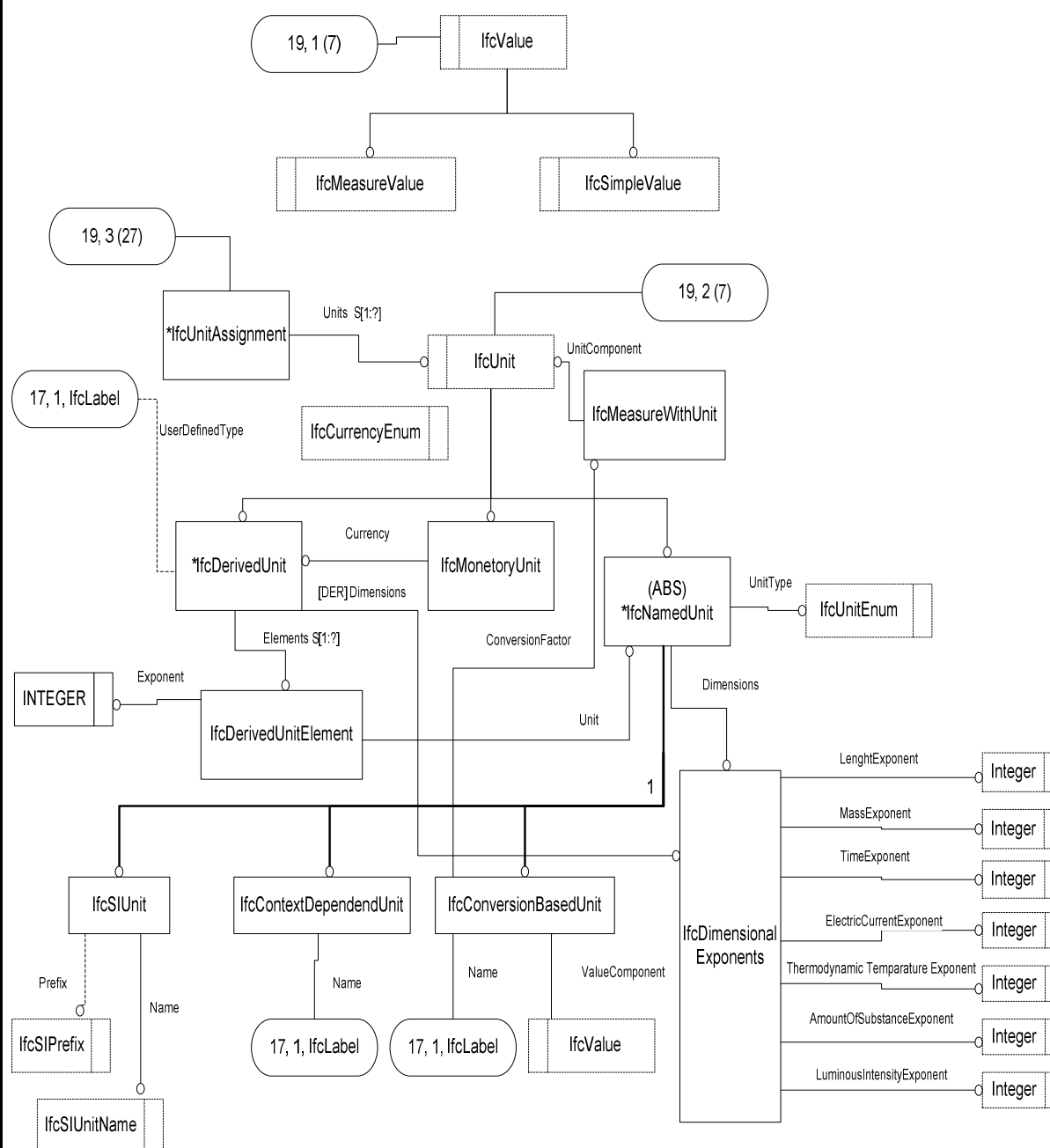
Usage in View Definition Diagram (EXPRESS G):

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Reference Page-3

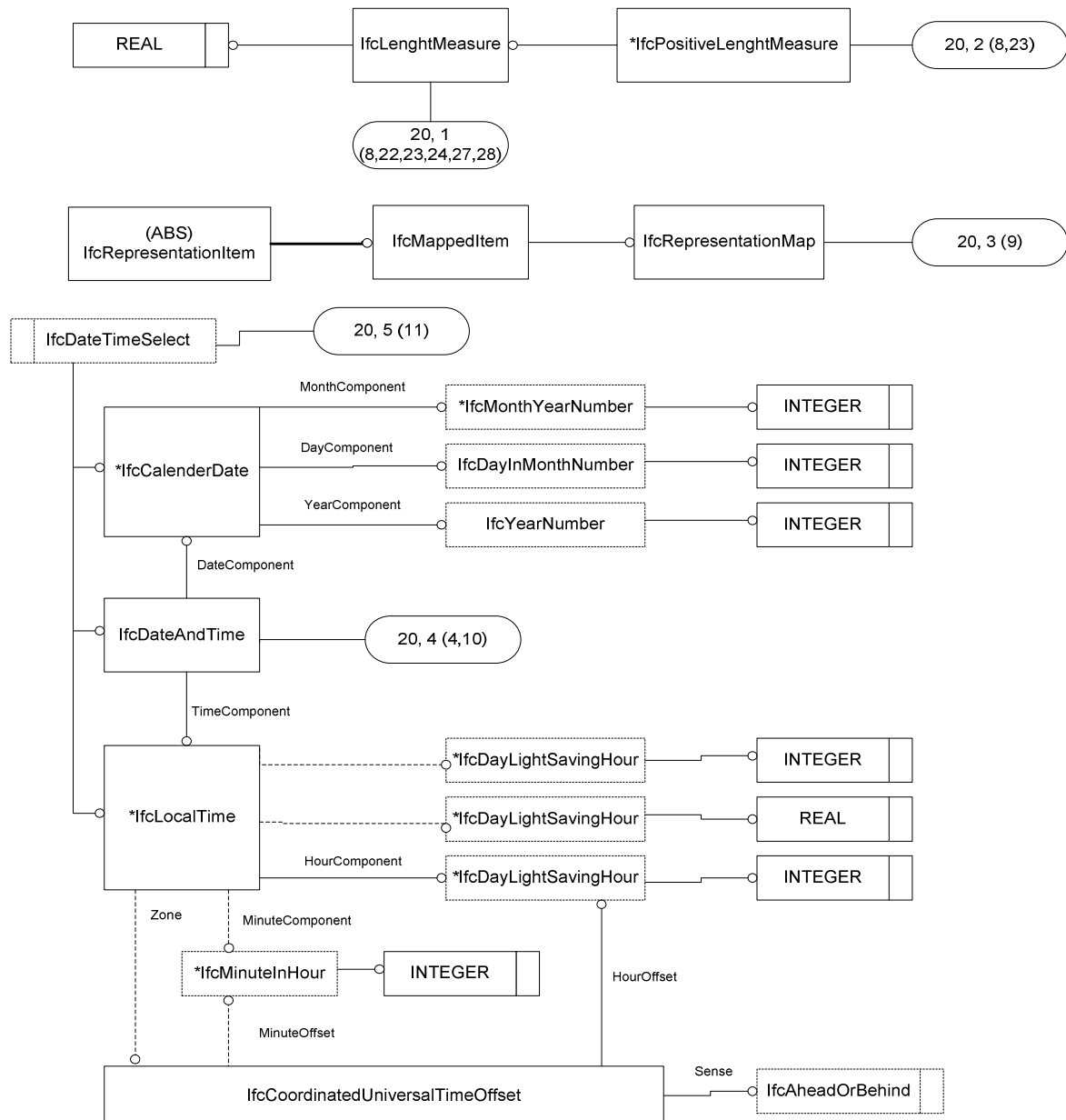
Reference, Page	UMG-19, 19	Version	V-1	Status	Draft
Relationships	IfcValue, IfcUnit			History	--
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)**Reference Page-4**

Reference, Page	UMG-20, 20	Version	V-1	Status	Draft
Relationships	<i>IfcLenghtMeasure, IfcPositiveLenghtMeasure, IfcDateAndTime</i>			History	--
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

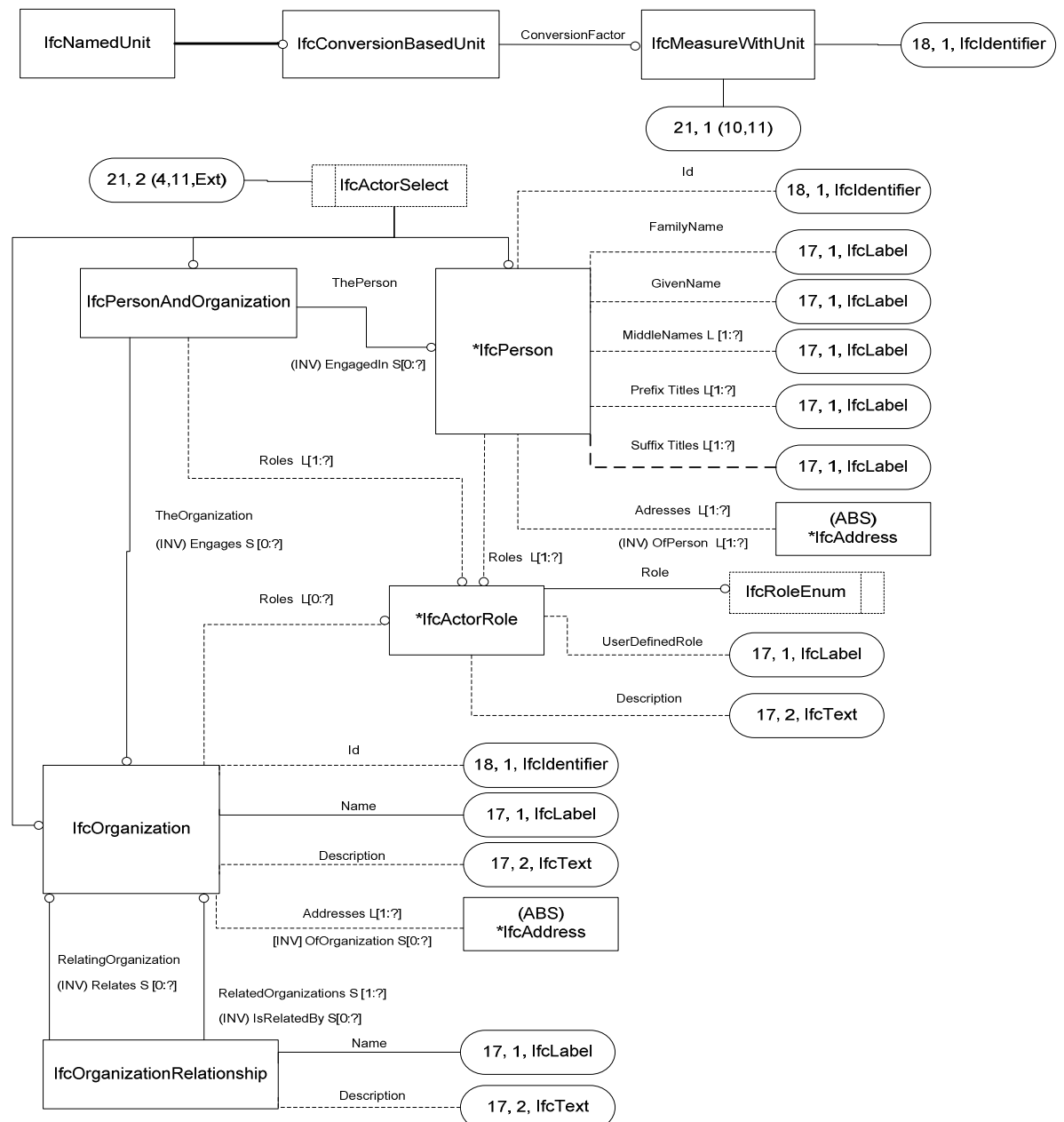
Usage in View Definition Diagram (EXPRESS G):

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Reference Page-5

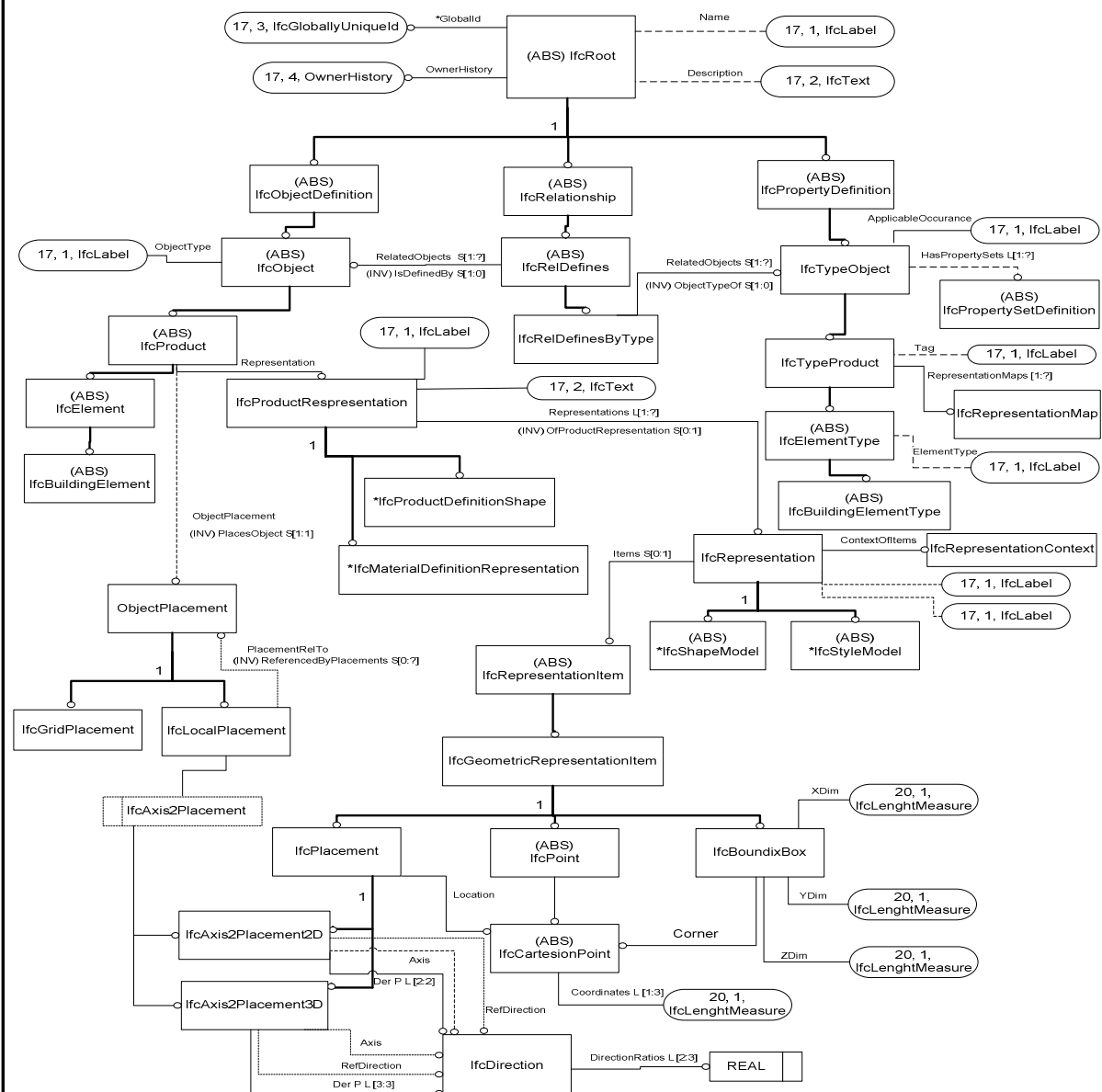
Reference, Page	UMG-21, 21	Version	V-1	Status	Draft
Relationships	IfcMeasureWithUnit, IfcActorSelect			History	--
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)**Building Element-Bounding Box**

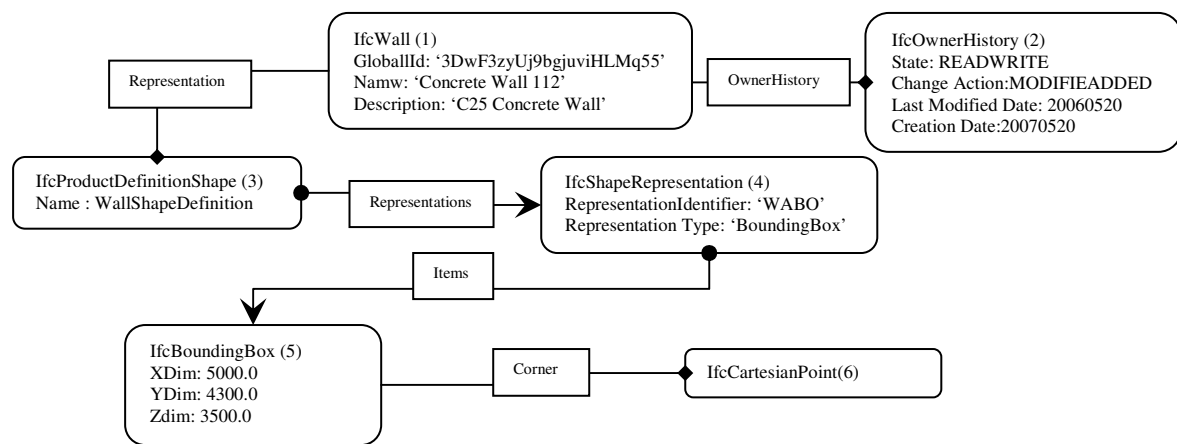
Reference, Page	UMG-22, 22	Version	V-1	Status	Draft
Relationships	IfcBoundingBox			History	Ifc Release 1.0
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):**Definition:**

This concept is formalized in order to show building element and its shape representation through the bounding box expression, according to the IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Building Element-Bounding Box					
Reference, Page	UMG-22, 22/1	Version	V-1	Status	Draft
Relationships	IfcBoundingBox			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI):</p> <p>Every semantic object having a physical extent might have a minimum default representation of a bounding box. The bounding box is therefore also used as minimal geometric representation for any geometrically represented object. Therefore the <i>IfcBoundingBox</i> is subtyped from <i>IfcGeometricRepresentationItem</i>.</p> <p><u>Definition from ISO/CD 10303-42:1992:</u> A box domain is an orthogonal box parallel to the axes of the geometric coordinate system which may be used to limit the domain of a half space solid. A box domain is specified by the coordinates of the bottom left corner, and the lengths of the sides measured in the directions of the coordinate axes.</p> <p>Entity Type Detailed Definition:</p> <p><i>IfcBoundingBox</i> is the main entity and subtype of <i>IfcGeometricRepresentationItem</i>. It facilitates representation of geometry which have three coordinate axes. It is identified by a corner point through the <i>Corner</i> attribute to an instance of <i>IfcCartesianPoint</i>. The attributes <i>Xdim</i>, <i>YDim</i> and <i>ZDim</i> provide lengths in three directions of the coordinate system as the type of <i>IfcLenghtMeasure</i>.</p>					

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element-Bounding Box					
Reference, Page	UMG-22, 22/2	Version	V-1	Status	Draft
Relationships	IfcBoundingBox			History	Ifc Release 1.0
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:**Instantiation Details:**

In this instantiation diagram a building element, 'wall' is illustrated with bounding box shape representation.

Instantiation Details:

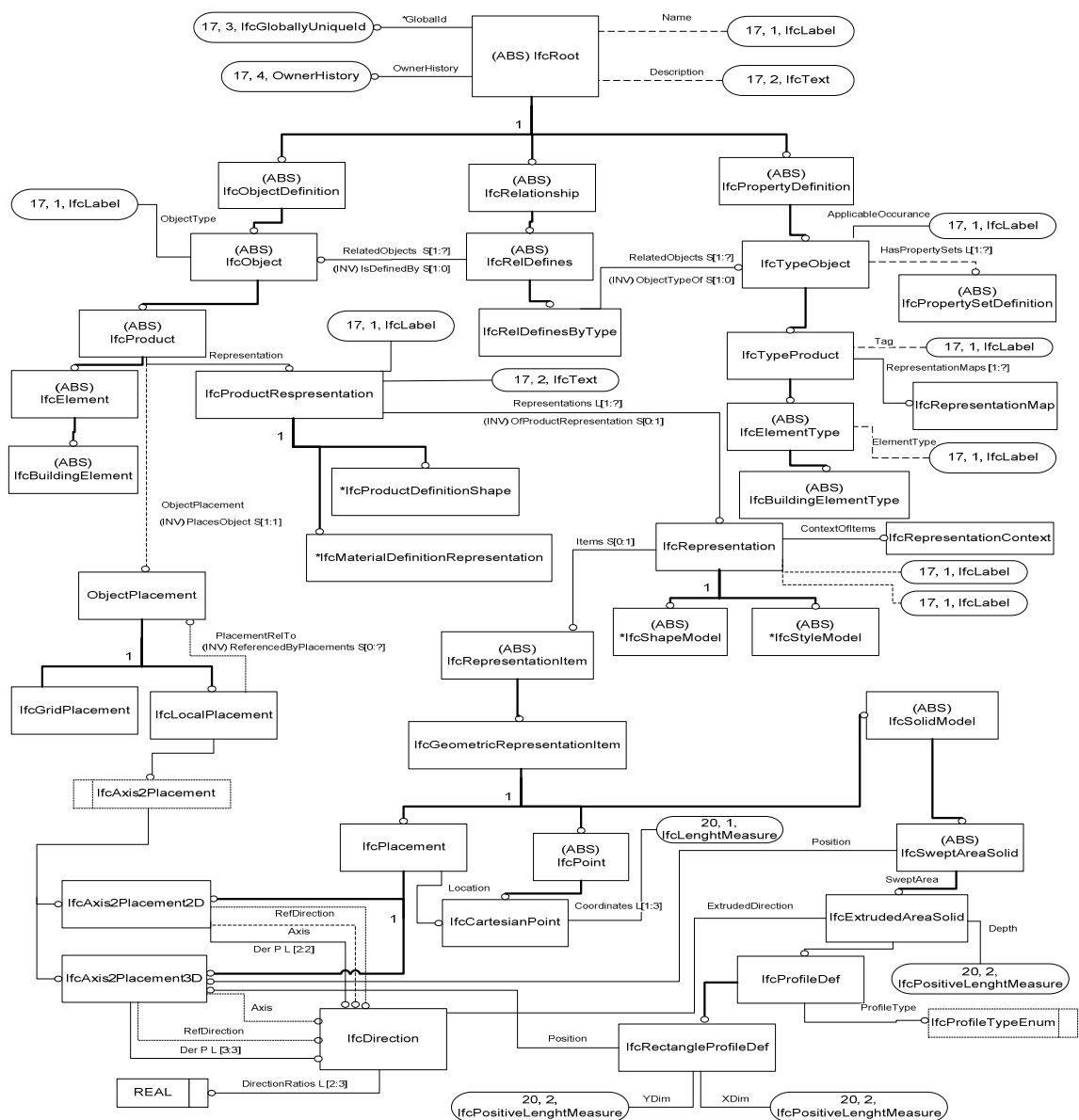
This instantiation diagram shows instance of *IfcWall* (1) and its representation via bounding box shape definition entities. *IfcWall* is associated directly with *Representation* attribute to an instance of *IfcProductDefinitionShape* (3) which keeps the instance of *IfcShapeRepresentation* (4). *IfcShapeRepresentation* keeps its *Items* attribute to an instance of *IfcBoundingBox* attribute (5) which also holds its *Corner* attribute to an instance of *IfcCartesianPoint* (6).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Building Element-Swept Area Solid

Reference, Page	UMG-23, 23	Version	V-1	Status	Draft
Relationships	IfcSweptAreaSolid			History	Ifc Release 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show building element and its shape representation through the swept shape expression, according to the IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element					
Reference, Page	UMG-23, 23/1	Version	V-1	Status	Draft
Relationships	IfcSweptAreaSolid			History	Ifc Release 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):

The swept area is defined by a cross section (also referred to as profile), which is given as a closed two-dimensional boundary on an implicit plane. The swept area is defined in the xy plane of the position coordinate system, which is given for the swept area solid.

The extruded area solid (*IfcExtrudedAreaSolid*) is defined by sweeping a bounded planar surface. The direction of the extrusion is given by the *ExtrudedDirection* attribute and the length of the extrusion is given by the *Depth* attribute. If the planar area has inner boundaries, i.e. holes defined, then those holes shall be swept into holes of the solid.

The *IfcProfileDef* is the supertype of all definitions of standard and arbitrary profiles within IFC. It is used to define a standard set of commonly used profiles by their parameters or by their explicit curve geometry. Those profile definitions are used within the geometry and geometric model resource to create either swept surfaces, swept area solids, or sectioned spines.

The purpose of the profile definition within the swept surfaces or swept area solids is to define a uniform cross section being swept:

along a line (extrusion) using *IfcSurfaceOfLinearExtrusion* or *IfcExtrudedAreaSolid*
along a circular arc (revolution) using *IfcSurfaceOfRevolution* or *IfcRevolvedAreaSolid*
along a directrix lying on a reference surface using *IfcSurfaceCurveSweptAreaSolid*

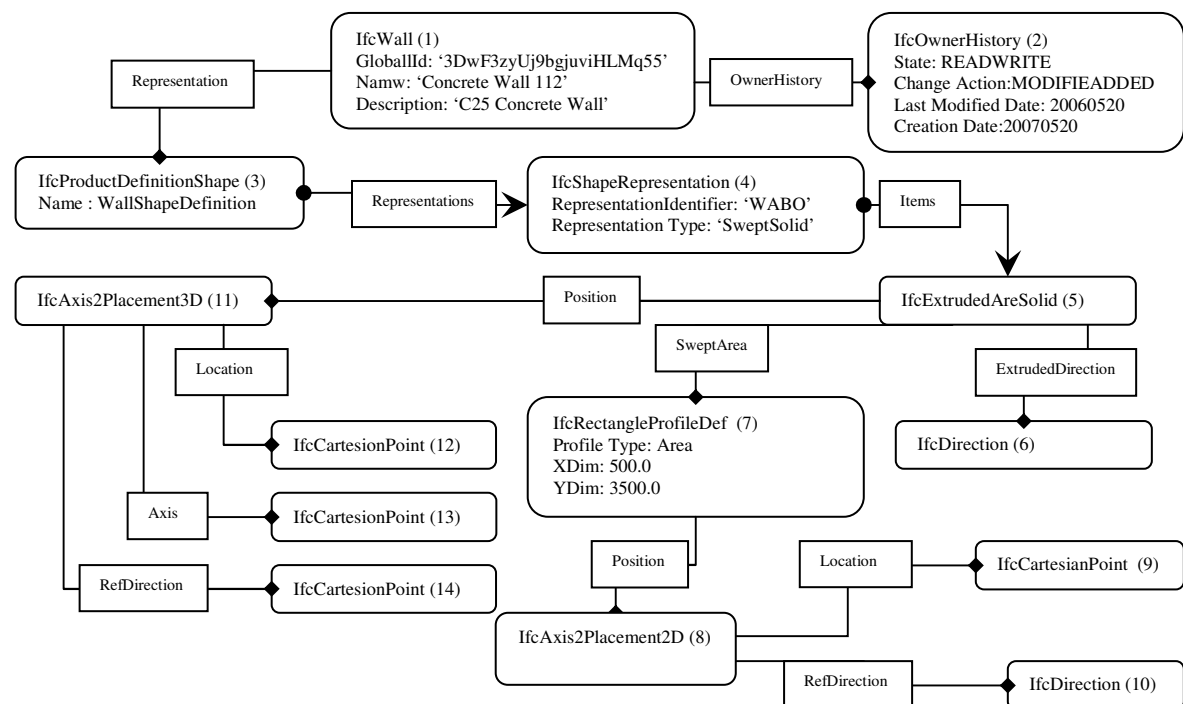
The purpose fo the profile definition within the sectioned spine is to define a varying cross sections at several positions along a spine curve. The subtype *IfcDerivedProfileDef* is particularly suited to provide the consecutive profiles to be based on transformations of the start profile and thus maintaining the identity of vertices and edges.

Entity Type Detailed Definition:

IfcSweptAreaSolid and *IfcExtrudedAreaSolid* are the main entities to represent cross section profile definition which extruded along a vector. These classes are the subtypes of *IfcGeometricRepresentationItem*. The extruded arae is represented via its swept area, position, direction and depth of extrusion. The position is represented through *Position* attribute and connects it to instance of *IfcAxis2Placement3D*. The swept area is represented through the attribute *SweptArea*, to be defined as a profile definition of type *IfcProfileDef* (Although there are several subtypes of *IfcProfileDef* is exist within IFC specification, only the *IfcRectangelProfileDef* is illustrated here). The direction is defined through *ExtrudedDirection* definition and connected to *IfcDirection* entity. These entities are subtype of *IfcProduct* which also provides to represent connection to building elements.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element-Swept Area Solid					
Reference, Page	UMG-23, 23/2	Version	V-1	Status	Draft
Relationships	IfcSweptAreaSolid			History	Ifc Release 1.0
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:



Instantiation Details:

In this instantiation diagram a building element, 'wall' is illustrated with extrusion shape representation.

Instantiation Details:

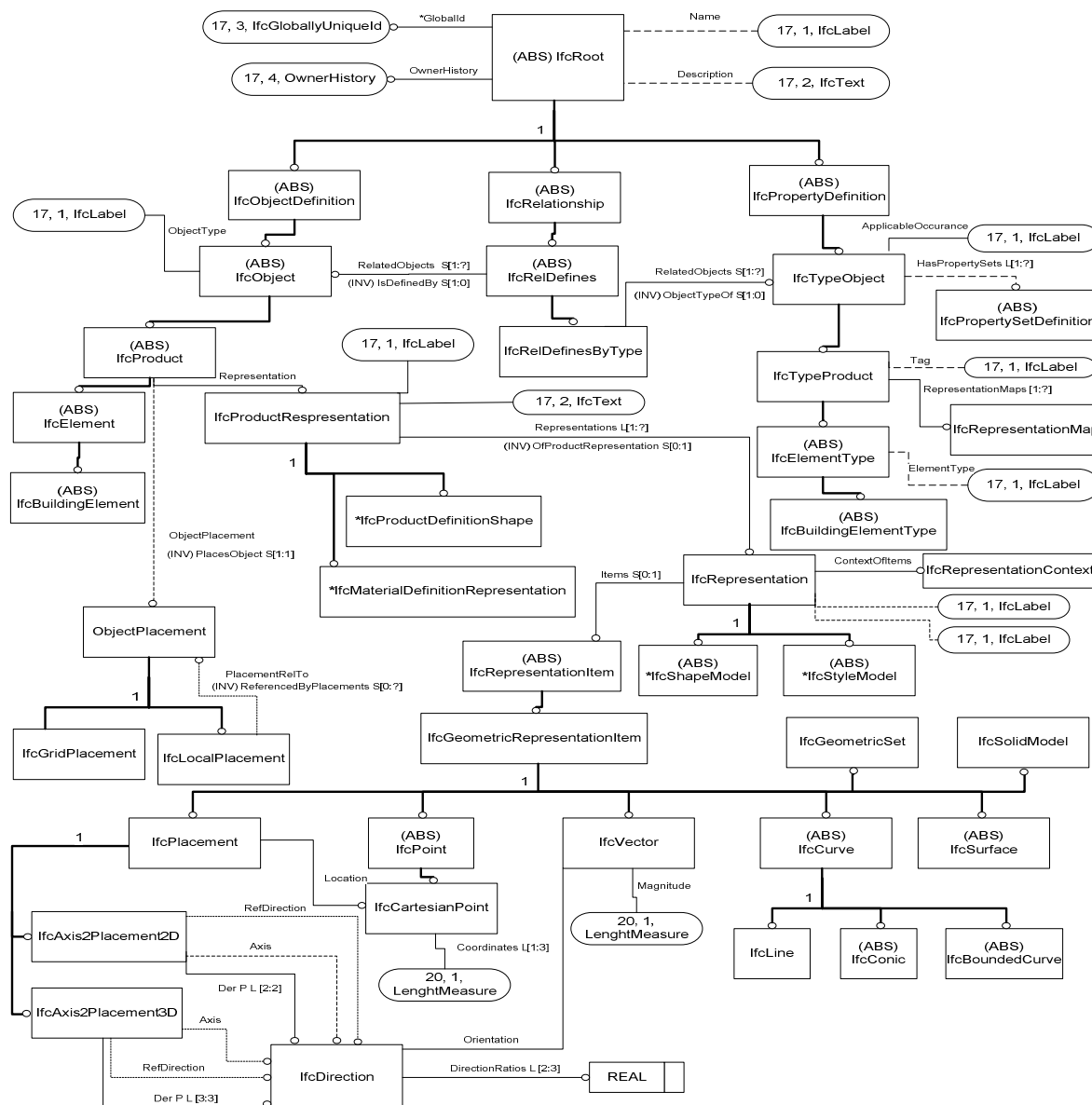
This instantiation diagram shows instance of *IfcWall* (1) and its representation via extrusion shape definition entities. *IfcWall* is associated directly with *Representation* attribute to instance of *IfcProductDefinitionShape* (3) which keeps the instance of *IfcShapeRepresentation* (4). *IfcShapeRepresentation* keeps its *Items* attribute an instance of *IfcExtrudedSolidArea* (5) which also holds its *Position* attribute an instance of *IfcAxis2placement3D* (11), its *SweptArea* attribute an instance of *IfcRectangleProfileDef* (7), and its *ExtrudedDirection* attribute an instance of *IfcDirection* (6).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Building Element-Geometric Representation Item

Reference, Page	UMG-24, 24	Version	V-1	Status	Draft
Relationships	IfcGeometricRepresentationItem			History	Ifc Release 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):

**Definition:**

This concept is formalized in order to show building element structure and its geometric representation, according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Building Element-Geometric Representation Item					
Reference, Page	UMG-24, 24/1	Version	V-1	Status	Draft
Relationships	IfcGeometricRepresentaitonItem			History	Ifc Release 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

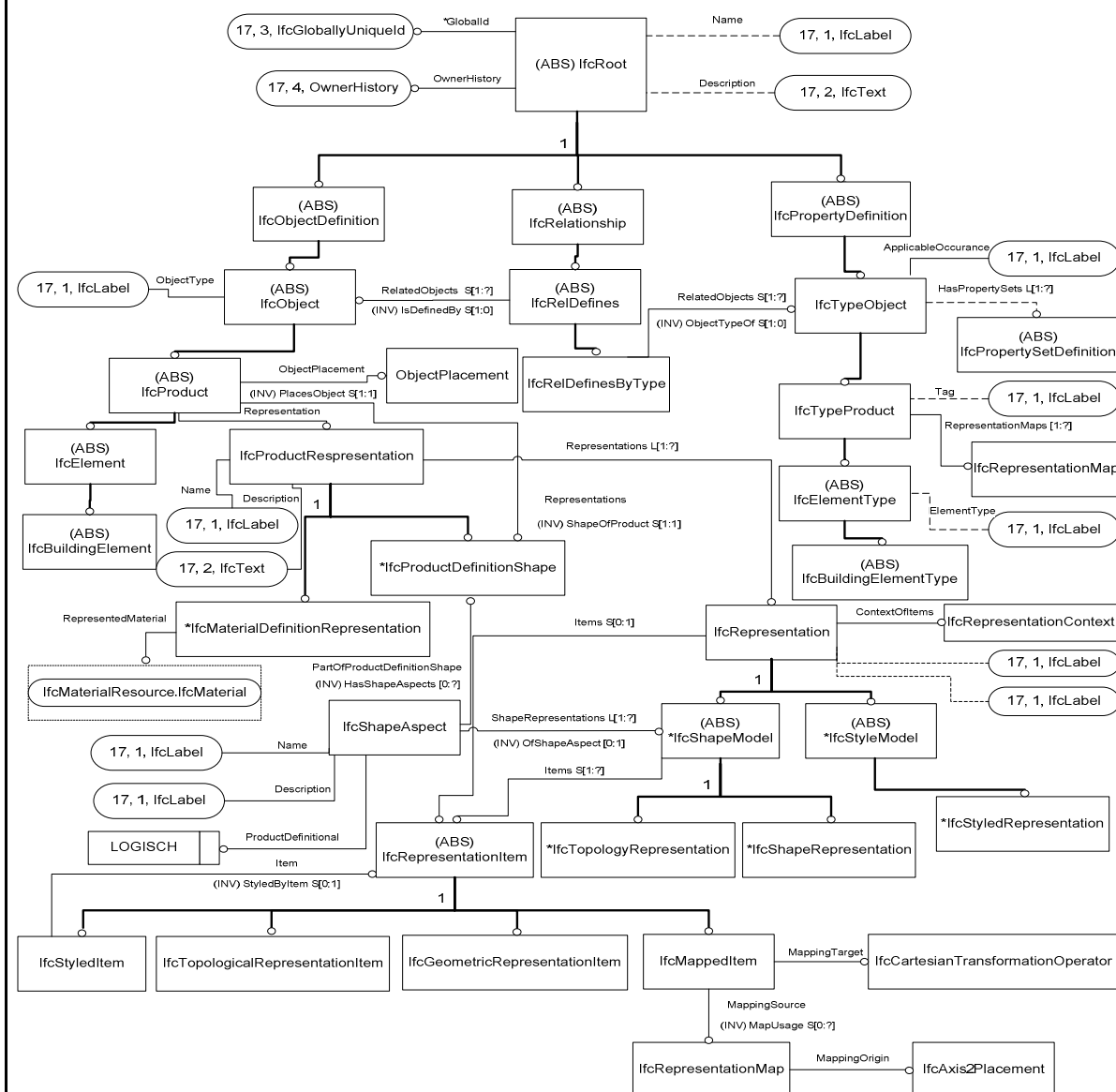
Entity Type Definition (Definition from IAI):
The derivation of the dimensionality of the *IfcGeometricRepresentationItem* is different to STEP, there is a specific derived attribute at each class that defines the dimensionality, whereas STEP does it for the representation_context and requires all geometric_representation_item's to have the same dimensionality therein.
The definition of swept area solids as goemetric representation items is different to STEP, it is based on a set of predefined profiles (or cross sections), i.e. a set of parameterized geometric primitives widely supported in the industry. Those profiles are used to create volumes through extrusion, revolution and cross section based sweep operations. This method was called attribute driven geometric representation and it was formerly known as implicit geometry in IFC.
NOTE: Corresponding STEP entity: geometric_representation_item. Please refer to ISO/IS 10303-42:1994, p. 22 for the final definition of the formal standard. The following changes have been made: It does not inherit from ISO/IS 10303-43:1994 entity representation_item. The derived attribute Dim is demoted to the appropriate subtypes. The WR1 has not been incorporated. Not all subtypes that are in ISO/IS 10303-42:1994 have been added to the current IFC Release.

Definition from ISO/CD 10303-43:1992: An geometric representation item is a representation item that has the additional meaning of having geometric position or orientation or both..

Entity Type Detailed Definition:
In order to formalize shape representations of *IfcProduct*, *IfcGeometricRepresentationItem* which defines dimensionality for each class attributes can be used. The geometric representation items as set of predefined profiles are used to derive volumes through, extrusion, revolution and cross section based sweep operations.
IfcPlacement is used to define the local environment for the definition of a geometry item. *IfcPoint* provides a location in some real Cartesian coordinate space R^m , for $m = 1, 2$ or 3 . *IfcVector* is defined in terms of the direction and magnitude of the vector. *IfcCurve* can be envisioned as the path of a point moving in its coordinate space. *IfcSurface* can be envisioned as a set of connected points in 3-dimensional space which is always locally 2-dimensional, but need not be a manifold. *IfcSolidModel* is a complete representation of the nominal shape of a product such that all points in the interior are connected. The *IfcGeometricSet* is used for the exchange of shape representations consisting of (2D or 3D) points, curves, and/or surfaces, which do not have a topological structure (such as connected face sets or shells) and are not solid models (such as swept solids, CSG or Brep). This concept does not include any instantiation diagram. The related instantiations are shown within Topological Representation Item concept.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)**Building Element-Representation Item**

Reference, Page	UMG-25, 25	Version	V-1	Status	Draft
Relationships	<i>IfcRepresentation, IfcRepresentationItem</i>			History	<i>Ifc Release 2x</i>
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	<i>1. Usage in View Definition Diagram</i>				

Usage in View Definition Diagram (EXPRESS G):**Definition:**

This concept is formalized in order to show building element and its representation through the representation item, according to the IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element-Representation Item					
Reference, Page	UMG-25, 25/1	Version	V-1	Status	Draft
Relationships	IfcRepresentation, IfcRepresentationItem			History	Ifc Release 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):
The *IfcRepresentation* defines the general concept of representing product properties.
Definition from ISO/CD 10303-43:1992: A representation is one or more representation items that are related in a specified representation context as the representation of some concept.
The *IfcRepresentationItem* is used within (and only within - directly or indirectly through other *IfcRepresentationItem*'s or *IfcShapeAspect*'s) an *IfcRepresentation* to represent an *IfcProductRepresentation*. Most commonly these *IfcRepresentationItem*'s are geometric or topological representation items, that can (but not need to) have presentation style information assigned.
Definition from ISO/CD 10303-43:1992: A representation item is an element of product data that participates in one or more representations or contributes to the definition of another representation item. A representation item contributes to the definition of another representation item when it is referenced by that representation item.

Entity Type Detailed Definition:
IfcRepresentation entity provides to represent all subtypes of *IfcProduct* such *IfcBuildingElements*. The *Representation* attribute connects *IfcProductRepresentation* and its subtypes, such as *IfcProductDefinitionShape* to an instance of *IfcRepresentation*. *IfcRepresentation* can be a shape which is represented by *IfcShapeRepresentation*, or topology which is represented by *IfcTopologyRepresentation* or styled which is represented by *IfcStyledRepresentation*. Each of them consist of representation items through the *Items* attribute. These items can be styled, geometric, topological and mapped items which together constitute the specific representation item.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element-Representation Item					
Reference, Page	UMG-25, 25/2	Version	V-1	Status	Draft
Relationships	IfcRepresentation, IfcRepresentationItem			History	Ifc Release 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:

```
graph TD
    Rep[Representation] --- IfcWall["IfcWall (1)  
GlobalId: '3DwF3zyUj9bgjuviHLMq55'  
Namw: 'Concrete Wall 112'  
Description: 'C25 Concrete Wall'"]
    IfcWall --- OwnerHistory["IfcOwnerHistory (2)  
State: READWRITE  
Change Action:MODIFIED  
Last Modified Date: 20060520  
Creation Date:20070520"]
    Rep --- IfcProductDefinitionShape["IfcProductDefinitionShape (3)  
Name : WallShapeDefinition"]
    IfcProductDefinitionShape --- Reps[Representations]
    Reps --> IfcShapeRepresentation4["IfcShapeRepresentation (4)  
RepresentationIdentifier: 'WASS'  
Representation Type: 'SweptSolid'"]
    Reps --> IfcShapeRepresentation5["IfcShapeRepresentation (5)  
RepresentationIdentifier: 'WABB'  
Representation Type: 'Bounding Box'"]
```

The diagram illustrates the instantiation of a building element 'wall'. It shows the following components and their relationships:

- Representation** (box) is connected to **IfcWall (1)** (box) and **IfcProductDefinitionShape (3)** (box).
- IfcWall (1)** is connected to **OwnerHistory** (box), which is then connected to **IfcOwnerHistory (2)** (box).
- IfcProductDefinitionShape (3)** is connected to **Representations** (box).
- Representations** is connected to **IfcShapeRepresentation (4)** (box) and **IfcShapeRepresentation (5)** (box).

IfcWall (1) details:
GlobalId: '3DwF3zyUj9bgjuviHLMq55'
Namw: 'Concrete Wall 112'
Description: 'C25 Concrete Wall'

IfcOwnerHistory (2) details:
State: READWRITE
Change Action:MODIFIED
Last Modified Date: 20060520
Creation Date:20070520

IfcProductDefinitionShape (3) details:
Name : WallShapeDefinition

IfcShapeRepresentation (4) details:
RepresentationIdentifier: 'WASS'
Representation Type: 'SweptSolid'

IfcShapeRepresentation (5) details:
RepresentationIdentifier: 'WABB'
Representation Type: 'Bounding Box'

Instantiation Details:

In this instantiation diagram a building element, ‘wall’ is illustrated with shape representations.

Instantiation Details:

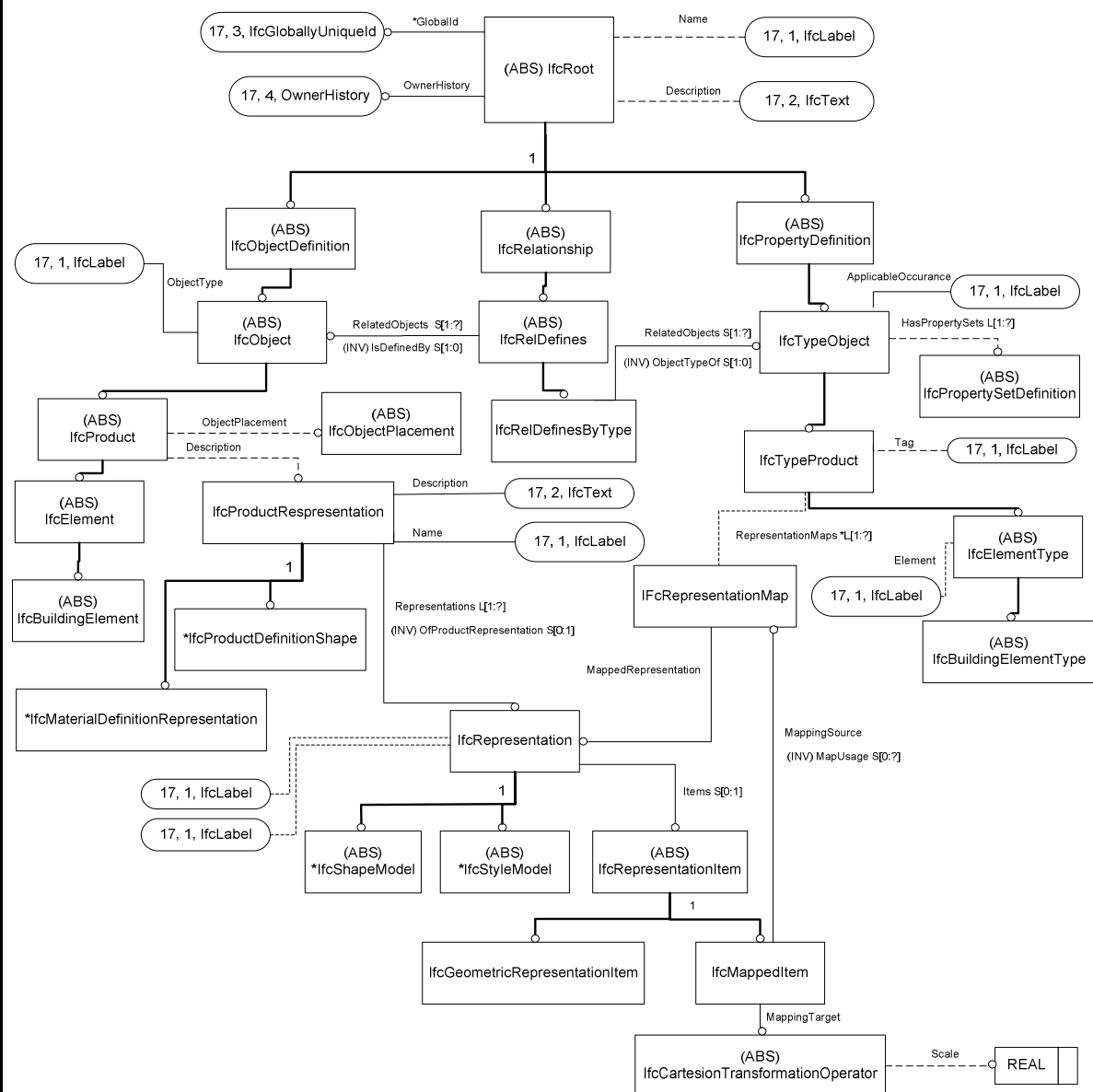
This instantiation diagram shows instance of *IfcWall* (1) and its shape representations. *IfcWall* is associated directly with *Representation* attribute to an instance of *IfcProductDefinitionShape* (3) which keeps the instance of *IfcShapeRepresentations* (4) (5).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Building Element-Representation Map

Reference, Page	UMG-26, 26	Version	V-1	Status	Draft
Relationships	IfcRepresentationMap			History	Ifc Release 2x
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

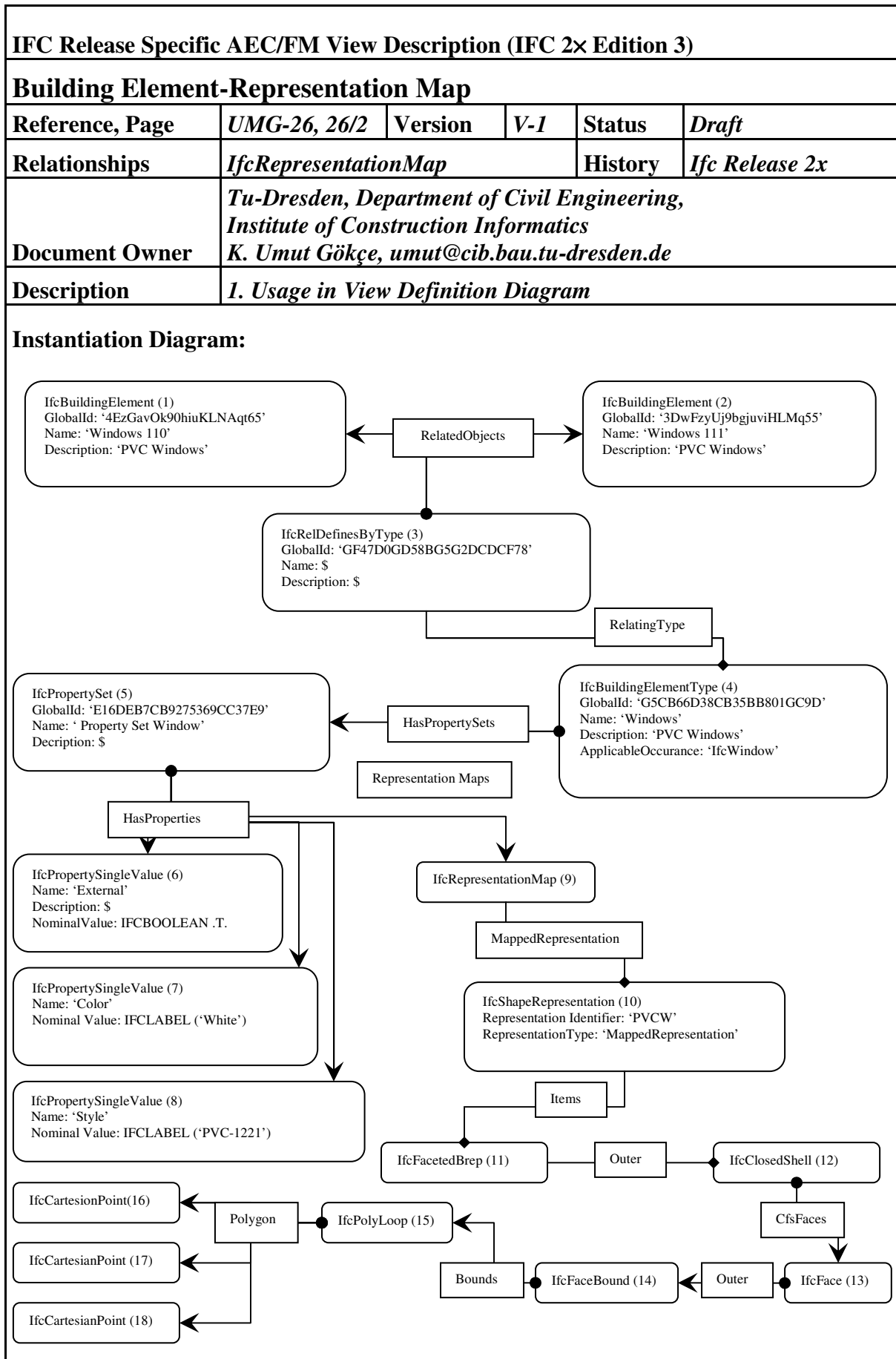
Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show building element structure and its shape via representation map according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element-Representation Map					
Reference, Page	UMG-26, 26/1	Version	V-1	Status	Draft
Relationships	IfcRepresentationMap			History	Ifc Release 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Entity Type Definition (Definition from IAI): An <i>IfcRepresentationMap</i> defines the base definition (also referred to as block, cell or macro) within the mapping origin, defined as the placement coordinate system. The representation map is restricted to Cartesian mapping. NOTE: Corresponding STEP entity: representation_map. Please refer to ISO/IS 10303-43:1994, for the final definition of the formal standard. The following changes have been made: The mapping_origin (MappingOrigin) is constrained to be of type axis2_placement (<i>IfcAxis2Placement</i>). <u>Definition from ISO/CD 10303-43:1992:</u> A representation map is the identification of a representation and a representation item in that representation for the purpose of mapping. The representation item defines the origin of the mapping. The representation map is used as the source of a mapping by a mapped item. NOTE: The definition of a mapping which is used to specify a new representation item comprises a representation map and a mapped item entity. Without both entities, the mapping is not fully defined. Two entities are specified to allow the same source representation (representation.map.mapped_representation) to be mapped into multiple new representations (mapped_item). Entity Type Detailed Definition: In order to define shape, reused it and to avoid unnecessary repetition, Representation Map is possessed. The <i>IfcMappedItem</i> which is the main class, supports representation of the supplement occurrence of a specific item which is referenced through the <i>MappingSource</i> attribute. This connect <i>IfcMappedItem</i> to <i>IfcRepresentationMap</i> instance. The <i>IfcRepresentationMap</i> referenced through <i>MappedRepresentation</i> attribute to a shape in this context.</p>					



IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Building Element-Representation Map					
Reference, Page	UMG-26, 26/3	Version	V-1	Status	Draft
Relationships	IfcRepresentationMap			History	Ifc Release 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Definition:
In this instantiation diagram, two windows occurrences which have common properties and shape are illustrated through building element type object.

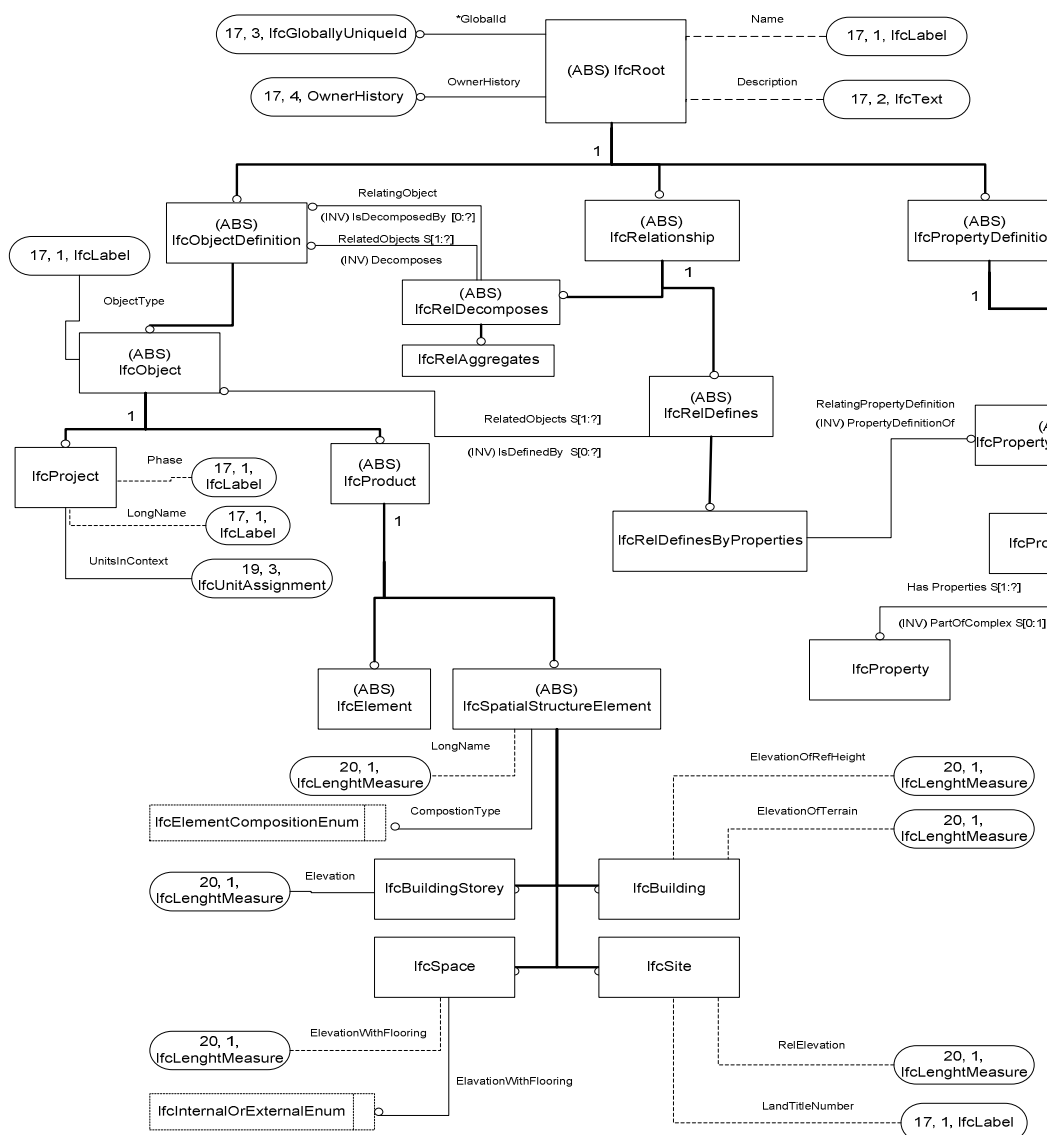
Instantiation Details:
This instantiation diagram illustrates two windows, as two instances of *IfcBuildingElement* (1), (2). The connection of type object are set-up through an objectified relationship to instance of *IfcRelDefinesByType* (3). *IfcBuildingElementType* illustrates common properties and shape with *IfcPropertySet* type named ‘Property Set Window’. This formalized to illustrate type of *IfcPropertySingle* values instances named ‘External’ (6), ‘Color’ (7), ‘Style’ (8). The shape of the Windows are represented through the representation map instances as *IfcRepresentationMap* (9), *IfcShapeRepresentation* (10), *IfcFacetedBrep* (11), *IfcClosedShell* (12), *IfcFace* (13), *IfcFaceBound* (14), *IfcPolyLoop* (15) and instances of *IfcCartesianPoint* (16), (17), (18).

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Spatial Elements

Reference, Page	UMG-27, 27	Version	V-1	Status	Draft
Relationships	IfcSpatialStructureElement			History	Ifc Release 2x
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):



Definition:

This concept is formalized in order to show Spatial Elements and illustrates the relation to their property information according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Spatial Elements					
Reference, Page	UMG-27, 27/1	Version	V-1	Status	Draft
Relationships	IfcBuildingElement			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):

A spatial structure element (*IfcSpatialStructureElement*) is the generalization of all spatial elements that might be used to define a spatial structure. That spatial structure is often used to provide a project structure to organize a building project.

A spatial project structure might define as many levels of decomposition as necessary for the building project. Elements within the spatial project structure are:

- site as *IfcSite*
- building as *IfcBuilding*
- storey as *IfcBuildingStorey*
- space as *IfcSpace*

or aggregations or parts thereof.

The composition type declares an element to be either an element itself, or an aggregation (complex) or a decomposition (part). The interpretation of these types is given at each subtype of *IfcSpatialStructureElement*.

The *IfcRelAggregates* is defined as an 1-to-many relationship and used to establish the relationship between exactly two levels within the spatial project structure. Finally the highest level of the spatial structure is assigned to *IfcProject* using the *IfcRelAggregates*.

Informal proposition:

- The spatial project structure, established by the *IfcRelAggregates*, shall be acyclic.
- A site should not be (directly or indirectly) associated to a building, storey or space.
- A building should not be (directly or indirectly) associated to a storey or space.
- A storey should not be (directly or indirectly) associated to a space.

Entity Type Detailed Definition:

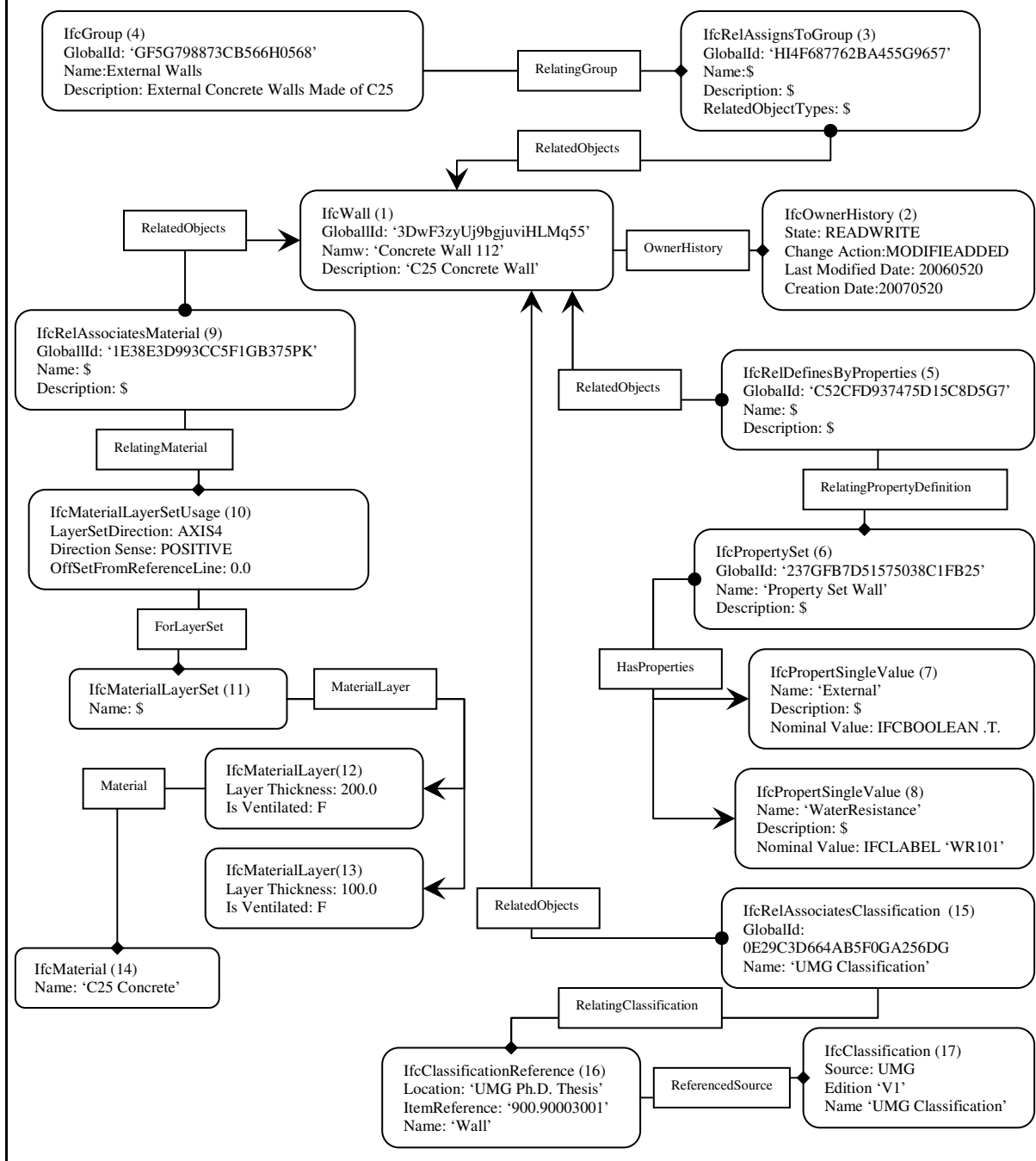
The *IfcSpatialStructureElement* provides elements within the spatial project structure. The subtypes are composed of *IfcSite* (building site), *IfcBuilding* (buildings), *IfcBuildingStorey* (storeys of a building), and *IfcSpace* which represents spaces. The subsequent decomposition is provided via instance of *IfcRelAggreagates* entity.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Spatial Elements

Reference, Page	UMG-27, 27/2	Version	V-1	Status	Draft
Relationships	IfcBuildingElement			History	Ifc Release 1.0
Document Owner	<i>Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de</i>				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:



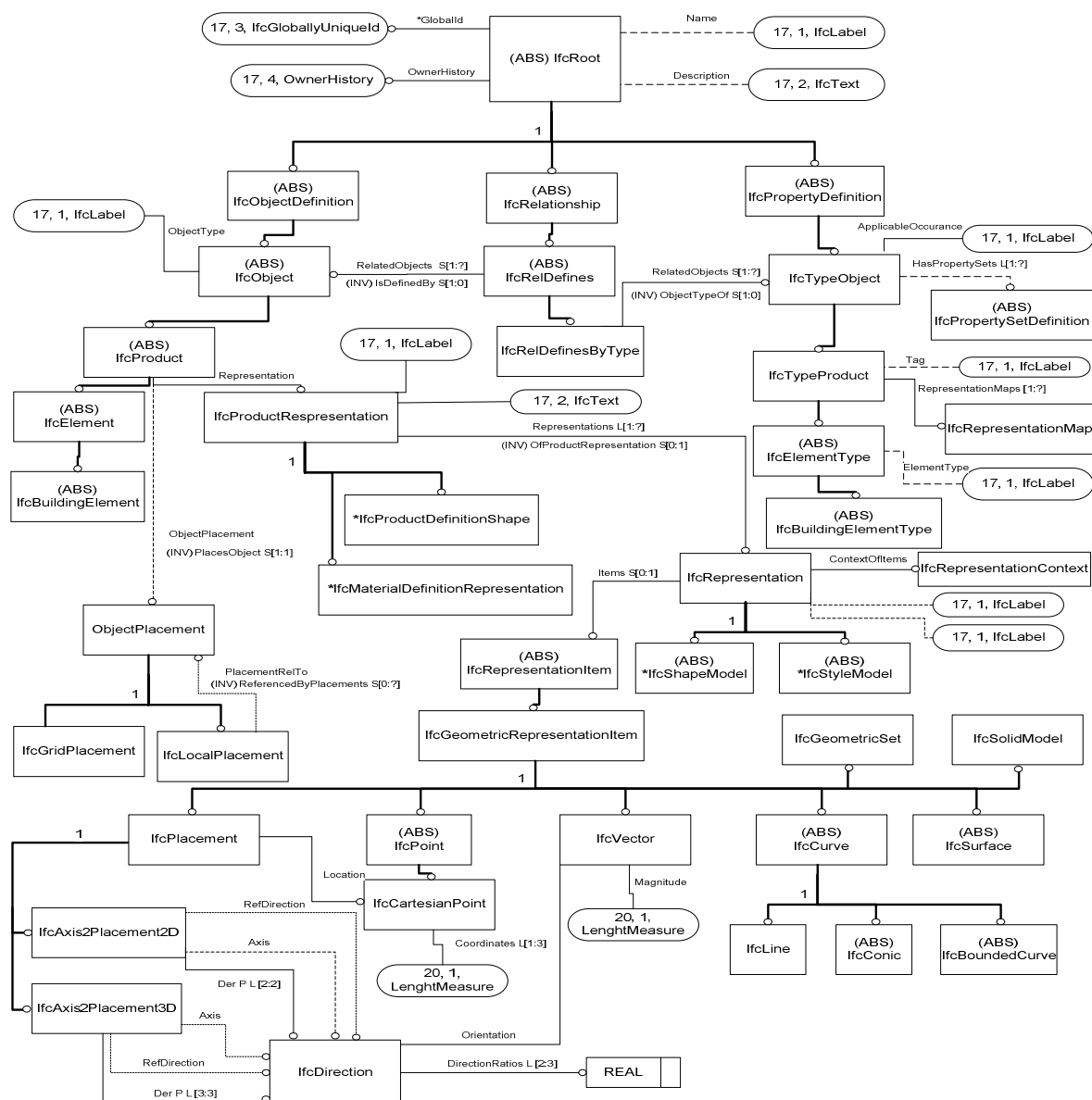
IFC Release Specific AEC/FM View Description (IFC 2× Edition 3)					
Spatial Elements					
Reference, Page	UMG-27, 27/3	Version	V-1	Status	Draft
Relationships	IfcBuildingElement			History	Ifc Release 1.0
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				
<p>Instantiation Definition: In this instantiation diagram, a typical building element with its occurrences are represented.</p> <p>Instantiation Details: In this instantiation, the instance of IfcWall (1) is generated with its related information. The wall is identified with additional classes as:</p> <ul style="list-style-type: none">• Owner History (2)• Grouping (3), (4)• Properties with property sets (5), (6), (7), (8)• Material information with material set. (9), (10), (11), (12), (13), (14)• Classification (15), (16), (17)					

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)

Topological Representation Item

Reference, Page	UMG-28, 28	Version	V-1	Status	Draft
Relationships	IfcTopologicalRepresentationItem			History	Ifc Release 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Usage in View Definition Diagram (EXPRESS G):

**Definition:**

This concept is formalized in order to show building element structure and its shape representation via topological item, according to IFC 2x3 specification.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Topographical Representation Item					
Reference, Page	UMG-28, 28/1	Version	V-1	Status	Draft
Relationships	IfcTopologicalRepresentationItem			History	Ifc Release 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Entity Type Definition (Definition from IAI):

The topological representation item is the supertype for all the topological representation items in the geometry resource. A `connected_face_set` is a set of faces such that the domain of faces together with their bounding edges and vertices is connected. A face is a topological entity of dimensionality 2 corresponding to the intuitive notion of a piece of surface bounded by loops. Its domain, if present, is an oriented, connected, finite 2-manifold in R^m . A face domain shall not have handles but it may have holes, each hole bounded by a loop. The domain of the underlying geometry of the face, if present, does not contain its bounds, and $0 < \Xi < \infty$.

A face is represented by its bounding loops, which are defined as face bounds. A face has a topological normal n and the tangent to a loop is t . For a loop bounding a face with defined geometry, the cross product $n \times t$ points toward the interior of the face. That is, each loop runs counter-clockwise around the face when viewed from above, if we consider the normal n to point up. With each loop is associated a BOOLEAN flag to signify whether the loop direction is oriented with respect to the face normal (TRUE) or should be reversed (FALSE).

A face shall have at least one bound, and the loops shall not intersect. One loop is optionally distinguished as the outer loop of the face. If so, it establishes a preferred way of embedding the face domain in the plane, in which the other bounding loops of the face are inside the outer bound. Because the face domain is arcwise connected, no inner loop will contain any other loop. This is true regardless of which embedding in the plane is chosen.

The edges and vertices referenced by the loops of a face form a graph, of which the individual loops are the connected components. The Euler equation (1) for this graph becomes:

$$(V - E) - \left(L - \sum_{i=1}^L (G_i^l) \right) = 0$$

where G_i^l is the graph genus of the i th loop.

Entity Type Detailed Definition:

IfcTopologicalRepresentationItem and its subclasses provide the shape, via connected faces. *IfcSolidModel*, *IfcMonifoldSolidBrep*, *IfcFacetedBrep* and *IfcFacetedBrepWithVoids* are the subtypes of *IfcGeometricRepresentationItem*. The shape representation is defined by a closed shell '*IfcClosedShell*'. If it is represented via voids (*IfcFacetedBrepWithVoids*), the attribute *Voids* connecting to a set of instances of *IfcClosedShell*. This is latter defined by a set of faces which are held in the *CfsFaces* attribute. These faces are represented as a set of bounds instances as '*IfcFaceBound*'. These are formalized as an instance of *IfcPolyLoop*, a polygon which is represented with cartesian points.

IFC Release Specific AEC/FM View Description (IFC 2x Edition 3)					
Topographical Representation Item					
Reference, Page	UMG-28, 28/2	Version	V-1	Status	Draft
Relationships	IfcTopologicalRepresentationItem			History	Ifc Release 1.5
Document Owner	Tu-Dresden, Department of Civil Engineering, Institute of Construction Informatics K. Umut Gökçe, umut@cib.bau.tu-dresden.de				
Description	1. Usage in View Definition Diagram				

Instantiation Diagram:

```
graph TD
    IfcWall1["IfcWall (1)  
GlobalId: '3DwF3zyUj9bgjuviHLMq55'  
Name: 'Concrete Wall 112'  
Description: 'C25 Concrete Wall'"]
    Representation
    IfcOwnerHistory2["IfcOwnerHistory (2)  
State: READWRITE  
Change Action:MODIFIED  
Last Modified Date: 20060520  
Creation Date:20070520"]
    IfcProductDefinitionShape3["IfcProductDefinitionShape (3)  
Name : 'WallShapeDefinition'"]
    Representations
    IfcShapeRepresentation4["IfcShapeRepresentation (4)  
RepresentationIdentifier: 'WABO'  
RepresentationType: 'Brep'"]
    Items
    IfcFacetedBrep5["IfcFacetedBrep (5)"]
    IfcClosedShell6["IfcClosedShell (6)"]
    Outer
    IfcFace7["IfcFace (7)"]
    CfsFaces
    IfcFaceBound8["IfcFaceBound (8)"]
    Bound
    IfcPolyLoop9["IfcPolyLoop (9)"]
    Polygon
    IfcCartesianPoint10["IfcCartesianPoint (10)"]
    IfcCartesianPoint11["IfcCartesianPoint (11)"]
    IfcCartesianPoint12["IfcCartesianPoint (12)"]

    Representation --- IfcWall1
    Representation --- IfcOwnerHistory2
    IfcProductDefinitionShape3 --> Representation
    IfcProductDefinitionShape3 --> Representations
    Representations --> IfcShapeRepresentation4
    IfcShapeRepresentation4 --> Items
    Items --> IfcFacetedBrep5
    IfcFacetedBrep5 --> Outer
    Outer --> IfcClosedShell6
    IfcClosedShell6 --> CfsFaces
    CfsFaces --> IfcFace7
    IfcFace7 --> Bounds
    Bounds --> IfcFaceBound8
    IfcFaceBound8 --> Bound
    Bound --> IfcPolyLoop9
    IfcPolyLoop9 --> Polygon
    Polygon --> IfcCartesianPoint10
    Polygon --> IfcCartesianPoint11
    Polygon --> IfcCartesianPoint12
```

Instantiation Definition:

In this instantiation diagram a building element, ‘wall’ is illustrated with its shape representation.

Instantiation Details:

This instantiation diagram shows instance of *IfcWall* (1) and its representation via shape definition classes. *IfcWall* is associated directly with *Representation* attribute to instance of *IfcProductDefinitionShape* (3) which keeps the instance of *IfcShapeRepresentation* (4). *IfcShapeRepresentation* keeps its *Items* attribute an instance of *IfcFacetedBrep* (5) which also holds its *Outer* attribute an instance of *IfcClosedShell* (6). This closed shell composed of faces within *CfsFaces* attribute. The instance of *IfcFace* (7) is detailed through it bounds attribute through the instance of *IfcFaceBound* (8). This is latter illustrate by the instance of *IfcPolyLoop* (9) which is defined by several cartesian instances (10), (11), (12).

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