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Self-learning Energy Efficient builDing and open Spaces

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D2.2 SEEDS modeling ontology. BIM methods and standards. IFC data models and IDM requirement analysis

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Executive Summary

The purpose of this report is to become familiar with the Building Information Modeling methodology and terminology, and to perform preliminary works regarding evaluation of the data modeling standards and particularly for the IFC product data model. The aim is to analyze the IFC data model in terms of its ability to describe building services, especially the HVAC equipment. Therefore, a simple example of a HVAC system will be represented by the means of the IFC specification and it will be investigated whether the IFC data format could fulfill the requirements of a SEED BEMS Building Model Library. Furthermore, an IDM requirement analysis will be performed in order to determine the required information of the SEEDS BEMS, which must be exchange during the building life cycle. The IDM requirement analysis will be a process analysis which helps to interface the SEEDS BEMS into a BIM process. The outcome of the IDM methodology will be the exchange requirements. These exchange requirements are the main purpose of this deliverable and will be the basis for a Model View Definition (MVD) and a following interface implementation. The interface integrates the SEEDS BEMS into a BIM process and provides the required data exchange. However, the specification of the MVD and the interface implementation will not be the scope of this deliverable. This may be the purpose of a following work.

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1 Introduction

1.1 Motivation

For existing buildings there are limited opportunities to minimize energy consumption. An optimized control of the installed HVAC system may be one opportunity to avoid high energy consumption. Since a large proportion of energy consumption is caused by the installed HVAC systems of existing building. To control a HVAC system in an energy optimized way, the building must be equipped with some intelligence.
The aim within the SEEDS project (Self Learning Energy Efficient Buildings and open Spaces) is to develop such a Building Energy Management System (BEMS) that reduces the energy consumption and the CO2 emission of the building services during the operation phase. An important element of the BEMS will consist on a Building Model, which includes some building services elements, especially the HVAC equipment, and their energy consumption information. The Building Model will be part of the performance optimization techniques which are involved in the BEMS. Developing the BEMS Building Model and the adaption of the BEMS to a specific building is intended to use the methodology of Building Information Modeling.

The purpose of this report is to become familiar with the Building Information Modeling approach and to perform preliminary works regarding an evaluation of the data modeling standards and particularly for the IFC product data model. The aim is to analyze the IFC data model in terms of its ability to describe building services, especially the HVAC equipment. Therefore, a simple example of a HVAC system will be represented by the means of the IFC specification and it will be investigated whether the IFC data format could fulfill the requirements of a SEED BEMS Building Model Library. Furthermore, an IDM requirement analysis will be performed in order to determine the required information of the SEEDS BEMS, which must be exchange during the building life cycle. The IDM requirement analysis will be a process analysis which helps to interface the SEEDS BEMS into a BIM process. The outcome of the IDM methodology will be the exchange requirements. These exchange requirements are the main purpose of this deliverable and will be the basis for a Model View Definition (MVD) and a following interface implementation. The interface integrates the SEEDS BEMS into a BIM process and provides the required data exchange. However, the specification of the MVD and the interface implementation will not be the scope of this deliverable. This may be the purpose of a following work.

1.2 Structure of the report

This deliverable is structured as follows. An approach of Building Information Modeling is introduced in Chapter 2. After presenting the basic idea, the benefits and possible access barriers of the BIM process will be introduced. Furthermore, the challenge of interoperability and the need of standardized data exchange will be discussed.

Chapter 3 provides an overview on product data modeling standards. Two common product data modeling standards within the BIM process will be introduced. Furthermore, two selected product data modeling standards regarding building service will be discussed.

Chapter 4 introduces BIM standards which are provided by the buildingSMART[1] International. The Industry Foundation Classes and the Information Delivery Manual will be introduced in detail.

[1] A neutral, international and unique non for profit organization supporting open BIM.

The main focus of this deliverable is to analyze the IFC data model in terms of its ability to describe HVAC systems and the integration of the developed BEMS into a BIM process. Chapter 5 presents some representation options of a simple HVAC system by the means of IFC and the results of the performed IDM requirement analysis.

Finally, a conclusion is given in Chapter 6.

2 Building Information Modeling

This Chapter introduces the basic idea behind the Building Information Modeling (BIM) methodology. Furthermore, the benefits of using BIM during the building life cycle and some access barriers to the philosophy of BIM will be discussed. Finally, the challenge of interoperability within the BIM process will be explained.

2.1 What is BIM?

The abbreviation BIM stands for Building Information Modeling and is the process of generating and managing building data during its life cycle. In other words, it is the creation and use of coordinated, consistent, computable information about a building project in design, in construction and in building operation and management. Even more, the building information model which is a central component of the whole BIM approach is commonly abbreviated as BIM. However, BIM actual meaning refers to the methodology of producing and handling the information during the building life cycle.

The Figure 2.1 shows a common illustration of the BIM process. As mentioned, the building information model plays a significant and centralized role. The building information model includes a digital representation of the building and the building components which are represented as parametric objects. The behavior of each parametric object is described by data attributes and parametric rules and associations to other objects. Another property of a building information model is the consistent and non-redundant data. That means, information which is added to the Model need not to be added a second time and changes of information are visible for all project participants. Besides the information of the building and the building components, the building information model may include further information, e.g. project management and control information and the representation of the building services.

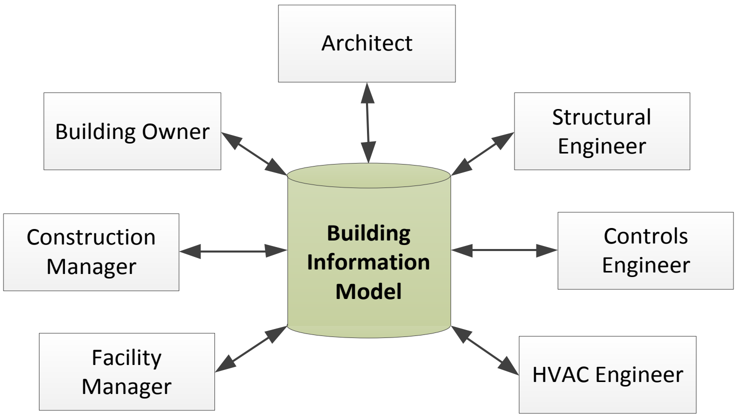


Figure 2.1: Illustration of the BIM process

Within the BIM process all project participants collaborate and communicate over this central building information model. Early collaboration and communication characterizes the BIM methodology. For instance, the architecture team designs the basic design of the building. After completing those design results are stored and given as building information model to the structural engineers. By means of the design results the structural engineers subsequently can perform a structural analysis. After that, this structural design results include some feedback and modified aspects to the architectural design [*1*]. The goal is that all project participants work on One building information model to fulfill the building owner requirements in an optimal way. Early stage collaboration by using one building information model improves and speeds up the design of the building. Building information model further facilitates the project participants on early and accurate visualization of the virtual building design. The several visualization opportunities (3D models and 2D drawings) help identifying possible error sources and offer a basis for discussion among the project participants. Finally, one can say an early collaboration and visualization leads to a general improvement of the project understanding.
For more information about BIM, please refer to [*1*] and [*2*].

2.2 Benefits and Access Barriers

Using the BIM approach during the building life cycle may support and improve many practices of the AEC/FM industry. The following descriptions of the BIM benefits are based on [*1*]. The benefits are divided into four parts. Each part encapsulates the benefits of a phase within the building life cycle.

Pre-Construction Benefits to Building Owner
In the pre-construction phase the building owner has to choose between different possibilities concerning the building design. Furthermore, he is responsible of determining whether a building of a given size, quality level and desired program requirements can be built within a given cost and time budget. Using BIM in the pre-construction phase increases the building performance and quality. An early evaluation of different design alternatives using analysis and simulation tools conducts to increasing the overall quality of the building.

Design Benefits
The project participants of a building project mainly benefit in the design phase. They profit from an earlier and more accurate visualizations of a design. For instance, they can use a 3D model which is generated by the BIM software to visualize the design at any stage of the design process with the expectation that it will be dimensionally consistent to every 2D view. Furthermore, BIM facilitates the accurate and consistent generation of every kind of drawing at any time during the project. This

benefit reduces the amount of time of producing the drawing in a manual way. Moreover BIM minimizes the number of errors associated with generating a construction drawing for all the design disciplines. Further advantage of BIM during the design phase is the early collaboration of multiple disciplines. Building Information Modeling enables simultaneous work by multiple knowledge domains. The exchange of one or more coordinated 3D models shortens the design time and significantly reduces design errors and omissions. Early collaboration facilitates to detect design problems in the early design stages and to present opportunities to overcome these problems. The result is a continuously improved and cost effective design.

Construction and Fabrication Benefits

The BIM approach enables a synchronized transition of the design to the construction planning. Linking a construction plan to the 3D objects which are created in the design phase of the building facilitates the simulation of the construction process. It is possible to visualize the construction progress at any time during the construction phase. Furthermore, the day-by-day construction simulation helps to detect sources of potential problems and opportunities for improvements. Adding temporary construction objects, like scaffolding, cranes and other construction objects to the building model and linking them to a construction plan is also a great benefit of using BIM for the construction planning. By means of the construction plan and the building model which represents all objects including their quantities and material of the design phase it is possible the synchronize the procurement with the design and the construction. A further benefit is the increased fault detection before construction. The collaboration among all domains in the design phase using a 3D building model leads to an early detection of errors and clashes (hard and soft clashes). Conflicts between the designs of the different disciplines can be identified in the design phase and do not occur during the construction. This reduces the costs, minimizes the chance of legal disputes and it mainly speed up the whole construction process.

Post Construction Benefits

Building Information Modeling does not only benefit the programming, design and construction phase of building. Also the operating phase can profit from using BIM. The building model after constructing a building includes an accurate representation of the as-built spaces and systems and provides a good basis for commissioning and operating the building. For instance, the building information model can provide necessary information for monitoring and operating a building management system. Furthermore, it can serve for the building owner as a means of verifying the design decisions once the building in use. In other words, the building owner has the ability to check whether the building fulfill his requirements by using the as-built building information model. An as-built model also facilitates a retrofitting of the spaces or the systems which is maybe desired in the future by the building owner.

This was just an excerpt of the benefits which are presented in [***1***]. However, some of the presented advantages of using BIM during the building life cycle have not reached the practice at the present time. To profit from the whole range of benefits requires a complete internalization, implementation and understanding of the BIM approach will be necessary. This fact has not become complete reality in the different disciplines which are involved in the building life cycle. Beside this main point there are some further facts which complicate the access to BIM within a building project. The following will discuss some selected access barriers of using BIM.

Access Barriers

To profit from all benefits of BIM the guarantee of collaboration and interoperability among all project disciplines is mandatory. Without a consistently collaboration and interoperability during the whole building life cycle the BIM approach does not work and the improvements compared to a paper-based design and construction process are rather small. A very important question within a BIM process is the question: Who is the owner of the information which are provided by the building information model? In other words, the Intellectual Property Rights (IPR) are a further obstacle while the BIM process and must be clarified in advance by contract. Beside the IPR the responsibility for

errors and liability should be addressed at the beginning of the BIM process. These additional points that must be considered against a standard project process deter many from starting to open up to the BIM approach. Furthermore, the mutual trust among project participants plays a significant role for the success of a BIM project. Confidence is the basis for a consistently collaboration and communication. As already mentioned BIM will only succeed to the degree that collaboration, communication and interoperability are ensured and practiced. In order words, the different project participants have to shift their fragmented thinking to teamwork thinking.
Beside these existing access barriers of the BIM approach the power of BIM definitely will overcome this in the future years.

2.3 Challenge of Interoperability

As mentioned in Chapter 2.2, the term "interoperability" plays an important role during the successful use of BIM. Without interoperability there is no efficient collaboration and communication and the BIM approach does not work.

What does interoperability mean? Interoperability within a BIM process is the capability to exchange data during the whole building life cycle, across different project domains and between different software applications. All project participants use their own specific software applications. It is necessary to ensure a smooth data exchange between the multiple applications. There are different ways to exchange data among different software application in the AEC industry. One opportunity is the use of proprietary file exchange formats. For the BIM approach a proprietary solution is not suitable, because only the applications which support this proprietary format are able to interact with each other. A well-known proprietary file exchange format is the DXF (Drawing Exchange Format). This format was developed by Autodesk[2] for interfacing between their own AEC applications. However, within a BIM project the data exchange by using a proprietary format is not suitable, because within the life cycle of a building many different computer applications from different software vendors are utilized. For the BIM approach a standardized data exchange format is more suitable than a proprietary exchange format. A selected standardized exchange format is the IFC data format (Industry Foundation Classes). The IFC provide an international recognized standard product data model for information exchange between software applications in the AEC/FM industry. Further information regarding the IFC are provided in Chapter 3.1.1 and the specification of the IFC data model and some basic concepts are introduced in Chapter 4.1.

[2] Autodesk is an American multinational corporation that focuses on 3D design software for use in the architecture, engineering, construction, manufacturing, media and entertainment industries.

3 Overview of Product Data Modeling Standards and Specifications.

3.1 Product Data Modeling in the BIM Process modeling

As forementioned, the interoperability among project participants and their different software applications within the BIM process plays a significant role. Open data standards help to overcome the challenge of interoperability and offer a solution to ensure them. A sort of common BIM product data modeling standards will be presented.

3.1.1 Industry Foundation Classes

The Industry Foundation Classes (IFC) is an open and neutral data format which is developed and maintained by the buildingSMART International. The buildingSMART International, formerly known as the International Alliance for Interoperability (IAI), is a neutral, international and unique non for profit organization supporting open BIM through the building life cycle.
IFC specification defines a standard data format to describe exchange and share information across domains and technical applications (e.g. CAD applications) along the building life cycle. The data format is an object based data format and can hold data from the architecture, engineering and construction industry. For instance, it can represent:

- Building elements
- Spaces, space structure
- HVAC equipment and systems
- Electrical elements
- Shape (explicit, extrusions, topology)
- Work plans and schedules
- Actors (people, organization, addresses)
- etc.

The IFC are specified using the EXPRESS data definition language, which is defined in [***3***]. EXPRESS provides a compact data modeling language which enables to describe data objects and the relationships among them. The EXPRESS standard offers a textual and a graphical (EXPRESS-G) notation. The EXPRESS-G notation has the advantage that the structure of a data model can be presented in a more understandable way. However, it merely represents a subset of the EXPRESS language and cannot display complex constraints. Nevertheless, EXPRESS-G helps to understand the structure of the IFC specification. An overview on the basic elements of the EXPRESS-G notation can be seen in annex A (1.1).
An IFC data model represents an instance of the IFC schema specification. In other words, the specification is filled with information. For the exchange of an IFC data model the 'STEP physical file' format [***4***] can be used. For further information to the EXPRESS data definition language and the 'STEP physical file' format it is referred to [***5***] and [***6***].
Beside the IFC-EXPRESS specification of the IFC data model there is an equivalent XML schema specification. For this the EXPRESS specification has been converted into a XML Schema Definition (XSD) by using a language binding. The IFC model in this case is represented by a XML document file. The correlation among IFC-EXPRESS and the ifcXML specification can be seen in Figure 3.1. For further information regarding ifcXML, please refer to [***7***].

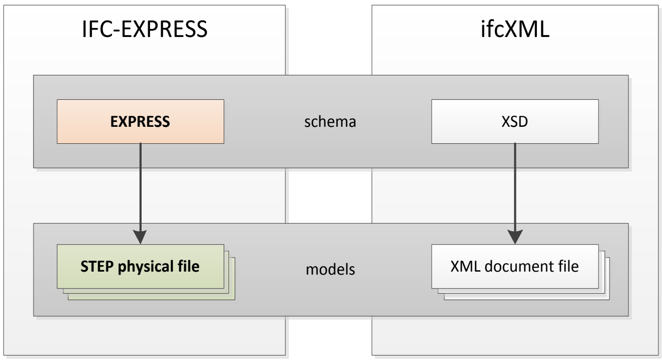


Figure 3.1: Schema and model distinction for IFC-EXPRESS and ifcXML

The current IFC release is IFC2x3 and the upcoming release will be IFC2x4. The upcoming release will include several extensions of IFC in building, building service and structural areas, enhancements of geometry and other resource components, and numerous quality improvements. Therefore the IFC2x4 release was the basis for this deliverable. A detailed explanation of the IFC2x4 schema including the basic modeling concepts is presented in Section 4.1.
The IFC data format is widely used in the AEC industry. It is supported by over 130 software applications. The buildingSMART provides an official and centralized list [***8***] of software applications which provide IFC import and/or export functionality. To ensure the interoperability for the end user and to support, the software developers quality assurance the buildingSMART uses a software certification process[3].

3.1.2 gbXML

The green building extensible mark-up language (gbXML) is an open, non-proprietary information model that was developed to facilitate intelligent information exchange, enabling integrated interoperability between building design models and a variety of engineering analysis tools.
The development of the gbXML was started in 1999 by the Green Building Studio and was funded by the California Energy Commission PIER Program and Pacific Gas and Electric. The first version of the gbXML was launched on June of 2000.
The gbXML information model is released in form of a XML (eXtended Markup Language) schema in which in a tree form hierarchy the data is stored.
The application of gbXML is mainly on the energy simulation domain. In terms of geometry, in opposition to the IFC, gbXML only accepts rectangular shape, which is enough for energy simulation. Geometries in conjunction with simulation engines are the core for building design phases. Currently there are available many tools that allow the translation from geometries definition formats to gbXML to be integrated on simulation engines.
The gbXML is widely supported and used by the CAD vendors in the AEC industry. For instance, the leading CAD vendors Autodesk, Graphisoft, and Bentley provide gbXML import and export in their engineering modeling tools. An overview on gbXML supporting 3D CAD/BIM and building energy analysis tools can be found on [***9***].
gbXML schema for information exchange is compatible with the most extended simulation engines such as DOE-2.1e, DOE-2.2 or TRNSYS. DOE and EnergyPlus simulation engine are one of the most well-known simulation engines in the building design domain. Many high level tools have incorporated these engines as their simulation mechanisms. TRNSYS, on the other hand, is a tool that has a wide acceptance at research environments.
gbXML is focused on building thermal load properties. It is then simpler and easier to use and more efficient than IFC to integrate with simulation software. Besides, gbXML is supported by many CAD, design and simulation tools.

[3] The certification process describes the certification of IFC interfaces.

While IFC is a widely used standard integrated as I/O data format by many software tools, including CAD or FM systems. It is more generic than gbXML due to its top-down approach, and more comprehensive since it covers the whole building life cycle.
In return, IFC suffers from a certain complexity (complex data schema, large data file) but in terms of geometry there are no obstacles.
For all these reasons, we have decided to interface with IFC, more extended and generalist than gbXML
Nevertheless, although the SEEDS project will use IFC as standard, this does not restrict the dissemination and exploitation of the project inasmuch as its developments could be extended and applied in others standard as gbXML.

3.2 Product Data Modeling in the Building Services

Product data modeling standards for building services were investigated in order to gain experiences in the field of modeling HVAC equipment. This section introduces the VDI-Guideline VDI 3805 and the cfiXML data schema. Both provide a product data schema for the data exchange of building services equipment.

3.2.1 VDI 3805

The scope of the VDI-Guideline VDI 3805 is to provide a product data schema for the electrical exchange of product data for building service systems. The VDI 3805 is accepted by the manufacturers in the building services and is established as a standard. By means of the product data schema it is possible to represent the manufacturers product catalogues of building services equipment in a computer readable way [***10***] .

The specified VDI 3805 product data schema contains product data, technical data and geometric data. Product data comprises major product groups, properties, accessories, as well as article numbers. The technical description of building services equipment includes performance information, characteristic curves and functions. The geometric data section contains information about interference spaces, connection data, as well as material data. However, the VDI 3805 does not provide any price information. Nevertheless, the guideline includes commercial date like DATANORM number, StLB-Bau number and EAN number. By means of this commercial data the price information for cost estimation will be available.

In the following an overview on the product data model specification and the structure of the product data exchange file will be given.

Product Data Model

For each product group exists a product structure specification. Currently the VDI 3805 provides product structure specifications for approximately 38 different building services equipment. The general representation of the product structure can be seen in annex A (1.2). The notation of the product structure corresponds to that of an entity-relationship diagram [***11***].
The structure of the product data model consists of entities and relationships among them. Each entity represents a data record which comprises a specific type of data. The general product structure is specialized for each product group (building services equipment). In other words, the data records contain equipment specific information. Some data records are mandatory and some are optional. Therefore, it may be that the product structure of specific product is a subset of the general structure. In order to describe the relevant product structure the BS number[4] is used. The BS number consists of numbers and question markers and is constructed according to the product structure specification [***12***].
The following shows an example of a BS number:

001132778564???000654000000465342???45600000054321000

[4] Building Services number

The BS number serves to identify the data records within a VDI 3805 file and is thus a construct which facilitates the computer readability.

Data Record Structure

Product data exchange files consists of many data records and have a unique file name. The content of the exchange file depends on the product-group-specific data records resulting from structure of the product data model. Each data record is presented in a file line and has the following format:

Record Type; Field1; Field2; Field3; …;

For each product-group-specific data record exists a specification which describes the content of the file line structure. The table below shows a sample data record description which was taken from the VDI 3805 Fundamentals [***12***].

Serial Number	Field name/field designation	Property ID	Unit	Format	Range of values/comments
1	Record type			A3	ZZZ
2	Sample value A			I	1 to 2147483647
3	Sample value B		kg	N	
4	Sample value C			A1	X, Y or Z

Table 3.1: Sample data record description

The table describes one data record that consists of four fields. Each field is defined by a serial number (position within the data record), a property ID, an unit, a format and range of the values respectively a comment. The format of a field defines the data type. For instance, the format 'A3' describes an alphanumeric character string of no more than three characters. The following file line represents a sample instance of the data record which is described in Table 3.1.

010; 399; 123.000; A;

A detailed description of all data records can be found in the several parts of the VDI 3805.

3.2.2 cifXML Data Schema

The AEX cfiXML data model was developed within the FIATECH Automating Equipment Information Exchange (AEX) Project. It defines a data schema for common facility equipment and facilitates the electronic data exchange of equipment items, engineering documents and material properties.

The data schema specification of the AEX cfiXML data model is based on the W3C standard XML Schema. The AEX cfiXML schema is a reusable, flexible and extendable data schema which is subdivided into four layers. The four layers are the Core Data Type schemas, the Core Object Schemas, the Subject Schemas and the Collection-Container Schemas. The following description of the individual layers and the illustration of the model layer structure (Figure 3.1) were extracted from [***13***].

Core data type schemas are built from the W3C XML schema standard basic data types to provide a common foundation of features available for all data in cfiXML. Some of the key core sets of data types support change tracking and revision history, provide physical quantities and units of measurement, and describe geometric shapes.

Core object schemas include reusable base engineering objects that can be used by multiple engineering disciplines and subject domains. These objects consist of a base set of data types and attributes which enable any item extended from an object to be uniquely identified throughout the life-cycle of the item.

Subject schemas are extensions of the core object schemas and provide details on specific engineering equipment items and accessories.

Collection-container schemas are used to combine core and subject-specific engineering objects in various ways to support required data transactions and usage scenarios. These can be considered as data sample exchange ‘documents’ such as data sheets, equipment lists and catalogues.

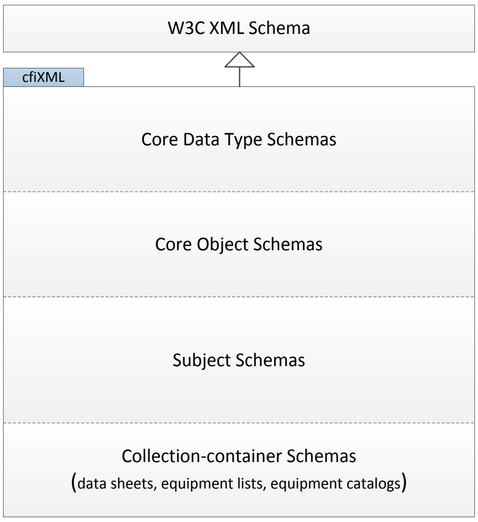


Figure 3.2: cfiXML layer structure

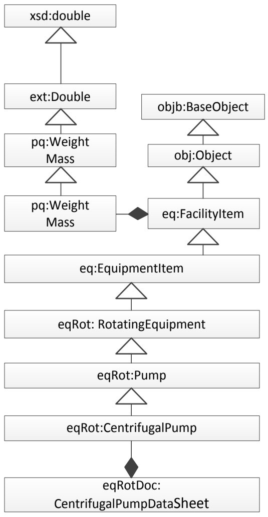


Figure 3.3: cfiXML - example centrifugal pump

An example of an AEX cfiXML representation according the layer structure (Figure 3.2) can be seen in Figure 3.3.
The current AEX cfiXML specification provides detailed equipment schemas for:

- centrifugal pumps and fans,
- shell and tube heat exchangers,
- air-cooled heat exchangers,
- centrifugal and reciprocating compressors,
- electric motors,
- control and block valves,
- air handling units and chillers.

Furthermore, base sets of data and accessories are available for several equipment items. The AEX cfiXML schema also provides a comprehensive set of material properties.
Finally, one can say the AEX cfiXML model is very suitable for the representation of building services equipment. The structure of the data schema is comparable to the IFC schema specification which is discussed in detail in section 4.1.1. Nevertheless, due to the limited number of specified equipment and the low level of awareness the IFC data schema will be more suitable for building services representation in the future.

4 BIM Standard of buildingSMART

Besides the IFC specification which provides a data model standard, the buildingSMART defines further corresponding BIM standards. They offer the Information Delivery Manual (IDM), a standard method to capture and specify processes and information flow during the building life cycle, and the International Framework of Dictionaries, a robust and flexible standard method of linking existing database with construction information to an IFC data model. The family of building SMART BIM standards is hereinafter extensively described.

4.1 Industry Foundation Classes

The IFC data model is specified using the EXPRESS data definition language [***3***]. The EXPRESS standard facilitates the specification of an object-based inheritance hierarchy which describes objects including their attributes as well as relationship to another. All objects in the EXPRESS language are called entities. As mentioned in Chapter 3.1.1 the EXPRESS standard facilitates a textual and a graphical specification of data models. In the following the EXPRESS-G notation (see annex A -1.1-) will be used to illustrate the structure and basic concepts of the IFC data schema specification.

4.1.1 Data Schema

The IFC specification provides an extensible and modular structure. The Figure 4.1 illustrates the IFC data schema. The IFC data schema consists of several data schemas. Each schema comprises a particular modeling concept and mainly consists of EXPRESS entities and type definitions. In addition, the particular data schemas belong to one of the four conceptual layers of the IFC structure. In other words, each of the four conceptual layers comprises a set of data schemas. The whole IFC data schema operates on a ‘ladder principle’; that means an entity may refer to an entity at the same or lower layer, however, it is not allowed to reference an entity from a higher layer. References within the same layer are only allowed in the Core Layer and the Resource Layer, however, should be avoided [***14***].

The main idea and the content of the four conceptual layers are briefly explained below.

Resource Layer

The Resource Layer is the lowest layer and the data schemas within this layer are independent from the other three layers. The data schemas consist of supporting data structure which can be used by the layer above and do not rely on other higher level concepts or entities. That means entities may only refer to higher level entities or use other resource entities. Each resource data schema stands for an individual business concept. For instance, the Material Resource contains all entities and types that are used to define materials, or even the Property Resource defines a basic set of property types that can be associated with objects[5] by using property sets (see Chapter 4.1.2).

[5] Subtypes of **IfcObject** respectively of **IfcTypeObject**.

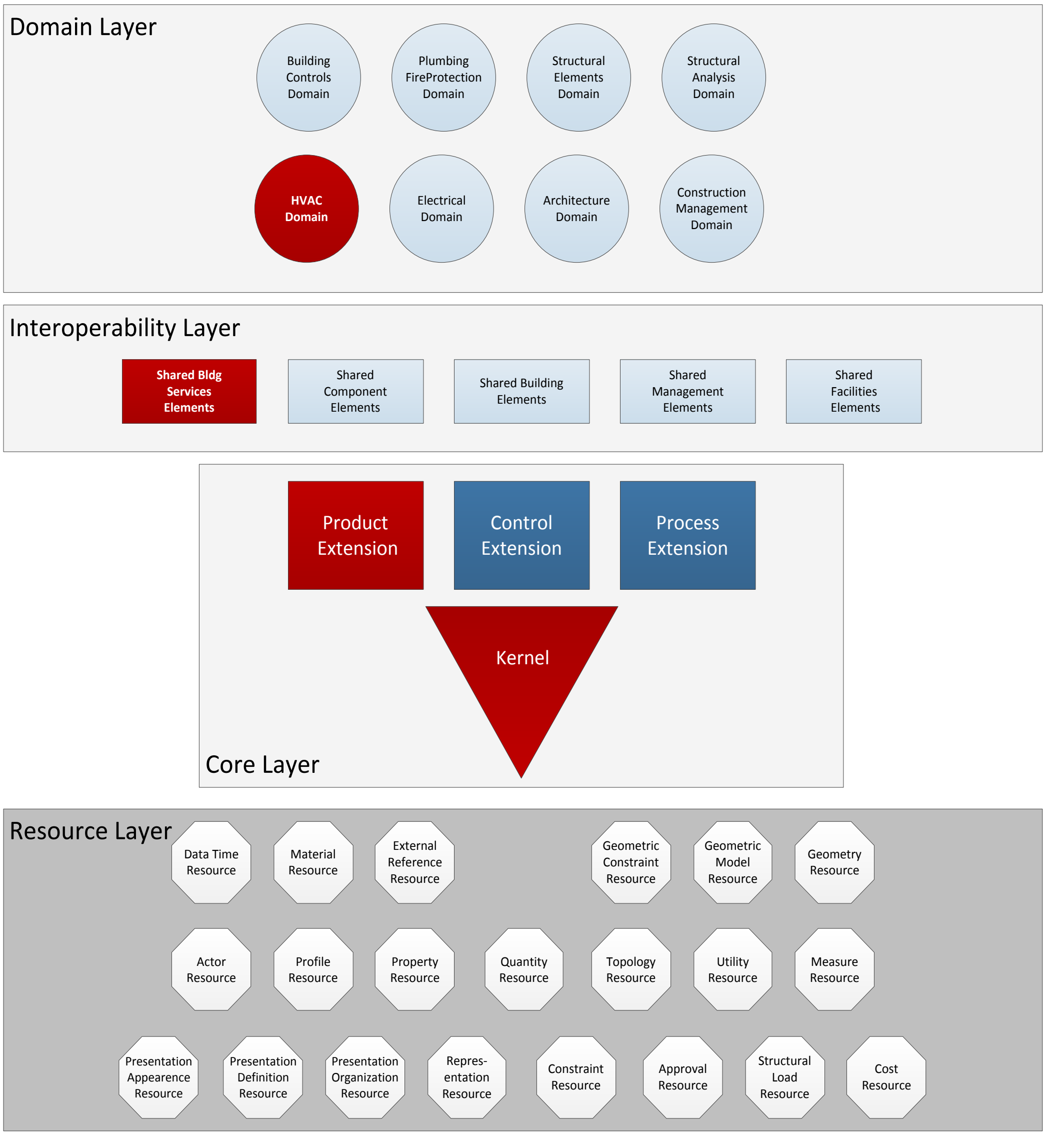


Figure 4.1: IFC data schemas

Core Layer

The Core layer defines the most abstract concept and provides the basic structure of the data model. Entities defined in this layer can be referred and specialized by all entities from layers above. The Core Layer consists on the Kernel and the Core Extension.

Kernel

The Kernel defines the basic concept of the IFC data schema and will be a mandatory part of any IFC implementation. The Kernel also includes fundamental concepts in terms of the provision of objects, relationships and property definitions. The Kernel works like a kind of Meta Model which provides the platform for model extensions. The Figure 4.1 illustrates a sample of the entity structure which is defined in the Kernel. The entity **IfcRoot** is the most abstract entity in the IFC data schema, all entities defined in the Core Layer, Interoperability Layer and Domain Layer inherit from the entity **IfcRoot**.

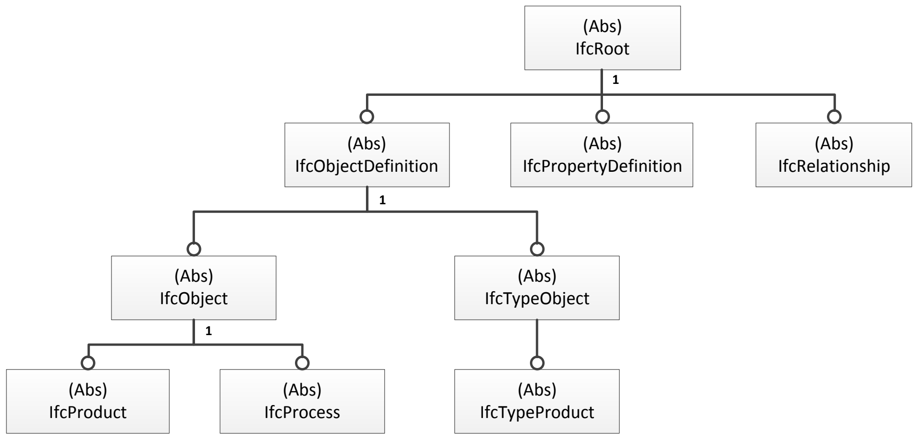


Figure 4.2: Kernel - fundamental entity structure (sample)

Core Extension

Core Extensions provide specialization of the concept defined in the Kernel. The Core Extension specializes the entities defined in the Kernel for the use within the AEC/FM industry. Entities that are defined in the Core Extension cannot be referenced by an entity within the Kernel or in the Resource layer. The Figure 4.3 shows a sample of the Core Extension. The entities **IfcElement**[6] and **IfcPort**[7] specialize the Kernel entity **IfcProduct**. That means they inherit the specified concepts and attributes from the entity **IfcProduct** including its supertypes. The entity **IfcDistributionElement** is a generalization of all elements that participate in a distribution system. Typical elements are for example building services elements in HVAC system.

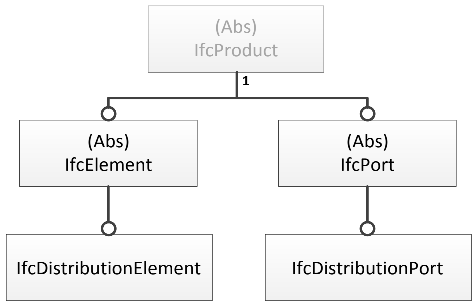


Figure 4.3: Entity specialization in the Core Extension (sample)

Interoperability Layer

The Interoperability Layer defines data schemas, which provide concepts and entities that are jointly used by two or more domain data schemas. This concept enables interoperability between different domain data schemas (e.g. HVAC Domain and Electrical Domain) and supports the outsourcing development of such a domain models. Entities defined in the Interoperability Layer may reference entities in the Core Layer and in the Resource Layer.

Regarding the purpose of this deliverable the SharedBldgServicesElement data schema plays a significant role and contains all fundamental building service elements which are shared between several domains. That means the data schema provides useful concepts respectively entity specification in terms of representing HVAC equipment by means of the IFC data model. As illustrated in Figure 4.4, several entities specializes the entity **IfcDistributionFlowElement**, which again is derived from the Core Extension entity **IfcDistributionElement**.

[6] An element is a generalization of all components that make up an AEC product.

[7] An **IfcPort** provides the means for an element to connect to other elements.

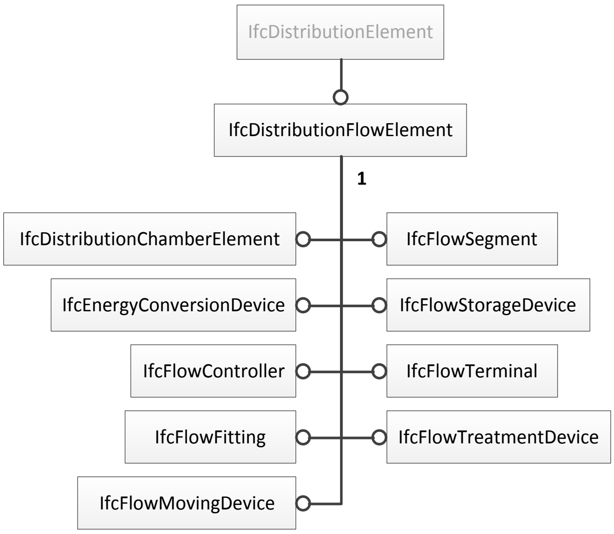


Figure 4.4: Entity specialization in the SharedBldgServicesElements data schema

Domain Layer

The Domain or Application layer is the highest layer and provides specific data schemas for an AEC/FM domain process or a type of application. Each domain specific data schema is a separate model which may use or reference any entity defined in the underlying layer. In other words, the domain specific data schemas contain final specializations of entities according to the industry discipline.

In this deliverable we will focus on the HVAC Domain as representative example. Along with lighting and hot water, HVAC is one of the most important domains in building automation. The HVAC Domain schema defines basic objects and concepts required for interoperability within the heating, ventilating and air conditioning business process. It extends the concepts defined in the SharedBldgServiceElements data schema.

In the IFC specification IFC2x4 the HVAC Domain comprises 33 entities which represent common HVAC components (e.g. fan, coil, pump, chiller and tank). The illustration of the final specialized entities including the way of specialization can be seen in annex A (1.3). The Figure shows the inheritance hierarchy from the entities which are defined in the HVAC Domain. The inheritance hierarchy can be found also in Figure 4.1. The red marked data schemas in Figure 4.1 show the most relevant part of the IFC specification regarding the purpose of this deliverable. Furthermore, a list of all 33 HVAC entities, which represent the occurrence of an HVAC component, can be seen in annex A (1.4).

4.1.2 Basic Concepts

An overview on the generally structure of the IFC data schema was given above. In the following some selected concepts will be introduced. It is noted that this explanations do not represent the whole functionality of the IFC specification. For a detail documentation of the IFC specification it is referred to the IFC-EXPRESS specification [***15***] respectively to the IFC Model Implementation Guide [***5***].

Root Entity

As mentioned each entity defined in the Core, Interoperability or Domain layer of the IFC model inherits from the **IfcRoot** entity. The entity **IfcRoot** provides some fundamental concepts which can be used by all derived entities. The following EXPRESS-G illustration (Figure 4.5) represents these fundamental concepts.

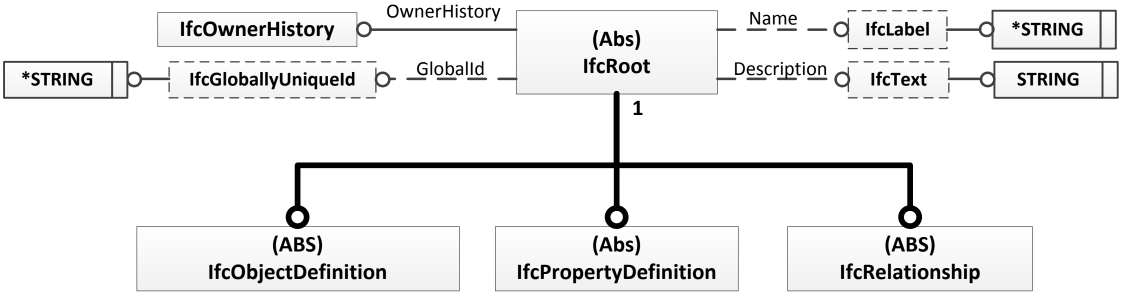


Figure 4.5: EXPRESS-G definition **IfcRoot**

The Figure 4.5 shows the references of the entity **IfcRoot** to other entities respectively to type specifications. These references represent the attributes including its data type, which describes the entity **IfcRoot**. It can be seen that the entity **IfcRoot** owns four attributes. The attribute *OwnerHistory* provides ownership and change information for each object in an IFC data model. The object identification is handled by assigning a globally unique identifier to the attribute *GlobalID*. The further attributes allow a naming and a description of each object within the IFC data model.
The Figure 4.6 shows an equivalent textual EXPRESS notation of Figure 4.5.

```
ENTITY IfcRoot
    ABSTRACT SUPERTYPE OF(ONEOF( IfcObjectDefinition, IfcPropertyDefinition, IfcRelationship ));
        GlobalId                    :IfcGloballyUniqueId;
        OwnerHistory                :OPTIONAL IfcOwnerHistory;
        Name                        :OPTIONAL IfcLabel;
        Description                 :OPTIONAL IfcText;
    UNIQUE
        UR1                         :GlobalId;
END_ENTITY;
```

Figure 4.6: EXPRESS definition **IfcRoot**

Fundamental Entities

Beside the attributes the entity **IfcRoot** has three direct subtypes (**IfcObjectDefinition**, **IfcPropertyDefinition**, **IfcRelationship**), these fundamental entities forms the first level of specialization within the IFC data model.
An **IfcObjectDefinition** is the generalization of any semantically treated thing. The direct subtypes of **IfcObjectDefinition** are **IfcObject**, which describes the occurrence of an object and **IfcTypeObject**, which represents a type of an object (see Figure 4.2: **Kernel - fundamental entity structure (sample)**). The differences and relationships of an object occurrence and an object type will be explained further below. There are several specializations of the entity **IfcObject**. The Figure 4.7 shows the direct subtypes of **IfcObject**.
The entity **IfcActor** defines all actors or human agents involved in a project during its full life cycle. Actors may be assigned to processes (**IfcProcess**) or resources (**IfcResource**). The entity **IfcControl** defines all concepts that control or constrain the utilization of products, processes, or resources in general (e.g. cost schedules, project orders, work plans). The entity **IfcGroup** is a generalization of any logical collection of objects. For instance, it describes a HVAC system including its HVAC components. The entity **IfcProduct** represents physical things, which describe manufactured, supplied or created objects. Subtypes of **IfcProduct** usually have a shape representation and a placement within the project structure (e.g. parts of the construction of the building, like floor, roof and walls or building service elements within a HVAC system, like fan, coil and chiller). The entity **IfcProcess** describes an activity, or an event, which takes usually place in building construction with the intent of designing, costing, acquiring, constructing, or maintaining products. The entity **IfcResource** defines concepts which describe the use of an object within a particular process.

For the purpose of the study thesis the entity **IfcProduct** including its subtypes, as well as the entity **IfcGroup** provide the basic entities for the representation of HVAC systems and their several components.

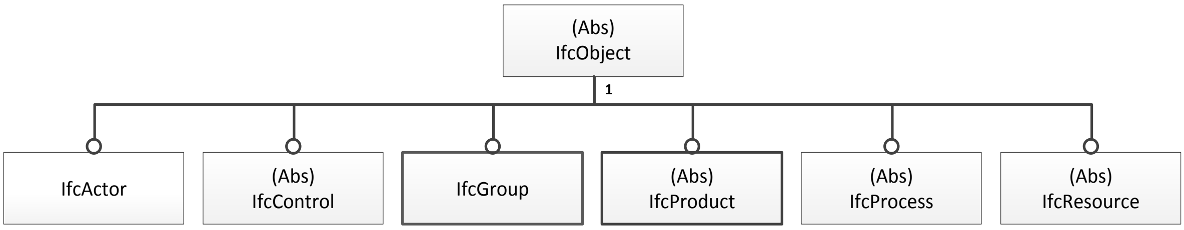


Figure 4.7: EXPRESS-G - Fundamental subtypes of **IfcObject**

A further fundamental entity represents the entity **IfcRelationship** (see Figure 4.5). This entity is the supertype of all objectified relationships in the IFC data model. An objectified relationship describes the relationship among different object, however, the relationship itself is represented by means of an object. The Figure 4.8 shows an example that illustrates the interrelation among objects and an objectified relationship. The entity **IfcRelConnectsElements** represents an objectified which describes the connectivity between an entity **IfcFan** and entity **IfcCoil**. In the following the entity **IfcRelationship** including its subtypes is represented in a light orange color.

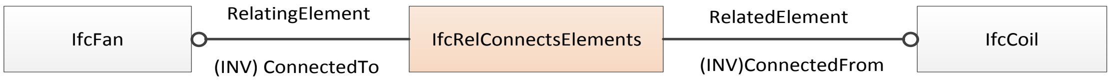


Figure 4.8: EXPRESS-G - Example objectified relationship

The advantage of objectified relationship is to specify the behavior of the relationship. That means relationships own attributes which describes their specific behavior. The entity **IfcRelationship** has several subtypes, which describes different kinds of relationships among objects. The Figure 4.9 shows the six fundamental relationship types. For a detail description of each relation type it is referred to the IFC-EXPRESS specification [***15***].

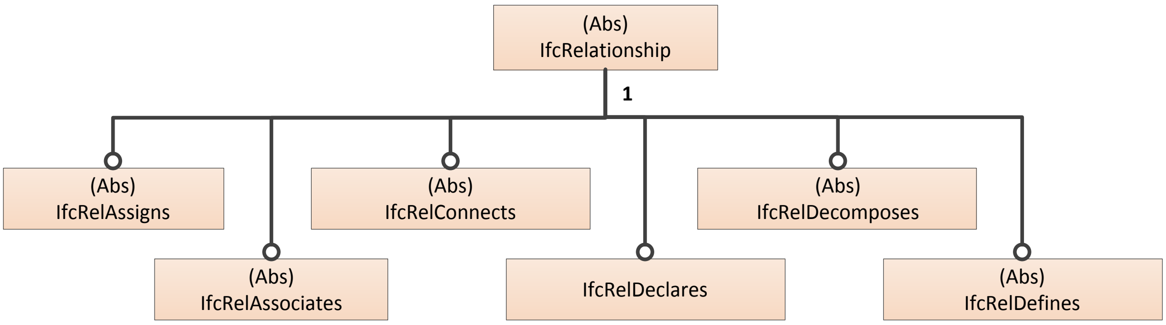


Figure 4.9: EXPRESS-G - Subtypes of **IfcRelationship**

The third fundamental entity **IfcPropertyDefinition** (see Figure 4.5) defines the generalization of all property definitions, which may be assigned to objects.
The property definition is a main concept within the IFC data model. It defines information that is shared among multiple instances of objects, either object occurrences or object types. Among another the property set definition (**IfcPropertySet**) respectively quantity set definition (**IfcQuantiySet**) is handled by the subtypes of **IfcPropertySetDefinition**. The current IFC specification includes some predefined property sets and quantity sets, which can be assigned either to an object occurrence, or an object type. It should be noted that it is also possible to define user defined property sets.

Object Occurrence and Object Type

The entity **IfcObject** and its subtypes represent the object occurrences. These object occurrences can be defined by a particular object type. The object types are represented by the entity **IfcTypeObject** and its subtypes. The Figure 4.10 shows the specialization of **IfcTypeObject**. The object types are used to describe common characteristics of the object occurrence. Such characteristics are common properties, shapes and materials. The entity **IfcTypeObject** and its subtypes are colored light blue in the following, in order to distinguish the object occurrence and the object type.

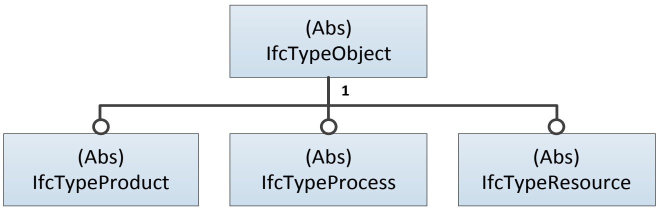


Figure 4.10: EXPRESS-G - Subtypes of **IfcTypeObject**

An IFC data model may include several instances of a particular object occurrence, however, it just include one instance of the corresponding object type. The object type can be assigned to its corresponding object occurrence by using the objectified relationship **IfcRelDefinesByType**. The Figure 4.11 illustrates the interrelation of the entity **IfcFan**, which is a final specialized entity of the HVAC Domain in the Domain Layer, and its corresponding type specification **IfcFanType**.

Figure 4.11: EXPRESS-G - Fan occurrence and fan type assignment

As mentioned above the IFC specification includes some predefined property sets and quantity sets. That means for each entity in the HVAC Domain property set and quantity set definitions are applicable. The property sets (type driven, occurrence driven sets) and quantity sets assignment can be seen in the following schema.

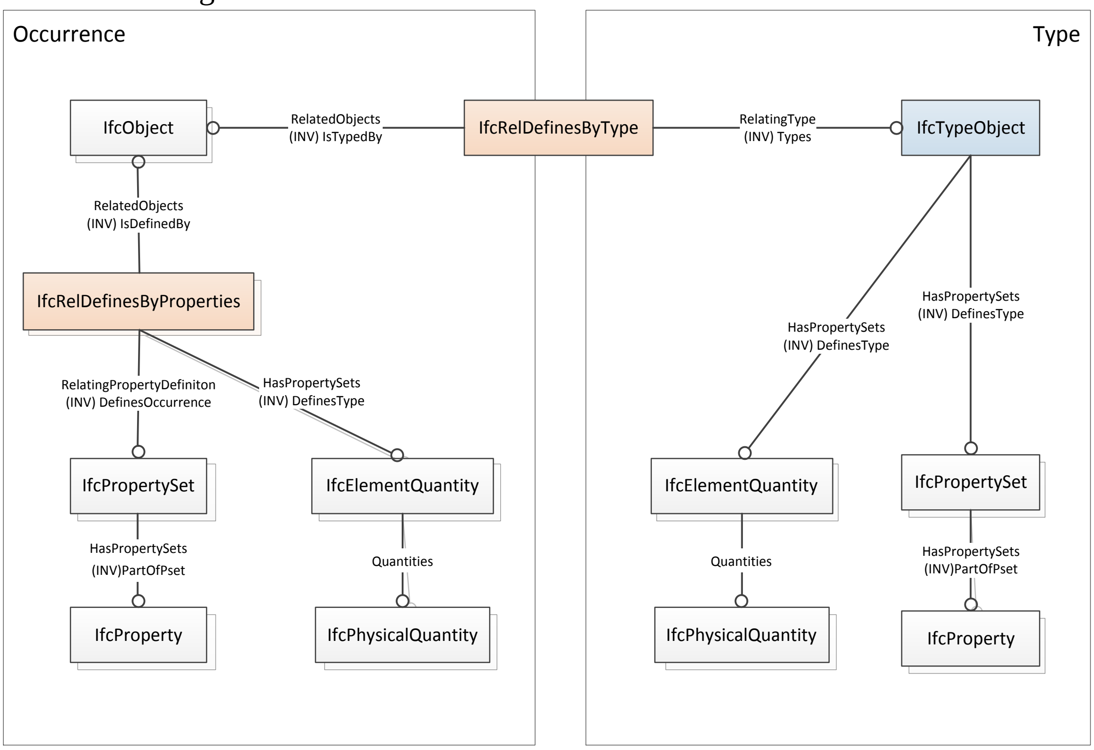


Figure 4.12: EXPRESS-G - Type/occurrence concept including property set assignment

There are occurrence driven and type driven property sets. Depending on the type of property set, the property set can be assigned to the object occurrence (**IfcObject**) or to the object type (**IfcTypeObject**). By means of the relationship **IfcReldefinesByProperties** it is possible to assign an occurrence driven property set to the entity **IfcObject**. Type driven property sets can be assigned to the entity **IfcTypeObject** using a direct reference. Object occurrences which are defined by an object type may use the type driven property sets.
The explanations above merely represent a selected part of the whole IFC specification. It does not represent the all functional concepts of the IFC data model. However, the introduced concepts will help to understand the IFC representation options of an air conditioning system, which is presented in Chapter 5. For further explanations of the whole IFC specification please refer to the IFC-EXPRESS specification [15].

4.1.3 Data Exchange

Interoperability has been mentioned as an important asset for the success of the BIM approach. The IFC schema provides the standard building information model; however, this is merely the first step towards deploying interoperability among the AEC/FM disciplines and their software applications.
Most software tools define their own internal data representation of information. To ensure the software interoperability the internal proprietary data format must be mapped to the IFC data model format. This is not a trivial task, because the IFC specification is very comprehensive and provides several possibilities to represent the internal data. The Information Delivery Manual [***16***] and the certification process of the buildingSMART [***17***] help to overcome the issue of IFC mapping.
The mapping and the exchange of IFC data can be accomplished in different ways. The Figure 4.13 illustrates the various implementation possibilities [***18***]. The Application A implements an internal import/export interface, which maps the internal data structure to an IFC data format and inversely. The mapping can also be done by an external import/export utility, as illustrated by Application B. These both approaches directly access data within an IFC Model File, which uses either the 'STEP physical file' format [***4***], or an XML format to represent IFC data. A further alternative is an IFC Model Server, which archives the content of an IFC Model File in a specialized database. In this approach, the IFC Model Sever provides indirect access to the IFC data. The clients to this server can then either be implemented externally to an application as illustrated by Application C, or embedded within the application as in Application D.

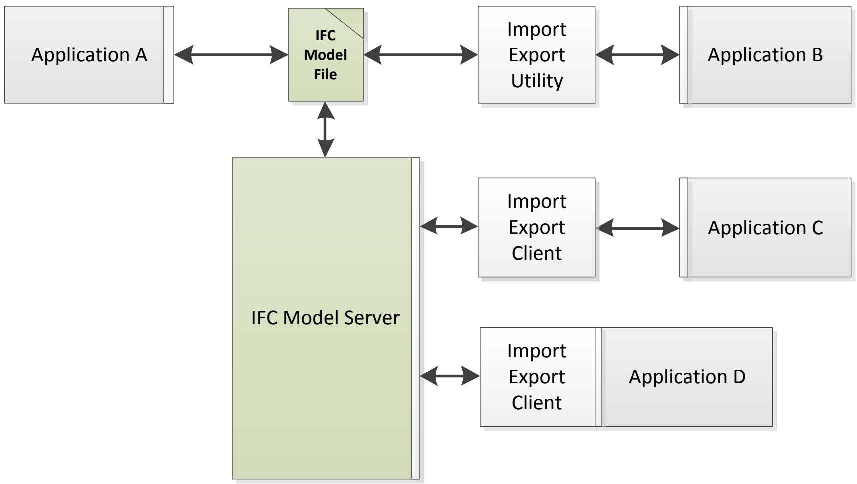


Figure 4.13: IFC data mapping and exchange

4.2 Information Delivery Manual

The Information Delivery Manual (IDM) provides a standard methodology to document and fulfill the exchange requirements at a particular project stage. The IFC schema is very comprehensive, because it deals with the whole field of the AEC/FM industry. Information exchange between project participants does not use the fully IFC schema, they commonly use a specific view of the IFC schema, which represents a subset of the comprehensive IFC schema specification. By means of the IDM it is possible to break down the IFC schema into usable parts regarding a specific AEC/FM business process in the building life cycle.
The IDM can be used for developing a specific IFC Model View, as well as for IFC Model Extension. That means entities, which are not specified in the current IFC specification, may be suggested on the basis of a performed IDM.
The execution of the IDM is the first step within a development process of BIM software, which provides an IFC interface for electrical data exchange during the building life cycle. The outcomes of the performed IDM are the exchange requirements of a concrete AEC/FM business process from the perspective of the end user. The following Model View Definition (MVD) represents rather the perspective of the software solution provider and describes how the exchange requirements can be fulfilled in detail by using the IFC. The Figure 4.14 shows an illustration of the several development steps of IFC compliant software.

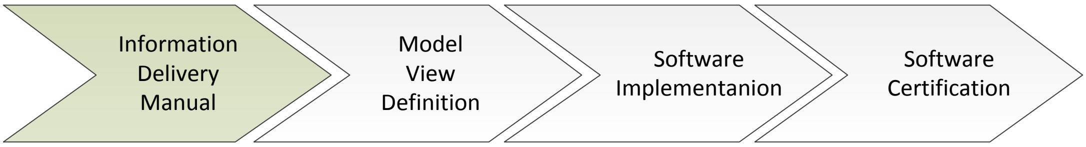


Figure 4.14: Development process

4.2.1 IDM Components

The IDM methodology consists of various components. The components in the IDM architecture are organized in layer schemas, the layer at the top are related to the process definition and description, the middle layers are related to data exchange specifications and the bottom layers are used to include IFC compliant software elements. The end users and practitioners are rather related to the layers at the top and the software solution providers are more related to the bottom layers.
The interrelationships of the several components are described in the technical architecture of the IDM (Figure 4.15).
In the following a short description of the IDM components in the red marked box (see Figure 4.15) is given. These components form the basis of the IDM and will be important regarding the understanding of the performed IDM requirements analysis in Chapter 5. For further information to the IDM components it is referred to the IDM ‘Guide to Components and Development Methods’ [***16***].

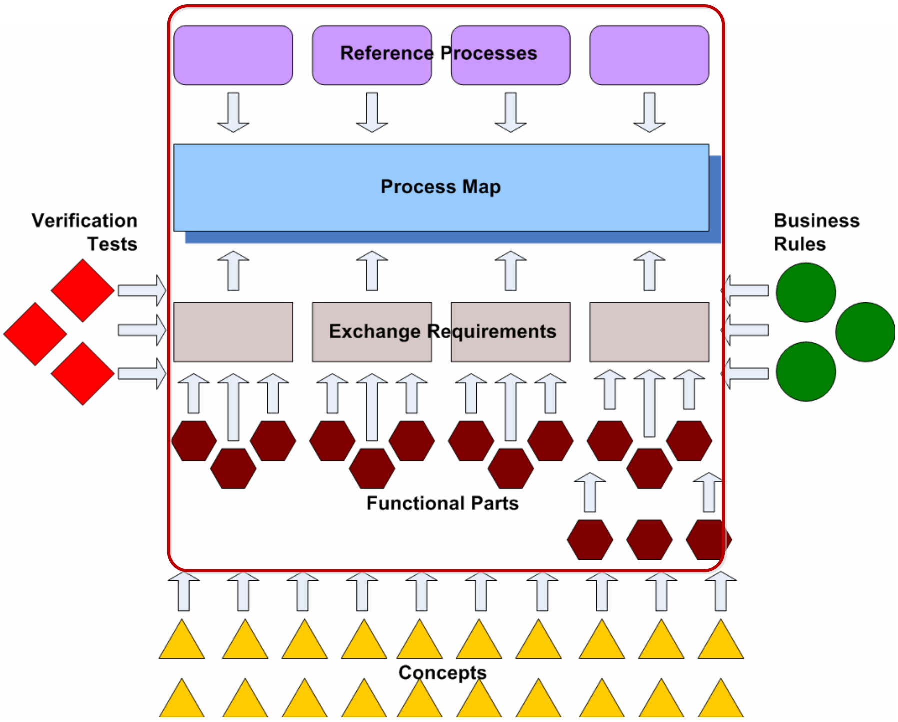


Figure 4.15: IDM technical architecture

Process Map

A process map is developed for a specific business process within the building lifecycle. It describes the flow of the activities and data exchange within a particular business process. Within the IDM the Business Process Modeling Notation (BPMN) is used to develop a process map. The BPMN is provided by the Object Management Group (OMG) and offers a widely used standard for specification of business processes [***19***]. A short introduction of the mainly used modeling elements regarding the IDM is given in [***20***].

Beside the actually process map using the BPMN, the process map component includes an overview section, that provides a comprehensive discussion of the specified business process, a specification of the activities, which comprises a detailed description of each activity, a specification of data objects, which represents imported or exported collections of non BIM data, a specification of exchange requirements, which includes the description of identified BIM data objects, as well as a specification of gateways, which specifies each BPMN gateway element within the process map.

Exchange Requirements

An exchange requirement represents a set of information (IFC data model information or other information model standards) to support a particular business requirement at a particular stage in the building life cycle. In other words, it represents a set of information that need to be exchanged between different actors within a process map. Normally, the description of the information should be provided in a non-technical form and information model independent way.

Functional Parts

A functional part represents a unit of information to support an exchange requirement and describes a standardized subset of the IFC data schema. An exchange requirement may be fulfilled with one or more functional parts. The functional parts are typically used by the solution provider of IFC compliant software.

4.2.2 Workflow

The IDM technical architecture (Figure 4.15: **IDM technical architecture**) represents a very abstract and not easy to understand illustration of the IDM methodology. This section aims to provide a simplified workflow (Figure 4.16) of the IDM regarding the purpose of this deliverable.
The first step of the IDM methodology is to determine the specific business process that has to be satisfied. The business process may comprise several sub-processes. After that a process map must be developed for the business process, or respectively for each sub-process. The development of the process map (using the BPMN) is performed by industry specialists (and maybe practitioners) and takes place in several iteration cycles. Developing the process map helps to identify:
the actors and their role
the activities of the actors
the dependency of activities
and the **exchange requirements** among different actors

for a specific AEC/FM business process. That means it aims to understand the whole business process in detail. However, the most important outcomes of developing the process map are the exchange requirements. As mentioned the exchange requirements represent a set of information that have to be exchanged among different actors within the business process. The specification of the exchange requirements takes place in a non-technical form using the industry specialist knowledge.

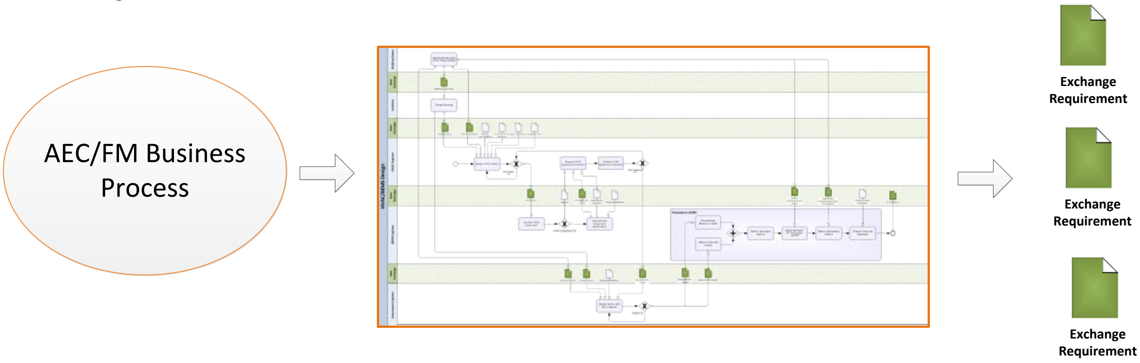


Figure 4.16: Common IDM workflow

The next step within the IDM will be the mapping of existing standardized functional parts. It has to be determined whether functional parts could satisfy the needs of each specified exchange requirement. In the case the existing functional parts cannot fulfill the exchange requirements, new functional parts must be developed. The Figure 4.17 shows the mapping of the functional parts to an exchange requirement. Each functional part represents a subset of the whole IFC data schema and may include other functional parts.

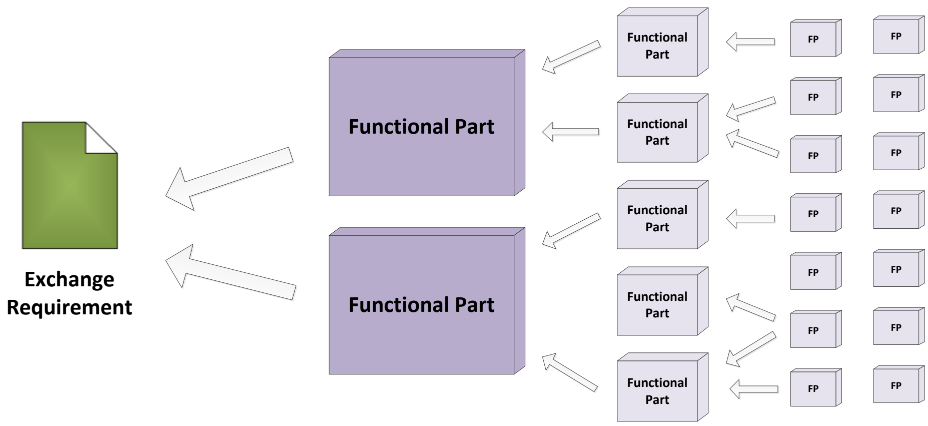


Figure 4.17: Mapping of Functional Parts to Exchange Requirements

The mapping of functional parts was indicated only for completeness and will not be the purpose of the IDM requirement analysis in Chapter 5. The intent of the performed IDM analysis is to identify the exchange requirements and to prepare the next steps within the IDM. Furthermore, the focus lies on the preliminary work of an evaluation of the IFC data model regarding its ability to describe HVAC equipment.

4.3 International Framework for Dictionaries.

Beside the format for information exchange (IFC) and the specification of which information to exchange and when to exchange the information (IDM), the buildingSMART provides a further standard to ensure the interoperability through the building life cycle. The International Framework for Dictionaries (IDF) is the third component of the buildingSMART technology and offers a robust and flexible method of linking existing database with construction information to the IFC data model. The purpose of using an IFD library in combination with an IFC data model is to provide semantic knowledge to the construction industry in a global and uniform way. In other words, an IFD library describes what the meaning of the exchanged data is and ensures computerized interoperability among the project participants. An IFD library in its simplest way offers a multilingual dictionary and allows project participants to use IFC exchange data in their own language. However, an IFD library may be more than merely a dictionary. It offers more flexibility for an IFC data model, because it allows the linking of an IFC data model with project and product specific data. Using the IFD library together with IFC data model enables the following opportunities [**21**]:

- Opens up for a model enrichment that will allow for advanced analysis, simulation and design checks at a very early phase
- Provides a real opportunity to generate an IFC data model for operational and maintenance purposes with storage of product specific data
- Provides a feasible method of linking existing knowledge systems to an IFC data model
- Provides multilingual and translation capabilities to the information in an IFC data model.

The IFD does not play an important role within this deliverable. However, it was mentioned because it is one of the fundamental components of the buildingSMART technology. Basically using all three standard together allows a consistently interoperability during the building life cycle. For further information regarding IFD, it is referred to [**21**], [**22**] and [**23**].

5 How to interface the SEEDS BEMS to a BIM process

The main purpose of the task is presented in this Chapter. It includes initial investigations of how suitable is the IFC data format regarding to its ability to represent HVAC systems, as well as their HVAC components and of how the SEEDS BEMS may be integrated into a BIM process.
For this purpose a simple example of a HVAC system is introduced in Chapter 5.1. and subsequently some IFC representation options of this example are explained in Chapter 5.2. The results of the IDM requirement analysis, which is based on different use case scenarios of the developed SEEDS BEMS, are documented in Chapter 5.3.

5.1 Simple HVAC System as example

In order to investigate the IFC data model regarding its ability to describe HVAC systems including their HVAC equipment a simple example of a HVAC system was chosen. The Figure 5.1 illustrates a simple air conditioning system. The air conditioning system consists of three sub-systems and each sub-system encapsulates common HVAC equipment.

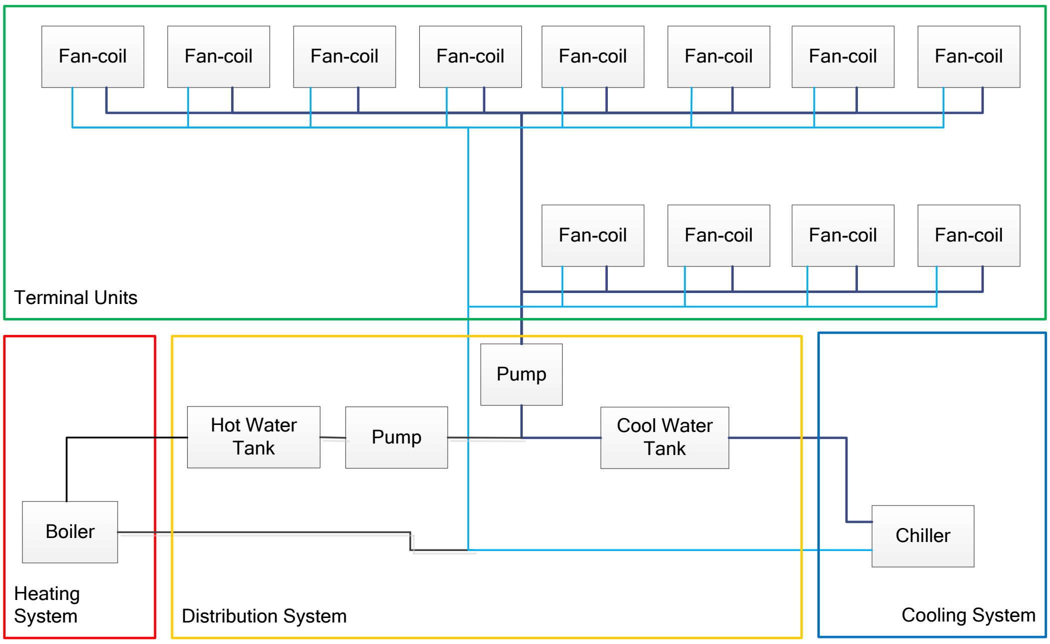


Figure 5.1: Air conditioning system

The air conditioning system is grouped into four subsystems according to SEEDS Deliverable D1.1

Terminal units:	include all fan-coils
Distribution subsystem:	include pumps and water tanks.
Production-conversion subsystem for heating:	include the boiler
Production-conversion subsystem for cooling:	include the chiller

Within SEEDS the purpose is to develop a BEMS, which optimizes the total energy consumption of the air conditioning system respectively of the building. For this the BEMS have to take into account the energy calculation specifications of the equipment. This energy calculation specification beside other useful information is defined in the Device Model Table which is developed for each HVAC component (e.g. fan-coil, pumps, water tanks, chiller, and boiler).

In order to develop a building model which is included in the BEMS it is intended to use the BIM approach. So the purpose in the following section is to represent the air conditioning system including the components by means of the IFC data format.

5.2 IFC Data Representation

In this section some selected representation options of the air condition system are presented. First the representation of a single HVAC component including its Device Model Table will be presented. After that an opportunity to describe a logical connection among different HVAC components will explained. Finally, the representation of the air conditioning system including its sub-systems, as well as all containing HVAC components will be presented.

5.2.1 Representation Options

HVAC Components and Device Model Table

The representation of a HVAC component including their Device Model Table is shown at the example of a fan. As mentioned in Section 4.1.2 each of the 33 HVAC components in the current IFC specification can be represented by an object occurrence and by an object type. For the fan example the entity **IfcFan** defines the occurrence of any fan in the real world and the common information about the fan types is handled by the entity **IfcFanType**. The entity **IfcFanType** works like a kind of template which describes common characteristics of a fan (e.g. common properties, materials or shapes) and can be assigned to the entity **IfcFan** by means of the relationship **IfcRelDefinesByType**. In memory to Section 4.1.2 an IFC data model includes just on instance of **IfcFanType**, however, it may include many instance of **IfcFan**. For the representation of the Fan Model Table of a fan the IFC data schema offers the following opportunities:

- Predefined Property Set
- User defined Property Set
- External Reference.

Predefined and user defined property sets can be assigned to **IfcFanType** and to **IfcFan**. The assignment of property sets to **IfcFanType** takes place by means of a direct reference. **IfcFan** uses the relation **IfcRelDefinesByProperties** which refers to a property sets. An external reference refers to external sources of information, like libraries (e.g. proprietary data bases) or documents, and can be content of a property set or can be associated to **IfcFanType** respectively to **IfcFan** by means of a relationship.
An illustration of the interrelation of the entities **IfcFan** and **IfcFanType** and the assignment of property sets can be seen in Figure 5.2. The Figure 5.3 shows an equivalent EXPRESS-G notation.

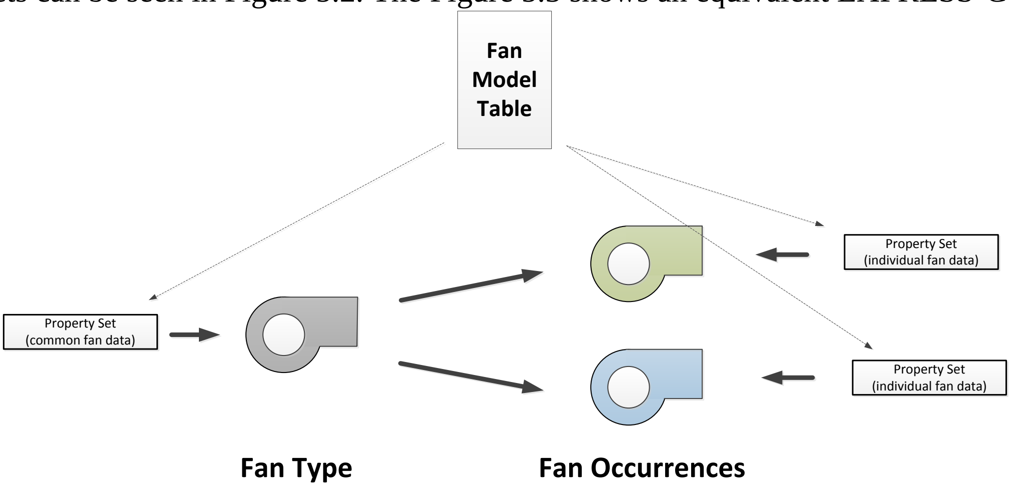


Figure 5.2: Fan type/occurrence illustration

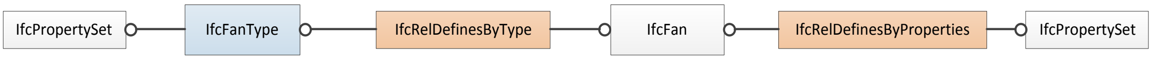


Figure 5.3: EXPRESS-G - Fan type/occurrence

For the representation of the Fan Model Table the use of user defined property sets will be the preferred option, because predefined property sets merely represent a portion of the information that is included in a Fan Model Table.
This kind of representation is applicable for all 33 HVAC components which are specified in the HVAC domain schema. An overview on all defined HVAC entities including a short description is located in annex A (1.4). In the current specification of the IFC data model there exists no HVAC component fan-coil, merely the entities **IfcFan** and **IfcCoil** does exist. Nevertheless, it is possible to describe the device fan-coil by means of the entity **IfcUnitaryEquipment**. Since the entity **IfcUnitaryEquipment** typically combine a number of components into a single product, such as air handlers or air-conditioning units.

Logical Connection among HVAC Components

After presenting an opportunity to represent a fan including its Fan Model Table using the IFC data schema, the next purpose is to describe a functional relationship respectively a logical connection among different HVAC components.
The Figure 5.4**: Port illustration of a fan-coil** shows an outline of a fan-coil. In order to connect the fan-coil with another HVAC component it is necessary to define ports. A port represents an inlet or an outlet of the fan-coil through which a particular substance may flow (e.g. a water flow or an air flow). The red markings in Figure 5.4**: Port illustration of a fan-coil** illustrate the ports of the fan-coil example.

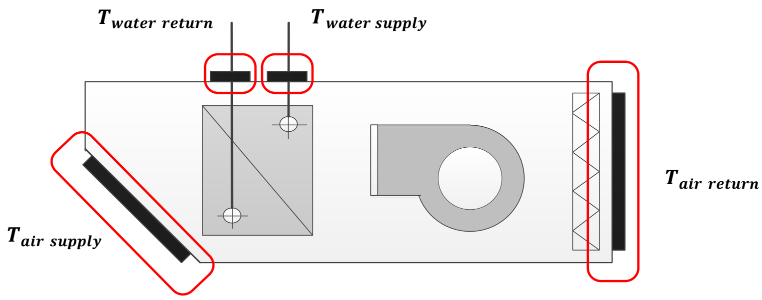


Figure 5.4: Port illustration of a fan-coil

As mentioned in the last section, the current IFC specification does not contain an entity which represents fan-coil. However, it can be represented using the entity **IfcUnitaryEquipment**. The Figure 5.5 shows the IFC representation of the fan-coil including its defined ports. The ports are described by the entity **IfcDistributionPort**. They are associated to the **IfcUnitaryEquipment** using the relationship **IfcRelConnectPortToElement**.

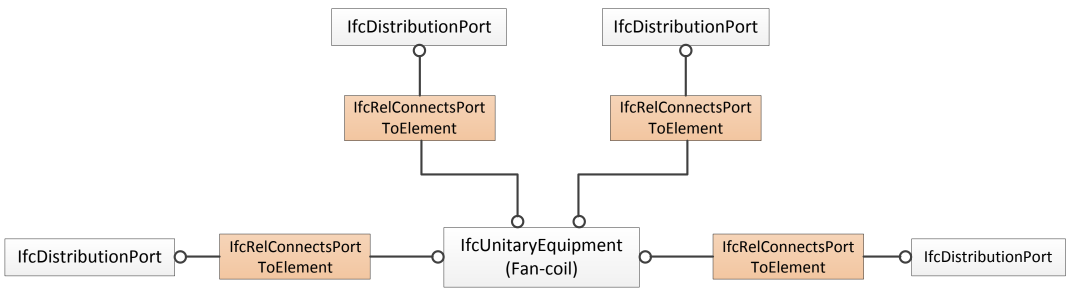


Figure 5.5: EXPRESS-G - Port definition fan-coil

By means of the entity **IfcDistributionPort** and a further relationship it is possible to connect the **IfcUnitaryEquipment** (fan-coil) with another HVAC component (e.g. with the entity **IfcPump**). The Figure 5.6 shows the logical connection among the fan-coil and other components from the air conditioning system. As you can see in Figure 5.6 the ports of the different components are connected with the aid of the relationship **IfcRelConnectsPorts**.
Since even for this small logical connection example the EXPRESS-G representation in Figure 5.6 is fairly confusing, the Figure 5.7 shows an equivalent, however, simplified illustration of the example above. As you can see the fan-coil (**IfcUnitaryEquipment**) owns four defined ports (*AirIn*, *AirOut*, *ChilledWaterIn* and *WaterOut*). For instance the port *WaterOut* is connected to the port *WaterIn* of the chiller. This connection describes a logical connection among the fan-coil and the chiller. In other words, it describes a water flow between these two devices. Furthermore, it should be mentioned, it is possible to describe the properties of this water flow by using property sets. This property sets can be assigned to the relevant ports of the devices.

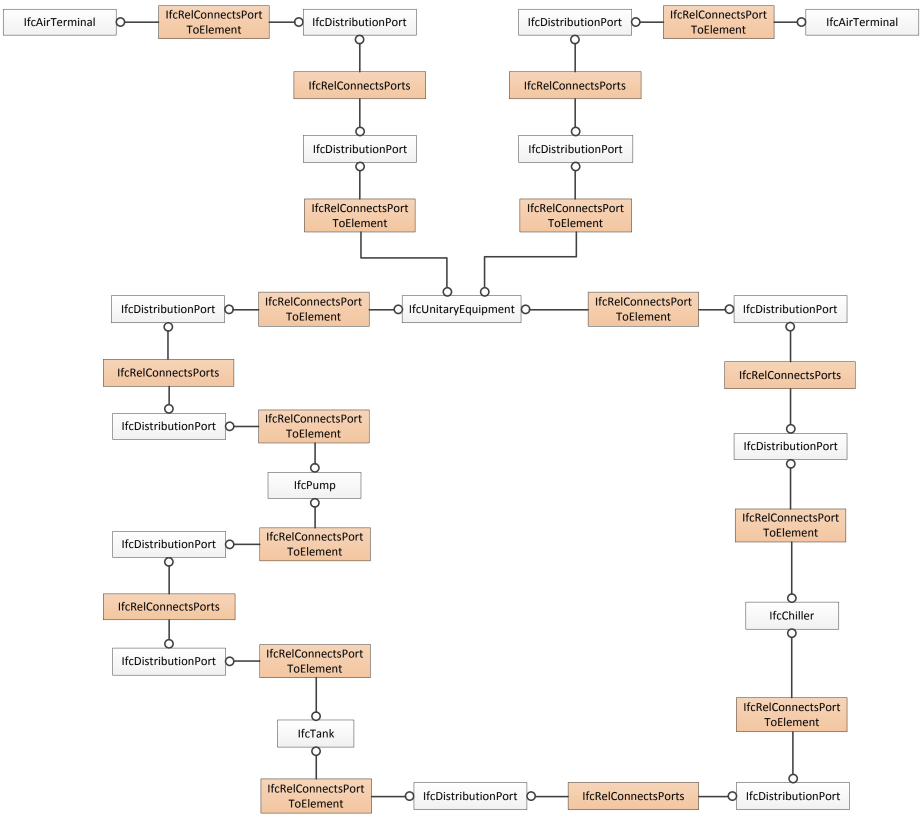


Figure 5.6: EXPRESS-G - Sample logical port connection of the air conditioning system

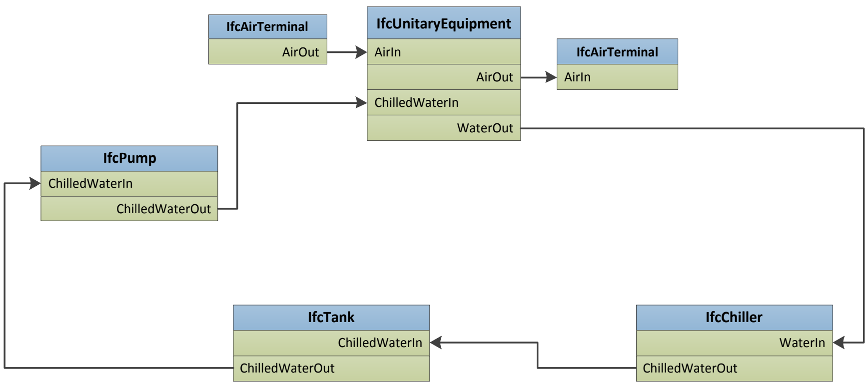


Figure 5.7: Illustration of the port connection

System Representation

In the previous sections the representation of a single HVAC device and its Device Table Model was presented for a fan. Furthermore, the description of logical relationships among different HVAC components was explained. The content of this section will be the description of the air conditioning system and its sub-systems on system level.
As mentioned the air conditioning system consists of four sub-systems and each sub-system encapsulates several HVAC components. The Figure 5.8 shows an EXPRESS-G representation of the air conditioning system by means of the IFC.

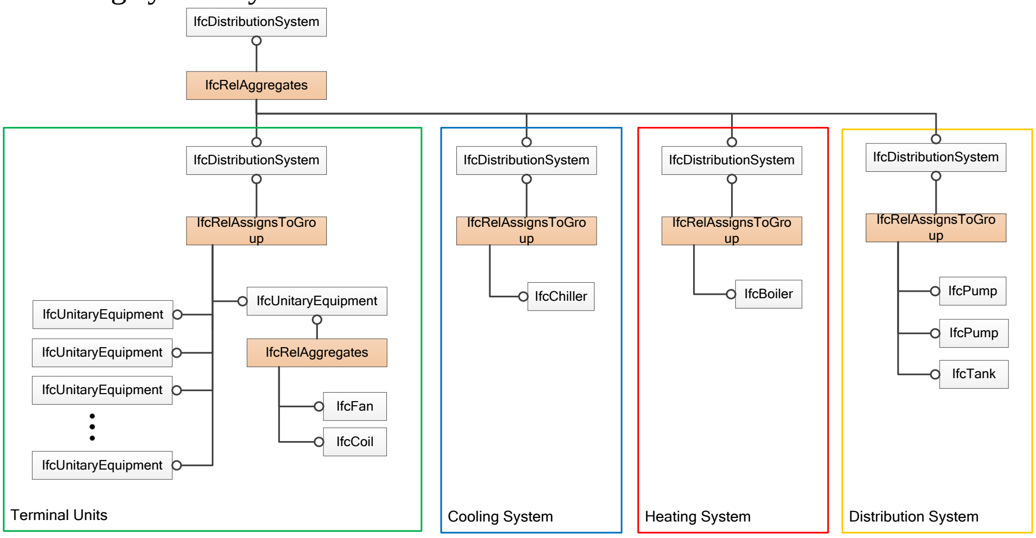


Figure 5.8: EXPRESS-G - System aggregation

The air conditioning system and each sub-system is represented by an entity **IfcDistributionSystem**. By the aid of the relationship **IfcRelAggregates** it is described that the air conditioning system consists of three sub-systems. Furthermore, it is possible to describe the content of each sub-system (**IfcDistributionSystem**) by means of the relationship **IfcRelAssignToGroup**, which groups the components into a system. For instance, the yellow box in Figure 5.8 represents the sub-system ‘Distribution System’, it is represented by the entity **IfcDistributionSystem** and includes the entities **IfcTank** and **IfcPump**.

5.2.2 Discussion of the IFC Representation

The presented representation options regarding the air conditioning system show that the IFC data format is basically suitable for the representation of HVAC systems including their HVAC component. It has been demonstrated that the IFC are suitable for the description of:

- HVAC components including their Device Model Tables
- Logical connections among HVAC components
- System aggregations.

Nevertheless, the presented options are merely one opportunity. The IFC data schema is comprehensive and provides several possibilities to represent such HVAC systems like the air conditioning system. From the perspective of the BIM approach which was introduced in Chapter 2 a standard representation of such HVAC systems is necessary. In other words, to ensure the interoperability among the different project participants within a BIM process it is essential to use a standardized representation of IFC data. In order to guarantee a standardized exchange of IFC data, the in Section4.2 introduced IDM provides a standard methodology.
As mentioned the IDM helps to identify the exchange requirements of a project participant at a particular project stage and to fulfill these exchange requirements by means of standard functional parts. The IFC representation of the air conditioning system could be a part of an exchange

requirement which arises during the integration of the SEEDS BEMS into a BIM process. This exchange requirement subsequently is fulfilled with the aid of functional parts which include a standard representation for HVAC systems and components. In the case the existing functional parts cannot satisfy the exchange requirements, new standard functional parts must be developed.

5.3 IDM Requirement Analysis

The following section describes the IDM workflow in terms of the integration of the SEEDS BEMS into a BIM process and presents the results of the IDM requirement analysis.

5.3.1 Overview on BIM Domains in SEEDS

The IDM is performed for a specific business process. Regarding the IDM workflow which was introduced in Section 4.2.2, the Figure 5.5 shows an illustration of the IDM workflow in terms of interfacing the SEEDS BEMS into a BIM process. As mentioned, the first step is to specify the desired business process. For the purpose of this deliverable the desired business process describes the application of the developed BEMS within a building life cycle and is called the ***'BEMS Engineering'***. The process ***'BEMS Engineering'*** consists of the four following sub-processes:

- ***BEMS Planning and Design***
  The process describes the interfacing of the SEEDS BEMS to the planning and design phase of the building life cycle. The project phase includes the basic design of the building, the design of the HVAC system, as well as the design of the building automation system.
- ***BEMS Commission***
  The process contains the commission of the HVAC system under control of the SEEDS BEMS. The interactions of the different project participants which are involved in the commissioning phase are described.
- ***BEMS Operation***
  The integration of the SEEDS BEMS in the operating phase of the building life cycle, especially in the operating phase of the HVAC equipment under control of the BEMS is described in this process.
- ***BEMS Retrofit***
  Handles the retrofitting phase of the building life cycle and describes the integration of the SEEDS BEMS into the retrofitting phase. This process partly includes portions of the other sub-processes.

After specifying the desired business process for each sub-process a process map was developed. As mentioned in Section 4.2, the process maps helps to identify the actors which are involved in the process, the activities (task, sub-process) of the actors, the dependencies of activities and the exchange requirements among the actors. For the purpose of the deliverable the identification of the exchange requirements is the most important result of the IDM requirement analysis. These exchange requirements describe a set of information that have to be exchanged to interface the SEEDS BEMS into a BIM process. In other words, they specify data that have to be exchanged in form of an IFC data model.

The results of the process maps and the specification of the exchange requirements are documented in the following section. The outcome of developing the process map for each of the specified process above is organized as follows:

- Overview Section
- Specification of the Activities
- Specification of the Data Objects
- Specification of Exchange Requirements Data Objects
- Specification of Gateways

The BPMN process maps in the overview sections can be seen in an enlarged form in annex (1.5).

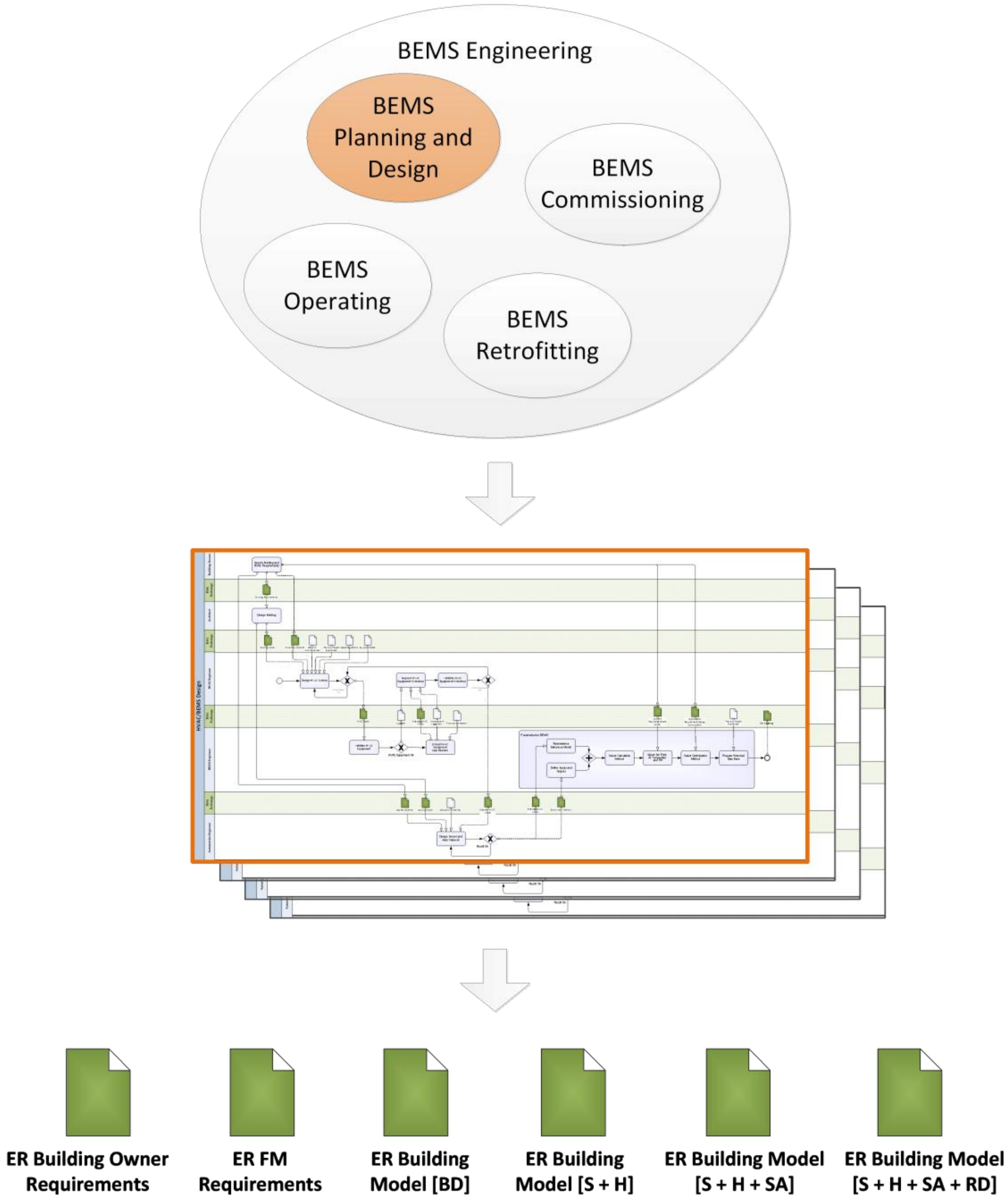


Figure 5.9: IDM workflow SEEDS BEMS

5.3.2 Process Maps

BEMS Planning and Design

The process 'BEMS Planning and Design' describes the parameterization of the building energy management system (BEMS) within the design phase of the building. The basis for the parameterization of the BEMS is the completed basic building design, HVAC system design and sensor and actor network design. The basic design of the building, HVAC system and sensor and actor network design is performed on the basis of the Building Owner requirements. After completing the HVAC system design the engineer, who is responsible for initializing the BEMS, validates the HVAC equipment. He evaluates HVAC equipment whether the product specification contains the required information to set up the BEMS. In the case of an unsatisfactory product specification the BEMS engineer extends the HVAC system design. The required information of the HVAC equipment is described in the Device Model Table which is specified for each HVAC component. By means of the basic design of the building, HVAC system design and sensor/actor network design the BEMS engineer prepare the BEMS for the commission phase of the HVAC system. For instance, he defines the inputs and outputs and selects calculation and optimization methods. Within the whole planning and design process the Building Owner (or the Facility Manager) observes and validates the design results.

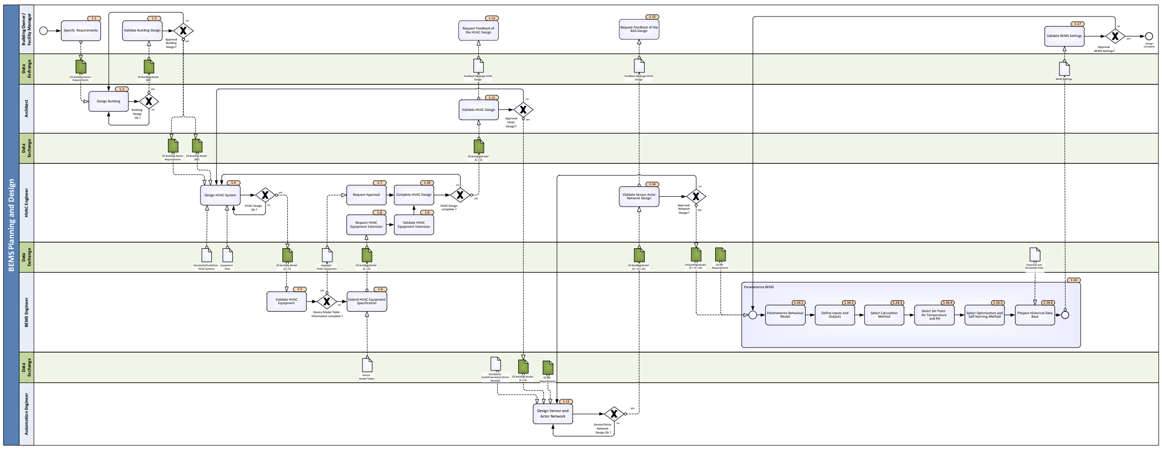


Figure 5.9: Process Map - BEMS Planning and Design

Specification of Activities

Specify Requirements [1.1]

Type	Task
Documentation	The Building Owner specifies the Building Owner Requirements. These requirements are the basis for the work of the Architect and the HVAC engineer.

Design Building [1.2]

Type	Task
Documentation	Considering the building requirements the Architect designs the building. The building design activity is an iterative process to find an acceptable solution. The result of this activity is a building model and includes the following: • Spatial Information • Building Elements The building model includes the basic design of the building and is the basis for the HVAC design.

Validate Building Design [1.3]

Type	Task
Documentation	The Building Owner/ Facility Manager validates and compares the building design with its building requirements. He approves the building design, if the building design fulfils the requirements or he instructs a new design iteration to improve the building design.

Design HVAC System [1.4]

Type	Task
Documentation	The activity describes an iterative design process of the HVAC system. It includes the simulation process and the cost estimation of the HVAC system. The HVAC engineer utilizes standards/guidelines, previous project experiences, space regulations and Equipment Data within the design activity. The basis for the HVAC system design is the building design provided by the Architect. The 'Design HVAC System' activities contains for instance the following tasks: • Estimate load • Estimate space requirements for technical spaces • Define technical spaces • Select HVAC equipment • Select, size and connect distribution routes • Request advices from the cost manager and the energy analyst

	The result is the HVAC system design which includes HVAC equipment and their product specific data and distribution system information.

Validate HVAC Equipment [1.5]

Type	Task
Documentation	The BEMS engineer receives the building model design including the space model and the HVAC design from the HVAC engineer and validate (evaluate) the product specific information of each HVAC component. He has to decide whether the containing information fulfill the information requirements of the BEMS. The required information of the HVAC equipment is described in Device Model Tables which are specified for each HVAC component. In the positive case he sends an approval to the HVAC engineer and in the other case he has to extend the HVAC model. An approval means no extension is needed.

Extend HVAC Equipment Specification [1.6]

Type	Task
Documentation	In the case the product specific information of the HVAC equipment does not satisfy the BEMS requirements the BEMS engineer extends the equipment specification. The BEMS engineer uses the Device Model Table of each HVAC component to extend the specification. The Device Model Tables contains the following information: • Name and type of the device • Photograph and outline • Description • Calculation specification of the thermal energy consumption • Control information • …

Request Approval [1.7]

Type	Task
Documentation	The HVAC engineer requests the approval for the HVAC equipment in form of a message. The BEMS engineer sends an approval, if the product specification of the HVAC equipment fulfills the requirements of the BEMS. The HVAC design will be complete after receiving an approval.

Request HVAC Equipment Extension [1.8]

Type	Task
Documentation	The HVAC engineer requests the extension of the HVAC components and their product specific data in form of an IFC data model. The BEMS engineer sends the IFC data model including the Device Model Table extension, if the product specification of the HVAC equipment does not fulfills the requirements of the BEMS.

Validate HVAC Equipment Extension [1.9]

Type	Task
Documentation	The HVAC engineer reviews and validates the extension of the HVAC equipment and their product specification. In the event of his agreement the HVAC design will be completed. Otherwise the HVAC engineer starts a new iteration cycle of the HVAC design.

Complete HVAC Design [1.10]

Type	Task
Documentation	The HVAC engineer decides the completion of the HVAC design. In the case of an approval or in the case of an agreement of the extended HVAC equipment the HVAC design will be completed and prepared for the Architects approval.

Validate HVAC Design [1.11]

Type	Task
Documentation	The Building Owner/Facility Manager receives the HVAC design including the extension of the Device Model Tables in form of an IFC data model. He validates the HVAC design

	and gives his approval. Otherwise he is instructing a new iteration cycle of the HVAC system design. Furthermore, the Architect sends a feedback message to the Building Owner/Facility Manager, in order to inform him about the current state of HVAC design.

Request Feedback of the HVAC Design [1.12]

Type	Task
Documentation	The Building Owner/Facility Manager requests a feedback from the Architect, which informs him about the current state of the HVAC design.

Design Sensor and Actor Network [1.13]

Type	Task
Documentation	The activity describes an iterative design process of the Building Automation System (BAS). After approving of the HVAC system design by the Building Owner/Facility Manager and the Architect the Automation Engineer starts the design of the sensor/ actor network (BAS). The automation engineer receives the building design (mainly a space model) and the HVAC system design in form of an IFC data model. On the basis of this IFC data model and the operational requirements specified by the Facility Manager the Automation engineer develops a sensor/actor network in order to control and operate the HVAC system. He extends the received IFC data model with the BAS design. The BAS design includes for instance the following information: • Sensor information • Actor information • Controller information After completing the BAS design the Automation engineer sends the design in form of an IFC data model to the HVAC engineer.

Validate Sensor Actor Network Design [1.14]

Type	Task
Documentation	The HVAC engineer receives the BAS design in form of an IFC data model. He validates the BAS design in terms of his and the Facility Managers requirements and gives his approval. In the case of an approval the HVAC engineer sends the building, HVAC system and BAS design to the BEMS engineer. Otherwise he instructs a new iteration cycle of the BAS design.

Request Feedback of the BAS Design [1.15]

Type	Task
Documentation	The Building Owner/Facility Manager receives the actual state of the BAS design in form of a feedback message.

Parameterize BEMS [1.16]

Type	Sub-Process
Documentation	This activity includes several activities to set up the BEMS for the specific building and its HVAC system. On the basis of the building design, HVAC system design and the BAS design the BEMS engineer accomplish the following activities: • Parameterize the behavior models • Define the inputs and outputs • Select calculation method • Select optimization method • Select set points for the air temperature and relative humidity • Prepare historical data base. The result of this sub-process is a digital list that includes all settings of the BEMS. This list is send to the Building Owner/Facility Manager.

Parameterize Behavior Model [1.16.1]

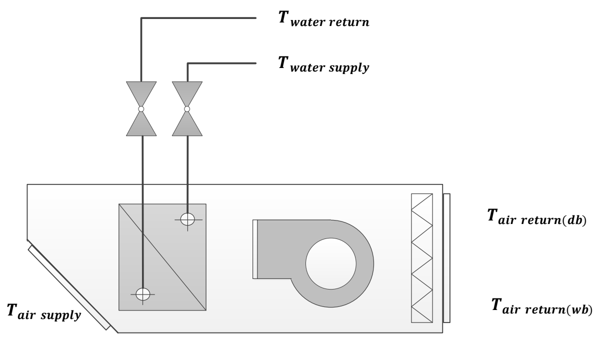
Type	Task
Documentation	The BEMS engineer parameterizes the behavior model on the basis of the HVAC system and the HVAC equipment. The system and equipment information is extracted from the

	IFC data model.

Define Inputs and Outputs [1.16.2]

Type	Task
Documentation	On the basis of the designed HVAC system and sensor/actor network (BAS) the inputs and the outputs of the BEMS are defined. The inputs provide the runtime sensor data. The sensor data is used e.g. to calculate the actual energy consumption. The outputs serve to control the HVAC equipment in an energy optimized way.

Select Calculation Method [1.16.3]

Type	Task
Documentation	In dependence on the available sensor data of each HVAC component a calculation specification of the thermal power consumption is selected. For instance a Fan-coil provides the following opportunities to calculate the actual thermal power: **Data sheet** For operating the fan-coil in data sheet mode the following values are mandatory: $T_{air\ return\ (db)}, T_{air\ return\ (wb)}, T_{water\ supply}, T_{water\ return}, Q_w$ By the means of these parameters the value of the thermal power can be obtained in the data sheet table of the fan-coil. **Data from water sensor** For operating the fan-coil in water sensor mode the following sensor values are mandatory: $T_{water\ supply}, T_{water\ return}, Q_w$ In the case of available water sensor data the thermal power can be obtained from the following calculation specification: $P_{th-FC}(W) = \Delta T_{water} Q_w \rho_w c_{pw}$ **Data from air sensor** For operating the fan-coil in air sensor mode the following sensor values are mandatory: $T_{air\ return\ (db)}, T_{air\ return\ (wb)}, T_{water\ supply}, T_{air\ supply\ (db)}, T_{air\ supply\ (wb)}$ 

Select Set Point Air Temperature and RH [1.16.4]

Type	Task
Documentation	The BEMS engineer selects for each room the air temperature (the temperature of the air which is supplied by the fan-coil) and the relative humidity on the basis of the operational requirements.

Select Optimization and Self-learning Method [1.16.5]

Type	Task
Documentation	On the basis of the operational requirements the BEMS engineer selects the optimization goal. For instance he can chose between an efficient performance of the HVAC components or of the whole HVAC system. Furthermore he selects a suitable forecast algorithm (Neural Networks, Bayesian Nets or Fuzzy Logic). The BEMS engineer maybe has the opportunity to select among different self-learning methods. All decisions are based on the information which are provided by the IFC data

	model.

Prepare Historical Data Base [1.16.6]

Type	Task
Documentation	The BEMS includes a historical database which stores the data that is generated during the operation phase. The forecast algorithms use this data to estimate the future state. To provide such a historical data base for the commission phase it is necessary to prepare the data base. The data base could be prepared by using empirical and simulation data.

Validate BEMS Settings [1.17]

Type	Task
Documentation	After the parameterization of the BEMS the BEMS engineer sends the BEMS settings in a digital form to the Building Owner/Facility Manager. The Building Owner/Facility Manager receives these settings and validates them. In the case he agrees the settings he complete the whole design phase and maybe instruct the commission phase. Otherwise he instructs to review and adjust the BEMS settings.

Specification of Data Objects

Standards/Guidelines HVAC Systems

Type	Data Objet
Documentation	Common standards/guidelines within the design process of a HVAC system. Such standard are provided for instance by ASHRAE or VDI.

Equipment Data

Type	Data Objet
Documentation	Product specification of the HVAC equipment. Data is provided by the manufacture of the HVAC equipment in form of a product catalog (e.g. VDI3805 file).

Device Model Tables

Type	Data Objet
Documentation	The Device Model Tables include all information required by the BEMS. For each HVAC devices a Device Model Table was developed within SEEDS. The Device Model Tables are provided in a digital textual form.

Standards/Guidelines Sensor Actor Network

Type	Data Objet
Documentation	Common standards/guidelines within the design process of sensor/actor networks. Using common message protocol standards like IEEE 802.15.4.

Empirical and Simulation Data

Type	Data Objet
Documentation	Empirical data from previous projects and simulation data, maybe provided in the form of an excel table.

BEMS Settings

Type	Data Objet
Documentation	The data object includes the actual BEMS settings. The BEMS settings maybe provided in an excel table or in a text file. The BEMS settings include the inputs/outputs, the set points of the air temperature/relative humidity, the calculation method for the energy consumption and the chosen optimization method.

Specification of Exchange Requirements Data Objects

ER Building Owner Requirements

Type	Data Object

Documentation	The Building Owner Requirements specify the programming and planning requirements. These requirements are the basis for the work of the Architect and the HVAC engineer. The Building Owner Requirement specification includes • Building program requirements • Space group program requirements • Space program requirements • Visual comfort requirements • Quality requirements • Energy requirements • …

ER FM Requirements

Type	Data Object
Documentation	The FM requirements specify the operational requirements for the Building Automation System (BAS) and Building Energy Management System (BEMS) The FM Requirement specification includes • Sensor/actor network requirements • Thermal comfort requirements (i.e. the air temperature and relative humidity of each room) • Indoor air quality requirements • Optimization requirements (e.g. energy consumption, Co2 emission) • …

ER Building Model Design [BD]

Type	Data Object
Documentation	This exchange requirement represents the basic information of the designed building. The basic design model of the building provides information about the building, the layout of spaces within it and the main building elements from which it is to be constructed. The basic design model includes the following information: • General project and building information • Spatial structure (storeys, rooms, spaces) • Technical space information • Building elements (walls, floors, roof, door, windows, openings) • Connection and dependencies of spatial and building elements • Material properties • Dimensional descriptions for geometric representation (2D, 3D representations)

ER Building Model Design [S + H]

Type	Data Object
Documentation	This exchange requirement represents a simplified model of building and the extension of the HVAC system. The model of the building mainly consists of the spatial structure of the building and includes some additional building information. The extension of the HVAC design includes the following information: • the design of the whole HVAC system and the containing sub-systems • the logical connection among different HVAC devices • the product specification data of the HVAC equipment (Device Model Tables) Furthermore, the model includes dependency information of the spatial structure and the HVAC system.

ER Building Model Design [S + H + SA]

Type	Data Object
Documentation	This exchange requirement includes in addition to the exchange requirement 'Building Model Design [S + H]' the design of the sensor and actor network. The sensor/actor network is added by the Automation engineer. The extension of the sensor/actor network includes the following information: • General Information of the Building Automation System

	• Sensor information • Actuator information • Controller information • Relations and dependencies to the spatial structure and the HVAC system

Specification of Gateways

Building Design Ok?

Type	Decision Point
Documentation	After completing an iteration cycle the Architect checks the building design whether it is acceptable to present it the Building Owner/Facility Manager. **YES:** The building design is sent to the Building Owner/Facility Manager in form of an IFC data model. **NO:** The Architect starts a new iteration cycle of the building design.

Approval Building Design?

Type	Decision Point
Documentation	At this point the Building Owner/Facility Manager has to approve the building design. **YES:** The building design and the Building Owner requirements are sent to the HVAC engineer in form of an IFC data model **NO**: The Building Owner/Facility Manager instructs a new iteration cycle of the building design.

HVAC Design Ok?

Type	Decision Point
Documentation	After completing an iteration cycle of the HVAC design the HVAC engineer checks the HVAC design whether it is acceptable to present it the BEMS engineer. **YES:** An IFC data model including the HVAC design is sent to the BEMS engineer. **NO:** A new iteration cycle of the HVAC design is started.

Device Model Table Information complete?

Type	Decision Point
Documentation	At this decision point the BEMS engineer has to decide whether the HVAC equipment and their product specific information fulfill the requirements of the BEMS or not. Or in other word, does the IFC data model contain all information of the Device Model Tables. **YES**: The BEMS engineer sends an approval message to the HVAC engineer. **NO**: The BEMS extend the HVAC design using the Device Model Table specification of the HVAC equipment

HVAC Design complete?

Type	Decision Point
Documentation	After the extension or the approval of the HVAC equipment the HVAC engineer has to decide whether the HVAC design is complete or a further iteration cycle of the HVAC design is necessary. **YES:** The HVAC design is completed and the HVAC design maybe including the HVAC equipment extension is sent to the Architect in form of an IFC data model. **NO:** HVAC engineer starts a new iteration cycle of the HVAC design process.

Approval HVAC Design?

Type	Decision Point
Documentation	At this point the Architect has validated the HVAC design in terms of his requirements and approves it or rejects it. **YES:** The Architect has approved the HVAC design and sends it to the Automation engineer in form of an IFC data model. **NO:** The Architect sends a reject message to the HVAC engineer and instructs him to start a new iteration cycle of the HVAC design.

Sensor/Actor Design Ok?

Type	Decision Point
Documentation	After completing an iteration cycle of the BAS design the Automation engineer decides whether the BAS design is acceptable, or not. **YES**: The Automation engineer sends the BAS design in form of an IFC data model to the HVAC engineer. **NO:** The Automation engineer starts a further iteration cycle of the BAS design.

Approval Network Design?

Type	Decision Point
Documentation	At this decision point the HVAC engineer has to decide whether the BAS design fulfills his requirements. **YES:** The HVAC engineer approves the BAS design and sends the building owner requirements and the whole building, HVAC and BAS design in form of an IFC data model to the BEMS engineer. **NO:** The HVAC engineer sends a reject message to the Automation engineer and instructs a new iteration cycle of the BAS design.

Approval BEMS Settings?

Type	Decision Point
Documentation	At this decision point the Building Owner/Facility Manager has to decide whether the BEMS setting fulfill his requirements or not. **YES:** The Building Owner/Facility Manager approves the BEMS settings which are chosen by the BEMS engineer. **NO**: The Building Owner/Facility Manager rejects the settings and instructs a review of these settings.

BEMS Commissioning

The process 'BEMS Commissioning' describes the commission of the HVAC system under control of the BEMS. The BEMS engineer and the Facility Manager are the main actors which are involved at the commissioning of the BEMS and the HVAC system. During the commission phase the BEMS engineer observes the BEMS regarding to possible error occurrences. Furthermore, he monitors the input and output data of the BEMS and compares them with the operational requirements. The goal of the commission phase is to adjust the BEMS in such a way that the operational requirements will be fulfilled. The process also describes how to deal with an error, which occurred during the commission phase.

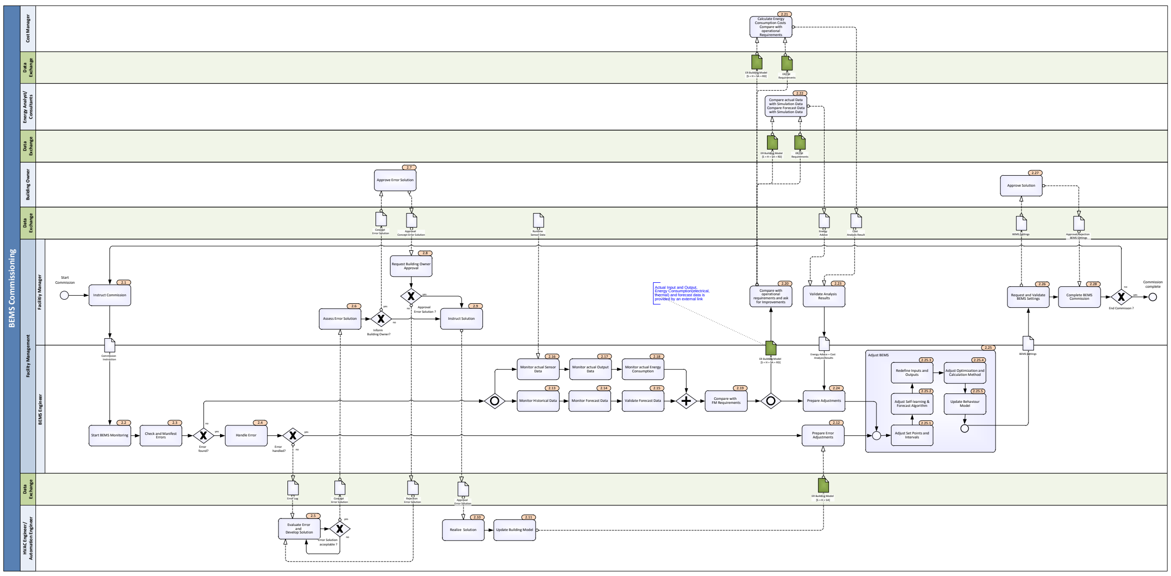


Figure 5.10: Process Map - BEMS Commissioning

Specification of Activities

Instruct Commission [2.1]

Type	Task
Documentation	After completing the planning and design phase of the BEMS the Facility Manager (FM) instructs the commission of the HVAC system under the control of the BEMS.

Start BEMS Monitoring [2.2]

Type	Task
Documentation	The BEMS engineer starts the commission of the HVAC system and the BEMS after receiving the commission instruction. He starts to monitor the BEMS with the goal to fulfill the operational requirements.

Check and Manifest Errors [2.3]

Type	Task
Documentation	A main part of the monitoring is to check and manifest errors which occur during the commissioning.

Handel Error [2.4]

Type	Task
Documentation	After noticing and manifesting an error the BEMS engineer has to decide whether he is able to handle the error, or not. If he is able to deal with the error he provides a solution to handle the error. Otherwise he sends an error log to the HVAC/Automation engineer and asks for help.

Evaluate Error and Develop Solution [2.5]

Type	Task
Documentation	After receiving an error log from the BEMS engineer the HVAC/Automation engineer has to provide a solution to handle the error. First he has to manifest the cause of the error (e.g. a defect of a HVAC device or a sensor within the BAS system). Subsequently he develops a concept to solve the error. The development of such an error solution takes place in some iteration cycles. After completing the design the HVAC/Automation engineer sends the concept to the FM.

Assess Error Solution [2.6]

Type	Task
Documentation	The FM assesses the received concept and instructs the realization of the concept or informs the Building Owner. His decision is based on the realization costs of the concept.

Approve Error Solution [2.7]

Type	Task
Documentation	The Building Owner approves the concept which was developed by the HVAC/Automation engineer to handle the error.

Request Building Owner Approval [2.8]

Type	Task
Documentation	The FM requests the approval message from the Building Owner. In the case the Building Owner approves the concept the FM has the possibility to instruct the realization of the developed concept.

Instruct Solution [2.9]

Type	Task
Documentation	The FM instructs the realization of the developed concept in form of an instruction message.

Realize Solution [2.10]

Type	Task

Documentation	The HVAC/Automation engineer provides the realization of the developed concept. The result of this activity is an accurate working HVAC system and BAS.

Update Building Model [2.11]

Type	Task
Documentation	After realizing the concept to handle the error, the Building Model is updated and the actual representation of the HVAC system and the BAS in form of an IFC data model is sent to the BEMS engineer.

Prepare Error Adjustments [2.12]

Type	Task
Documentation	After providing an error handling solution it necessary to adjust the BEMS. The prepared adjustments base on the solution of the BEMS engineer or on the updated Building Model which is received from the HVAC/Automation engineer.

Monitor Historical Data [2.13]

Type	Task
Documentation	The BEMS engineer monitors the data of the historical data base and evaluates them.

Monitor Forecast Data [2.14]

Type	Task
Documentation	The BEMS engineer monitors the calculated forecast data.

Validate Forecast Data [2.15]

Type	Task
Documentation	The Forecast data is not used in the commission phase but the BEMS engineer validates and assesses the plausibility of the calculated forecast states.

Monitor actual Sensor Data [2.16]

Type	Task
Documentation	The BEMS engineer monitors the measured input values of the HVAC equipment provided by the sensors and validate them.

Monitor actual Output Data [2.17]

Type	Task
Documentation	The BEMS engineer monitors the actual output values of the BEMS and verifies them in terms of plausibility.

Monitor actual Energy Consumption [2.18]

Type	Task
Documentation	The BEMS engineer monitors the calculated energy consumption (electrical/thermal energy/power consumption) and evaluates them regarding their plausibility.

Compare with FM Requirements [2.19]

Type	Task
Documentation	One of the main goals of the commission phase is to achieve the operational requirements. For this reason the BEMS engineer compares all data inputs/outputs and calculated values with the operational requirements. If there exists a discrepancy of the actual performance values and the operational requirements the BEMS must be adjusted. The BEMS engineer has the opportunity to ask the FM for advices.

Compare with operational requirements and ask for Improvements [2.20]

Type	Task
Documentation	The FM compares the current runtime data with the building owner requirements and gives some advices. He furthermore asks the Energy Analyst/Cost Manager for advices and

	improvements. The current runtime-data is provided in the form of an IFC data model. The IFC data model includes an external reference, which associate an external database with the IFC data model.

Calculate Energy Consumption Costs compare with operational requirements [2.21]

Type	Task
Documentation	After receiving the IFC data model the Cost Manager calculates the energy consumption and compare them with the operational requirements, specified by the Facility Manager. Subsequently he sends the cost analysis results and his advices to the FM Facility Manager.

Compare actual Data with Simulation Data & Compare Forecast Data with Simulation Data [2.22]

Type	Task
Documentation	After receiving the IFC data model the Energy Analyst compares the simulation result with runtime data taking into account the operational requirements, specified by the Facility Manager. Subsequently he sends the energy analysis results and his advices to the Facility Manager.

Validate Analysis Results [2.23]

Type	Task
Documentation	The Facility Manager validates the received analysis results and advices. He summarizes the advices and analysis results and presents them to the BEMS engineer.

Prepare Adjustments [2.24]

Type	Task
Documentation	On the basis of his monitoring results and the analysis results including the advices, the BEMS engineer prepares the adjustments of the BEMS.

Adjust BEMS [2.25]

Type	Sub-Process
Documentation	To achieve the operational requirements the BEMS engineer has the opportunity to adjust the BEMS. This activity ‘Adjust BEMS’ includes the following activities: • Adjust the set point of the air temperature and the relative humidity • Adjust the self-learning and forecast algorithm • Adjust optimization methods and calculation methods • Redefine the inputs or outputs (e.g. after an exchange of a sensor) • Update the behavior model

Adjust Set Points and Intervals [2.25.1]

Type	Task
Documentation	Depending on the monitoring results and the advices from the Energy Analyst, Cost Manager and the Facility Manager, the BEMS engineer has the opportunity to adjust the set points of the air temperature and of the relative humidity. An adjustment may affect the energy consumption and may reduce the energy costs.

Adjust Self-learning & Forecast Algorithm [2.25.2]

Type	Task
Documentation	On the basis of the monitoring results the BEMS engineer has the opportunity to adjust the self-learning and forecast algorithms. The accuracy can be improved by the means of the experiences which grow within the commission phase. Improved forecast and self-learning algorithms affect the energy consumption and reduce the energy costs.

Redefine Inputs and Outputs [2.25.3]

Type	Task
Documentation	In the case of the exchange of the HVAC equipment including their sensors, it is necessary to redefine the inputs/outputs of the BEMS. The required information can be extracted

	from IFC data model. The IFC data model includes the updated design of the HVAC equipment and BAS design. The redefinition of the inputs/outputs is just necessary in the case of a modification of the HVAC system or of the BAS. A redefinition has no effect to the energy consumption.

Adjust Optimization and Calculation Method [2.25.4]

Type	Task
Documentation	The BEMS engineer maybe wants to test different calculation methods within the commission phase. He maybe chose the different methods and compares the results of the energy calculation. Furthermore he has to possibility to change the optimization goal (optimize the whole HVAC system or optimize the several HVAC devices). Changes in the optimization and calculation methods affect the energy consumption and energy costs in a huge way.

Update Behavior Model [2.25.5]

Type	Task
Documentation	The BEMS engineer has to update the Behavior Model in the case of changes within the HVAC system or the BAS. The update is based on the updated IFC data model which includes the realization of an error solution. After a certain time within the commission phase, the Regression Models could be improved on the basis of empirical data.

Request and Validate BEMS Settings [2.26]

Type	Task
Documentation	After each monitoring and adjustment cycle the Facility Manager requests the current BEMS settings and validates them. He furthermore sends the BEMS settings to the Building Owner and asks for his approval.

Approve Solution [2.27]

Type	Task
Documentation	After receiving the BEMS settings from the Facility Manager the Building Owner approves or rejects them.

Complete BEMS Commission [2.28]

Type	Task
Documentation	In the case the Building Owner approves the BEMS settings and the BEMS operates in an acceptable way, the Facility Manager may complete the commission phase. Otherwise the Facility Manager starts a new iteration cycle of the HVAC system commission under control of the BEMS.

Specification of Data Objects

Error Log

Type	Data Objet
Documentation	The error log includes error messages, which are appear after the error occurrence. The error log maybe is an excel file which includes error messages, time stamp, advices from the FM/BEMS engineer and other useful information to handle the error.

Concept Error Solution

Type	Data Objet
Documentation	After identifying the error the HVAC/Automation engineer presents a solution in form of a concept. The concept is a textual description of how he wants to fix the error occurrence. It also includes a quotation to realize the developed concept.

Runtime Sensor Data

Type	Data Objet
Documentation	Describes the sensor data to be queried by the BEMS during runtime.

Energy Analysis Result

Type	Data Objet
Documentation	The data object includes the results of the comparison of the runtime data and the simulation results. During the comparison the operational requirements are taken into account. Furthermore it includes some advices for the adjustment of the BEMS.

Cost Analysis Result

Type	Data Objet
Documentation	The cost analysis result includes the cost calculation and the comparison of them with the operational requirements. It also includes advices from the cost manager in terms of cost optimization.

Energy + Cost Analysis Results

Type	Data Objet
Documentation	Includes the summarization of the *Cost Analysis Result* and the *Energy Analysis Result.* Furthermore it includes additional advices which are formulated by the Facility Manager. This data object is exchanged in a digital textual form or in an Excel table.

BEMS Settings

Type	Data Objet
Documentation	The data object includes the actual BEMS settings. The BEMS settings maybe provided in an excel table or in a text file. The BEMS settings include for instance the inputs/outputs, the set points of the air temperature/relative humidity, the calculation method for the energy consumption and the chosen optimization method.

Specification of Exchange Requirements Data Objects

ER FM Requirements

Type	Data Object
Documentation	The FM requirements specify the operational requirements for the Building Automation System (BAS) and Building Energy Management System (BEMS) The FM Requirement specification includes • Sensor/actor network requirements • Thermal comfort requirements (i.e. the air temperature and relative humidity of each room) • Indoor air quality requirements • Optimization requirements (e.g. energy consumption, Co2 emission)

ER Building Model [S + H + SA + RD]

Type	Data Object
Documentation	**see:** *BEMS Planning and Design/ Building Model Design [BD + HE + SA]* This exchange requirement includes in addition a link to an external data base. The external data base provides the runtime data of the BEMS. The runtime data consists of the following data: • Actual input and output of the BEMS • Current energy consumption (calculated) • Actual calculated forecast data • Historical data which is added to the Historical data base • …

ER Building Model [S + HE + SA]

Type	Data Object
Documentation	**see:** *BEMS Planning and Design/Building Model Design [BD + HE + SA]*

Specification of Gateways

Error found?

Type	Decision Point
Documentation	At this point the BEMS engineer has to decide whether an error occurred, or not? **YES:** The BEMS engineer tries to handle the error. **NO:** The BEMS engineer starts a monitoring cycle and maybe adjusts the BEMS.

Error handled?

Type	Decision Point
Documentation	At this decision point the BEMS engineer has to decide whether he is able to handle the error, or not. **YES**: The BEMS engineer develop an error solution and has to prepare the adjustments for the BEMS. **NO:** The BEMS engineer sends an Error Log to the HVAC/Automation engineer and asks for help.

Error Solution acceptable?

Type	Decision Point
Documentation	After evaluating the occurred error and developing a concept for its solution the HVAC/Automation engineer has to decide whether his solution is acceptable, or not. **YES:** The HVAC engineer prepares the concept and sends it in a textual form to the Facility Manager. **NO:** The HVAC/Automation engineer starts a new iteration cycle of the concept development.

Inform Building Owner?

Type	Decision Point
Documentation	At this point the Facility Manager has to decide whether he inform the Building Owner, or not (e.g. in the case the error solution is expensive the FM has to inform the Building Owner). **YES:** The Facility Manager sends the concept of the error solution to the Building Owner. **NO:** The Facility Manager instructs the realization of the concept which handles the error.

Approval Error Solution?

Type	Decision Point
Documentation	At this point the Facility Manager has received the approval for the realization of the concept that provides a solution for the error, or not. **YES:** The Facility Manager may instruct the realization error solution. **NO:** The Facility Manager sends a rejection message to the HVAC/Automation engineer.

End Commission?

Type	Decision Point
Documentation	At this point the Facility Manager has to decide whether the commission phase can be completed or a new iteration cycle of the commission is necessary, or not. **YES:** The Facility Manager completes the commission. **NO:** The Facility Manager starts a new iteration cycle.

BEMS Operating

The process 'BEMS Operating' describes the operation phase of the HVAC system under control of the BEMS. The Facility Manager observes the accurate function of the HVAC system and of the BEMS. Furthermore, the Facility Manager has the opportunity to carry out several adjustments of the BEMS. The adjustment of the BEMS may base on the monitoring results or on the occurrence of an error. In the case of an error occurrence the Facility Manager may asks the BEMS engineer and the HVAC/Automation engineer for help.

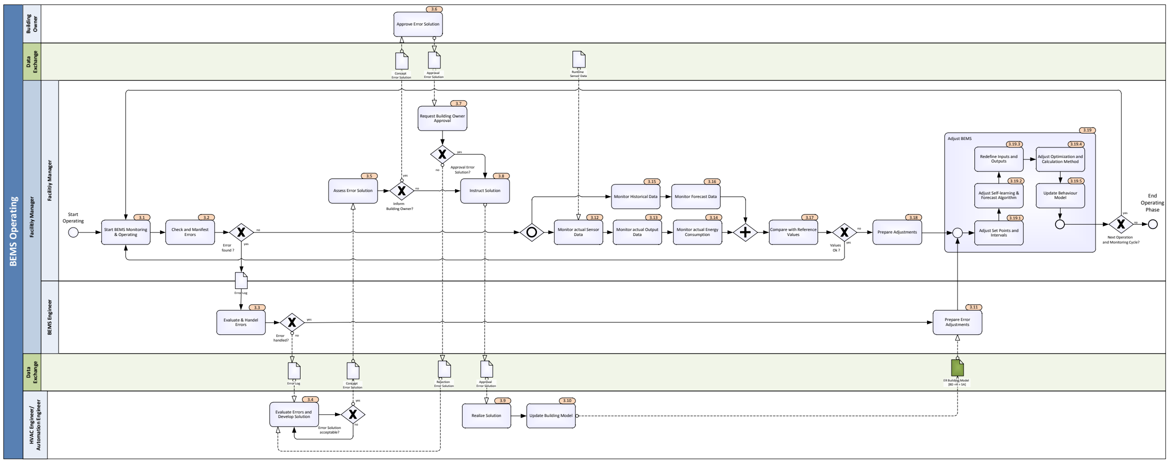


Figure 5.11: Process Map - BEMS Operating

Specification of Activities

Start BEMS Monitoring & Operating [3.1]

Type	Task
Documentation	After completing the commissioning phase which was mainly carried out by the BEMS engineer, the Facility Manager starts the operating phase of the HVAC system under control of the BEMS. Within the operating phase the Facility Manager has to ensure the accurate function of the HVAC system and the BEMS. During the operating phase he has to take into account the operational requirements.

Check and Manifest Errors [3.2]

Type	Task
Documentation	A main part of the operating and the monitoring is to check and manifest errors which occur during the operating phase of the HVAC system and the BEMS. In the case of an error occurrence the Facility Manager sends the error log of the BEMS to the BEMS engineer.

Evaluate & Handel Errors [3.3]

Type	Task
Documentation	After noticing and manifesting an error the BEMS engineer has to evaluate the error. After that he has to decide whether he is able to handle the error, or not. If he is able to deal with the error he provides a solution to handle the error. Otherwise he sends an error log to the HVAC/Automation engineer and asks for help.

Evaluate Errors and Develop Solution [3.4]

Type	Task
Documentation	After receiving an error log from the BEMS engineer the HVAC/Automation engineer has to provide a solution to handle the error. First he has to manifest the cause of the error (e.g. a defect of a HVAC device or a sensor within the BAS system). Subsequently he develops a concept to solve the error. The development of such an error solution takes place in some iteration cycles. After completing the design the HVAC/Automation engineer sends the concept to the Facility Manager.

Assess Error Solution [3.5]

Type	Task
Documentation	The Facility Manager assesses the received concept and instructs the realization of the concept or informs the Building Owner. His decision is based on the realization costs of the concept.

Approve Error Solution [3.6]

Type	Task
Documentation	The Building Owner approves the concept which was developed by the HVAC/Automation engineer to handle an error.

Request Building Owner Approval [3.7]

Type	Task
Documentation	The FM requests the approval message from the Building Owner. In the case the Building Owner approves the concept the Facility Manager has the possibility to instruct the realization of the developed concept.

Instruct Solution [3.8]

Type	Task
Documentation	The Facility Manager instructs the realization of the developed concept in form of an instruction message.

Realize Solution [3.9]

Type	Task
Documentation	The HVAC/Automation engineer provides the realization of the developed concept. The result of this activity is an accurate working HVAC system and BAS.

Update Building Model [3.10]

Type	Task
Documentation	After realizing the concept to handle the error, the Building Model is updated and the actual representation of the HVAC system and the BAS in form of an IFC data model is sent to the BEMS engineer.

Prepare Error Adjustments [3.11]

Type	Task
Documentation	After providing an error handling solution it necessary to adjust the BEMS. The prepared adjustments base on the solution of the BEMS engineer or on the updated Building Model which is received from the HVAC/Automation engineer.

Monitor actual Sensor Data [3.12]

Type	Task
Documentation	The Facility Manager monitors the measured input values of the HVAC equipment provided by the sensors and validate them.

Monitor actual Output Data [3.13]

Type	Task
Documentation	The Facility Manager monitors the actual output values of the BEMS and validates them in terms of plausibility.

Monitor actual Energy Consumption [3.14]

Type	Task
Documentation	The Facility Manager monitors the calculated energy consumption (electrical/thermal energy/power consumption) and validates them regarding to their plausibility. Furthermore he compares the energy consumption costs with the operational requirement.

Monitor Historical Data [3.15]

Type	Task
Documentation	The Facility Manager monitors the data of the historical data base and evaluates them.

Monitor Forecast Data [3.16]

Type	Task
Documentation	The Facility Manager monitors the calculated forecast data and assesses the plausibility of them.

Compare with Reference Values [3.17]

Type	Task
Documentation	Within the commissioning phase the BEMS was adjusted to achieve the operational requirements. The experiences of the commissioning phase were stored as reference values. These reference values serve to identify discrepancies within the current runtime data of the BEMS. The comparison of the runtime data and the reference value helps the Facility Manager to ensure the accurate function of the HVAC system under control of the BEMS.

Prepare Adjustments [3.18]

Type	Task
Documentation	On the basis of the monitoring results and the comparison of the runtime data and the reference values the Facility Manager has to decide whether adjustments of the BEMS are necessary or useful.

Adjust BEMS [3.19]

Type	Sub - Process
Documentation	To achieve the operational requirements the Facility Manager has the opportunity to adjust the BEMS. This activity 'Adjust BEMS' includes the following activities: • Adjust the set point of the air temperature and the relative humidity • Adjust the self-learning and forecast algorithm • Adjust optimization methods and calculation methods • Redefine the inputs or outputs (e.g. after an exchange of a sensor) • Update the behavior model Normally the Facility Manager has not to adjust the BEMS. Just in the case of discrepancies between the reference values and actual runtime data, he maybe has to adjust the BEMS.

Adjust Set Points and Intervals [3.19.1]

Type	Task
Documentation	The Facility Manager has the opportunity to adjust the set points of the air temperature and the relative humidity. An adjustment may affect the energy consumption and may reduce the energy costs.

Adjust Self-learning & Forecast Algorithm [3.19.2]

Type	Task
Documentation	On the basis of the monitoring results and the comparison of the actual runtime data and the reference values the Facility Manager has the opportunity to adjust the self-learning and forecast algorithms. The accuracy can be improved by the means of the experiences which grow during the operation phase. Improved forecast and self-learning algorithms affect the energy consumption and reduce the energy costs. Normally the self-learning and forecast algorithms are not adjusted during the operation phase.

Redefine Inputs and Outputs [3.19.3]

Type	Task
Documentation	In the case of the exchange of the HVAC equipment including their sensors, it is necessary to redefine the inputs/outputs of the BEMS. The required information can be extracted from IFC data model. The IFC data model includes the updated design of the HVAC equipment and the BAS. The redefinition of the inputs/outputs is just necessary in the case of a modification of the HVAC system or the BAS. A redefinition has no effect to the energy consumption.

Adjust Optimization and Calculation Method [3.19.4]

Type	Task
Documentation	Normally the Facility Manager does not change or adjust the optimization goal or calculation method of the energy consumption. Nevertheless, the Facility Manager has the possibility to adjust the optimization and calculation method during the operation phase.

Update Behavior Model [3.19.5]

Type	Task
Documentation	The Facility Manager has to update the Behavior Model in the case of changes within the HVAC system or the BAS. The update is based on the updated IFC data model which includes the realization of an error solution.

Specification of Data Objects

Error Log

Type	Data Objet
Documentation	The error log includes error messages, which are appear after the error occurrence. The error log maybe is an excel file which includes error messages, time stamp, advices from the Facility Manager /BEMS engineer and other useful information to handle the error.

Concept Error Solution

Type	Data Objet
Documentation	After identifying the cause of an error the HVAC/Automation engineer presents a solution in form of a concept. The concept is a textual description of how he wants to fix the error occurrence. It also includes a quotation to realize the developed concept.

Runtime Sensor Data

Type	Data Objet
Documentation	Describes the sensor data to be queried by the BEMS during runtime.

Specification of Exchange Requirements Data Objects

ER Building Model [S + H + SA]

Type	Data Object
Documentation	**see:** *BEMS Planning and Design/Building Model Design [S + H + SA]*

Specification of Gateways

Error found?

Type	Decision Point
Documentation	At this point the Facility Manager has to decide whether an error occurred, or not? **YES:** The Facility Manager informs the BEMS engineer and sends an error log. **NO:** The Facility Manager continues the current operating cycle.

Error handled?

Type	Decision Point
Documentation	At this decision point the BEMS engineer has to decide whether he is able to handle the error, or not. **YES**: The BEMS engineer develop an error solution and has to prepare the adjustments for the BEMS. **NO:** The BEMS engineer sends the Error Log to the HVAC/Automation engineer and asks for help.

Error Solution acceptable?

Type	Decision Point
Documentation	After evaluating the occurred error and developing a concept for its solution the

	HVAC/Automation engineer has to decide whether his solution is acceptable, or not. **YES:** The HVAC engineer prepares the concept and sends it in a textual form to the Facility Manager. **NO:** The HVAC/Automation engineer starts a new iteration cycle of the concept development.

Inform Building Owner?

Type	Decision Point
Documentation	At this point the Facility Manager has to decide whether he inform the Building Owner, or not (e.g. in the case the error solution is expensive the Facility Manager has to inform the Building Owner). **YES:** The Facility Manager sends the concept of the error solution to the Building Owner. **NO:** The Facility Manager instructs the realization of the concept which handles the error.

Approval Error Solution?

Type	Decision Point
Documentation	At this point the Facility Manager has received the approval for the realization of the concept that provides a solution for the error, or not. **YES:** The Facility Manager may instruct the realization error solution. **NO:** The Facility Manager sends a rejection message to the HVAC/Automation engineer.

Values Ok?

Type	Coordination Point
Documentation	At this point the Facility Manager has to decide whether there is a discrepancy among the reference values and the runtime data, or not. **YES:** The Facility Manager completes the current operating cycle and starts the next iteration **NO:** The Facility Manager investigates the opportunities of adjusting the BEMS.

Next Operation and Monitoring Cycle?

Type	Coordination Point
Documentation	At this decision point the Facility Manager has to decide whether the operating phase is complete, or not. **YES:** The Facility Manager complete the operating phase, maybe caused by a retrofitting decision. **NO:** The Facility Manager starts a new iteration cycle of the operating phase.

BEMS Retrofitting

The process ‘BEMS Retrofitting’ describes the retrofitting of the building and the HVAC equipment and the following parameterization of the BEMS. The Facility Manager may suggest the Building Owner retrofitting opportunities, which are based on the experiences of the operating phase. Furthermore, in case the HVAC equipment does not fulfill any more the requirements (e.g. technical, economical or comfort requirements) the Facility Manager may suggest the Building Owner some retrofitting advices. If the Building Owner desires the retrofitting of the building and the HVAC equipment, a retrofitting design is performed on the basis of the new specified Building Owner requirement. Due to the retrofitting it is necessary to assess the retrofitting design in terms of the BEMS requirements and to adjust the BEMS regarding the retrofitting design. After completing the retrofitting phase starts the commissioning phase of the retrofitted HVAC system under control of the BEMS.

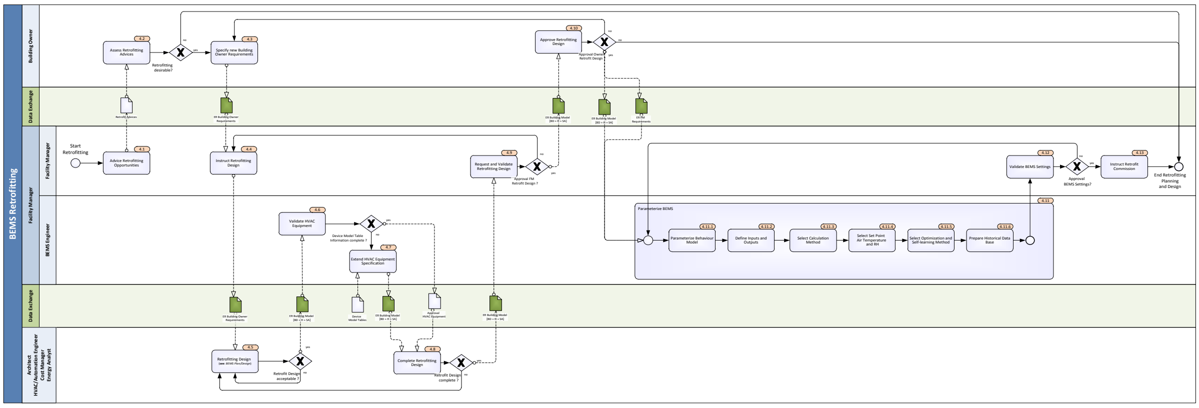


Figure 5.12: Process Map - BEMS Retrofitting

Specification of Activities

Advice Retrofitting Opportunities [4.1]

Type	Task
Documentation	The Facility Manager formulates retrofitting advices. The advices base on the achieved experience during operating the HVAC system under control of the BEMS or the occurrences of defects and errors within the HVAC system or the building and the HVAC equipments does not fulfill any more the technical/ecological requirements.

Assess Retrofitting Advices [4.2]

Type	Task
Documentation	The Building Owner receives the retrofitting advices from the Facility Manager. He reviews and evaluates the advices. Furthermore he has to decide whether he desires a retrofitting of the building and the HVAC equipment, or not.

Specify new Building Owner Requirements [4.3]

Type	Task
Documentation	The new Building Owner specifies the new Building Owner Requirements regarding to the retrofitting advices.

Instruct Retrofitting Design [4.4]

Type	Task
Documentation	After receiving the new Building Owner requirements the Facility Manager instructs the retrofitting design.

Retrofitting Design [4.5]

Type	Task
Documentation	Considering the Building Owner requirements the Architect, HVAC engineer and the Automation engineer develop the retrofitting design of the building components, the HVAC equipment and the sensor/actor network (BAS). **see:** *BEMS Planning and Design/ Design Building, Design HVAC System, Design Sensor and Actor Network*

Validate HVAC Equipment [4.6]

Type	Task
Documentation	The BEMS engineer receives the retrofitting design in form of an IFC data model and validate (evaluate) the product specific information of the HVAC equipment. He has to decide whether the containing information fulfill the information requirements of the BEMS. The required information of the HVAC equipment is described in Device Model Tables which are specified for each HVAC component. In the positive case he sends an approval and in the other case he extends the product specific information of the HVAC equipment. An approval means no extension is needed.

Extend HVAC Equipment Specification [4.7]

Type	Task
Documentation	In the case the product specific information of the HVAC equipment does not satisfy the BEMS requirements the BEMS engineer extends the equipment specification. The BEMS engineer uses the Device Model Table of each HVAC component to extend the specification. The Model Tables contains the following information: • Name and type of the device • Photograph and outline • Description • Calculation specification of the thermal energy consumption • Control information

Complete Retrofitting Design [4.8]

Type	Task
Documentation	Before the retrofitting design can be completed, the HVAC engineer reviews the extension of the product specification of the HVAC equipment. In the case of an approval by the BEMS engineer the retrofitting design can be completed immediately and can be prepared for the approval of the Facility Manager.

Request and Validate Retrofitting Design [4.9]

Type	Task
Documentation	The Facility Manager requests the retrofitting design and validates it. He evaluates the retrofitting design in terms of the Building Owner requirements. In the case the retrofitting design does not satisfy the Facility Manager, he may instruct a new iteration cycle of the retrofitting design. Otherwise he sends the completed retrofitting design in form of an IFC data model to the Building Owner.

Approve Retrofitting Design [4.10]

Type	Task
Documentation	After receiving the retrofitting design from the Facility Manager, the Building Owner approves the retrofitting design taking into account its requirements.

Parameterize BEMS [4.11]

Type	Sub-Process
Documentation	This activity includes several activities to set up the BEMS for the retrofitted building and HVAC system. On the basis of the retrofitting design of the building, HVAC system and the BAS the BEMS engineer accomplishes the following activities: • Parameterize the behavior models • Define the inputs and outputs • Select calculation method • Select optimization method • Select set points for the air temperature and relative humidity • Prepare historical data base. The result of this sub-process is a digital list that includes all settings of the BEMS. This list is checked by the Facility Manager regarding the operational requirements.

Parameterize Behavior Model [4.11.1]

Type	Task
Documentation	The BEMS engineer parameterizes the behavior model on the basis of the HVAC system and the HVAC equipment. The system and equipment information is extracted from the IFC data model.

Define Inputs and Outputs [4.11.2]

Type	Task
Documentation	On the basis of the designed HVAC system and sensor/actor network (BAS) the inputs and the outputs of the BEMS are defined. The inputs provide the runtime sensor data. The sensor data is used e.g. to calculate the actual energy consumption. The outputs serve to control the HVAC equipment in an energy optimized way.

Select Calculation Method [4.11.3]

Type	Task
Documentation	In dependence on the available sensors of each HVAC component a calculation specification of the thermal power consumption is selected. **see:** *BEMS Planning and Design /Select Calculation Method*

Select Set Point Air Temperature and RH [4.11.4]

Type	Task
Documentation	The BEMS engineer selects for each room the air temperature (e.g. the temperature of the air which is supplied by the fan-coil) and the relative humidity on the basis of the new Building Owner and operational requirements.

Select Optimization Method [4.11.5]

Type	Task
Documentation	On the basis of the operational requirements the BEMS engineer selects the optimization goal. For instance he can choose between an efficient performance of the HVAC components or of the whole HVAC system. Furthermore, he selects a suitable forecast algorithm (Neural Networks, Bayesian Nets or Fuzzy Logic). The BEMS engineer maybe has the opportunity to select among different self-learning methods. All decisions are based on the information which are provided by the IFC data model.

Prepare Historical Data Base [4.11.6]

Type	Task
Documentation	The BEMS includes a historical database which stores the data that is generated during the operation phase. The forecast algorithms use this data to estimate the future state. To prepare an optimal commissioning the historical data of the operating phase is validated by the BEMS engineer. Furthermore the historical data base may be extended with the simulation data of the retrofitting design.

Validate BEMS Settings [4.12]

Type	Task
Documentation	After the parameterization of the BEMS the BEMS engineer sends the BEMS settings in a digital form to the Facility Manager. The Facility Manager receives these settings and validates them. In the case he agrees the settings he may complete the retrofitting phase. Otherwise he instructs a review and an adjustment the BEMS.

Instruct Retrofit Commission [4.13]

Type	Task
Documentation	After the realization of the retrofitting design including BEMS parameterization, the Facility Manager completes the retrofitting phase and may instruct a further commissioning phase.

Specification of Data Objects

Retrofit Advice

Type	Data Objet
Documentation	The Data Object includes the advices of the Facility Manager regarding the retrofitting opportunities. The retrofit advice is exchanged in a digital textual form.

Device Model Tables

Type	Data Objet
Documentation	

The Device Model Tables include all information required by the BEMS. For each HVAC devices

a Device Model Table was developed within SEEDS. The Device Model Tables are provided in a digital textual form.

Specification of Exchange Requirements Data Objects

ER Building Owner Requirements

Type	Data Object
Documentation	The Building Owner Requirements specify the programming and planning requirements. These requirements are the basis for the work of the Architect and the HVAC engineer. The Building Owner Requirement specification includes • Building program requirements • Space group program requirements • Space program requirements • Visual comfort requirements • Quality requirements • Energy requirements

ER Building Model [S + H + SA]

Type	Data Object
Documentation	**see:** *BEMS Planning and Design/ ER Building Model[S + H + SA]*

ER FM Requirements

Type	Data Object
Documentation	**see:** *BEMS Planning and Design/ ER Building Model[S + H + SA]*

Specification of Gateways

Retrofitting desirable?

Type	Decision Point
Documentation	At this decision point the Building Owner has to decide whether he desires a retrofitting, or not. **YES:** The Building Owner desires a retrofitting and the next step is to specify the new requirements. **NO:** The Building Owner rejects all retrofitting advices and desires no retrofitting. The retrofitting phase ends.

Retrofit Design acceptable?

Type	Decision Point
Documentation	After developing a retrofitting design the involved actors have to decide whether their retrofitting design is acceptable, or not. **YES**: They send the retrofitting design in form of an IFC data model to the BEMS engineer. **NO**: They start a new iteration cycle of the retrofitting design.

Device Model Table Information complete?

Type	Decision Point
Documentation	At this decision point the BEMS engineer has to decide whether the HVAC equipment and their product specific information fulfill the requirements of the BEMS, or not. **YES**: The BEMS engineer sends an approval message to the HVAC engineer. **NO**: The BEMS extend the HVAC design using the Device Model Table specification of the HVAC equipment (specified within SEEDS).

Retrofit Design complete?

Type	Decision Point
Documentation	At this point the actors which are involved within the retrofitting design have to decide whether the retrofitting design can be completed, or not. **YES**: They send the retrofitting design in form of an IFC data model to the Facility Manager. **NO**: They start a new iteration cycle of the retrofitting design.

Approval FM Retrofit Design?

Type	Decision Point
Documentation	At this point the Facility Manager has to approve or to reject the provided retrofitting design. **YES**: The Facility Manager sends the retrofitting design in form of an IFC data model to the Building Owner. **NO**: The Facility Manager instructs a new iteration cycle of the retrofitting design.

Approval Owner Retrofit Design?

Type	Decision Point
Documentation	At this point the Building Owner has to decide whether he approves or rejects the retrofitting design. **YES**: The Building Owner sends his operational requirements and the retrofitting design in form of an IFC data model to the BEMS engineer. **NO**: The Building Owner either stops the retrofitting design or he starts a new iteration cycle of the retrofitting design.

Approval BEMS Settings?

Type	Decision Point
Documentation	At this point the Facility Manager has to approve the BEMS settings regarding the operational requirements, or not. **YES**: The Facility Manager may instruct the retrofitting commissioning. **NO**: The Facility Manager instructs a further iteration of the BEMS parameterization.

5.3.3 Exchange Requirements

An important outcome of developing the process maps are the exchange requirements. In the case of the business process 'BEMS Engineering' and its sub-processes six exchange requirements have been identified. The Table 5.1 shows an overview on the sub-process and the corresponding exchange requirements.

Process Map	ER Name
BEMS Planning and Design	ER Building Owner Requirements ER FM Requirements ER Building Model[BD] ER Building Model[S + H] ER Building Model[S + H + SA]
BEMS Commissioning	ER FM Requirements ER Building Model[S + H + SA + RD] ER Building Model [S + H + SA]
BEMS Operating	ER Building Model [S + HE + SA]
BEMS Retrofitting	ER Building Owner Requirements ER FM Requirements ER Building Model[S + H + SA]
Legend: **BD** … Building Design, **S** … Space model, **H** … HVAC design, **SA** … Sensor/Actor network design, **RD** … Runtime Data	

Table 5.1: Overview on exchange requirements

The basic content and the usage of the most important exchange requirements regarding the interfacing of the SEEDS BEMS into a BIM process are described hereinafter.

ER FM Requirements

The exchange requirement 'ER FM Requirements' contains the operational requirements for the building, the HVAC system, the Building Automation System (BAS) and also for the SEEDS BEMS. The thermal comfort requirements (e.g. room temperature, humidity) and the air quality requirements for the partial spaces of the building are specified. Furthermore, the requirements for the sensor/actor network are described in terms of operating the HVAC system under control of the SEEDS BEMS. In addition, the optimization requirements for the building and the HVAC system are specified (e.g. energy consumption, CO2 emission).

The exchange requirement 'ER FM Requirements' is used in 'BEMS Planning and Design' and in 'BEMS Retrofitting' for the design of the sensor/actor network (e.g. measure requirements) and for the parameterization of the SEEDS BEMS (e.g. thermal comfort requirements). During the 'BEMS Commissioning' it is serves as reference for the comparison with the current runtime data.

ER Building Model[S + H]

The exchange requirement 'ER Building Model[S + H]' mainly contains the spatial structure of the building (e.g. storeys, spaces, partial spaces) and the HVAC system including the HVAC components (e.g. air conditioning system including fan-coils, chiller etc.). Furthermore, it includes dependency information between the spatial structure and the HVAC equipment. The description of the HVAC equipment includes the following information:

- HVAC system and the containing sub-systems
- Logical connection among different HVAC components
- Product specification data of the HVAC components (Device Model Tables).

The exchange requirement 'ER Building Model[S + H]' provides the basic information for the Device Model Table extension and the design of the sensor/actor network in the 'BEMS Planning and Design' process.

ER Building Model[S + H + SA]

This exchange requirement includes in addition to the exchange requirement 'Building Model Design [S + H]' the design of the sensor/ actor network. It contains general information of the Building Automation System (e.g. topology, architecture), as well as information about the sensors, actors and the controller which are installed in the building. Furthermore, it contains the relations and dependencies of the sensors and actors to the spatial structure of the building and the HVAC equipment. Optionally it may contain information about building elements (e.g. walls materials). This information are currently not taken into account by the SEEDS BEMS.

The exchange requirement 'ER Building Model[S + H + SA]' is the basis for the parameterization of the SEEDS BEMS in the 'BEMS Planning and Design', 'BEMS Retrofitting' and for the adjustment of the BEMS in the 'BEMS Commissioning' respectively 'BEMS Operating' phase. It provides all information of the HVAC equipment (e.g. Device Model Tables) which is needed for the internal behavior model of the BEMS, as well as sensor/actor information for the definition of the inputs and outputs of the BEMS.

ER Building Model[S + H + SA + RD]

The exchange requirement 'ER Building Model[S + H + SA + RD]' bases on the exchange requirement 'Building Model Design [S + H + SA]'. It additionally contains the actual runtime data of the SEEDS BEMS. The runtime data may be provided in form of a link to an external data base which could comprise the following information:

- Actual input and output of the BEMS
- Current calculated energy consumption
- Actual calculated forecast data
- Historical data
- etc.

The exchange requirement 'ER Building Model[S + H + SA + RD]' is used in the 'BEMS Commissioning' phase and is the basis for the calculation of the actual energy consumption costs and for the comparison with the energy analysis results of an energy expert.

A detailed specification of the discussed exchange requirements and the further exchange requirements can be seen in annex A (1.5). The table of the exchange requirement specification has the following structure.

ER Building Model[S + H + SA]										
Property concept	Property group	Property name	Definition	Examples	MAN	REC	OPT	Data Source	IFC Representation
Building Spatial Structure									
	Building Storey								IfcBuildingStorey
		General Information				✓			
		Storey identifier	Unique number of the storey	"00", "01"		✓		IFC	IfcBuildingStorey.GobalID
		Storey name	Desciptive name of the storey	"EG", "OG"		✓		IFC	IfcBuildingStorey.Name
		Storey quantities					✓		
		Storey area	Net area as covered by base quantities	[m2]			✓	IFC	IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities
		Storey volume	Net volume as covered by base quantities	[m3]			✓	IFC	IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities

Table 5.2: Structure exchange requirements table

Each exchange requirement specification contains a set of information which is classified in 'Property concept', 'Property group' and 'Property name'. The column 'Property name' represents a basic information that has to be exchanged. This property is described in the column 'Definition' and further explanation respectively an example is given in column 'Examples'. Furthermore, it is marked whether the property is mandatory, recommend or optional. In the case the source of the property (column 'Data Source') is an IFC data model the representation of the property by means of the IFC is given.

5.3.4 Evaluation of the Integration of the BEMS into the BIM Process

The specification of the exchange requirements is the basis for the next steps within the IDM and a following interface implementation for the SEEDS BEMS. As mentioned in Section 4.2 the next step within the IDM is the mapping of functional parts to the specified exchange requirements. In other words, it must be investigated which standard functional parts can fulfill these exchange requirements. After performing the mapping of the functional parts it can be evaluated whether the

IFC data model is suitable for the interfacing of the SEEDS BEMS into a BIM process. Furthermore, statements for possible extensions of the IFC data model can be made. However, the purpose of this deliverable is to perform the IDM requirement analysis to identify the exchange requirements.

By the aid of the outcomes of this IDM requirement analysis it can be recognized that the required information of the SEEDS BEMS may be fulfilled by the BIM approach. That means they major part of the information which were specified in the exchange requirements (Section5.3.3) can be represented by the IFC data model respectively can be made accessible.

Nevertheless, for a final evaluation of the IFC data model regarding its ability for the integration of the SEEDS BEMS into a BIM process a further IDM requirement analysis will be necessary. By means of the experiences of the performed IDM requirement analysis and the development of the BEMS within SEEDS a more accurate process analysis will be possible.

6 Conclusion

In the future years, reduction of the CO_2 emissions as well as the energy use will play a significant role. Residential and commercial buildings which include building services represent a vast potential for energy saving. In order to optimize the energy consumption of HVAC equipment which is installed in buildings, a Building Energy Management System (BEMS) is developed in the context of the SEEDS project. Developing this BEMS, focusing on the modeling of the building including the HVAC equipment is the objective of this BIM approach.

In this deliverable, basic concepts regarding Building Information Modeling methodology and an overview of common product data modeling standards regarding BIM, as well as in terms of building services were presented. The BIM standards of the buildingSMART technology were further introduced. The Industry Foundation Classes, the specification of a comprehensive standard building information model and the Industry Delivery Manual, a standard method for specifying process and identifying the data exchange requirements within a BIM process were introduced in detail.

After introducing the background knowledge regarding BIM, IFC and IDM, some representation options of a simple air conditioning system using the IFC data format were demonstrated. It was shown that the IFC data schema is suitable for the representation of:

- HVAC components including their Device Model Tables
- Logical relationships among HVAC components
- HVAC systems including their sub-systems, as well as HVAC components.

On the next section, the outcomes of an IDM requirement analysis in terms of the interfacing of the SEEDS BEMS into a BIM process were presented. Detail of the process maps including their specification of activities, data objects and exchange requirements were developed. Subsequently the identified exchange requirements were specified in detail. The specification of the exchange requirements describes the information that has to be exchanged to interface the SEEDS BEMS into a BIM process and they are the basis for the next steps within the IDM and a following interface implementation. However, this was not the purpose of the deliverable.

A subsequent further extensive task may include the mapping of functional parts to the specified exchange requirements, the specification of a Model View Definition (MVD) which defines a standard subset of the IFC data schema that satisfies specific AEC business process (e.g. interfacing the BEMS to a BIM process) and finally the implementation of the SEED BEMS interface on the basis of the MVD.

7 Acknowledgements

The research results of the SEEDS deliverable D2.2 were obtained in close cooperation between the FP7 projects SEEDS and HESMOS ("ICT Platform for Holistic Energy Efficiency Simulation and Lifecycle Management Of Public Use Facilities"). Prof. Raimar Scherer (TU Dresden, Head of the Institute of Civil Engineering) is coordinating the HESMOS project which is developing a platform for energy-efficient Building Information Modeling (eeBIM).

The Institute of Civil Engineering of the TU Dresden belongs to the most important BIM competence centres in Germany and in Europe.

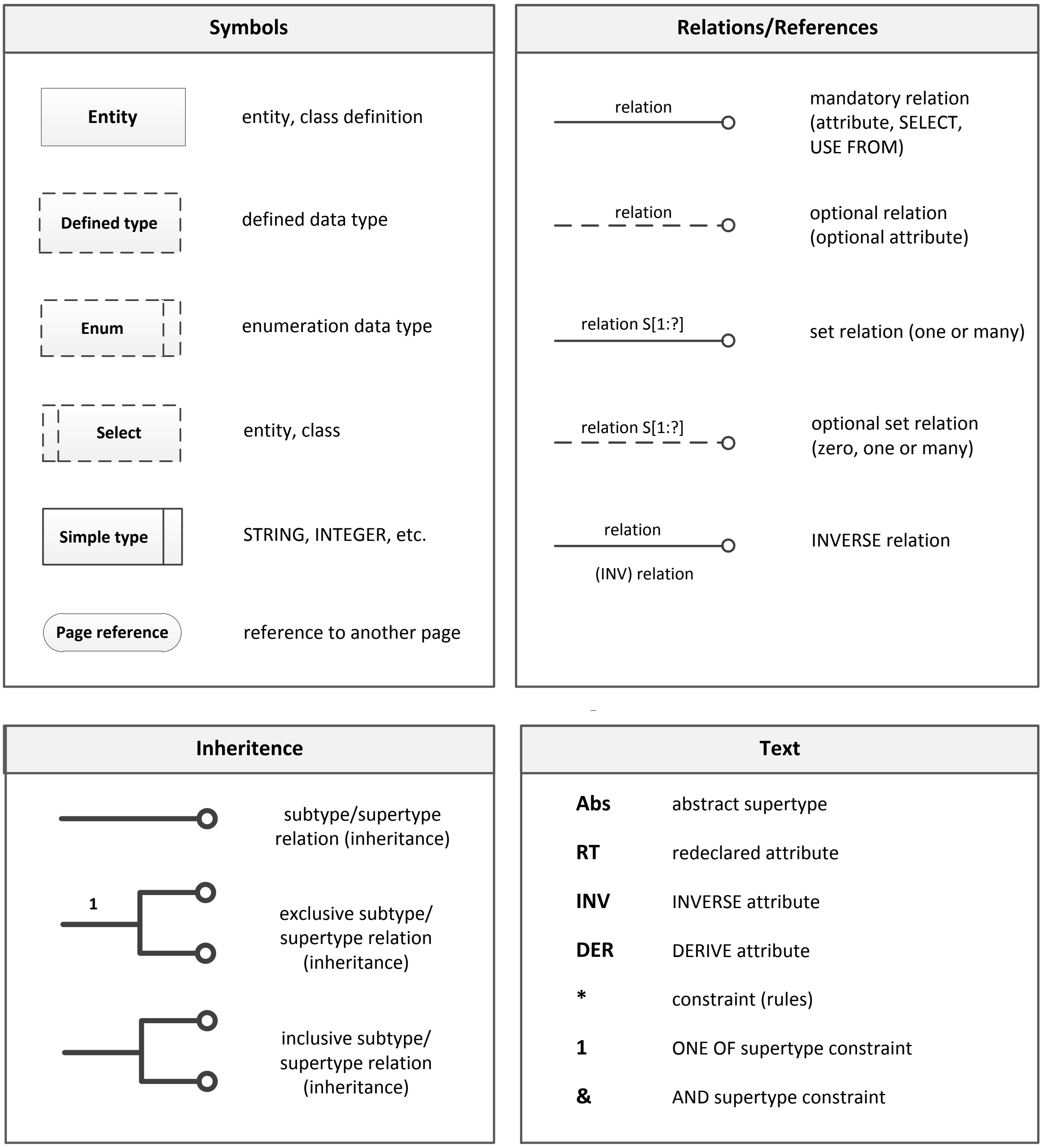
Chapter two to five of the deliverable base on the study thesis "Analysis and evaluation of the IFC project model with respect to its ability to describe building automation components for HVAC systems" by Pit Stenzel [24]. The study this was jointly supervised by SEEDS and HESMOS research staff members of Fraunhofer EAS and the TU Dresden, Institute of Civil Engineering.

The authors would like the thank Prof. Raimar Scherer and his staff for the fruitful on-going cooperation.

ANNEX A – IFC data schema specification

List of Tables

1.1. *Overview EXPRESS-G Notation*



1.2. *VDI 3805 - Structure of the Product Data Model*

Figure 1

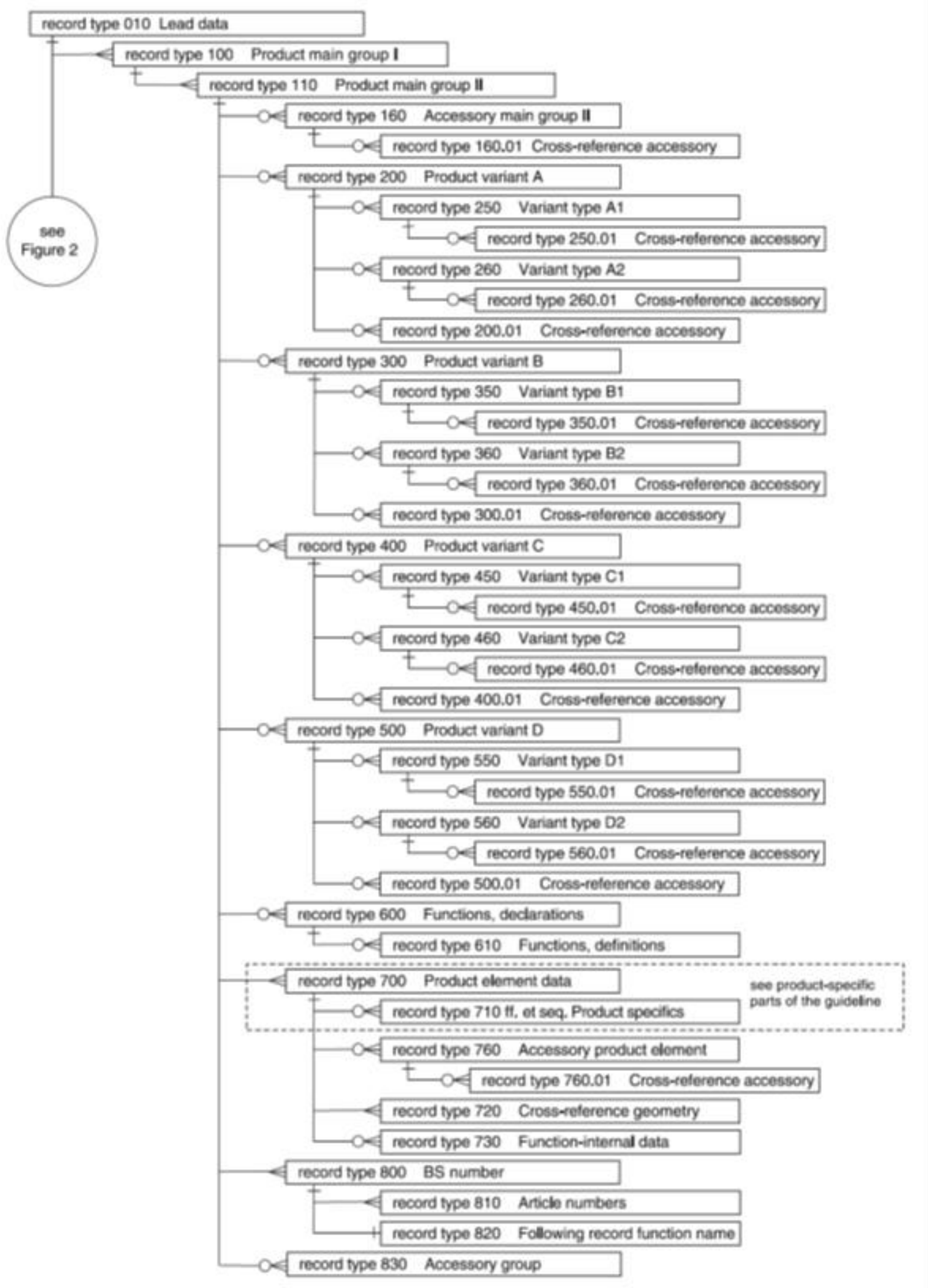
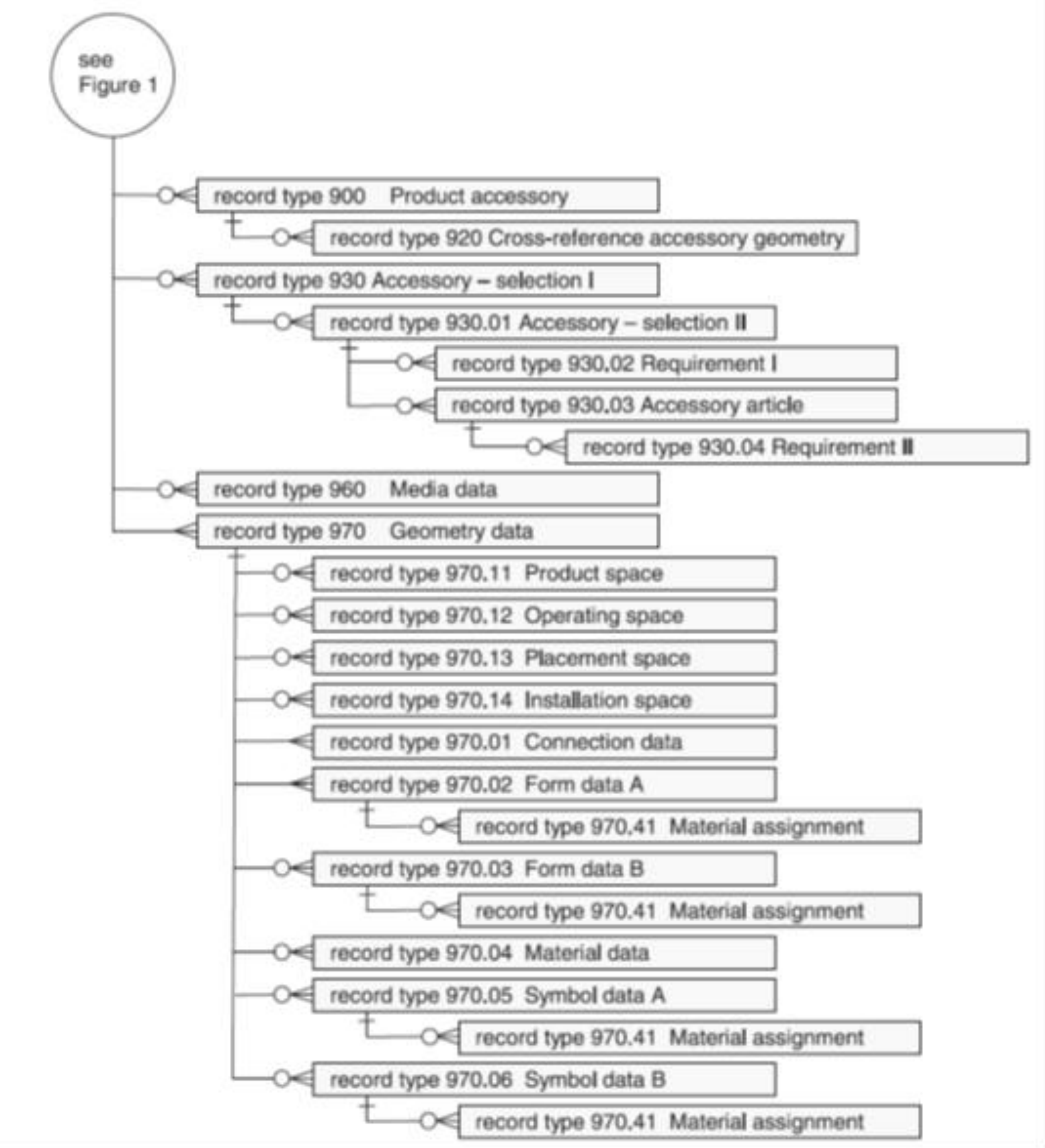
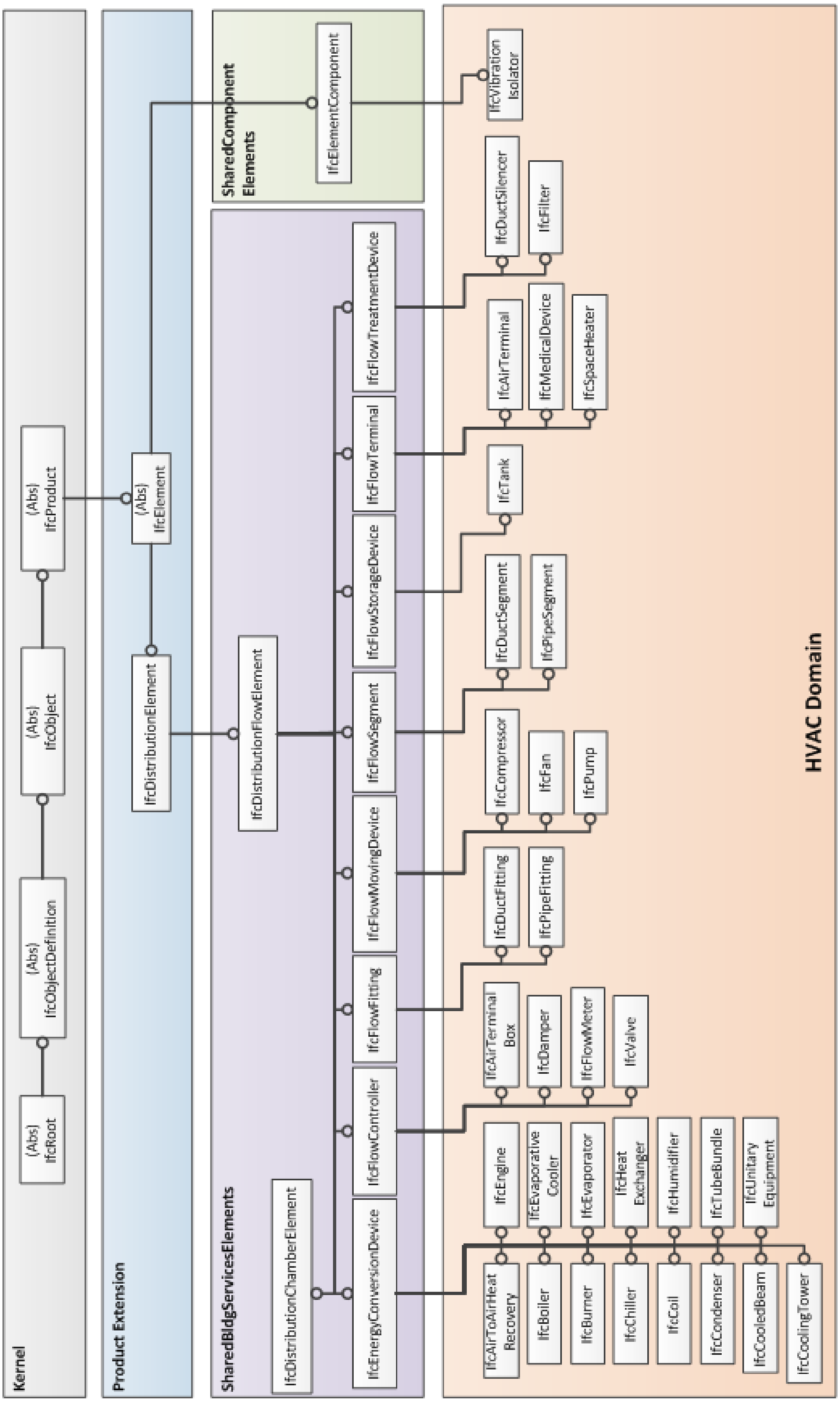


Figure 2


see Figure 1
record type 900 Product accessory
record type 920 Cross-reference accessory geometry
record type 930 Accessory – selection I
record type 930.01 Accessory – selection II
record type 930.02 Requirement I
record type 930.03 Accessory article
record type 930.04 Requirement II
record type 960 Media data
record type 970 Geometry data
record type 970.11 Product space
record type 970.12 Operating space
record type 970.13 Placement space
record type 970.14 Installation space
record type 970.01 Connection data
record type 970.02 Form data A
record type 970.41 Material assignment
record type 970.03 Form data B
record type 970.41 Material assignment
record type 970.04 Material data
record type 970.05 Symbol data A
record type 970.41 Material assignment
record type 970.06 Symbol data B
record type 970.41 Material assignment

1.3. *HVAC Entities Inheritance Hierarchy*



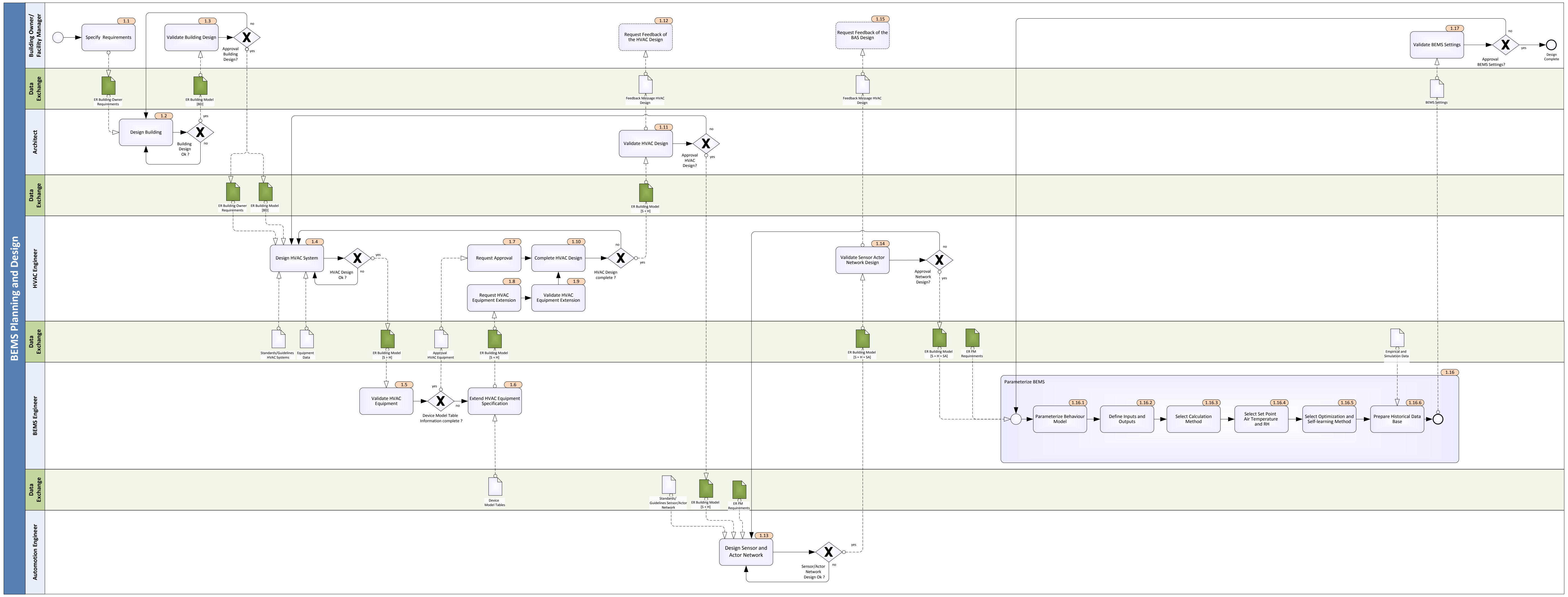
1.4. *HVAC Domain Entities*

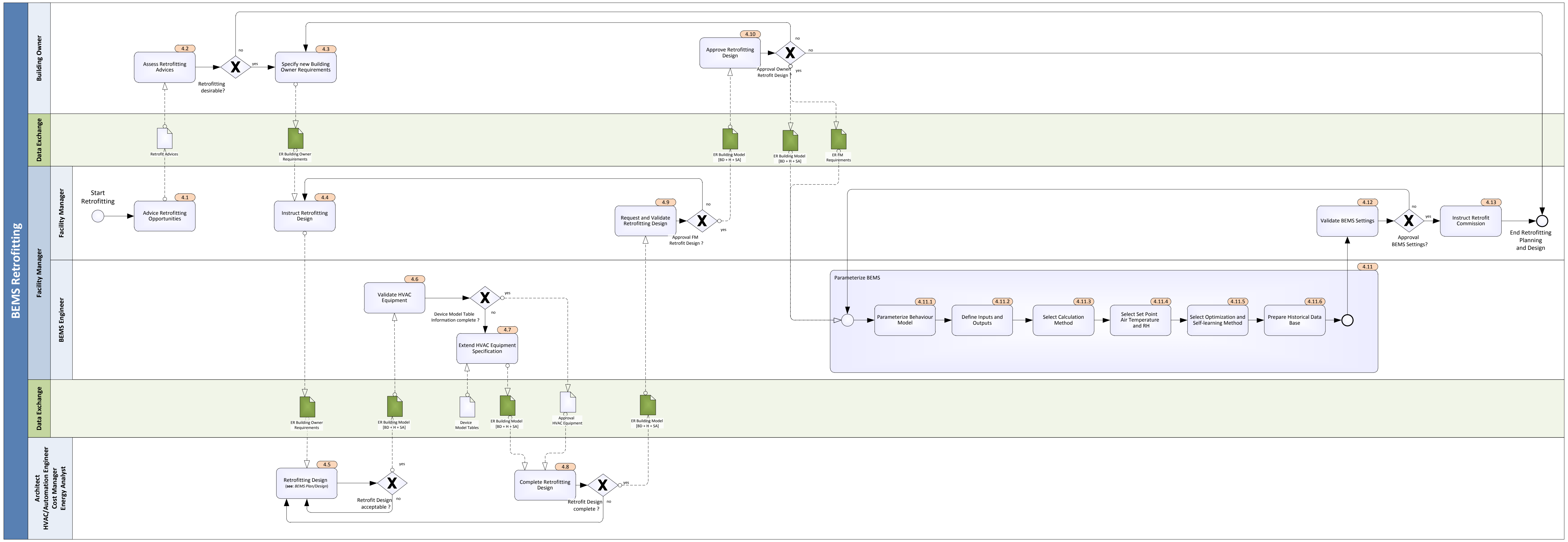
HVAC Entity (Occurrence)	Description
IfcAirTerminal	An air terminal is a terminating or origination point for the transfer of air between distribution system(s) and one or more spaces. It can also be used for the transfer of air between adjacent spaces.
IfcAirTerminalBox	An air terminal box typically participates in an HVAC duct distribution system and is used to control or modulate the amount of air delivered to its downstream ductwork. An air terminal box type is often referred to as an "air flow regulator".
IfcAirToAirHeatRecovery	An air-to-air heat recovery device employs a counter-flow heat exchanger between inbound and outbound air flow. It is typically used to transfer heat from warmer air in one chamber to cooler air in the second chamber (i.e., typically used to recover heat from the conditioned air being exhausted and the outside air being supplied to a building), resulting in energy savings from reduced heating (or cooling) requirements.
IfcBoiler	A boiler is a closed, pressure-rated vessel in which water or other fluid is heated using an energy source such as natural gas, heating oil, or electricity. The fluid in the vessel is then circulated out of the boiler for use in various processes or heating applications.
IfcBurner	A burner is a device that converts fuel into heat through combustion. It includes gas, oil, and wood burners.
IfcChiller	A chiller is a device used to remove heat from a liquid via a vapor-compression or absorption refrigeration cycle to cool a fluid, typically water or a mixture of water and glycol. The chilled fluid is then used to cool and dehumidify air in a building.
IfcCoil	A coil is a device used to provide heat transfer between non-mixing media. A common example is a cooling coil, which utilizes a finned coil in which circulates chilled water, antifreeze, or refrigerant that is used to remove heat from air moving across the surface of the coil. A coil may be used either for heating or cooling purposes by placing a series of tubes (the coil) carrying a heating or cooling fluid into an airstream.
IfcCompressor	A compressor is a device that compresses a fluid typically used in a refrigeration circuit.

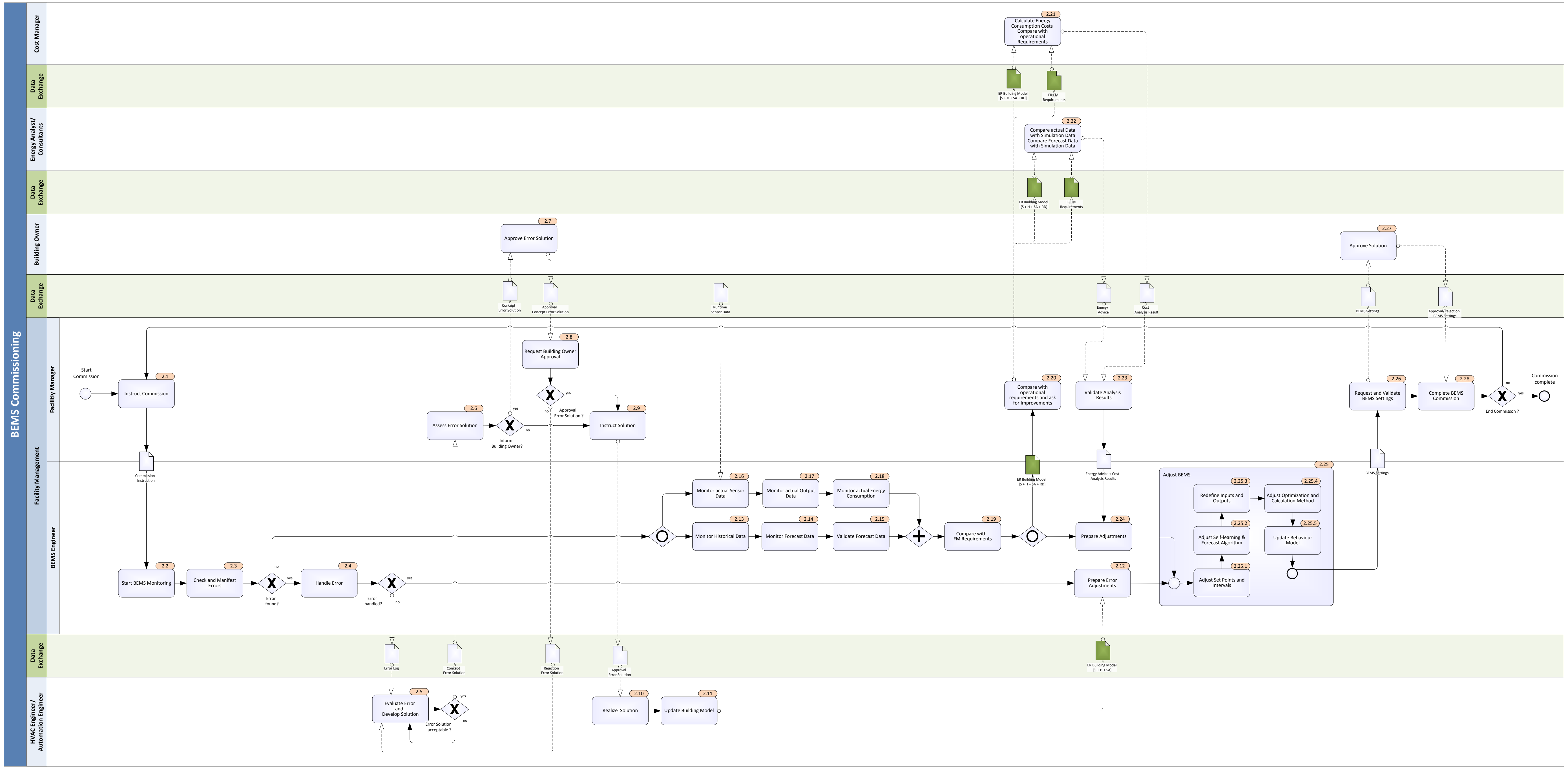
IfcCondenser	Is a device that is used to dissipate heat, typically by condensing a substance such as a refrigerant from its gaseous to its liquid state.
IfcCooledBeam	A cooled beam (or chilled beam) is a device typically used to cool air by circulating a fluid such as chilled water through exposed finned tubes above a space. Typically mounted overhead near or within a ceiling, the cooled beam uses convection to cool the space below it by acting as a heat sink for the naturally rising warm air of the space. Once cooled, the air naturally drops back to the floor where the cycle begins again.
IfcCoolingTower	A cooling tower is a device which rejects heat to ambient air by circulating a fluid such as water through it to reduce its temperature by partial evaporation.
IfcDamper	A damper typically participates in an HVAC duct distribution system and is used to control or modulate the flow of air.
IfcDuctFitting	A duct fitting is a junction or transition in a ducted flow distribution system or used to connect duct segments, resulting changes in flow characteristics to the fluid such as direction and flow rate.
IfcDuctSegment	A duct segment is used to typically join two sections of duct network.
IfcDuctSilencer	A duct silencer is a device that is typically installed inside a duct distribution system for the purpose of reducing the noise levels from air movement, fan noise, etc. in the adjacent space or downstream of the duct silencer device.
IfcEngine	An engine is a device that converts fuel into mechanical energy through combustion.
IfcEvaporativeCooler	An evaporative cooler is a device that cools air by saturating it with water vapor.
IfcEvaporator	An evaporator is a device in which a liquid refrigerant is vaporized and absorbs heat from the surrounding fluid.
IfcFan	A fan is a device which imparts mechanical work on a gas. A typical usage of a fan is to induce airflow in a building services air distribution system.
IfcFilter	A filter is an apparatus used to remove particulate or gaseous matter from fluids and gases.
IfcFlowMeter	A flow meter is a device that is used to measure the flow rate in a system.

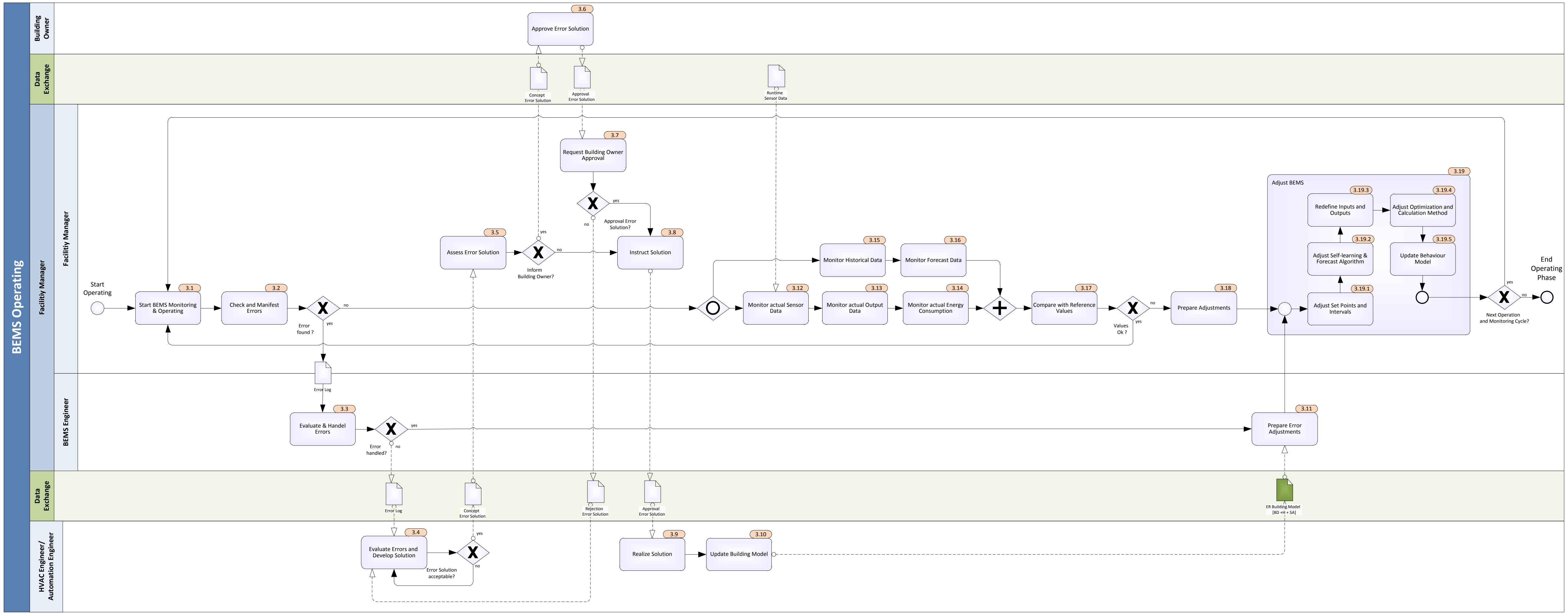
IfcHeatExchanger	A heat exchanger is a device used to provide heat transfer between non-mixing media such as plate and shell and tube heat exchangers. A heat exchanger is commonly used on water-side distribution systems to recover energy from a liquid to another liquid (typically water-based).
IfcHumidifier	A humidifier is a device that adds moisture into the air.
IfcMedicalDevice	A medical device is attached to a medical piping system and operates upon medical gases to perform a specific function. Medical gases include medical air, medical vacuum, oxygen, carbon dioxide, nitrogen, and nitrous oxide.
IfcPipeFitting	A pipe fitting is a junction or transition in a piping flow distribution system or used to connect pipe segments, resulting changes in flow characteristics to the fluid such as direction or flow rate.
IfcPipeSegment	A pipe segment is used to typically join two sections of a piping network.
IfcPump	A pump is a device which imparts mechanical work on fluids or slurries to move them through a channel or pipeline. A typical use of a pump is to circulate chilled water or heating hot water in a building services distribution system.
IfcSpaceHeater	Space heaters utilize a combination of radiation and/or natural convection using a heating source such as electricity, steam or hot water to heat a limited space or area. Examples of space heaters include radiators, convectors, baseboard and finned-tube heaters.
IfcTank	A tank is a vessel or container in which a fluid or gas is stored for later use.
IfcTubeBundle	A tube bundle is a device consisting of tubes and bundles of tubes used for heat transfer and contained typically within other energy conversion devices, such as a chiller or coil.
IfcUnitaryEquipment	Unitary equipment typically combine a number of components into a single product, such as air handlers, pre-packaged rooftop air-conditioning units, and split systems.
IfcValve	A valve is used in a building services piping distribution system to control or modulate the flow of the fluid.
IfcVibrationIsolator	A vibration isolator is a device used to minimize the effects of vibration transmissibility in a building.

1.5. *Process Maps*




BEMS Retrofitting
Building Owner
Data Exchange
Facility Manager
BEMS Engineer
Architect
HVAC/Automation Engineer
Cost Manager
Energy Analyst
Start Retrofitting
Advice Retrofitting Opportunities
Assess Retrofitting Advices
Retrofitting desirable?
Specify new Building Owner Requirements
Instruct Retrofitting Design
Retrofitting Design
Retrofit Design acceptable ?
Validate HVAC Equipment
Device Model Table information complete ?
Extend HVAC Equipment Specification
Complete Retrofitting Design
Retrofit Design complete ?
Request and Validate Retrofitting Design
Approval FM Retrofit Design ?
Approve Retrofitting Design
Approval Owner Retrofit Design ?
Parameterize BEMS
Parameterize Behaviour Model
Define Inputs and Outputs
Select Calculation Method
Select Set Point Air Temperature and RH
Select Optimization and Self-learning Method
Prepare Historical Data Base
Validate BEMS Settings
Approval BEMS Settings?
Instruct Retrofit Commission
End Retrofitting Planning and Design




BEMS Operating
Building Owner
Data Exchange
Facility Manager
BEMS Engineer
HVAC Engineer/ Automation Engineer
Approve Error Solution
Request Building Owner Approval
Assess Error Solution
Instruct Solution
Start Operating
Start BEMS Monitoring & Operating
Check and Manifest Errors
Error found ?
Monitor actual Sensor Data
Monitor Historical Data
Monitor Forecast Data
Monitor actual Output Data
Monitor actual Energy Consumption
Compare with Reference Values
Values Ok ?
Prepare Adjustments
Adjust BEMS
Redefine Inputs and Outputs
Adjust Optimization and Calculation Method
Adjust Self-learning & Forecast Algorithm
Update Behaviour Model
Adjust Set Points and Intervals
Next Operation and Monitoring Cycle?
End Operating Phase
Evaluate & Handel Errors
Error handled?
Prepare Error Adjustments
Evaluate Errors and Develop Solution
Error Solution acceptable?
Realize Solution
Update Building Model
Inform Building Owner?
Approval Error Solution?

1.6. *Exchange Requirements*

ER Building Owner Requirements							
Property concept / Property group / Property name	Definition	Examples and further explanations	MAN	REC	OPT	Data Source	IFC Representation
Planning requirements							
Building Use Information							
Type of building	Describes the type of the building		X			IFC	IfcBuilding + Pset_BuildingCommo(OccupancyType)
Number of users	Number of users for the calculation of the demand.		X			IFC	Pset_SpaceCommon(OccupancyNumber)
Schedule of use	Period of use.		X				
...							
Building Program							
Energy Requirements							
Primary energy demand	DIN 18599	kWh/m2	X			IFC	
Regulation for energy savings			X			IFC	
Passive house standard		True/False	X			IFC	
Percentage of renewable energy ressources			X			IFC	
...							
Space group program							
General space group requirements							
Number of rooms	Number of rooms for this functional zone. Non-dimensional value	5	X			IFC	IfcZone + IfcRelAssignsToGroup.RelatedObjects (Number of IfcSpace)
Area of room		[m2]	X			IFC	IfcZone + Pset_ZoneCommon(NetAreaPlanned)
...							
Space program							
General space requirements							
Space name/ identifier			X			IFC	IfcSpace.Name, IfcSpace.GlobalId
Space number			X			IFC	IfcSpace.Name
...			X				
Visual Comfort Requirements							
Artificial lighting	Is it mandatory, or not.	True/False	X			IFC	Pset_SpaceLightingRequirements(ArtificialLighting)
Illuminance		[lux]	X			IFC	Pset_SpaceLightingRequirements (Illuminance)
Lighting Control	Manual, automatic, daylight dependent	On / of / gradual dimmed	X				
...			X				
Quality Requirements							
Quality of construction		high-quality / medium-quality / standard	X				
Structure		massive construction, timber construction	X				
Windows structure		fix / turn-tilt-window; frame made of steel / wood / plastics; mullion / transom	X				
Indoor walls structure		high-quality / medium-quality / standard	X				
Indoor doors structure		frame/panel made of steel / wood / plastics; mullion / transom; fire prevention class	X				
Furnishings and equipment		high-quality / medium-quality / standard	X				
Heating device	Thermal power station		X				
Energy Source	Gas, coal		X				
Cooling device	Chiller, air handling unit		X				

Table 1.1: ER Building Owner Requirements

ER FM Requirements							
Property concept / Property group / Property name	Definition	Examples and further explanations	MAN	REC	OPT	Data Source	IFC Representation
Operational requirements							
Partial Space requirments							
Thermal Comfort Requirements			X				
Temperature summer	Required temperature for each space/room in summer time.	DIN EN 15251, 20°C	X			IFC	IfcSpace + Pset_SpaceThermalRequirements (SpaceTemperatureSummerMax)
Temperature winter	Required temperature for each space/room in winter time.	DIN EN 15251, 23°C	X			IFC	IfcSpace + Pset_SpaceThermalRequirements (SpaceTemperatureWinterMin)
Range of temperature	Range of temperature for SDC and SDH	15°C - 20°C	X				
Relative Humidity summer	Required temperature for each space/room in summer time.	DIN EN 15251, 40%	X			IFC	IfcSpace + Pset_SpaceThermalRequirements (SpaceHumiditySummer)
Relative Humidity winter	Required temperature for each space/room in winter time.	DIN EN 15251, 55%	X			IFC	IfcSpace + Pset_SpaceThermalRequirements (SpaceHumidityWinter)
Range of relativ humidity	Required range of the reative humidity.	40 % - 50 %	X				
Indoor Air Quality Requirements							
Fresh air requirement	Real number that describes the ventilation interval.	1/h	X			IFC	Pset_SpaceCommon (MechanicalVentilationRate, NaturalVentilationRate)
Room air quality	Maximum value of the average for the whole volume of the room	e.g. < 1500ppm	X				
Optimiztion requirements							
Energy consumption	Minimize the electrical energy consumption of the Building Services system.		X				
Thermal Energy concumption	Minimize the thermal energy concumption of the Building Services system.		X				
Power Concumption	Minimize the electrical power concumption of the Building Services system.		X				
Thermal Power consumption	Minimize the thermal power concumption of the Building Services system.		X				
Co2 emission	Minimize the Co2 emission of the Building Services system.		X				
BAS requirements							
Measurement Requirements							
Temperature measurement	Locations/placement of temperature measurements.	Fan-Coil, Chiller	X				
Relative humidity measurement	Locations/placement of relative humidity measurements.	Fan-Coil	X				
Air quality measurement	Locations/placement of air quality measurements.	Fan-Coil, space/room	X				
Water flow measurement	Locations/placement of water flow measurements.	Pump, Coil	X				
Equipement Requirements							
Architecture requirements	Which hardware should be used for the sensors/actors	Open source / proprietary	X				
Topological requirements	Wired or wireless sensor-actor-network, and the description of the network topology.	TREE, STAR; MASH,...	X				
Energy supply	Power supply or energy harvesting	True/False	X				
Software requirements							
Open Source	Basically it has to be specified whether the SW should be open source or proprietary.	True/False	X				
Protocol requirements	Describes the prefered data protocol format.	802.15.4 or 802.11, ZigBee or EnOcean	X				
Quality Requirements							
Response time		< 1 s	X				
Latency	Time between sending and receiving a message	< 2 ms	X				
Failure safty	Requirements of failure safty	Use redundancy, use certified equipment	X				

Table 1.2: ER FM Requirements

ER Building Model[BD]

Property concept	Property group	Property name	Definition	Examples and further explanations	MAN	REC	OPT	Data Source	IFC Representation
Basic Project Information									
Project									IfcProject
		Identifier	Unique identifier of the project.	"274218401813460217"	x			IFC	IfcProject.Name or IfcProject.GlobalId
		Owner/Client Information	Descriptive name of the building owner.	"Max Miller"	x			IFC	
		...							
Basic Building Spatial Structure									
Site									
	General Information								
		Site Identifier	Unique identifier of the site.		x			IFC	IfcSite.GlobalId
		Site name	Descriptive name of the site.				x	IFC	IfcSite.Name
		Postal adress	Postal adress of the site.	"Gewandhausstr. 7, 01067 Dresden"			x	IFC	
	Dimensional/Representation Information								
		...						IFC	
Building									IfcBuilding
	General Information								
		Identifier	Unique identifier of the building.		x			IFC	IfcBuilding.Name or IfcBuilding.GlobalID
		Geographical location	Longitude, latitude	51° 02' N /13° 73' E		x		IFC	IfcSite.RefLatitude , IfcSite.RefLongitude
		Occupancy Type	Occupancy of the building	"school"		x		IFC	IfcBuilding + Pset_BuildingCommon(OccupancyType)
		Decomposition type	Describes the complexity of the building	COMPLEX, ELEMENT, PARTIAL	x			IFC	
	Dimensional/Representation Information								
		Elevation	Relative high above sea level	222m over sea level	x			IFC	IfcSite.RefElevation
		Orientation	North arrow	+ 45° from the project-y-axis	x			IFC	
		Building quantities	The area, height, length, width, ...	[m2],[m]	x			IFC	
		Geometric representation	Foot print and bodey representation of the building	2D, 3D representations	x			IFC	
		...							
Building Storey									IfcBuildingStorey
	General Information								
		Storey identifier	Unique number of the storey	"00", "01"		x			IfcBuildingStorey.GobalID
		Storey name	Desciptive name of the storey	"EG", "OG"		x			IfcBuildingStorey.Name
		Decomposition type	Describes the complexity of the building	COMPLEX, ELEMENT, PARTIAL		x		IFC	
		...							
	Storey quantities								
		Storey area	Net area as covered by base quantities	[m2]			x		IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities (NetFloorArea)
		Storey volume	Net volume as covered by base quantities	[m3]			x		IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities (NetVolume)
		...							
Space/Room									IfcSpace
	General Information								
		Space identifier	Unique number of the space	"OG-001"	x			IFC	IfcSpace.GloblId
		Space name	Desciptive name of the space	"Foyer", "Office"		x		IFC	IfcSpace.Name
		Space decomposition type	Describes the decompsition of the space, whether the space represents a mutiple space, a room or a partial room.	COMPLEX, ELEMENT, PARTIAL		x		IFC	IfcSpace.CompositionType
		Link to decomposing spaces	Describes the link between a partial and an elemental space.			x		IFC	IfcSpace.IsDecomposedBy + IfcRelAggregates.RelatedObjects
		Link to space boundories	Describes the links between a space and the space boundories				x	IFC	IfcSpace.BoundedBy + IfcRelSpaceBoundary.RelatedBuildingElement
		...							
	Space quantities								
		Space area	Net area as covered by base quantities	[m2]	x			IFC	IfcSpace + Qto_SpaceBaseQuantities(NetFloorArea)
		Space volume	Net volume as covered by base quantities	[m3]	x			IFC	IfcSpace + Qto_SpaceBaseQuantities(NetVolume)
		...							
	Space occupancy								
		Type of the room	Occupancy type, according th the space naming	"Office", "Foyer"			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements(OccupancyType)
		Average number of users	Average number of people, who use the space.	5			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements(OccupancyNumber, OccupancyNumberPeak)
		Time period of activity	The daily and weekly schedule.	Monday till Friday from 7:00 am to 9:00 pm			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements()
		...							
Space Boundary									IfcRelSpaceBoundary
		Link to space	Describes the link between the space boundary and a space.		x			IFC	IfcRelSpaceBoundary.RelatingSpace
		Link to building element	Describes the link between the space boundary and the bounding building element.		x			IFC	IfcRelSpaceBoundary.RelatedBuildingElement
		...							
Basic Building Elements									
Slab									IfcSlab
	General Information							IFC	
		Identifier	Unique name/identifier of the slab.		x			IFC	IfcSlab.GlobalID or IfcSlab.Name
		Construction Type	Foundation type, Floor type, roof type		x			IFC	IfcSlab.PredefinedType
		...							
	Slab quantities								
		Slab area			x			IFC	IfcSlab + Qto_SlabBaseQuantities
		Slab volume			x			IFC	IfcSlab + Qto_SlabBaseQuantities
		Slab length			x			IFC	IfcSlab + Qto_SlabBaseQuantities
		Slab width			x			IFC	IfcSlab + Qto_SlabBaseQuantities
		Slab weight			x			IFC	IfcSlab + Qto_SlabBaseQuantities
	Material Information							IFC	
		Material layer set	Material information provided as material layer set (Name of the material per layer, position of the layer, thickness of the layer).		x		x	IFC	IfcSlab.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
	Associations/connections to building elements								
		...			x			IFC	
	Representation Information								
		...			x			IFC	
Roof									IfcRoof
	General Information				x			IFC	
	Roof quantities				x			IFC	IfcRoof + Qto_RoofBaseQuantities
	Material Information				x			IFC	
	Associations/connections to building				x			IFC	
	Representation Information				x			IFC	
Wall									IfcWall
	General Information							IFC	
		Identifier	Unique name/identifier of the wall.		x			IFC	IfcWall
		Construction Type	Wall type		x			IFC	IfcWall.PredefinedType
		Internal/external wall	Indicates whether the wall is part of the outer envelop, or not.	True/False	x			IFC	IfcWall + Pset_WallCommon(IsExternal)
	Wall quantities								
		Wall Length		[m]	x			IFC	IfcWall + Qto_WallBaseQuantities
		Wall Hight		[m]	x			IFC	IfcWall + Qto_WallBaseQuantities
		Wall Thickness		[d = m]	x			IFC	IfcWall + Qto_WallBaseQuantities
		Wall Gross Side Area		[m2]	x			IFC	IfcWall + Qto_WallBaseQuantities
		Wall Net Side Area		[m2]	x			IFC	IfcWall + Qto_WallBaseQuantities
		Wall Gross Volume		[m3]	x			IFC	IfcWall + Qto_WallBaseQuantities
		Wall Net Volume		[m3]	x			IFC	IfcWall + Qto_WallBaseQuantities
	Material Information							IFC	
		Material layer	Material information provided as material layer set (Name of the material per layer, position of the layer, thickness of the layer).		x			IFC	IfcWall.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
		...							
	Associations/connections to building elements				x				
		...						IFC	
	Representation Information				x				
		...						IFC	

Door								IFC	IfcDoor
	General Information								
		Identifier	Unique name/identifier of the door.		x			IFC	IfcDoor.GlobalId or IfcDoor.Name
		Construction Type	Door type	DOOR, GATE, TRAPDOOR	x			IFC	IfcDoor.PredefinedType
	Material Information							IFC	IfcDoor.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
		Proportion of glass	Percentage of glass (percentage of framing)	70%		x			
		Type of glass	heat protection glass / sun protection glass		x				
		Number of glass layers		3		x		IFC	Pset_DoorWindowGlazingType(GlassLayers)
		Thickness of the glass layers	The thickness of each glass layer.	[mm]		x		IFC	Pset_DoorWindowGlazingType(GlassThickness)
	Associations/connections to building elements				x				
		...						IFC	
	Representation Information				x				
		...						IFC	
Window									IfcWindow
	General Information								
		Identifier	Unique name/identifier of the window.		x			IFC	IfcWindow.GlobalId or IfcWindow.Name
		Construction Type	Window type	e.g. SKYLIGHT, LIGHTDOME	x			IFC	IfcWindow.PredefinedType
	Material Information							IFC	IfcWindow.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
		Proportion of glass	Percentage of glass (percentage of framing)	70%		x			
		Type of glass	heat protection glass / sun protection glass			x			
		Number of glass layers		3		x		IFC	IfcWindow + Pset_DoorWindowGlazingType(GlassLayers)
		Thickness of the glass layers		[mm]		x		IFC	IfcWindow + Pset_DoorWindowGlazingType(GlassThickness)
	Associations/connections to building elements				x				
		...						IFC	
	Representation Information				x				
		...						IFC	
Openings									IfcOpeningElement
	General Information				x			IFC	
	Opening quantities				x			IFC	
	Associations/connections to building elements				x			IFC	
	Representation Information				x			IFC	
		...							

Table 1.3: ER Building Model [BD]

ER Building Model[S + H]

Property concept / Property group / Property name	Definition	Examples and further explanations	MAN	REC	OPT	Data Source	IFC Representation
Basic Project/Building Information							
Project							IfcProject
Identifier	Unique identifier of the project.	"274218401813460217"			x	IFC	IfcProject.Name or IfcProject.GlobalId
Owner/Client Information	Descriptive name of the building owner.	"Max Miller"			x	IFC	
Building							IfcBuilding
Identifier	Unique identifier of the building.			x		IFC	IfcBuilding.Name or IfcBuilding.GlobalID
Geographical location	Longitude, latitude	51° 02' N /13° 73' E		x		IFC	IfcSite.RefLatitude , IfcSite.RefLongitude
Elevation	Relative high above sea level	222m over sea level		x		IFC	IfcSite.RefElevation
Building Spatial Structure							
Building Storey							IfcBuildingStorey
General Information							
Storey identifier	Unique number of the storey	"00", "01"		x			IfcBuildingStorey.GobalID
Storey name	Desciptive name of the storey	"EG", "OG"		x			IfcBuildingStorey.Name
Storey quantities							
Storey area	Net area as covered by base quantities	[m2]			x		IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities (NetFloorArea)
Storey volume	Net volume as covered by base quantities	[m3]			x		IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities (NetVolume)
Space							IfcSpace
General Information							
Space identifier	Unique number of the space	"OG-001"	x			IFC	IfcSpace.GloblId
Space name	Desciptive name of the space	"Foyer", "Office"		x		IFC	IfcSpace.Name
Space decomposition type	Describes the decompsition of the space, whether the space represents a mutiple space, a room or a partial room.	COMPLEX, ELEMENT, PARTIAL		x		IFC	IfcSpace.CompositionType
Link to decomposing spaces	Describes the link between a partial and an elemental space.			x		IFC	IfcSpace.IsDecomposedBy + IfcRelAggregates.RelatedObjects
Link to space boundories	Describes the links between a space and the space boundories				x	IFC	IfcSpace.BoundedBy + IfcRelSpaceBoundary.RelatedBuildingElement
Space quantities							
Space area	Net area as covered by base quantities	[m2]		x		IFC	IfcSpace + Qto_SpaceBaseQuantities(NetFloorArea)
Space volume	Net volume as covered by base quantities	[m3]		x		IFC	IfcSpace + Qto_SpaceBaseQuantities(NetVolume)
Space occupancy							
Type of the room	Occupancy type, according th the space naming	"Office", "Foyer"			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements(OccupancyType)
Average number of users	Average number of people, who use the space.	5			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements(OccupancyNumber, OccupancyNumberPeak)
Time period of activity	The daily and weekly schedule.	Monday till Friday from 7:00 am to 9:00 pm			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements()
Building Services Equipment of the Space							
Link to HVAC system (equipment)	Describes the link to the HVAC system and all HVAC devices which are attached in this space.		x			IFC	IfcSpace.ServicedBySystems + IfcRelServicesBuildings.RelatingSystem + IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Space Boundary							IfcRelSpaceBoundary
Link to space	Describes the link between the space boundary and a space.		x			IFC	IfcRelSpaceBoundary.RelatingSpace
Link to building element	Describes the link between the space boundary and the bounding building element.		x			IFC	IfcRelSpaceBoundary.RelatedBuildingElement
Basic Building Element (bounding elements of spaces)							
Slab							IfcSlab
General Information						IFC	
Identifier	Unique name/identifier of the slab.				x	IFC	IfcSlab.GlobalID or IfcSlab.Name
Construction Type	Foundation type, Floor type, roof type				x	IFC	IfcSlab.PredefinedType
Material Information						IFC	
Material layer set	Material information provided as material layer set (Name of the material per layer, position of the layer, thickness of the layer).				x	IFC	IfcSlab.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcSlab + Pset_SlabCommon(ThermalTransmittance)
Wall							IfcWall
General Information						IFC	
Identifier	Unique name/identifier of the wall.				x	IFC	IfcWall
Construction Type	Wall type				x	IFC	IfcWall.PredefinedType
Internal/external wall	Indicates whether the wall is part of the outer envelop, or not.	True/False			x	IFC	IfcWall + Pset_WallCommon(IsExternal)
Material Information						IFC	
Material layer	Material information provided as material layer set (Name of the material per layer, position of the layer, thickness of the layer).				x	IFC	IfcWall.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcWall + Pset_SlabCommon(ThermalTransmittance)
Door						IFC	IfcDoor
General Information					x		
Identifier	Unique name/identifier of the door.				x	IFC	IfcDoor.GlobalId or IfcDoor.Name
Construction Type	Door type	DOOR, GATE, TRAPDOOR			x	IFC	IfcDoor.PredefinedType
Material Information						IFC	IfcDoor.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Proportion of glass	Percentage of glass (percentage of framing)	70%			x		
Type of glass	heat protection glass / sun protection glass				x		
Number of glass layers		3			x	IFC	Pset_DoorWindowGlazingType(GlassLayers)
Thickness of the glass layers	The thickness of each glass layer.	[mm]			x	IFC	Pset_DoorWindowGlazingType(GlassThickness)
Infiltration	Infiltration flowrate of outside air.	[m3/s]			x	IFC	IfcDoor + Pset_DoorCommon(Infilatration)
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcDoor + Pset_DoorCommon(ThermalTransmittance)
Window							IfcWindow
General Information							
Identifier	Unique name/identifier of the window.				x	IFC	IfcWindow.GlobalId or IfcWindow.Name
Construction Type	Window type	e.g. SKYLIGHT, LIGHTDOME			x	IFC	IfcWindow.PredefinedType
Material Information						IFC	IfcWindow.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Proportion of glass	Percentage of glass (percentage of framing)	70%			x		
Type of glass	heat protection glass / sun protection glass				x		
Number of glass layers		3			x	IFC	IfcWindow + Pset_DoorWindowGlazingType(GlassLayers)
Thickness of the glass layers		[mm]			x	IFC	IfcWindow + Pset_DoorWindowGlazingType(GlassThickness)
Infiltration	Infiltration flowrate of outside air.	[m3/s]			x	IFC	IfcWindow + Pset_DoorCommon(Infilatration)
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcWindow + Pset_DoorCommon(ThermalTransmittance)
Building Services system							
Ventilation system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of theventilation system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Service zone	Group of spaces, served by the ventilation system		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Outside air	Is outside air used within the ventilation system?	True/False			x	IFC	
Link to HVAC devices	References to the HVAC devices, which the ventilation system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Heating system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the heating system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the heating system		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the heating system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Cooling system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the cooling system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the cooling system		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the cooling system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Hot water system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the hot water system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the hot water system.		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the hot water system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Cold water system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the cold water system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the cold water system.		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the cold water system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects

Hot water system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the hot water system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the hot water system.		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the hot water system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Cold water system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the cold water system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the cold water system.		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the cold water system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Building Services equipment							
HVAC equipment							
General Information							
Identifier/name	Unique descriptive name or identifier of the heating device.		x			IFC	IfcDistributionFlowElement.GlobalID or IfcDistributionFlowElement.Name
Type device	Heating, cooling or ventilation and air conditioning devices.		x			IFC	e.g. IfcFan.PredefinedType, IfcCoil.PredefinedType, IfcPump.PredefinedType
Photograph	A photogrpah of the HVAC device.				x	Model Table	
Outline	A outline of the HVAC device, may also contain quantities and control signals.			x		Model Table	
Description	Description of the HVAC device. It may includes overview of the usage and the connection to other HVAC devices.			x		Model Table	
Energy calculation specification							
Type of Calculation method	Describes the way of calculating the thermal/electrical energy consumption of the HVAC device.	Data sheet or data from sensor	x			Model Table	
Calculation specification	Decribes the mathematical calculation specification, is dependent on the calculation method.	P_(th-FC) (W)= ⟦ΔT⟧_water Q_w ρ_w c_pw	x			Model Table	
Needed sensor values	The sensor values which are needed to calculate the energy consumption of the HVAC device.	Air temperature (db, wb), water temperature, relative humidity, ...	x			Model Table	
COP	Coefficient of performance, reation between cooling load and the electrical power, non- dimensional parameter.	2.28	x			Model Table	
EER	Energy Efficiency Ratio, non- dimensional parameter.	5.65	x			Model Table	
Operating limits (device dependent)							
Temperatur limits	Minimum and maximum of the air or water temperature.	277.15 K - 353.15 K	x			Model Table	
Presure limits	Minimum and maximum of a flow preasure.		x			Model Table	
			x				
Device Parameters (device dependent)	Parameters that affects energy efficiency.						
e.g fan speed			x			Model Table	
Connection Information							
Link to HVAC system	Reference to the enclosing HVAC system.		x			IFC	IfcDistributionFlowElement.Decomposes + IfcRelAggregates.RelatingObject
Link to connected HVAC devices	References all HVAC devices which have a logical connection.		x			IFC	IfcDistributionFlowElement.HasPorts + IfcRelConnectsPortToElement.RelatingPort + IfcRelConnectsPorts
Link to space	Reference to the space where the HVAC device is located.		x			IFC	IfcDistributionFlowElement.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcSpace)

Table 1.4: ER Building Model [S + H]

ER Building Model[S + H + SA]

Property concept / Property group / Property name	Definition	Examples and further explanations	MAN	REC	OPT	Data Source	IFC Representation
Basic Project/Building Information							
Project							IfcProject
Identifier	Unique identifier of the project.	"274218401813460217"			x	IFC	IfcProject.Name or IfcProject.GlobalId
Owner/Client Information	Descriptive name of the building owner.	"Max Miller"			x	IFC	
Building							IfcBuilding
Identifier	Unique identifier of the building.			x		IFC	IfcBuilding.Name or IfcBuilding.GlobalID
Geographical location	Longitude, latitude	51° 02' N /13° 73' E		x		IFC	IfcSite.RefLatitude , IfcSite.RefLongitude
Elevation	Relative high above sea level	222m over sea level		x		IFC	IfcSite.RefElevation
Building Spatial Structure							
Building Storey							IfcBuildingStorey
General Information				x			
Storey identifier	Unique number of the storey	"00", "01"		x			IfcBuildingStorey.GobalID
Storey name	Desciptive name of the storey	"EG", "OG"		x			IfcBuildingStorey.Name
Storey quantities					x		
Storey area	Net area as covered by base quantities	[m2]			x		IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities (NetFloorArea)
Storey volume	Net volume as covered by base quantities	[m3]			x		IfcBuildingStorey + Qto_BuildingStoreyBaseQuantities (NetVolume)
Space							IfcSpace
General Information							
Space identifier	Unique number of the space	"OG-001"	x			IFC	IfcSpace.GloblId
Space name	Desciptive name of the space	"Foyer", "Office"		x		IFC	IfcSpace.Name
Space decomposition type	Describes the decompsition of the space, whether the space represents a mutiple space, a room or a partial room.	COMPLEX, ELEMENT, PARTIAL		x		IFC	IfcSpace.CompositionType
Link to decomposing spaces	Describes the link between a partial and an elemental space.			x		IFC	IfcSpace.IsDecomposedBy + IfcRelAggregates.RelatedObjects
Link to space boundories	Describes the links between a space and the space boundories				x	IFC	IfcSpace.BoundedBy + IfcRelSpaceBoundary.RelatedBuildingElement
Space quantities							
Space area	Net area as covered by base quantities	[m2]		x		IFC	IfcSpace + Qto_SpaceBaseQuantities(NetFloorArea)
Space volume	Net volume as covered by base quantities	[m3]		x		IFC	IfcSpace + Qto_SpaceBaseQuantities(NetVolume)
Space occupancy							
Type of the room	Occupancy type, according th the space naming	"Office", "Foyer"			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements(OccupancyType)
Average number of users	Average number of people, who use the space.	5			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements(OccupancyNumber, OccupancyNumberPeak)
Time period of activity	The daily and weekly schedule.	Monday till Friday from 7:00 am to 9:00 pm			x	IFC	IfcSpace + Pset_SpaceOccupancyRequirements()
Building Services Equipment of the Space							
Link to HVAC system (equipment)	Describes the link to the HVAC system and all HVAC devices which are attached in this space.		x			IFC	IfcSpace.ServicedBySystems + IfcRelServicesBuildings.RelatingSystem + IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Link to sensors	Describes the link to all sensor attached in this space.		x			IFC	IfcSpace.ServicedBySystems + IfcRelServicesBuildings.RelatingSystem + IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Space Boundary							IfcRelSpaceBoundary
Link to space	Describes the link between the space boundary and a space.		x			IFC	IfcRelSpaceBoundary.RelatingSpace
Link to building element	Describes the link between the space boundary and the bounding building element.		x			IFC	IfcRelSpaceBoundary.RelatedBuildingElement
Basic Building Elements (bounding elements of spaces)							
Slab							IfcSlab
General Information						IFC	
Identifier	Unique name/identifier of the slab.				x	IFC	IfcSlab.GlobalID or IfcSlab.Name
Construction Type	Foundation type, Floor type, roof type				x	IFC	IfcSlab.PredefinedType
Material Information						IFC	
Material layer set	Material information provided as material layer set (Name of the material per layer, position of the layer, thickness of the layer).				x	IFC	IfcSlab.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcSlab + Pset_SlabCommon(ThermalTransmittance)
Wall							IfcWall
General Information						IFC	
Identifier	Unique name/identifier of the wall.				x	IFC	IfcWall
Construction Type	Wall type				x	IFC	IfcWall.PredefinedType
Internal/external wall	Indicates whether the wall is part of the outer envelop, or not.	True/False			x	IFC	IfcWall + Pset_WallCommon(IsExternal)
Material Information						IFC	
Material layer	Material information provided as material layer set (Name of the material per layer, position of the layer, thickness of the layer).				x	IFC	IfcWall.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcWall + Pset_SlabCommon(ThermalTransmittance)
Door						IFC	IfcDoor
General Information							
Identifier	Unique name/identifier of the door.				x	IFC	IfcDoor.GlobalId or IfcDoor.Name
Construction Type	Door type	DOOR, GATE, TRAPDOOR			x	IFC	IfcDoor.PredefinedType
Material Information						IFC	IfcDoor.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Proportion of glass	Percentage of glass (percentage of framing)	70%			x		
Type of glass	heat protection glass / sun protection glass				x		
Number of glass layers		3			x	IFC	Pset_DoorWindowGlazingType(GlassLayers)
Thickness of the glass layers	The thickness of each glass layer.	[mm]			x	IFC	Pset_DoorWindowGlazingType(GlassThickness)
Infiltration	Infiltration flowrate of outside air.	[m3/s]			x	IFC	IfcDoor + Pset_DoorCommon(Infilatration)
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcDoor + Pset_DoorCommon(ThermalTransmittance)
Window							IfcWindow
General Information							
Identifier	Unique name/identifier of the window.				x	IFC	IfcWindow.GlobalId or IfcWindow.Name
Construction Type	Window type	e.g. SKYLIGHT, LIGHTDOME			x	IFC	IfcWindow.PredefinedType
Material Information						IFC	IfcWindow.HasAssociations + IfcRelAssociatesMaterial.RelatingMaterial
Proportion of glass	Percentage of glass (percentage of framing)	70%			x		
Type of glass	heat protection glass / sun protection glass				x		
Number of glass layers		3			x	IFC	IfcWindow + Pset_DoorWindowGlazingType(GlassLayers)
Thickness of the glass layers		[mm]			x	IFC	IfcWindow + Pset_DoorWindowGlazingType(GlassThickness)
Infiltration	Infiltration flowrate of outside air.	[m3/s]			x	IFC	IfcWindow + Pset_DoorCommon(Infilatration)
Thermal Transmittance	Thermal transmittance coefficient of a material.	[W/(m2* K)]			x	IFC	IfcWindow + Pset_DoorCommon(ThermalTransmittance)
Building Services system							
Ventilation system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of theventilation system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Service zone	Group of spaces, served by the ventilation system		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Outside air	Is outside air used within the ventilation system?	True/False			x	IFC	
Link to HVAC devices	References to the HVAC devices, which the ventilation system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Heating system							IfcDistributionSystem
General Information			x				
Identifier	Unique identifier or name of the heating system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the heating system		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the heating system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Cooling system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the cooling system.		x			IFC	IfcDistributionSystem.GlobalID or IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the cooling system		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the cooling system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects

Hot water system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the hot water system.		x			IFC	IfcDistributionSystem.GlobalID **or** IfcDistributionSystem.Name
Type of system	Additional specification of the system.					IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the hot water system.		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the hot water system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Cold water system							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the cold water system.		x			IFC	IfcDistributionSystem.GlobalID **or** IfcDistributionSystem.Name
Type of system	Additional specification of the system.			x		IFC	IfcDistributionSystem.PredefinedType
Service zone	Group of spaces, served by the cold water system.		x			IFC	IfcDisrtibutionSystem.ServicesBuildings + IfcRelServicesBuildings.RelatedBuildings (SET [1:?] of IfcSpace)
Link to HVAC devices	References to the HVAC devices, which the cold water system includes.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects
Building Automation System							IfcDistributionSystem
General Information							
Identifier	Unique identifier or name of the sensor-actor system (sub system)					IFC	IfcDistributionSystem.GlobalID **or** IfcDistributionSystem.Name
Data Protocol	The name of the used data protocol.	"ZigBee", "EnOcean"			x		
Network topology	Descriptive name of the layout pattern of interconnections of the various network elements.	"Star", "Tree", "Mash", "Ring", ...			x		
Architcture information	Type and description of the installed network architecture.	Wired or wireless sensor- actor - network.			x		
Redundancy	Exist redundant sensor nodes, e.g to decrease the failur rate of the network.	True/false			x		
Link to sensors	References to the sensor, which belong to the sensor actor network.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects (SET [1:?] OF IfcSensor)
Link to acors	References to the actors, which belong to the sensor-actor network.		x			IFC	IfcDistributionSystem.IsGroupedBy + IfcRelAssignsToGroup.RelatedObjects (SET [1:?] OF IfcActuator)
Building Services equipment							
HVAC equipment							
General Information							
Identifier/name	Unique descriptive name or identifier of the heating device.		x			IFC	IfcDistributionFlowElement.GlobalID **or** IfcDistributionFlowElement.Name
Type device	Heating, cooling or ventilation and air conditioning devices.		x			IFC	e.g. IfcFan.PredefinedType, IfcCoil.PredefinedType
Photograph	A photogrpah of the HVAC device.				x	Model Table	
Outline	A outline of the HVAC device, may also contain quantities and control signals.			x		Model Table	
Description	Description of the HVAC device. It may includes overview of the usage and the connection to other HVAC devices.			x		Model Table	
Energy calculation specification			x				
Type of Calculation method	Describes the way of calculating the thermal/electrical energy consumption of the HVAC device.	Data sheet or data from sensor	x			Model Table	
Calculation specification	Decribes the mathematical calculation specification, is dependent on the calculation method.	P_(th-FC) (W)= 〖ΔT〗_water Q_w ρ_w c_pw	x			Model Table	
Needed sensor values	The sensor values which are needed to calculate the energy consumption of the HVAC device.	Air temperature (db, wb), water temperature, relative humidity, ...	x			Model Table	
COP	Coefficient of performance, reation between cooling load and the electrical power, non- dimensional parameter.	2.28	x			Model Table	
EER	Energy Efficiency Ratio, non- dimensional parameter.	5.65	x			Model Table	
Operating limits (device dependent)							
Temperatur limits	Minimum and maximum of the air or water temperature.	277.15 K - 353.15 K	x			Model Table	
Presure limits	Minimum and maximum of a flow preasure.		x			Model Table	
Device Parameters (device dependent)	Parameters that affects energy efficiency.						
e.g fan speed			x			Model Table	
Connection Information							
Link to HVAC system	Reference to the enclosing HVAC system.		x			IFC	IfcDistributionFlowElement.Decomposes + IfcRelAggregates.RelatingObject
Link to connected HVAC devices	References all HVAC devices which have a logical connection.		x			IFC	IfcDistributionFlowElement.HasPorts + IfcRelConnectsPortToElement.RelatingPort + IfcRelConnectsPorts
Link to space	Reference to the space where the HVAC device is located.		x			IFC	IfcDistributionFlowElement.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcSpace)
Link to sensors	References to the sensors, which are attached to the HVAC device.		x			IFC	IfcDistributionFlowElement.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcSensor) **or** IfcDistributionFlowElement.HasControlElements + IfcRelFlowControlElements. RelatedControlElements (IfcSensor)
Linkt to actors	References to the actors, which are attached to the HVAC device.		x			IFC	IfcDistributionFlowElement.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcActuator) **or** IfcDistributionFlowElement.HasControlElements + IfcRelFlowControlElements. RelatedControlElements (IfcActuator)
Linkt to controller	Reference to the control system of the HVAC device.		x			IFC	IfcDistributionFlowElement.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcController) **or** IfcDistributionFlowElement.HasControlElements + IfcRelFlowControlElements. RelatedControlElements (IfcController)
Building Automation Equipment							
Sensor Information							IfcSensor
Identifier/name	Unique identifier of the sensor device.	"T001" or Device ID, or network ID	x			IFC	IfcSensor.GlobalId **or** IfcSensor.Name
Sensor node	To which sensor node the indivudaul sensor consists.		x				
Sensor type	What kind of sensor.	Temperature Sensor, Flow Sensor, ...	x			IFC	IfcSensor.PredefinedType
Signal	Analog, Digital	4 - 20 mA, 0 -10 V	x				
Unit of measurement	The unit of the provided measurement.	SI-Unit	x				
Sensor range	Measurment interval of the sensor.		x				
Resolution	Quantisation, sampling time	8 Bit, time interval	x				
Quality of measurement	Indicates the quality of measurement	True/False	x			IFC	IfcSensor + Pset_SensorPHistory
Link to space	Reference to a space/partial space/room, where the sensor is attached.		x			IFC	IfcDistributionFlowElement.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcSpace)
Link to HVAC device	Reference to the HVAC equipment, where the sensor is attached.		x			IFC	IfcSensor.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcDistributionFlowElement) **or** IfcSensor.AssignedToFlowElement +IfcRelFlowControlElements.RelatingFlowElement
Link to controller	Reference to the controller which processes the sensor value.		x			IFC	IfcSensor.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcController)
Actuator Information							
Identifier/name	Unique name of the individual actor.	"P001"	x			IFC	IfcActuator.GlobalId **or** IfcActuator.Name
Type of actuator	Describes the type of the installed actuator.	ELECTRIC, HYDRAULIC, PNEUMATIC	x			IFC	IfcActuator.PredefinedType
Control signal/input	Name or description of the signal which is used to control the actuator.	Pressure, power	x			IFC	Pset_ActuatorTypeElectricActuator, Pset_ActuatorTypeHydraulicActuator, Pset_ActuatorTypePneumaticActuator
Fail position	Required fail-safe position of the actor.	OPEN, CLOSED	x			IFC	IfcActuator + Pset_ActuatorTypeCommon (FailPosition)
Link to space	Reference to a space/partial space/room, where the actor is attached.		x			IFC	IfcDistributionFlowElement.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcSpace)
Link to HVAC device	Reference to the HVAC equipment, where the actor is attached.		x			IFC	IfcActuator.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcDistributionFlowElement) **or** IfcActuator.AssignedToFlowElement +IfcRelFlowControlElements.RelatingFlowElement
Link to controller	Reference to the controller produces the control signal.		x			IFC	IfcSensor.HasAssignments + IfcRelAssignsToProduct.RelatingProduct (IfcController)
Controller Information							
Identifier/name			x			IFC	IfcController.GlobalId **or** IfcController.Name
Location	Where is the location of the control?	"Central", "local" or "primary", "secondary"	x			IFC	
Controller Type	The type of the controller.	SPS, Microcontroller	x			IFC	IfcController.PredefinedType
Control Algorithm/Strategy	Description of the control algorithm/ implementation.	ON/OFF,P, PID, PD, ...	x				
Input signals	Link to all input signals and sensors.		x			IFC	IfcController.HasPorts + IfcRelConnectsPortToElement.RelatingPort + IfcRelConnectsPorts (IfcSensor as INLET)
Output signals	Link to all actors		x			IFC	IfcController.HasPorts + IfcRelConnectsPortToElement.RelatingPort + IfcRelConnectsPorts (IfcActuator as OUTLET)
Contolling Devices	Groups of all controlled HVAC devices		x			IFC	IfcController.AssignedToFlowElement +IfcRelFlowControlElements.RelatingFlowElement

Table 1.5: ER Building Model [S + H + SA]

ER Building Model[S + H + SA + RD]

Property concept	Property group	Property name	Definition	Examples and further explanations	MAN	REC	OPT	Data Source	IFC Representation
Basic Project/Building Information									
		see 'ER Building Model [S + H +SA]'							
Building Spatial Structure									
		see 'ER Building Model [S + H +SA]'							
Basic Building Elements (bounding elements of spaces)									
		see 'ER Building Model [S + H +SA]'							
Building Services system									
		see 'ER Building Model [S + H +SA]'							
Building Services equipment									
		see 'ER Building Model [S + H +SA]'							
BEMS Runtime Data									
	Input data								
	Sensor data							IFC	IfcSensor
		Sensor identifier	A unique identifier or name of the sensor which provides the measured data.	"T001"	x			IFC	IfcSensor.GlobalId or IfcSensor.Name
		Sensor value	The measured value of the sensor. Real type.	1.566	x			IFC	IfcSensor + Pset_SensorPHistory or IfcExternalRefernce
		Time stamp	The moment of the measurement.	"9:00:12"	x			IFC	IfcSensor + Pset_SensorPHistory or IfcExternalRefernce
	Set Point Information								
		Air temperature	The current set point of the of the air temperature.	20°C	x			IFC	IfcExternalReference
		Relative humidity	The current set point of the of the relative humidity.	40%	x			IFC	IfcExternalReference
		…							
	Output data								
	Control signal data								
		Actuator identifier	Unique identifier or name, in order to determine the actor including the control signal.	"P001"	x			IFC	IfcActuator.GlobalId or IfcActor.Name
		Control signal value	The current value of control signal.	e.g. True/False	x			IFC	IfcExternalReference
		…							
	Consumption/emission data								
		Electrical energy		[kWh]	x			IFC	IfcExternalReference
		Thermal energy		[kWh]	x			IFC	IfcExternalReference
		Co2 emission		[kg]	x			IFC	IfcExternalReference
		…							
	Forecast data								
		Electrical energy		[kWh]	x			IFC	IfcExternalReference
		Thermal energy		[kWh]	x			IFC	IfcExternalReference
		Co2 emission		[kg]	x			IFC	IfcExternalReference
		…							
	Histrorical data							IFC	IfcExternalReference
		…							

Table 1.6: ER Building Model [S + H + SA + RD]

ANNEX B - References and Bibliography

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ANNEX C - Abbreviations and acronyms

AEC	**A**rchitectural, **E**ngineering, **C**onstruction
AEC/FM	**A**rchitectural, **E**ngineering, **C**onstruction and **F**acilities **M**anagement
AEX	**A**utomating **E**quipment Information E**x**change
BEMS	**B**uilding **E**nergy **M**anagement **S**ystem
BIM	**B**uilding **I**nformation **M**odeling
BPMN	**B**usiness **P**rocess **M**odeling **N**otation
BS	**B**uilding **S**ervices
CAD	**C**omputer-**A**ided **D**esign
cfiXML	**C**apital **F**acility **I**ndustry **XML**
DXF	**D**rawing E**x**change **F**ormat
gbXML	**G**reen **B**uilding **XML** schema
HVAC	**H**eating, **V**entilation and **A**ir **C**onditioning
IAI	**I**nternational **A**lliance for **I**nteroperability
IDM	**I**nformation **D**elivery **M**anual
IFC	**I**ndustry **F**oundation **C**lasses
IFD	**I**nternational **F**ramework for **D**ictionaries
IPR	**I**ntellectual **P**roperty **R**ights
MVD	**M**odel **V**iew **D**efinition
OMG	**O**bject **M**anagement **G**roup
SEEDS	**S**elf-learning **E**nergy **E**fficient Buil**d**ings and open **S**pace
STEP	**S**tandard for **T**he **E**xchange of **P**roduct Data
XML	E**x**tensible **M**arkup **L**anguage
XSD	**X**ML **S**chema **D**efinition