

1. Session: eeB

1.1. Using a BIM flow for the design and operation of Building Energy Management Systems

<i>Pit Stenzel</i>	FRAUNHOFER (INSTITUTE FOR INTEGRATED CIRCUITS IIS, DESIGN AUTOMATION DIVISION EAS), GERMANY	pit.stenzel@eas.iss.fraunhofer.de
<i>Jürgen Haufe</i>	FRAUNHOFER (INSTITUTE FOR INTEGRATED CIRCUITS IIS, DESIGN AUTOMATION DIVISION EAS), GERMANY	juergen.haufe@eas.iis.fraunhofer.de
<i>Noemi Jimenez Redondo</i>	CEMOSA, SPAIN	noemi.jimenez@cemosa.es

Abstract

This paper reports our experiences using the Building Information Modeling (BIM) approach within the FP7 project SEEDS (Self Learning Energy Efficient Buildings and open Spaces). SEEDS focuses on the development of an optimized Building Energy Management System (BEMS) that reduces the energy consumption and the CO₂ emission of the building services during its operation phase based on self-learning techniques. One of the core components of the SEEDS architecture is the Building Model which calculates the energy consumption of the building. In this paper, we introduce an approach for the automatic creation of this SEEDS' Building Model from an IFC data model. For an application case, the ability of IFC data models to describe building services is discussed. The introduced methodology was implemented for the energy management of an HVAC system using the CAD tool DDS-CAD 7.3.

1 Introduction

Buildings consume over 35% of energy in the EU. An optimized control of the installed building services using Building Energy Management Systems (BEMS) is a promising possibility to sustainably reduce their energy consumption. The aim within the SEEDS¹ FP7 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. A main part of the BEMS will be a Building Model, which includes the considered building services elements, especially the HVAC equipment and their energy consumption information. The Building Model allows the calculation of the energy demands of the operating building services as part of the performance optimization techniques which are involved in the BEMS. For the development of the BEMS Building Model and the adaption of the BEMS to a specific building it is intended to use the methodology of Building Information Modeling (BIM).

This paper reports our experiences with the Building Information Modeling approach within SEEDS. The purpose of the work was to analyze the Industry Foundation Classes (IFC) data model in terms of its ability to describe building services and to setup a flow for automatic creation of SEEDS Building Model. In this paper, we introduce the energy management for a HVAC system of a helicopter garage as an application case. For this application case we describe all steps to create a running SEEDS Building Model from the IFC. These steps include an IDM (Information Delivery Manual) based requirement analysis. The outcomes of the IDM are used to define a specific view of the whole IFC schema and provide the basis for a validation of the IFC regarding its ability to represent the building services including their energy properties. The specific view is defined in an IFC Model View Definition (MVD). For the

¹ <http://www.seeds-fp7.eu>

complete description of the building service system and its control we have derived IFC extensions which are currently not available in the IFC standard.

The proposed methodology was implemented for the energy management of an HVAC system using the CAD tool DDS-CAD 7.3.

The paper is organized as follows. After a short introduction, an overview on SEEDS is given. Section 3 introduces the development steps of the proposed BIM flow. In section 4, the results of the performed IDM requirement analysis are presented. Based on that, the specification of the MVD is shown in section 5. Subsequently, the enrichment of the IFC schema to fulfill unsatisfied exchange requirements is discussed in section 6. In section 7, the implementation of the proposed BIM flow is presented for an application case. Finally, a conclusion is given in section 8.

2 Overview on SEEDS

The objective of SEEDS is the optimization of the energy behavior of the operating building services – especially the Heating, Ventilation, and Air Conditioning (HVAC) equipment, which is by far the largest energy consumer in buildings – using an innovative model predictive control strategy based on measurements and self-learning techniques.

The SEEDS BEMS architecture is divided into three layers: the controller layer, the data management layer, and the process interface layer (Figure 1). Each layer consists of one or several main components. The controller layer comprises the *Building Model Evaluator* (composed by the components *Building Model* and *Energy Calculator*), *Building Model Library*, *Optimizing*, and *Self-learning*. The component *Archiving* stores and manages the historical and runtime data and is located in the data management layer. The process interface layer includes the *WISAN* (Wireless Intelligent Sensors and Actuators Network) communication server and the *Graphical User Interface* [1].

This paper focused on one of the core components in SEEDS: the *Building Model Evaluator* which includes *Building Model (BM)* and *Building Model Library (BM Library)*. The *BM* represents an executable model of a real residential or commercial building including all building services. It facilitates the calculation of the energy consumption of the HVAC equipment during its operation. It is created from instances of the *BM Library* which provides a portfolio of building services components and building structure elements. The structure of the *BM Library* will be discussed in section 6.

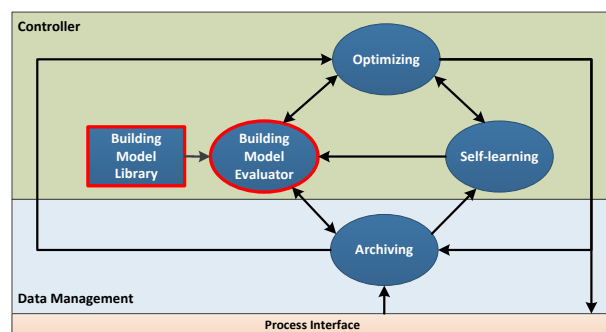


Figure 1: Simplified SEEDS BEMS architecture

Helicopter garage - HVAC system

The first developments of SEEDS have been validated in a test bench which is a Helicopter Garage (located in Barajas airport in Madrid). The Helicopter Garage includes two building storeys and several office rooms. For the air conditioning of individual rooms an HVAC system is operating in cooling mode (because the validation was applied in summer time). The HVAC system consists of four sub-systems: the Thermal Energy Distribution System, the Heat and Cool Thermal Energy Plant, the Cool Thermal Energy Plant, and the Heat Thermal Energy Plant. Specifically, the HVAC system contains the following components: 12 fan Coils, chiller, heat pump, boiler, 3 pumps, and 3 water storage tanks.

SEEDS plays special emphasis to HVAC systems. References [2] and [3] provide some information on the energy modeling applied in SEEDS. A *Device Model Table* was included in Annexes C and D of [2]. For each device, its model table includes a schematic representation and a functional description together with the mathematical relationships among comfort, health, safety, and energy consumption. This information allows to model/determine, the energy behavior of each HVAC device. Furthermore, the operating limits and the local control system are also included in this document.

3 Development methodology

In order to implement a successful BIM based workflow [4] for the design and the operation of the SEEDS BEMS several steps are necessary. In this section the development methodology for interfacing the BEMS-EC into a BIM process is introduced. Figure 2 illustrates the desired BIM based workflow.

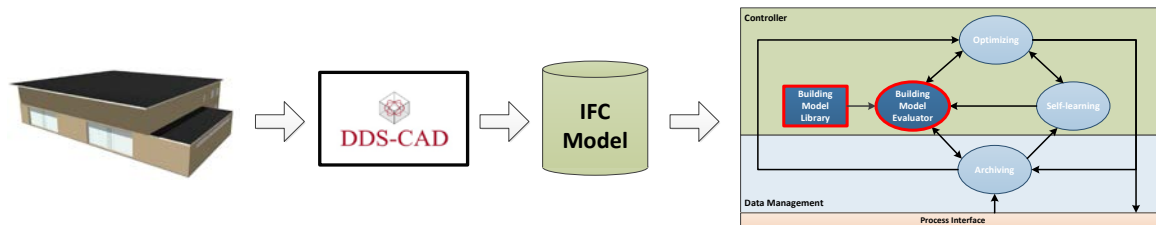


Figure 2: BIM based workflow

For the purpose of this paper the following tasks are performed:

- (1) Identification of the data that must be exchanged within a BIM process:** By means of a requirement analysis according to the Information Delivery Manual (IDM), the Exchange Requirements (ER) are identified and specified. The ER describes the information that has to be exchanged in a model independent way. The ERs are the basis for integration of the BEMS-ER into a BIM process and therefore they are important for the specification of the IFC interface.
- (2) Specification of the IFC interface of the BEMS-EC:** The next step is the mapping of the model independent requirements to the Industry Foundation Classes (IFC), an Open BIM data exchange format. The mapping is defined in an IFC Model View Definition (MVD). A MVD basically represents a subset of the whole IFC schema specification. Furthermore, with the definition of the MVD the IFC schema is validated regarding its ability to represent the Helicopter Garage example including its HVAC equipment and its energy properties.
- (3) Enriching the IFC data schema:** In case the IFC cannot fulfill all the required data exchange, it is necessary to enrich the IFC schema. However, there are several options to extend the IFC, e.g. external or internal enrichment. The extensions that have to be done are added to the specified MVD afterwards.
- (4) Design and implementation of the BEMS-EC:** To estimate the energy behavior for the operating reference example the components *BM* and *BM Library* as well as the IFC interface are implemented. Thereby, the IFC interface implementation bases on the specified MVD. Furthermore, the instantiation of IFC data model of the helicopter garage is done. For this purpose, DDS-CAD 7.3 [5] is used.

Sections 4-7 below explain details on the implementation of the four tasks above into the SEEDS Project and its validation in the Helicopter Garage test bench.

4 IDM requirements analysis

As mentioned above, the first step of BIM based workflow is the determination of the information that must be exchanged within a specific business process. Therefore, a requirement analysis according to the Information Delivery Manual (IDM) [6] was performed for the business process “BEMS Engineering”. In the paper it was assumed the business process describes the interfacing of the already developed BEMS-EC into a BIM process. The basis for this IDM requirement analysis were the outcomes of the IDM in [7] and [8]. In [7], the IDM was performed for the more general business process of interfacing the whole SEEDS BEMS into the building life cycle. In this case, the business process “BEMS Engineering” was divided into the four sub-processes: i) *BEMS Planning and Design*, ii) *BEMS Commissioning*, iii) *BEMS Operating*, and iv) *BEMS Retrofitting*.

For each of those sub-processes, a process map² was developed. The process maps assisted to identify the actors which are involved in the process, the activities of the actors, the dependencies of activities, and the exchange requirements among the actors. The specifications of the exchange requirements in [9] describe the information that have to be exchanged to interface the SEEDS BEMS into a BIM process in a non-technical form. For the developments shown on this paper, the process maps were summarized and the specifications of identified exchange requirements were reworked.

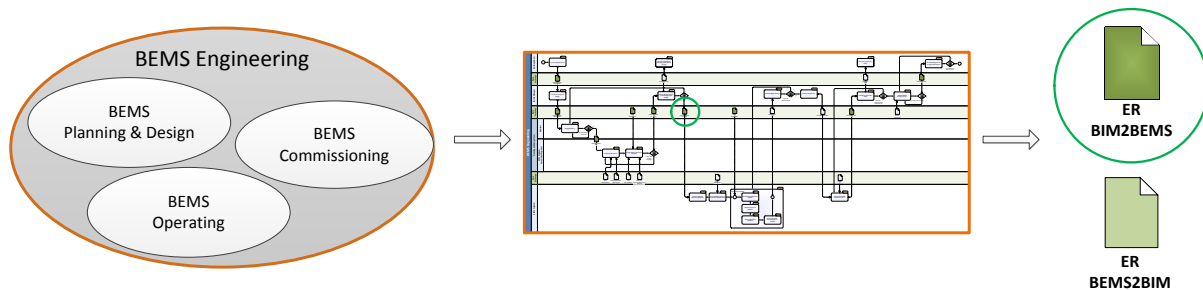


Figure 3: IDM workflow

The main outcomes were the Exchange Requirements from BIM to BEMS (ER *BIM2BEMS*) and from BEMS to BIM (ER *BEMS2BIM*). The ER *BIM2BEMS* specifies the information that has to be exchanged to generate the BEMS-EC automatically during the planning and design phase. The required data exchange while operating the BEMS-EC is described in the ER *BEMS2BIM*. The ER *BIM2BEMS* is structured as follows (for details see [9]):

- | | |
|---|---|
| <ul style="list-style-type: none"> • Project Information <ul style="list-style-type: none"> – Project Attributes – Unit Assignment – Project Decomposition • Building Structure <ul style="list-style-type: none"> – Site, Building, Building Storey, Space – Spatial Decomposition – Spatial Containment | <ul style="list-style-type: none"> • Building Services Equipment <ul style="list-style-type: none"> – HVAC Equipment (including energy properties) – BA Equipment • Building Services System <ul style="list-style-type: none"> – HVAC System, BAS – Component System Assignment – Service Spatial Element |
|---|---|

5 Specification of the IFC interface

On the basis of the outcomes of the IDM requirement analysis, the specification of the IFC interface is done by mapping the identified exchange requirement to the corresponding IFC schema representation. The following section gives an overview of the development of the Model View Definition *BIM2BEMS* (MVD *BIM2BEMS*) which is based on the mentioned ER *BIM2BEMS* and the specified MVD in [10].

In general, a MVD represents a specific view of the comprehensive IFC schema specification. In the context of this paper, the IFC Model View Definition format [11] is utilized. The main idea of developing a MVD is to reuse standardized Concepts and their generic relationships. Whereby, each Concept represents a subset of the whole IFC schema and is defined in a Concept Definition. The generic relationships among different Concepts are specified in the Binding Concept Model. Figure 4 shows the Overview Page of the Binding Concept Model of the MVD *BIM2BEMS*. It demonstrates the correspondence between the MVD *BIM2BEMS* and the ER *BIM2BEMS*.

The Concepts in Figure 4 are composed of other Concepts. For instance, the Concept *Fan-Coil* consists of several Concepts which fulfill the exchange requirements regarding a fan coil within the MVD *BIM2BEMS*. This includes, the:

- General identification of the fan coil
- Assignment of specific product data using type and property set definition
- Representation of physical and logical connections using ports

² For developing the process maps the Business Process Modeling Notation (BPMN) was used. The BPMN is provided by the Object Management Group (OMG) and offers a widely used standard for specification of business processes.

- Assignment of the local control equipment
- Realization of the decomposition of the fan coils
- Relation to the HVAC system level and the basic building structure.

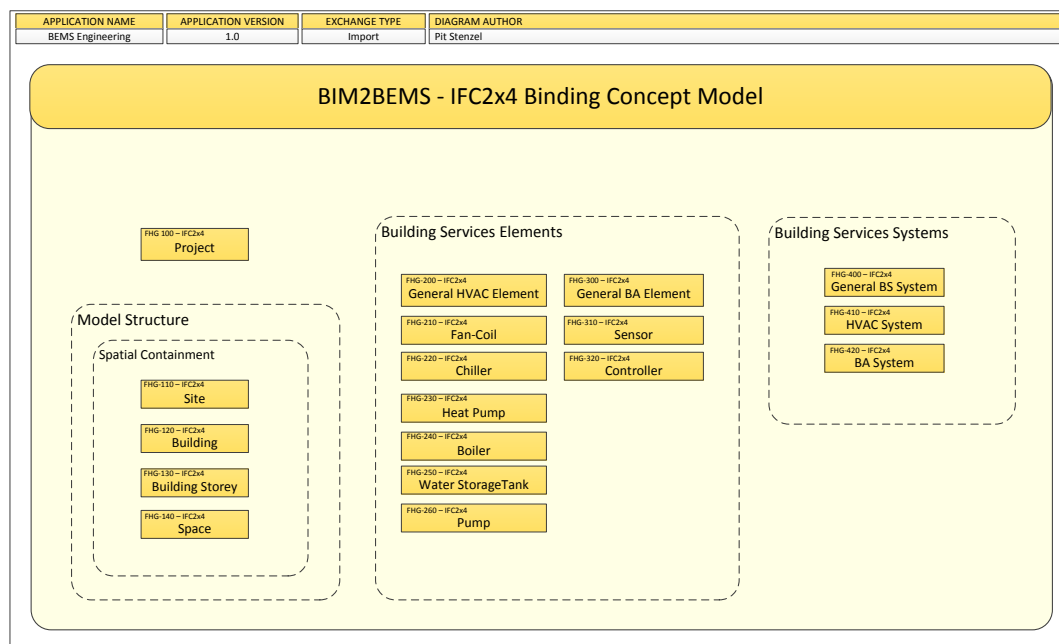


Figure 4: MVD BIM2BEMS - Binding Concept Model

The general identification of the fan coil is done by the IFC object occurrence *IfcUnitaryEquipment* and the corresponding IFC object type *IfcUnitaryEquipmentType*. A further refinement of the fan coil is done by the direct attribute *PredefinedType*, which is set to AIRHANDLER. An overview of the specified IFC representation of the remaining HVAC equipment of the reference example is given in Table 1 and Table 2.

Besides the pure representation of the fan coil, the MVD specifies some relationships. For instance, the assignment of the IFC object type (*IfcUnitaryEquipmentType*) is made by means of the relationship object *IfcRelDefinesByType*. The IFC schema specification provides a range of predefined property sets which can be assigned either to *IfcUnitaryEquipment* using the relation *IfcRelDefinesByProperties* or to the direct attribute *HasPropertySets* of *IfcUnitaryEquipmentType* [7, 12].

BS Equipment Helicopter Garage	IFC object (occurrence)	IFC type	PredefinedType
HVAC components			
Fan coil 1-12	IfcUnitaryEquipment	IfcUnitaryEquipmentType	AIRHANDLER
Pumps	IfcPump	IfcPumpType	CIRCULATOR
Heat pump	IfcHeatPump	IfcHeatPumpType	AIRCOOLED
Water storage tanks	IfcTank	IfcTankType	STORAGE
Chiller	IfcChiller	IfcChillerType	AIRCOOLED
Boiler	IfcBoiler	IfcBoilerType	STEAM
BA components			
Two-point controller	IfcController	IfcControllerType	TWOPOSITION
Temperature sensor	IfcSensor	IfcSensorType	TEMPERATURESENSOR
Humidity sensor	IfcSensor	IfcSensorType	HUMIDITYSENSOR
Mass flow sensor	IfcSensor	IfcSensorType	FLOWSENSOR

Table 1: IFC representation component level

HVAC systems Helicopter Garage	IFC object (occurrence)	PredefinedType
Air Conditioning System	IfcDistributionSystem	AIRCONDITIONING
Thermal Energy Distribution System	IfcDistributionSystem	AIRCONDITIONING
Heat and Cool Thermal Energy Plant	IfcDistributionSystem	-
Cool Thermal Energy Plant	IfcDistributionSystem	COOLING
Heat Thermal Energy Plant	IfcDistributionSystem	-

Table 2: IFC representation system Level

However, in the context of the paper it is not possible to introduce the whole content of the MVD BIM2BEMS. The remarks regarding the MVD specification are intended to present only the idea. Further details are described in [9].

6 Enriching of the IFC data schema

During the development of the MVD *BIM2BEMS* it was found that the IFC schema [12] does not meet all requirements of the ER *BIM2BEMS*. These include the description and the identification of the heat pump (which is one of the HVAC components) as well as the representation of the specific energy behavior of all HVAC equipment. Because the latter plays a significant role regarding to the energy calculation, the IFC data had to be enlarged.

Pset_FanCoilEnergyProperties		(Type and Occurrence driven)
Property Name	IFC Object	IFC Data Type
CalcModeThermalPower	IfcPropertySingleValue	IfcInteger
CalcModeElectricalPower	IfcPropertySingleValue	IfcInteger
CalcSpecThermalPower_Air	IfcPropertySingleValue	IfcText
CalcSpecThermalPower_Water	IfcPropertySingleValue	IfcText
ElectricalPowerMassflowTable	IfcPropertyReferenceValue	IfcExternalReference
ThermalCoolingPowerTable	IfcPropertyReferenceValue	IfcExternalReference
ThermalHeatingPowerTable	IfcPropertyReferenceValue	IfcExternalReference
FixedElectricalPowerValue	IfcPropertySingleValue	IfcPowerMeasure
ControlMode	IfcPropertyEnumeratedValue	IfcLabel
CommandVariable	IfcPropertyEnumeratedValue	IfcLabel

Table 3: Property Set Definition - *Pset_FanCoilEnergyProperties*

There are several options to extend the IFC schema. Basically there are two possibilities, the internal and the external extension [9]. To overcome the mentioned issues both options were used. In order to represent the heat pump, the entities *IfcHeatPump* and *IfcHeatPumpType* were defined in the HVAC domain of the IFC schema. These entities are defined as specializations of the entity *IfcEnergyConversionDevice* and *IfcEnergyConversionDeviceType* respectively and inherit the corresponding attributes [9].

To represent the energy behavior of the HVAC equipment for each component, a user defined property set was specified. Table 3 shows the property set definition for a fan coil. Besides the specific energy properties which are represented as single values or external references, it includes configuration data, e.g. control mode or command variable. Furthermore, the property set facilitates the choice of the calculation mode of the energy consumption.

7 Design and implementation of the BEMS-EC

The following section describes the design and the concrete implementation of the BEMS-EC. The structure of the *BM Library* and the architecture of the whole BEMS-EC are introduced.

The *BM Library* consists of three main sections *Flow Component*, *Control Component*, and *Spatial Structure Element*. The section *Flow Component* provides the components of the HVAC equipment, such as chiller, heat pump, and fan coil. The components of the Building Automation System (BAS), e.g. controller and sensors, are provided in the section *Control Component*. The section *Spatial Structure Element* facilitates to represent basic spatial structure of the building within the *BM*.

The target of the design of the *BM Library* was to develop a generic data structure to help modeling a fundamental building structure and the building services equipment. For this purpose, the Industry Foundation Classes (IFC) [12] was the basis for the design of the *BM Library*. In particular the schemes *IfcSharedBldgServiceElements*, *IfcHVACDomain*, and *IfcBuildingControlsDomain* served as an orientation for the hierarchy of the building services components. As reference for the section *Spatial Structure Element*, the IFC entity *IfcSpatialStructureElement* and their specializations were used.

In terms of the energy calculation of the operating building services the components of the HVAC equipment are most important. Besides the simple HVAC components and their inheritance hierarchy the *BM Library* facilitates the representation of relationships. The class structure in Figure 5 clarifies these relationships. A detailed description of the *BM Library* structure is given in [9].

Architecture of the BEMS-EC

Besides the components *BM Library* and *Building Model Evaluator* of the SEEDS BEMS architecture (Figure 1), the architecture of the BEMS-EC comprises further components to implement the BIM based workflow. Figure 6 illustrates all involved components of the BEMS-EC.

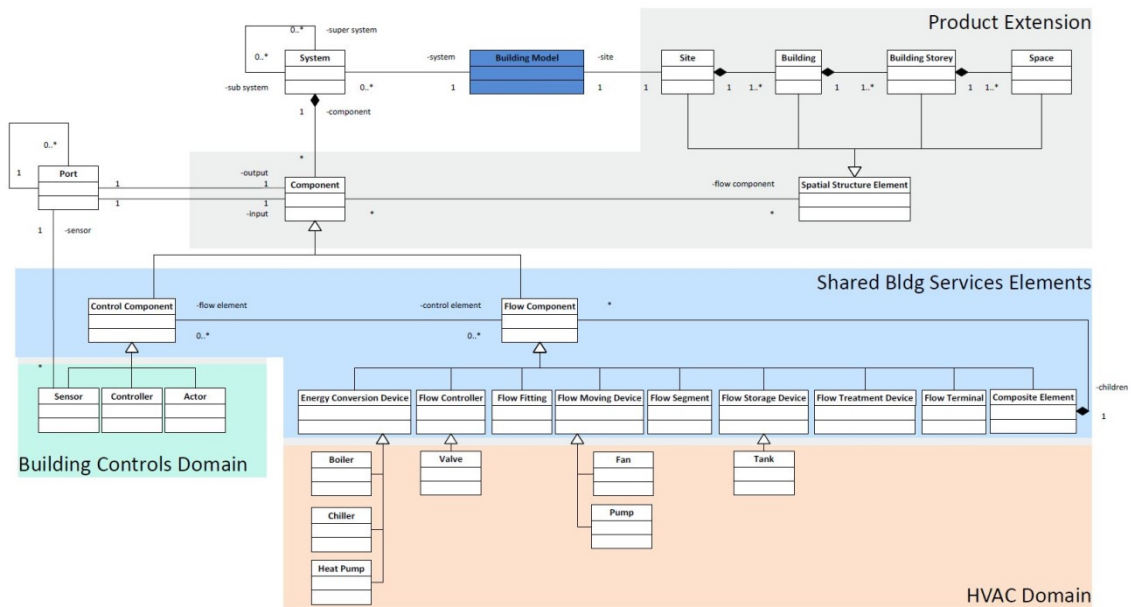


Figure 5: Class structure according to IFC structure

The components *IFC Parser* and *Inter Container* represent the IFC interface and facilitate the reading of an IFC data model in STEP Physical File format (SPF) [14]. Both components are implemented based on MVD *BIM2BEMS*.

The *Inter Container* is an internal data structure. This data structure is nearly equivalent to the subset of the IFC schema which was defined in the MVD *BIM2BEMS*. On the basis of the *Inter Container* the *Model Builder* creates the executable *BM*. For this, the *Model Builder* uses the *BM Library*, which provides a set of building services components and spatial building elements including their relationships and creates the corresponding instances. Among others, the *Model Builder* gets external references to the specific datasheets of the HVAC equipment. These are used for the final configuration of the HVAC components for the energy calculation. Finally, the *Energy Calculator* component is created. This part of the *Building Model Evaluator* calculates the energy consumption of each HVAC component for a given time period. Furthermore, the *Energy Calculator* is able to estimate the energy consumption of the HVAC equipment on system level as well as for partial building structures.

IFC instantiation of the helicopter garage example

In order to generate the BEMS-EC, an IFC model of the Helicopter Garage including the HVAC equipment is needed. Therefore, the necessary instantiation of the IFC data model is done using the already mentioned BIM tool DDS-CAD 7.3 [5]. This step within the proposed BIM workflow is equivalent to the planning and design phase of the building and the building services.

The implementation of the Helicopter Garage using DDS-CAD 7.3 was not easy. Some difficulties have to be overcome. Firstly, the strict separation of the trades caused problems. For instance, the fan coils had to be modeled using two DDS devices, because a fan coil can be assigned to the plumbing domain as well as to the air conditioning domain. Furthermore, the limited expandable product database was difficult to handle. Nevertheless, it was possible to model and instantiate the Helicopter Garage example by means of DDS CAD 7.3. The following figures show the results of the architectural design and the planning of the air conditioning system.

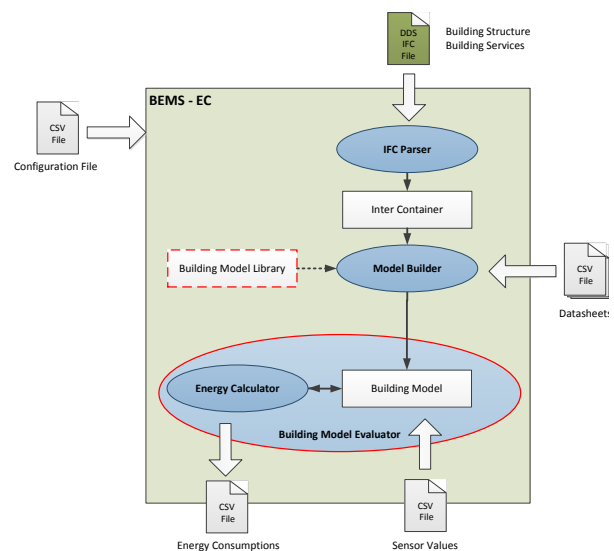


Figure 6: BEMS-EC architecture

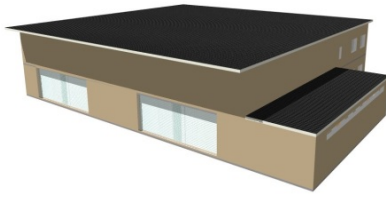


Figure 7: Building structure

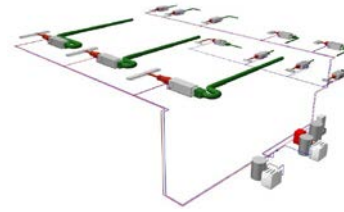


Figure 8: Air conditioning system

As well as the above design difficulties, other problems arose regarding the implementation of the purposed BIM based workflow. The DDS IFC export did not satisfy the exchange requirements. This was found in a comparison of the DDS IFC model and a resumed IFC model. The resumed IFC model was instantiated using the MVD *BIM2BEMS*. In order to use the DDS IFC model for the generation of the BEMS-EC, it has to be reworked manually. Some of the modifications performed are listed below:

- Achieving an unique representation of the HVAC as well as BA components
- Adding the user defined property sets including the energy properties to HVAC components
- Adding representations of the air conditioning system at system level
- Adding relationships of the HVAC components to the air conditioning system and the spatial structure.

Operating the BEMS-EC for the Helicopter Garage example

The inputs (DDS IFC model and sensor values) and the outputs (energy consumptions) as well as the values of the operating parameters (simulation time and sampling time) required to operate the BEMS-EC are provided using a configuration file such as the one shown in Table 4. The sensor values were generated by means of a corresponding Modelica model of the Helicopter Garage [15], because there was no real sensor data available.

BEMS Config-File	
Input	
DDS IFC-Modell	HelicopterGarage.ifc
Sensor Values	SensorValues.csv
Output	
Energy Consumption	EnergyConsumption.csv
Operating Parameter	
Simulation Time	259200 sec
Sampling Time	120 sec

Table 4: BEMS-EC Configuration file

The results of the energy consumptions were validated. It was, therefore, proved the performance of the BEMS-EC for several HVAC components.

8 Conclusions

This paper presents the main steps for the development of the BEMS Energy Calculator (called BEMS-EC throughout the paper) which comprises the core components *Building Model Evaluator* and *Building Model Library* of the BEMS developed by the on-going FP7 project SEEDS. The proposed BEMS-EC was developed using a BIM based workflow for the design and the operating phase. In order to interface the BEMS-EC into a BIM process, an IDM requirement analysis for the business process “BEMS Engineering” was performed. The main outcome of the IDM was the ER *BIM2BEMS*. Subsequently, the MVD *BIM2BEMS* was specified on the basis of the ER *BIM2BEMS*. It was noted that the IFC schema specification (IFC2x4) could not fulfil all requirements. As a consequence, the IFC schema had to be extended. Furthermore, the concrete design and implementation of the BEMS-EC was presented. The structure of the *BM Library* and the final architecture of the implementation were presented in detail.

The feasibility of the developed workflow the BEMS-EC was demonstrated into a test bench based on the Helicopter Garage example. The application of the IFC model to this example was instantiated using DDS-CAD 7.3. Because the DDS IFC export did not meet all the requirements of the BEMS-EC, the exported IFC model had to be reworked manually. Finally, the calculation results were validated and the ability of the BIM based workflow for the design and the operation of the SEEDS BEMS was demonstrated. Further works regarding the proposed BIM based workflow are:

- Integration of the BEMS-EC into the SEEDS BEMS
- Extension of the *Building Facility Model Library*
- Rework of the IDM and MVD
 - Requirement analysis for the other SEEDS BEMS components, e.g. Optimizing
 - Defining the MVD *BIM2BEMS* using the mvdXML format [16]

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