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Describing HVAC controls in IFC – Method and application

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Abstract

This paper describes a method to overcome current limitations in BIM software to design Building Automation and Control Systems (BACS) functions of Heating Ventilation and Air Conditioning (HVAC) systems through the extension of the IFC-files with information on control functions. The method is illustrated with the description of control functions for a use case including a boiler, a thermal storage, an air handling unit and a floor heating system modelled with a widely used BIM software tool. The focus is set on the description of three simple control functions: the definition of a heating curve, the setup of time schedules for the air handling unit and the flow temperature control for the heating circuit. The proposed method is based on available software tools linked together and enables adding complementary information on controls into the IFC-file, checking it for consistency, extracting and converting the IFC content into a linked data format. The use of semantic web technology allows for interoperability with various applications like e.g. software used for the commissioning or the supervision of HVAC systems and thus can contribute to reduce current quality and performance deficits of these systems.

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Keywords: Building Information Modelling; controls; heating; ventilating and air conditioning

1. Introduction

The use of digital representations of building characteristics and functionalities – the Building Information Modelling (BIM) method - has been gaining a growing interest in the building sector in the recent years. To a large extent, this is due to the promising benefits which are associated with an integral planning and seamless data exchange between several actors and different software tools. BIM includes a central data storage and management

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for digital building data across different disciplines and along the different life cycle phases of buildings. The open data model standard Industrial Foundation Classes (IFC) is widely used for data exchange in BIM-based processes [1]. Commonly used BIM programs comply with the IFC standard for geometrical modelling and data exchange. The IFC standard offers the possibility to describe functions of Building Automation and Control Systems (BACS) for the control of Heating, Ventilation and Air-Conditioning (HVAC) systems for example via the class IfcDistributionControlElement. However, some limitations exist in the current BIM software that hinder detailed descriptions of control functions. These descriptions – provided in a BIM compatible standard - offer yet many advantages as they can support the design and commissioning of BACS. Furthermore, they can provide important information for facility management tasks during the post-occupancy operation of buildings and thus contribute to enhance the building performance. In this paper, we describe a method and a tool chain enabling the description of detailed control functions for HVAC systems in BIM. The conversion of the IFC file to a semantic web ontology based model aims also at enabling the access to the control function descriptions to various applications supporting e.g. BACS setting and commissioning or operation and maintenance tasks. We consider a simple use case including a boiler, a thermal storage, an Air Handling Unit (AHU) and a floor heating system designed with a widely spread BIM software tool. We focus on the digital description using the IFC data model of three standard control functions: the definition of a heating curve, the setup of time schedules for the AHU and a temperature control for the heating circuit. We then investigate the possibilities to describe the control functions in the used BIM software and in IFC4 and present a method and a tool chain to enable the IFC file export, its extension with additional control rules and its conversion to a Linked Data format enabling its access from heterogeneous applications. The application checks first the converted IFC-file for consistency extracts the complementary information and displays its content. This information can then be used for different purposes like for e.g. the analysis of control scenarios, to support tendering in the design phase, to setup the BACS during the commissioning or for the supervision of the building operation by means of algorithms for automated Fault Detection and Diagnosis.

2. State of the art

Building Automation and Control Systems (BACS) are designed to control and monitor autonomously the mechanical, security, fire, lighting and HVAC systems in buildings. BACS aim at facilitating maintenance and at monitoring and optimizing the energy efficiency of buildings during their operation phase. Many BACS manufacturers provide also libraries with function blocks or software macros for the parametrization of HVAC standard control functions and thus facilitate commissioning tasks. Because of these benefits, BACS have been widely adopted in commercial buildings and the BACS market is expected to grow rapidly in the coming years. Nevertheless, the operation of BACS is often impacted by shortcomings due to malfunctions, programming errors or sensor and actuators faults. These faults are hardly identifiable for facility managers as, in most of the buildings, the installed BACS do not provide fault detection functions and the documentation of the functions and parameters of BACS is either not available or not adapted to support maintenance tasks. The growing complexity of building services, the lack of systematic and structured information on BACS functions as well as information losses between design, commissioning and operation phases of buildings lead to wrong interpreted and implemented control functions in BACS and arbitrary maintenance. This situation causes energy waste and comfort disagreement, lowers the acceptance of building occupants and operators for BACS and increases the economic risk for building stakeholders [2–4]. The use of a BIM based approach can support the design, the commissioning and the operation of BACS by providing a standardized data model and enabling a seamless data exchange between several actors and different software tools along the whole building life cycle and thus remedy to the current quality shortcomings of BACS. A prior condition to a BIM-based design of BACS is the availability of methods and tools allowing for detailed descriptions of control functions of buildings services like HVAC systems. In the design phase of buildings, standards like the ISO 16484-3, the VDI3813-2 or the VDI 3814 in Central Europe describe specifications and procedures to document systematically the control functions to be implemented in BACS [5–7]. The compliance with these standards enables a systematic design, documentation and commissioning of BACS. Nevertheless, in many building projects including BACS, these standards are not or insufficiently applied leading to the above mentioned shortcomings in the operation of BACS. At the same time, the use of semantic web technologies is emerging in BIM based approaches as it enables improving the interoperability between systems and software through a common representation of knowledge, concepts and relationships and to overcome some current limitations of the IFC standard [8,9]. Methods using semantic web technologies for the description of devices used in BACS have been developed to allow for an automated design of BACS in compliance with design standards like the German guideline VDI3813-2 and to enable data exchange between heterogeneous applications [10–11]. These approaches however are not currently based on the IFC standard and are thus not compatible with current BIM based design methods.

3. IFC file extension and conversion method

3.1. Method and use case

We consider a simple use case including a boiler, a thermal storage, an AHU and a floor heating system and focus on two standard control schemes: the setup of time schedules for the AHU and a temperature control for the heating circuit. The system is modelled in the widely used BIM software Revit® and exported as IFC4. The current version of this software does not enable time schedules descriptions for the AHU volume flow but only fixed values. Thus, we implemented a function for the time-schedule that considers two air volume flow values for off and on cycles of the AHU. The second function models a PID controller that regulates the heating circuit flow temperature by setting the valve position. We analyse in detail the possibilities to describe these functions in IFC4 and propose an exemplary method and a tool chain enabling checking the modified IFC-File for consistency, adding complementary information and converting the file content in linked data format (see Figure 1). This information can then be used for different purposes like for e.g. the analysis of control scenarios to setup the parameters of a BACS during the commissioning or for the supervision of building operation.

3.2. IFC file export

To read and export our digital model, we used the Revit tool which is widely spread in the AEC industry. In this first step, for the export to IFC, we used a mapping in Revit to ensure that HVAC components are represented as elements of the class IfcDistributionFlowElement in IFC, and not as elements of the class IfcBuildingElementProxy. This is important, because controllers (elements of the class IfcDistributionControlElement) can only be associated to elements of the class IfcDistributionFlowElement.

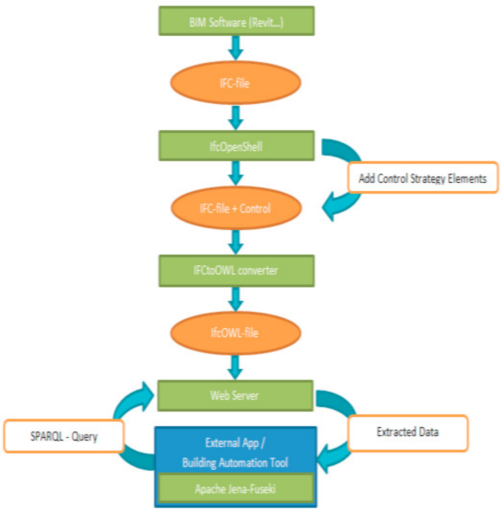

Figure 1: Toolchain for IFC-file conversion and access via semantic web technology

3.3. IFC file extension with IfcOpenShell

Commonly used BIM software in the design phase of buildings do not allow describing the control functions of HVAC systems but can export the developed models as IFC files. Alternative methods and tools are necessary to extend the models with information regarding the control functions. To do this, we developed a software piece using the open-source library IfcOpenShell and enabling the extension of the original file with new IFC entities [12]. In a first step, the code identifies distribution elements like valves, pipes among IfcSystem entities and creates the control entity with its different properties (see Table 1). It then connects the new entities to the existing entities and saves the modified IFC-file.

3.4. IFC file conversion to Linked Data format

To enable a future interoperability with BACS applications used for commissioning or supervision of the building operation, we have adopted the emerging semantic web and linked data technology ifcOWL [9,13]. The access to the data for different kind of users is then enabled by a Linked Data approach based on the converted original IFC file to a RDF file via an IFCtoRDF converter. After conversion, the RDF file can be queried via SPARQL requests over the Apache Jena-Fuseki application, allowing for example data exchange between design models and tools used for commissioning of BACS.

4. Attributes and Properties of the Ifc Entities

4.1. Heating Curve

To model the heating curve, a new property of the class IfcPropertyTableValue describes the dependency between the outside air and the set flow temperatures. Via this property, a dependent quantity - the set flow temperature- can be related to an independent quantity - the outside air temperature - and specified in terms of a table (see Table 1). The interpolation method can be chosen via the attribute CurveInterpolation as LINEAR, LOG_LINEAR, LOG_LOG or UNDEFINED. The new property is either added to an already existing property set for the considered heating circuit or associated to a new property set. The property set is related to the heating circuit (here: IfcSystem, named "H VL") via the entity IfcRelDefinesByProperties (see Figure 2).

Table 1: Attributes of the heating curve in the IfcPropertyTableValue entity

DefiningValue (outside air temperature)	DefiningValue Type	DefiningUnit	Defined Value (set flow temperature)
-20	IfcThermodynamic-TemperatureMeasure	DEGREE_CELSIUS	53
-10	IfcThermodynamic-TemperatureMeasure	DEGREE_CELSIUS	45
0	IfcThermodynamic-TemperatureMeasure	DEGREE_CELSIUS	37
10	IfcThermodynamic-TemperatureMeasure	DEGREE_CELSIUS	29
20	IfcThermodynamic-TemperatureMeasure	DEGREE_CELSIUS	20

4.2. Time Schedule

In order to specify a time-dependent set volume flow, for e.g. an air volume flow controller, we define a new property "volume flow" of type IfcPropertyListValue. This property is added to an existing property set for volume flow controller. The new property stores two values, the first for the maximal volume flow and the second for the reduced volume flow. The IfcPropertyDependencyRelationship is then used to describe the dependency of the volume flow on the time. The exact dependency can only be given in terms of a textual expression. Here, the textual expression follows the formalism for function definitions given in the VDI 3805 standard. The time schedule is specified via the entity IfcRecurrencePattern, which allows for defining the recurrence frequency and the profile. The whole procedure is schematically represented in Fig. 3.

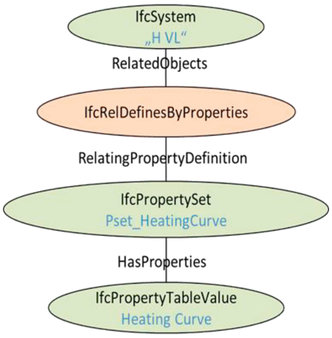

Fig. 2: Schematic representation of property set assignment, including the new property "Heating Curve" to a given (sub)-system

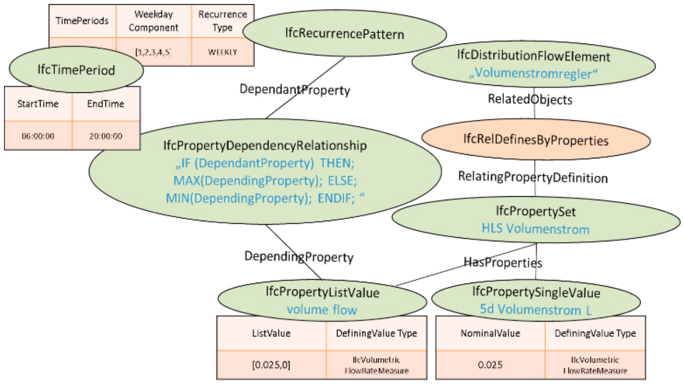

Fig. 3: Schematic representation of the assignment of a new property “volume flow” to an HVAC component

4.3. Temperature Control

The implementation of the temperature-controlled heating circuit in IFC uses an element of class IfcController (of type PROPORTIONAL), defined and equipped with a predefined property set, called Pset_ControllerTypeProportional. This property set contains nine properties, specifying the parameters of the PID controller. The next step consists of the instantiation of an element of class IfcSensor (of type TEMPERATURESENSOR) and of an element of class IfcActuator (of type ELECTRICACTUATOR). The measured temperature from the sensor serves as an input for the controller, while the output signal of the controller triggers the actuator which activates the valve. In order to represent this relationship in IFC, the sensor, the actuator and the controller are equipped (using the relationship class IfcRelNests) with ports (IfcDistributionPort) of type cable and suitable flow directions. More precisely, this implies one SOURCE-port for the sensor, one SINK-port for the actuator and one SOURCE- and one SINK-port for the controller. The connections between the ports are schematically illustrated in Figure 4. All ports are communication ports (type “CABLE”) and the direction of the signal is defined via the attribute “FlowDirection” (“SINK” or “SOURCE”). Additionally, the actuator is associated to a 3-way-valve in the heating circuit and the sensor is associated to the respective pipe segment, connected to the valve, where the temperature is to be controlled. In our case, the actuator is a three-way-valve and is associated to the respective element of the class IfcValve via the relationship entity IfcRelFlowControlElements. Similarly, the sensor is associated to the respective pipe segment, connected to the three-way-valve, where the temperature is to be measured and controlled (see Figure 5).

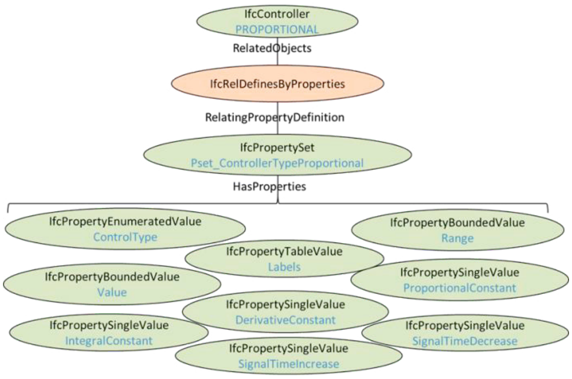

Figure 4 Schematic representation of assignment of the predefined property set "Pset_ControllerTypeProportional", to a controller of type "Proportional"

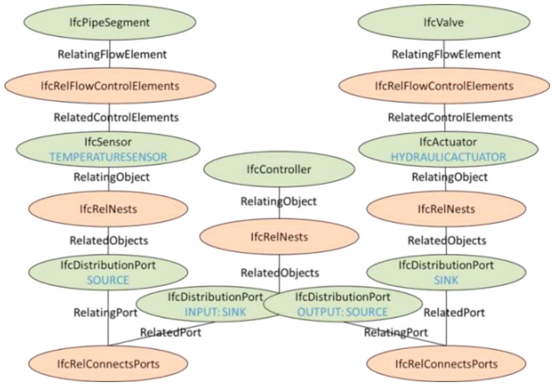

Figure 5 Schematic representation of the connections between the controller and the sensor and actuator via ports

5. Conclusion and outlook

In this paper, we describe an exemplary method and a tool chain to extend IFC files exported from a widely used BIM software tool with control functions descriptions. We illustrated the method with three simple examples of HVAC control functions. The used tool chain is based on available software and enables the extension of the IFC file and its conversion to a linked data format whose information can then easily be accessed from applications used for example for the commissioning of BACS or for the supervision of the building performance. However, the use of BIM in the commissioning and operation of BACS is still in its infancy and further developments are needed to define a general procedure for the description of BACS functions in BIM and to transfer this information in a standardized and automated way to applications used during the operation phase of buildings.

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