MODEL VIEW DEFINITION FOR ADVANCED BUILDING ENERGY PERFORMANCE SIMULATION

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ABSTRACT

Recent demand for higher energy efficiency within the building sector has led to the use of Building Energy Performance Simulation (BEPS) tools. These powerful predictive tools enable investigation of environmental and energy performance for different design and retrofit design alternatives. However, integrating BEPS with Building Information Modelling (BIM) based building design tools still experiences limitations due to a lack of standardised methods of information exchange between these domains. As a result, this paper presents a Model View Definition (MVD) for advanced BEPS. In doing so this work enables a standardised exchange of data from BIM to BEPS tools, such as Modelica, using the Industry Foundation Classes (IFC) standard. The entire process becomes available through the open source software framework emerged from the IEA EBC Annex 60.

INTRODUCTION

A societal demand for low energy and net-zero energy buildings coupled with the rise in the use of electrical equipment and advanced controls mandates the development and use of more sophisticated building design tools. More complex buildings that meet more stringent performance codes require standardised testing methods and more advanced Building Energy Performance Simulation (BEPS) tools (Attia et al. 2013). EnergyPlus, for example, is a state-of-art building energy simulation tool and among the top-most used software tools in buildings. However, in recent years more advanced tools are being developed for bridging the gap between different modelling domains such as electrical, thermal and hydraulic systems. Thus, object-oriented simulation languages such as the Modelica standard are becoming increasingly important in the BEPS field (Wetter et al. 2015). As an advanced BEPS tool, Modelica is non-proprietary, industrial-strength, industry-driven standard that allows technology transfer between multiple domains and multiple disciplines. In contrast to conventional building simulation software, advanced BEPS tools aim to investigate the interaction between buildings, district heating/cooling and electricity, which is required to evaluate new energy concepts (Wetter et al. 2013).

Advanced BEPS tools predict the annual energy performance of a building and its energy systems including advanced controls and can be used to predict differences in energy consumption for different design alternatives. Results from simulation models provide designers with the necessary information about a building design that will offer thermal comfort and minimised energy consumption (Asmi et al. 2015). In order to carry out an energy performance analysis, an energy simulation expert needs to collect building information from different sources. At the same time, experts need to manually transform this information into specific input and add any missing information as required by energy simulation software. Outcomes from this non-standardised subjective process can widely vary from person to person, even given the same initial building design information (Berkeley et al. 2014).

Recent studies (Lu & Olofsson 2014; Lee et al. 2014; Chen & Luo 2014; van Treeck & Rank 2006) show that using Building Information Modelling (BIM) can improve the exchange of data between design representations and energy simulation representations. BIM is widely adopted in the Architectural, Engineering, Construction and Facilities Management (AEC/FM) industry for uses such 3D-viewing, drawing, clash detection, cost estimations, building materials, and so on (Eastman et al. 2008). Linking a building model to energy analysis tools can facilitate a more accurate and efficient analysis process.

One of the key obstacles for the integration of BIM and BEPS analysis tools is the lack of a standardised data exchange process. The absence of such a process raises problems in the AEC/FM industry with interoperability being the most common issue (Guzmán et al. 2015). According to Shen et al. (2010), interoperability is the ability to ensure that data generated by any one party can be properly interpreted by all other parties. Achieving this level of communication between applications is the first step towards any system integration and collaboration.

In order to overcome the noted issues in the AEC/FM workflow a common and standardised language needs to be in place. This challenge is likely to be solved through the advent of the buildingSMART Industry Foundation Classes (ISO 16739), which is widely recognised as the only non-proprietary standard for BIM based data exchange (Asmi et al. 2015). However, the IFC schema does not define the information exchange requirements specific to different project stages and between different actors and software applications. Development of methodologies such as Information Delivery Manual (IDM) and Model View Definition (MVD) has been a significant initiative to identify and define the subset of the IFC data model needed to support a user defined business process. In this way, the IDM methodology identify the exchange requirements and serves as a reference for processes and data required in the process, while the MVD defines a subset of the IFC schema that is needed to satisfy the exchange requirements defined in the IDM. A corresponding subset definition should include the relevant information for BEPS such as control parameters, HVAC system topologies and component parameters, operation schedules, etc.

The work presented in this paper is a contribution from a common effort within IEA EBC Annex 60, Activity 1.3 to provide new methods for the integration of BIM and BEPS tools (Wetter & Treeck 2016). It aims to facilitate the transfer of information from IFC BIM to BEPS tools through the development of an MVD for advanced BEPS. By doing so, the potential of BIM-based simulation can be fully unlocked, and a reliable and consistent IFC subset to serve as input for energy simulation software was defined.

The remainder of the paper is structured as follows. The next section presents a review of existing MVDs developed in the AEC/FM industry. Followed by an overview of the Annex 60 project together with the motivation for this work. Later a description of the methodology adopted in this paper is presented. Next a use case demonstrates the approach and status of the MVD. Finally, the discussion section concludes with the limitations encountered in the development of the MVD, which leads into the conclusions and next steps of the development.

BACKGROUND

IFC is the most commonly used (open) and complete data format in the AEC/FM industry. It is an open source object oriented standard that was developed by buildingSMART (formally International Alliance for Interoperability (IAI)) to facilitate information exchange across the entire building life-cycle. Given its ability to represent elements of a building as objects with properties and references to other objects, the IFC format can be easily managed and

understood by various tools (Asmi et al. 2015). However, this ability can also work against its implementation, due to the fact that many applications can have different interpretations of the same data set.

In order to facilitate model exchange between applications using the IFC schema, buildingSMART has developed the MVD methodology. This methodology focuses on the definition of the exchange requirements which are assembled of IFC subset and MVD concepts that satisfies a specific exchange scenario. This data definition is defined as a subset of the building product model schema that provides a complete representation of the information concepts needed for a particular use case in an AEC/FM workflow (Venugopal et al. 2015). It can thus be seen as some kind of filter of the entire class scheme emphasizing a respective task.

The first and most popular views is the Coordination View (CV) which is extensively implemented in most of the commercially available BIM technologies (Hu et al. 2016). CV was developed by buildingSMART to support sharing of building models between the major disciplines of architecture, structural and mechanical engineering (buildingSMART 2016a). This MVD is based on the previous release of the IFC schema, IFC2x3.

In 2015, buildingSMART published the latest version of the IFC schema, IFC4 Addendum 1 (IFC4 Add1), together with two new MVDs to support IFC4 Add1 implementation: Reference View (RV) and Design Transfer View (DTV). The main purpose of the RV is to define a standardised subset of the schema that supports exchange in one-direction only. In case changes need to be made in the model, the requested modification has to be communicated to the original source. This MVD is characterised by the ability to provide workflow for a widest array of software applications where the imported IFC model is displayed, analysed, compared and clashed but not modified (buildingSMART 2016c).

The second MVD proposed is an extension of the Reference View. Contrary to the Reference View, the Design Transfer View enables model editing by design software platforms. Its main objective is to promote collaboration between multiple disciplines. DTV is considered the successor of the IFC2x3 Coordination View and is intended to be compatible with IFC2x3 CV import (buildingSMART 2016b). Figure 1 shows a comparison of the three MVDs developed by buildingSMART against the full IFC schema.

Since the introduction of the MVD concept, many institutions and national organizations started developing their own MVDs to support internal processes. For instance, the National BIM Standard –

United States (NBIMS – US) developed different MVDs to support information exchange in different levels and stages (e.g. COBie, BPie, SPARKie, HVACie, etc.) from project inception through building design and construction and into facility management (buildingSMART alliance 2015). In a similar approach, the HESMOS (Holistic Energy Efficiency Simulation and Management of Public Use Facilities) project employed the IDM methodology in their process to provide decision makers with advanced simulation capabilities by describing the associated information that have to be exchanged between parties (Liebich et al. 2013). This is the first step in the process to define a MVD, however, in the HESMOS project the final MVD definition was not completed.
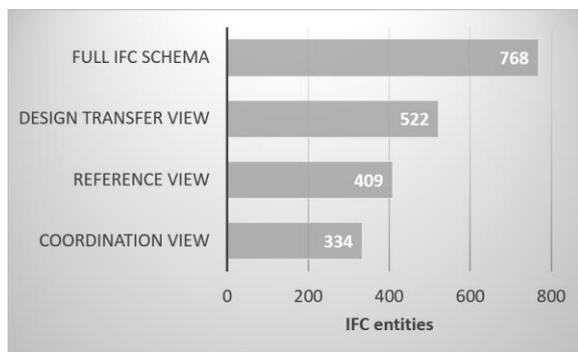

Figure 1 – Comparison of IFC schema against official MVDs published by buildingSMART

Concept Design BIM 2010 is another example of a project that undertook the MVD methodology to coordinate IFC implementation in different domains. The model views developed in the project support various domains such as architectural design, energy analysis, HVAC design, quantity take off and cost estimation, thermal load calculations, and construction management/scheduling. The MVDs resulting from this project are documented and published in a web base tool (BLIS Consortium and Digital Alchemy 2012). Despite covering a large set of domains, there is currently no specific MVD developed that supports the connection of BIM and advanced BEPS tools. Therefore, the proposed MVD, which is based on the latest release of IFC specification (IFC4 Add1), defines a subset of information necessary for energy performance analysis, and that is the main focus of this paper.

ANNEX 60 PROJECT OVERVIEW

The International Energy Agency in Buildings and Communities programme (IEA-EBC) Annex 60 is a project to promote research and development of new methods to help design and operate energy efficient buildings and communities (Wetter & Treeck 2016). The primary focus of the Annex 60 project is to develop and demonstrate next-generation computational tools for buildings and systems within

buildings, based on Modelica and the Functional Mockup Interface standards. The Annex 60 project is comprised of three subtasks: 1) Technology Development; 2) Validation & Demonstration and 3) Dissemination. These subtasks are further divided into several activities. The motivation for the work presented in this paper came from Activity 1.3, which aims to facilitate the process of information exchange from BIM to Modelica (Figure 2).
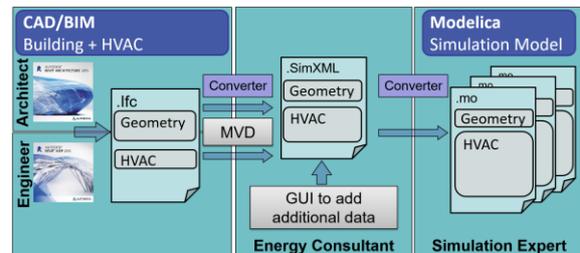

Figure 2 – Tool chain to connect BIM to Modelica

A successful exchange between BIM and BEPS tools can only be achieved when the exchange incorporates the required semantic subset of each domain description in the exchange. For this reason, the MVD developed in the Annex 60 project focuses on the definition of exchange requirements specific for advanced energy simulation tools, in our case Modelica. Despite this, the work proposed for this paper aims to expand its output to a wide range of energy simulation tools. The process of connecting BIM to any energy simulation tool requires a well-defined MVD, which captures all the relevant information to carry out a simulation.

METHODOLOGY

The approach taken to accomplish the task defined for this paper mainly consists of specifying the information exchange requirements. These exchange requirements are essential for realizing data exchange between BIM and BEPS tools for advanced energy performance analysis. The core objective of the development is to capture energy simulation domain knowledge and translate it to the IFC schema. Our approach defines the business rules and agreements necessary to assist the implementation of import and export functions by BIM application. At the same time, the entities, attributes, relations and properties from the IFC data model that are relevant for energy performance analysis have to be defined. Whenever the required information is not available in the current IFC specification, user-defined property sets can be defined to extend the IFC schema.

The configuration of the subset is communicated by means of an Information Delivery Manual (IDM). The IDM provides a standardised method to describe the stakeholders and the role of these stakeholders involved in the exchange process, also what information is being exchanged, who needs the

information extracted and at which point in time this information is needed. The IDM also provides a graphical representation of the exchange process called Process Map. The process map gives an understanding of the configuration of activities within a particular exchange scenario (Wix & Karlshoej 2010), and uses the Business Process Modelling Notation (BPMN) to facilitate the understanding of internal business procedures (Eastman et al. 2010).

To be able to understand a process map, additional information must be provided in a consistent manner. Eastman et al. (2009) developed a template to capture the information needed to support the user specification of an information exchange (Table 1).

The next step in the MVD development defines the required input data for energy analysis to be exchanged between actors or stakeholders in different stages of the project life-cycle. According to Maile et al. (2007), the information needed to conduct a simulation is usually the following:

- Building Structure – geometry, spaces and thermal zones, building orientation and construction, building usage.

- HVAC Systems – heating, lighting, ventilation and air conditioning system.

- Internal Loads – Schedules for lighting, equipment and people.

- Weather data and other simulation specific parameters.

Table 1 - Exchange model content template to support user specification

Project Stage	What is the Omniclass design stage?
Exchange Disciplines	Who are the parties to this exchange? By Omniclass discipline number and name? (can>2 disciplines, but using the same basic data)
Description	Verbal description of: 1. The purpose of the exchange 2. The required contents of the exchange 3. The optimal contents of the exchange 4. Example software in the exchange 5. Whether the exchanges are round trip or one-way
Related Exchange Models	Other exchanges this one interacts with (proceeding and succeeding exchanges)

The IDM is applied exclusively to capture the information exchange requirement definition for energy simulation analysis, while the task of mapping these information exchange requirements to a particular IFC release is defined in the MVD.

MVD Definition

Specifying the MVD is a relatively straight-forward process, the first step being the translation of IDM exchange requirements into entities, property sets and generic concepts which are reusable among different MVDs. Once this has been completed, the second step is to determine the inheritance concepts and relationships between entities and types. During the MVD development, approximately 22 IFC concepts were reused or added to the MVD. During the development of the concepts, a common language and format was used that aligns with solutions provided by buildingSMART.

For the last step in the MVD development, users must have an in-depth knowledge of the IFC schema. It is necessary to know which concepts and relations are relevant and should be used for the targeted subset. It is left to the user to identify and define the relevant concepts or create new ones. Nonetheless, the IfcDoc tool is the only application available which enables the development of a MVD (buildingSMART 2016d). It has to be noted that IfcDoc is intended for developers who have in-depth knowledge of IFC and not general use.

IFC Documentation Generator (IfcDoc)

The IFC Documentation Generator (IfcDoc) tool is a free tool developed by buildingSMART whose primary objective is the documentation of the IFC MVD by generating diagrams, schema definition, indices and contents of the user specification (Lee et al. 2015). In addition to documentation support, the IfcDoc tool can also provide limited validation of MVDs and ensure consistent and computer interpretable definitions, via mvdXML export functionality.

The first step in the process of MVD production is to load a baseline file that includes all entities for a particular schema. This type of file can be found in the buildingSMART website (buildingSMART 2016d). Once the file is open the hierarchy is displayed and populated with the IFC schema definitions for the specific IFC release. In this way, the information exchange requirements identified in the IDM can be linked to the MVD definition.

On the IfcDoc interface, users can define two types of rules: 1) a structure and 2) a constraint. The first rule can be defined for validating relationships and references, while the second is used for validating specific values and properties (Lee et al. 2015). For example, users can define that IfcBoiler must have attributes for Name, ObjectType, PortNesting and MaterialConstituents. Figure 3 illustrates part of the exchange requirements definition using IfcDoc tool. This definition consists of existing entities and also entities defined specific for energy performance analysis that were not available in the latest release of

Figure 3 – Subset of the exchange requirements for energy performance analysis

the IFC schema. It is important to highlight that this subset is not the final version because the MVD is still under development within the Annex 60 project. In summary, the IfcDoc tool, provided the capabilities for defining the exchange requirements compliant with the IDM/MVD for BEPS.

Energy modelling using IFC

The exchange of data between building design representation and energy simulation representations has been a major challenge in the past decade (Jeong et al. 2014). A wide range of tools to study energy performance and thermal comfort are available but they differ in many ways, specifically their capabilities to use BIM formats. The task of data exchange between BIM and BEPS tools often relies on two open non-proprietary formats: IFC or green building XML (gbXML) schemas. However, gbXML does not provide any methodology similar to IFC/MVD that allows subset definitions to support end user requirements.

On the other hand, many tools take a different approach to transforming IFC to formats that are supported by simulations engines. In this manner, the Lawrence Berkeley National Laboratory (LBNL) developed various interfaces that convert IFC to EnergyPlus syntax enabling interoperable data exchange between BIM and BEPS (Rose & Bazjanac 2013). In a study carried out by Attia (2011) where she compared ten Building Performance Simulations (BPS) tools that can support early design stages, she concluded that interoperability problems are present in all of the examined tools. The study also showed that only ECOTECT supported the IFC format as an input file. Another study from Korhonen & Laine (2008) investigated six software tools with the focus on determining their compatibilities with open format BIM. In addition to ECOTECT they showed that EnergyPlus v2.1, IDA ICE 3.0 and RIUSKA 4.4 included IFC import functions. These were earlier efforts that tried to import IFC files, but currently there are a few products available that solve this problem, such as Simergy and IFC compatible user interfaces for EnergyPlus.

In the past years, Lawrence Berkeley National Laboratory (LBNL) and Digital Alchemy developed an interface for EnergyPlus called Simergy. It provides versatile workflow options allowing users to import geometry from BIM (e.g. IFC) to enable more effective creation of a Building Energy Model (BEM). Similarly, the Space Boundary Tool (SBT) is a standalone tool for processing IFC files and converting the geometry to a format (e.g. an .idf file

for EnergyPlus) for use by building simulations tools (LBNL 2013). Despite the challenges of interoperability, the use of IFC for energy performance analysis is increasing over the past years,

USE CASE DEMONSTRATION

With use cases that enable control over the export to IFC we specified the necessary content for the exchange between BIM and BEPS to be successful. Within the Annex 60 project Activity 1.3, five use cases were defined with varying the level of complexity from a single room to a large commercial building. For demonstration purposes this conference paper concentrates on the most basic case, which will be thoroughly extended in a subsequent publication.

The use case consists of a single thermal zone and HVAC system with gas-boiler for heat generation, pipes for distribution and a radiator for emission. The system is installed in a single room following the German guideline VDI 6007 (VDI 2012); likewise, the materials of the walls. A rendered 3D view of the room and the HVAC system is illustrated in Figure 4.
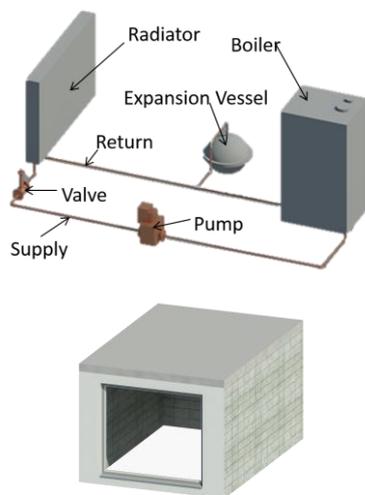
Figure 4 –Designed HVAC system & use case geometry model based on VDI 6007

Autodesk Revit was used to model the use cases. Revit permits the user to model both the architectural design and the Mechanical Electrical and Plumbing (MEP) systems in the same work environment. For the walls, ceiling and floor each material layer was defined, including physical characteristics such as density, thermal conductivity and thickness, as well as specific details for the windows. For the HVAC system topology, the dimensions of all components and also data concerning their placement were added to the model. Still most of the contemporary applications do not support the export of the IFC4 Add1 schema. Therein Revit is no different so an add-on had to be installed that enabled basic IFC4 Add1 export functionality (Autodesk 2016).

ANALYSIS, DISCUSSION AND LIMITATIONS

The results from this case study showed that the new IFC4 Add1 brought major improvements in the HVAC extension with more complex and complete definitions of components and systems needed in the design and simulation performance. However, IFC4 Add1 still lacks some definitions, such as heat pumps or Combined Heat and Power (CHP) systems, and fundamental property sets needed for simulation of HVAC components are as yet undefined. For instance, the nominal thermal efficiency and the design water flow rate for a standard boiler or the control type of a hot water pump (continuous or intermittent) currently lack definitions in the IFC4 Add1, requiring the creation of user defined properties sets. The definition of property-sets is one of the key features of IFC. These provide valid substitutes to the definition of object/attribute/relationship sets for entities that are not yet completely ready for inclusion in the data model (Bazjanac & Maile 2004).

Another issue encountered while working with the IFC schema is that internal loads with complex schedules are difficult to define properly because of the lack of export functionalities of BIM applications and limited functionalities of the IFC schema. Up to the time of this paper, most tools do not provide in house IFC4 export capabilities. Some of them provide an add-on to overcome this issue but still lack a flawless IFC4 Add1 file generation, according to the buildingSMART documentation. It should be noted that these add-ons, while enabling IFC4 Add1 export are not officially certified for this. Once official certification begins the quality of IFC4 Add1 export should drastically improve.

Since the MVD definition consists of modularised concepts defined by the end-user it is necessary to pass through a process of checking and validation. This process ensures that attributes are correct, inheritances are correspondent with the IFC schema, local and global uniqueness of references, etc. It also ensures that the IFC subset contains accurate information required by the specific exchange scenario. Moreover, this validation process improves the quality of the output and helps in the certification process.

CONCLUSION

In this paper we present a standardised process of information exchange between BIM and BEPS tools. This process is based on the IDM/MVD methodology, which defines and documents the information exchange requirements for a specific exchange scenario, in our case energy analysis. As part of our work a use case demonstration was presented in order to identify the missing entities,

concepts and property sets in the latest release of the IFC schema that are relevant for energy performance analysis. To improve our results, more use cases will be applied. The purpose of the use cases is to represent the following different HVAC-systems:

1. Boiler with radiator
2. Boiler and domestic hot water system
3. Combined heat and power system
4. Heat pump with floor heating
5. Air handling unit for heating
6. Air handling unit for cooling

These systems cover 26 different HVAC components. Some of them are not available in the latest release of the IFC schema. Coupling BIM and BEPS tools is not an easy task mainly because of the level of details required by the simulation environment, and MVD is without a doubt a possible solution in this matter. MVD also allows data to be transferred in a higher level of automation, which results in less manual work and lower risk of human error.

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