SENSOR HANDLING IN BUILDING INFORMATION MODELS. DEVELOPMENT OF A METHOD AND APPLICATION ON A CASE STUDY

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ABSTRACT

Considering the rapidly growing application of Building Information Modelling (BIM) for all Life-cycle stages of buildings and the use of BIM as a natural information source for Building Energy Simulation (BES) models, this paper presents a complementary aspect: the integration of handling of measured performance data into a BIM-based workflow.

The proposed method facilitates the comparison of the actual, measured performance of buildings with the predicted performance, based on simulation results. It complements existing BIM to BES interface methods that help to transfer geometry and material information, by providing easier access to measured input-data (e.g. weather data and building occupancy) and measured performance.

The method is applied to a full-scale test facility located on the Technology Campus Gent of KU Leuven (Belgium). The main aim here is to facilitate the calibration of BES models and the development, implementation and test of model- and rule-based fault detection methods (FDD) and model predictive control strategies (MPC).

INTRODUCTION

The concept of a Building Information Model (BIM) describes an integrated data model that stores all of the information relevant to a building throughout the building life cycle (O’Sullivan & Keane 2005). BIM contains precise geometry and relevant data needed to support the design, procurement, fabrication, and construction activities required to realize the building (Eastman et al. 2011). It is also used for operations and maintenance purposes after building delivery and commissioning and therefore can be used to support the entire building life cycle (Bazjanac 2004).

Although being a recent process, the past decade has seen the use of BIM as a central information-management in the Construction industry (Venugopal et al. 2012). Some countries (e.g. UK, USA, Norway and Finland) have made up their strategic plans to set BIM as part of the regulation within the construction industry (Wang et al. 2013).

Considering its features, BIM constitutes an obvious source of data for Building Energy Simulation (BES) model implementation. Several interfaces and middleware has been developed to simplify geometrical data input to BES by using BIM standard Industry Foundation Classes (IFC) (Ahn et al. 2014; Bazjanac 2004; Bazjanac 2008; Bazjanac 2009; Jokela M, Keinänen A, Lahtela H n.d.). Some BIM compliant commercial tools for energy simulation can also be cited such as IDA-ICE (Equa Website n.d.) and DesignBuilder (DesignBuilder Website n.d.), using either IFC or gbXML to transfer information.

In the IEA EBC Annex 60 framework, activity 1.3 focuses on the mapping of IFC objects into Modelica components for BES. The innovative aspect lies in the use of the equation based, object-oriented modelling language Modelica which has the ability to overcome traditional building energy simulation tool (Energy plus, DOE-2,…) limitations such as the difficulty to integrate models from different discipline or the presence of significant numerical noise within the simulation results (Wetter 2009). The above-mentioned studies indicate the interest of the building simulation community in the use of BIM as “database” for BES implementation and strengthens the relevance of BIM for energy simulation.

Different BES models are currently used during all life cycle phases of a building. During the consecutive design phases, BES models of increasing complexity and level of detail are used to define the optimal characteristics of the building envelope and the technical equipment and to assess the future energy performance of the building.

During the operational phase, BES models are used to compare the real performance of the building with the designed performance or for control and operation strategy development such as Fault Detection Diagnosis or Model Predictive Control (Maile et al. 2007). Monitoring data is required as input-data (e.g. measured local climate) or to assess the actual performance of the building during the operational phase. This underlines the necessity to efficiently handle data from a monitoring system during the operational phase and to be able to automatically retrieve corresponding parameters on both sides: in the simulation model as well as in the measured data.

A convenient approach would be the use of BIM to handle and manage the data access for the monitoring system and the measured data. This provides a unique platform for BES implementation and monitoring data access and is a less error prone and more efficient approach as it reduces human involvement in establishing the match between monitored and simulated quantities. One implementation of this approach was proposed by (Wang et al. 2013). Their work focuses on the combination of sensor data models with semantic building information models and uses MATLAB as simulation platform for a case study.

The present contribution proposes a method where IFC object features are used to link BIM with a monitoring system for measured data retrieval for BES validation and for the semi-automatic creation of the BES model. Figure 1 shows how the proposed method could be integrated within a building simulation workflow process.

The proposed method provides access to measured data by using a virtual representation of all physical sensors as part of the BIM of the facility.

Virtual sensors are linked to physical sensors and their Globally Unique Identifier (GUID) is used as a key to handle and access the monitoring data. The use of a commercial software for the creation of a Building Information Model containing virtual sensors in the topological and semantic context of the building provides many additional benefits. Some examples are:

- A better integration of the design and construction of the monitoring system in the global design process of the building and its technical equipment, enabling early clash-detection and helping to find possible conflicts and dependencies.
- Visualization of the geometrical position of the sensor and of neighbouring or containing objects that might have adverse effects on the measured quantities.
- Semantic context of the sensor, that helps to establish rules for FDD or to calculate derived quantities from several sensors, like operative temperatures.

Two aspects of the proposed method are further explained in the following sections of this paper:

(1) The presentation of the case study and the relevance of the proposed method for this case.
(2) The main steps for the implementation of the proposed workflow into a prototype software tool.

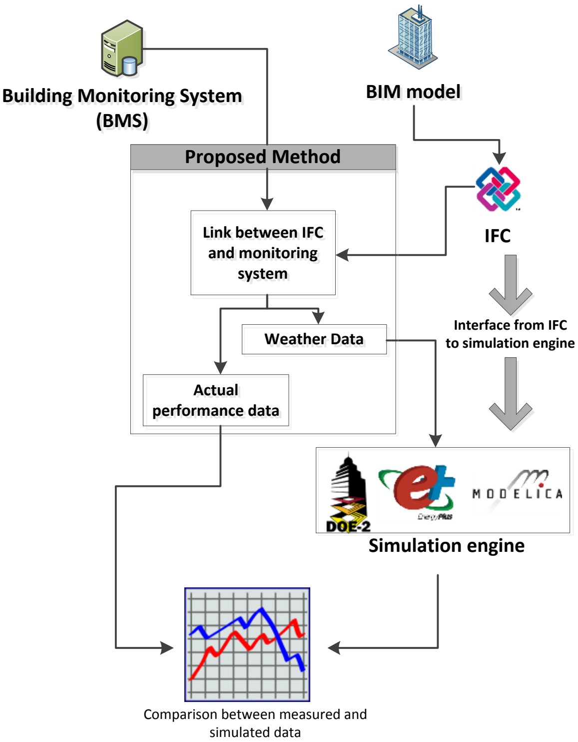

Figure 1: The integration of the here developed method within the simulation process using BIM

PRESENTATION OF THE CASE STUDY

The proposed BIM-based method is used for the full-scale test facility on the Technology Campus Ghent of the University of Leuven (Belgium). This building has two lecture rooms for 80 students each. The new facility consists of two levels, constructed on top of an existing building (ground-floor only) and designed and certified according to the Passive-House standard. Thermal insulation was placed also in-between the two lecture rooms and in the internal walls towards the staircase. This results in a layout with two identical, box-shaped volumes with different thermal mass (one in the first floor with massive brick-walls and one in the second floor with a light-weight timber-frame structure). The facility is equipped with a high performance Air Handling Unit (AHU) (heating and cooling), a wood pellet boiler, motor-controlled exterior sun-shading and high performance lighting fixtures with daylight control. A large number of sensors has been installed in the classrooms and in the ventilation system of the building. Local weather data is provided by sensors on top of the buildings technical room.

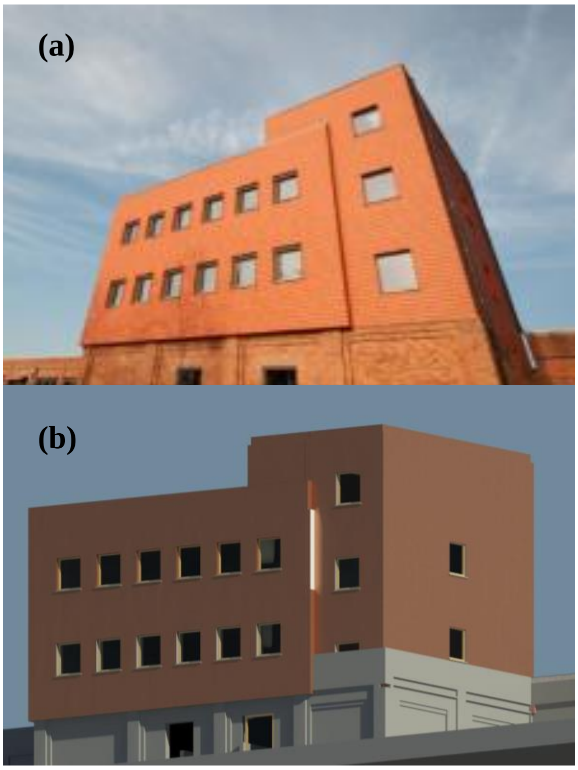

Figure 2: (a): Test facility, (b) 3D rendering of the BIM model

The monitoring and data acquisition system is integrated into the Building Management System (BMS), which provides full access to the control of the technical equipment. The BMS is implemented using open standard protocols, such as BACnet for the communication with the Air Handling Unit (AHU) and the VAV-boxes, the Digital Addressable Lighting Interface (DALI) protocol for lighting control and monitoring and KNX for actuators (window operation and shading devices) and user-interaction devices in the lecture rooms.

Decentralized input/output (I/O) units are placed in the lecture rooms and next to the weather station, avoiding long cables for the analogue signals and enabling easy extension of the system. The I/O-units are connected to the main system via the EtherCAT protocol. A virtual Programmable Logic Controller (PLC) constitutes the core of the facility monitoring and management system. This provides the control of the building equipment and provides a real-time and long-term monitoring of all building parameters and the outdoor climate. The recorded data from the system is stored within a standard query language (SQL) database.

The virtual PLC is running in a standard PC environment that enables the use of standard libraries, object oriented programming (C++) and diverse software tools for simulation, data-management and remote access.

A BIM model implemented and used by architects, engineers and contractors during building design and construction is available and was updated to reflect the as-built situation. The model was complemented with information specific for Facility Management (FM). It consists of two parts: (1) Architectural model and (2) “MEP”-model containing detailed information about the mechanical equipment and plumbing (AHU, VAV-boxes, duct-systems, pipes, boiler, …) as well as the electrical systems (Lighting, plugs, circuits, switches, …) and the monitoring systems components.

The information contained in the proprietary models (created with Autodesk REVIT) is exported to IFC.

Figure 3 shows the role of the here developed method within the test facility.

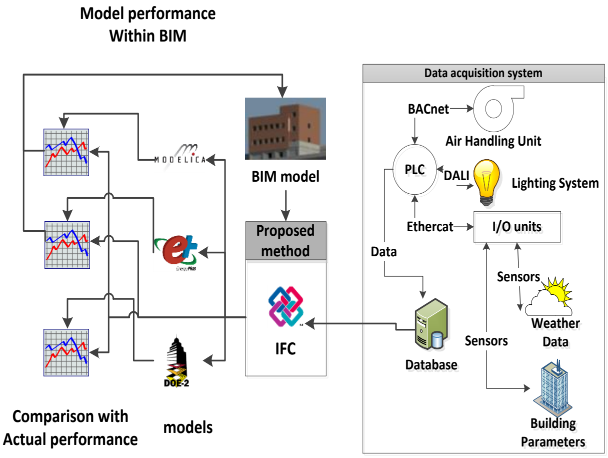

Figure 3: The role of the here developed method within the test facility.

As part of the infrastructure of the Civil Engineering Department of KU Leuven, the facility on the Technology Campus Ghent provides a unique combination of full-scale test facility for researchers and learning environment for Civil Engineering students. It constitutes a “laboratory building” for testing diverse methods and scenarios for building envelope characterisation and Air Handling Unit control optimisation. Since its design, until now, numerous numerical models using different simulation engines and boundary conditions either for the building envelop or for the AHU were developed and numerous are still under development. The proposed method is used to coordinate data handling and facilitate access to the measured data but also to provide the ability to centralize the BES models around the BIM. Hence, results from all the models are stored with a clear link to the BIM, which allows keeping track of the different performance predictions of each of the models. Future research will focus on the increased possibilities for feedback created by the formal link between operation phase data and the models used during the different design stages. This research will provide valuable insights about the different causes for the observed gap between predicted and actual (measured) performance of most very low energy buildings.

PROPOSED METHOD IMPLEMENTATION

According to figure 4, which represents the implementation steps of the method within the building lifecycle, three main points have to be implemented in order to use the proposed method:

- The first step is the implementation of the virtual sensors on the BIM during the design phase. The GUID of the IFC entity representing the virtual sensors are required for the linking of BIM and monitoring system.
- The second step is the practical implementation of the above-mentioned link. In practice, physical sensors are characterized by the data measured by the sensors over time. For the present case study and for most of the research on building monitoring study present in literature, measured data is stored in a database. Hence, a formal link between virtual sensors and physical sensors needs to be established by providing database access by means of the GUIDs of the virtual sensors.
- The third part of the workflow is the implementation of the data server tool. This tool parses the IFC file, retrieves virtual sensors GUID and by means of the link between physical sensors and virtual sensors performs a data request on the database. It therefore constitutes the bridge between the IFC linked with the monitoring system and the simulation engine.

For each point within this section, first a general description of the method is given followed by its application to the case study.

VIRTUAL SENSORS

Virtual sensors implementation within the BIM is a process which requires a prior knowledge of the monitoring system structure. During the design phase, this is achieved by using a design BES model used for building documentation. This allows to identify and select the most influential or relevant parameters of the building which need to be monitored during building operation (see figure 4). It also gives a mean to ensure that all required parameters for comparison with the BES models are monitored once the building construction is finished.

Virtual sensors are implemented by means of a BIM modeller's sensor object (An instance of a custom, purpose made class or "family" in REVIT terminology). All required information about the different sensors such as type, brand, serial number, manufacturer, calibration coefficient… are therefore inserted into the properties of these objects.

Hence, the entity representing virtual sensors within IFC, and the requirements to export virtual sensors from BIM modeller software need to be defined, tested and later standardized to become available for general use.

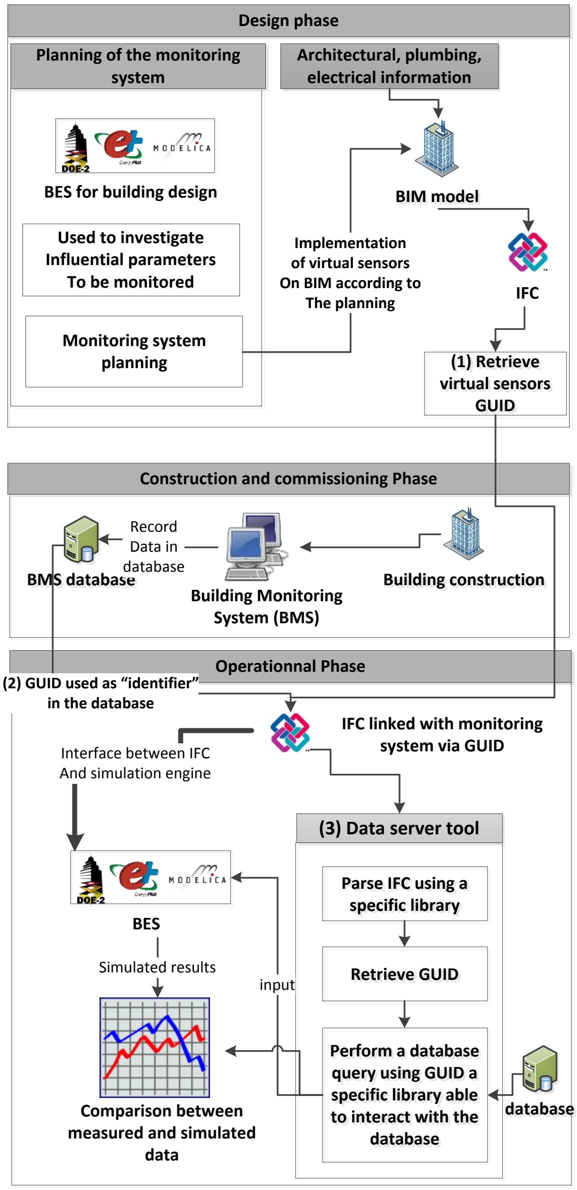

Figure 4: Proposed method implementation steps within the building lifecycle

IFC is an object based data model, that is specific to the construction and building management processes. The data models are built from building entities such as walls, doors… and their relationships to one another (topology and semantic). Industry Foundation Classes are inspired by the Standard for Exchange of Product model (STEP ISO 1033) and uses the same language EXPRESS (BuildingSmart.org 2015). Hence, IFC is an entity-relationship model consisting of several hundred entities organized into an object-based inheritance hierarchy. Among entities within IFC, we can cite the IfcWall entity which defines a wall object in the building, IfcExtrudedAreaSolid which defines the geometry of an object…. An entity of interest is the

IfcSensor which defines the occurrence of any sensor. Common information about sensor types is handled by IfcSensorType which is described by common type name, usage (predefined type), properties, materials, ports, composition, assignments, and representations. The IfcSensor may be connected to other objects like a flow element, the exterior of an element, an element in certain location using the indicated relationship (BuildingSmart.org 2015). A IfcSensor property set can be used to store physical sensors information.

Also to export sensor information from BIM modeller software into IFC, a Model View Definition (MVD) containing the IfcSensor definition and properties need to be defined. Within the IFC standard, the MVD defines a subset of the IFC schema, that is needed to satisfy one or many Exchange Requirements of the AEC industry. In other words, MVD defines what building data must be included to define a scenario (BuildingSmart.org 2015). Among the existing MVDs, we can refer to the BuldingSmart's well-known coordination view 2.0. This MVD contains definitions of spatial structure, building, and building service elements that are needed for coordinating design information among these disciplines. In order to export BIM modeller sensor objects into IFC, one has to implement its own MVD which describes the export of the IfcSensor and its property sets or to extend an existing MVD to support the IfcSensor export. To develop and modify an MVD, buildingSmart has implemented the free and open tool IfcDoc tool (BuildingSmart.org 2015).

The work presented in this paper will serve as a starting point for a contribution to a common effort within IEA EBC Annex 60, Activity 1.3 to provide MVDs that guarantee the integration of BES models and monitoring data into an innovative workflow for the design, construction, operation and maintenance of high performance buildings, e.g. Net-Zero Energy Solar Buildings.

PRACTICAL IMPLEMENTATION OF THE LINK BETWEEN VIRTUAL AND PHYSICAL SENSORS

Physical sensors are characterized by the data measured by the sensors over time. Hence, a formal link between the virtual sensors contained in the BIM and the physical sensors is established by providing database access using IFC. This step is a one time and manual process within the proposed method implementation where this practical link between database and virtual sensors is established. The idea is based on a feature of IFC objects, which provide a Globally Unique Identifier (GUID) for each object present in the project. In our method, the GUID is used due to its uniqueness and automated creation during object instantiation. This avoids also possible confusion due to sensor name duplicates (same brand, same type, same name..). Above all, the GUID is used to link the virtual sensors to its corresponding physical sensors and to serve as a key to access measured data in the database.

A first step in the linking of the virtual and physical sensor is the retrieval of GUID of each virtual sensor present in the BIM. For this purpose, a set of free and open tools (IfcStoreyView, IfcBrowser, IfcFileAnalyzer,…) (Freeware n.d.) developed under BuildingSmart association are available to parse and get the GUID of the IfcDistributionControlElement. Once the GUID retrieved, a second step is to insert the GUID within the database structure in a way that the use of the GUID presents a mean to access recorded data from the corresponding physical sensor. However, the practical implementation of the link between virtual sensor GUID and database depends on the database type and structure. In our case and for demonstration purpose, a Standard Query Language (SQL) based database is used. Measured data is recorded as time series within the database and data from each physical sensors is stored within a column in a defined database table. For simplification, the GUID is used as column name or identifier of the measured data from corresponding physical sensors. Therefore, a basic database query using the GUID can be performed to access data. Hence by implementing this link for each virtual sensors, we can consider that the IFC file is linked to the measured data and therefore to the monitoring system. The next section is the implementation of the developed software tool which allows data requests to the database using the IFC file.

DATA SERVER TOOL IMPLEMENTATION ALGORITHM

Having an IFC file linked with the database via GUIDs, it constitutes a mean to obtain data from the database. For this purpose, the proposed tool has two main characteristics which are:

1. The ability to parse an IFC step File and to retrieve the GUID of virtual sensors object .
2. The ability to perform a data query according to a GUID.

Figure 5 shows the global structure of the implementation of the data server tool. (1) To parse an IFC file, free and open C++ libraries such as IFCplusplus and IFCengine DLL (Freeware n.d.) are available. (2) Those libraries are also used to retrieve all virtual sensor type instance information within the project following the relationship diagram between IfcSensorType and IfcSensor. (3) Once all sensor type instance retrieved, the GUID is retrieved from each virtual sensor object.

(4) The GUIDs are stored within a temporary buffer. (5) The request on the database is performed using the GUIDs stored in the buffer. The query is done by another library which can interact with the database. A distinction is made between measured data required as input for a BES model and measured

data required for validation of the results of that BES model.

The detailed implementation of the tool depends on the libraries used by the one who implements the method and also on the database type.

In the case of our facility, a C++ tool has been implemented following the algorithm of figure 6. In order to parse the IFC file, the IFCengineDll library has been used. The library provides the ability to handle an entity based on a given entity name using sdaiGetEntity function. This call is used to retrieve all IfcDistributionControlElement entities present on the BIM project. To access entity's attribute, the library provides a function to access attribute by name (sdaiGetAttrBN). SdaiGetEntity and SdaiGetAttrBN functions are used according to figure 6 algorithm to retrieve sensors GUID and keywords. To make the distinction between measured data required for input and comparison, keywords "input" and "comparison" are inserted within the IfcSensor properties. To interact with our SQL database, the QtSql class of the Qt framework (The Qt Company 2015) library is used. Its role is to implement a query on the database using the GUID. The data can then be written into a file as an output for later usage or the developed tool can be integrated as library into a framework for data-handling, -processing and -visualisation.

PROSPECTIVE NEXT STEPS

An important step that need to be done next within the further development of this method is to implement a user-friendly virtual sensors selection capability based on the IFC file. This means that visualization and keywords insertion will be provided directly through the IFC file without the intermediate use of the proprietary BIM modeller software. This implies that a tool which allows building visualization from IFC and virtual sensors selection need to be implemented or existing viewer software needs to be extended. Taking into account the availability of IFC libraries and viewers, such a development represents a relevant future work. The use of IFC enables a tool that do not depend on proprietary formats and expensive commercial software. It seems preferable to decouple the task of BIM model-creation and the later stages of data-handling, as these tasks are often executed by different users with different knowledge and needs.

A well-defined MVD and its proper implementation in the commercial modelling software would enable the implementation of one part of the functionality using the modeller's API (definition of the virtual sensors as part of the global design process) and insuring consistency of the GUIDs also in the case of repeated IFC-exports and incremental addition or modifications of sensors. Beyond the data handling process through BIM, the BES model validation and calibration constitute an important aspect towards the completion of this work. The calibration process which is intended to be applied lies on two main steps: (1) A first step which aims at identifying the most influential parameters towards a specific measured output by using sensitivity analysis method and (2) a second step which minimizes the error between simulated and measured values and guess the optimal values of the influential parameters. The integration of this process within the proposed method allows to achieve a seamless workflow from data handling through model implementation to model calibration and validation based on BIM and open languages.

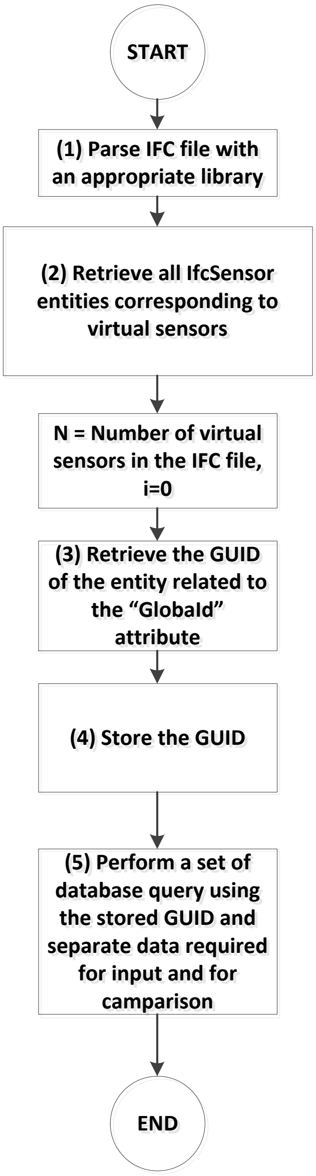

Figure 5: Global structure of the implementation of the data server tool.

CONCLUSION

Within this work, a method to handle physical sensors through a BIM representation is developed. The proposed method provides a convenient way to select and access monitored data for Building Energy Simulation model validation and constitutes a way to centralize building performance assessment studies around BIM. The proposed method has proven its advantages in the presented case study and will be further extended and generalized.

ACKNOWLEDGEMENT

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