
Requirements for a BIM-Based Life-Cycle Performance Evaluation Framework to Enable Optimum Building Operation

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Abstract

Buildings rarely perform as well in practice as anticipated during design, and often consume 20-30% more energy than necessary. One of the main causes of inefficient operation is the lack of data integration and system interoperability inherent in the AEC/FM industry. In many cases, the assumptions and specifications defined during design are not transferred throughout the life-cycle of the building, and actual operation deviates from design intent. Building Information Modelling enables designers to create digital models of buildings. Theoretically, these models should be exchangeable between disciplines and over different life-cycle stages, but in practice the lack of information exchange protocols in the building performance area inhibits such exchanges. In order to improve building operation throughout the building life-cycle, this paper proposes a BIM-based performance evaluation framework to compare design intent with actual operation. The framework uses the IFC schema to facilitate the information exchange process for better qualification and validation of data.

Keywords: Building Information Modelling, IFC, information exchange, operation

1 Introduction

The building life-cycle process is complex and prone to fragmentation as it moves through its various stages (Hitchcock 1995). At each stage of the Building Life-Cycle (BLC), the information requirements are different and serve different purposes. From a life-cycle perspective, the information generated in one phase should be available in the following phases in a continuous process throughout the entire life-cycle of the building (Quingpeng et al. 2013). However, most of the time this information is created and maintained in disconnected islands at each phase of the process, and when communicated, the transfer occurs as one-off event to the next phase (Figure 1). This handover process traditionally includes voluminous hard copy drawings and free-form text documents, stored in the building & estates office, and consulted when necessary (Corry 2014). The lack of feedback to designers after handover inhibits improvements in both existing buildings and future designs (Menezes et al. 2012).

The current flow of information throughout the building life-cycle is primarily limited due to inefficient exchange of information among deployed information system in the AEC/FM (Architectural, Engineering, Construction and Facilities Management) industry. Building design and delivery call for building information data to be exchanged between various stakeholders in different stages of the life-cycle in order to integrate the various types of expertise needed to realise the overall project. Building operation suffers more because it depends heavily on the information originated from design and construction phases.

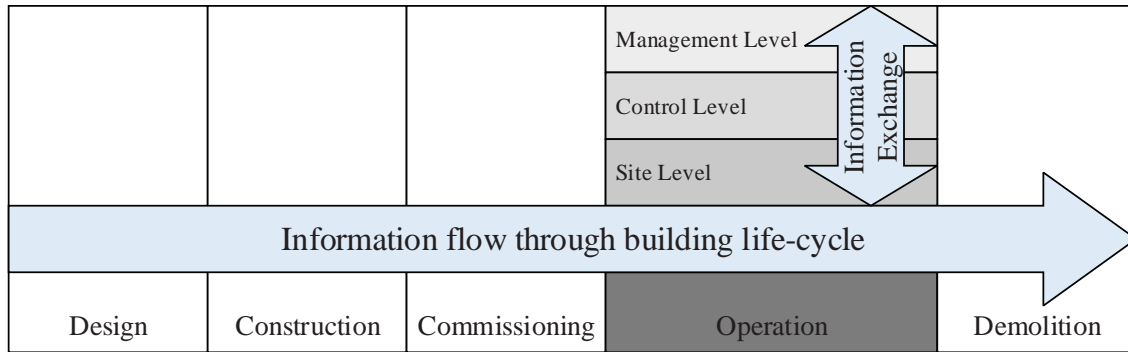


Figure 1 Current flow of information throughout life-cycle of buildings. Adapted from: (Motawa & Carter 2013)

In contrast to traditional design methods, Building Information Modelling (BIM) is a front loaded process with substantial benefits aiming toward the end of the life-cycle process which consist of manipulation of data. BIM allows for the building to be built in a virtual environment before being actually built. The approach generates a digital, parametric model of the building, which in theory can be used throughout the entire life-cycle of the building. This data centric modelling approach, should fundamentally, improve coordination, enhance information exchange and accuracy, promote interoperability, and enable better-informed decisions than conventional methodologies (Azhar et al. 2012; Love et al. 2013).

BIM models can be used in conjunction with Building Energy Performance Simulation (BEPS) tools, to analyse energy performance throughout life-cycle (Cemesova 2013). For such integration to take place the exchange of information needs to be done using a common format that is understood by both parties. An example of common data exchange format is Industry Foundation Classes (IFC) schema. This open format schema developed by buildingSMART (formerly International Alliance for Interoperability) uses an object oriented description to ensure consistent data exchange and interoperability between several applications, for example the management of performance information in buildings such as geometry models, HVAC design, energy analysis, and facility management data (Motawa & Carter 2013).

The goal of this paper is to present a BIM-based life-cycle performance evaluation framework which defines the information exchange requirements needed to enable optimum building operation. Central to this approach is the accurate capture and transformation of exchange requirements into usable performance metrics throughout building life-cycle. These set of performance data will enhance building performance control and maintenance. An overview of energy management systems and their advantages is presented in Section 2. It also describes the importance of defining metrics that fully represent the owner’s performance information requirements in a standardised way. Section 3 illustrates how building data can be described and exchanged using open standards. In Section 4 a description of the evaluation framework is presented and Section 5 concludes our findings and presents the next steps of the development.

2 Energy performance in buildings

A key step in establishing the level of energy usage within buildings is the implementation of an Energy Management System (EMS) and Building Management System (BMS). The first is a continuous approach to ensure operational improvements in buildings. It helps facilities establish policies and procedures to systematically track, analyse and improve energy efficiency. The latter is mainly used for real-time control of building services components such as sensors, valves, actuators, etc. Over time the traditional clear delineation between these two systems has been blurred as EMS functionality is added to BMS and vice-versa. Most modern buildings adopted both EMS and BMS to control, monitor and manage energy performance.

ISO 50001, the global energy management systems standard, specifies requirements for establishing, implementing, maintaining and improving an EMS. The standard is based upon The Plan-Do-Check-Act (PDCA) cycle. It requires organisations to review energy use, consumption and efficiency at defined intervals; documents the methodology and criteria used during the process; establishes energy baselines and identifies Energy Performance Indicators (EPI) for monitoring and measuring energy performance (NSAI 2011).

The Global Superior Energy Performance (GSEP) program provides industrial facilities and commercial buildings with guidance, tools and protocols to implement the ISO 50001 standard to improve their energy performance. GSEP is one of 11 ongoing Clean Energy Ministerial initiatives that various governments support in order to accelerate the global transition to clean energy technologies (Scheihing 2012). It also promotes the implementation of EMS as common practice for continual improvement of energy performance.

For a successful implementation of an EMS, the information related to energy use must be documented, communicated and understood within the organisation. The CIBSE TM31 Building Log Book provides building facilities managers with a clear and concise summary of how buildings are meant to operate. Log books also serve as a document where building performance can be recorded, helping managers to make decisions in sympathy with design intent.

Continuing advances in building technology and construction practices have not only increased the amount and detail of data generated and exchanged but have also further raised expectations about its use and value as an asset for performance and energy analysis.

2.1 Metrics for performance and energy analysis

During the early phases of design the owner's requirements are represented in a qualitative form and appears as a series of performance objectives. In order to reuse this set of information during operational phase it needs to be transformed into performance metrics. Each performance metric must be capable of being either predicted or measured at various stages of the project. The transformation involves a structured process where the performance objectives and performance metrics are encapsulated inside Exchange Requirements (ER), and assigned to specific stakeholders for evaluation and reuse throughout buildings life-cycle. Standardised performance metrics are a powerful way of quantifying building performance objectives, identifying and measuring key variables that impact on the particular performance objectives of a building. They facilitate the analysis of overall building performance, and meaningful comparison of building performance with other dissimilar buildings.

Usually performance objectives originate from prescriptive code compliance, energy performance guidelines, rules of thumbs and from energy simulation models. It is critical that they are written in a neutral language to effectively communicate with stakeholders with different background and knowledge. These specifications will form the basis of future performance analysis, stating what should be measured and to what level of resolution the data should be presented.

For example, a company called Synavision has developed a web-based platform for energy analysis called Energy Navigator (Plesser et al. 2010). This platform enables engineers to create a comprehensive and precise functional description for building services. This methodology defines functional specification during design and reuses it to control building operation and energy efficiency over time. This innovative approach combines design and control within one artefact (functional specification) for building life-cycle performance (Plesser et al. 2012). In a similar way, Scenario Modelling captures and communicates the complex interdependencies of organisational requirements into five categories: building functions, thermal loads, system and energy performance and legislation, and use them for a holistic performance analysis (O'Donnell et al. 2013). By making this separation, building managers can tackle individual scenarios for each of the categories, get a better understanding of the whole system and check if the building is operating optimally.

Other analyses methods might use annual readings and utility bills as performance metrics, and compares it with previous year's performance or normalized data from similar buildings to demonstrate how buildings are operating (O'Donnell et al. 2013). Such approaches do not ensure the optimum operation of building systems. Building owners and operators usually lack the resources necessary to break down energy use by type for a better understanding of the system.

In summary, standards are required to define data, processes and terms in the building industry and we will use these standards to define an information exchange requirement in order to avoid inefficiency and problems related to reuse of information in the building industry. The following sections explain some of these standards in more detail.

3 Information exchange framework

The creation of consistent, continuous and unambiguous building performance information throughout building life-cycle is seen as a key enabler for building optimisation. Stakeholders from various business processes can share and exchange information based on the same exchange framework. According to Zhang et al. (2012) for a real open process to occur, three factors need to be in place: a common data format for the exchange of information (IFC - Industry Foundation Classes), rules of which data is to be exchanged and who shall exchange them (IDM - Information Delivery Manual) and a standardized data model which is properly interpreted on each side of the exchange (IFD - International Framework for Dictionaries) (Figure 2).

The framework works as a guideline for standardised data exchange. In the framework IDM

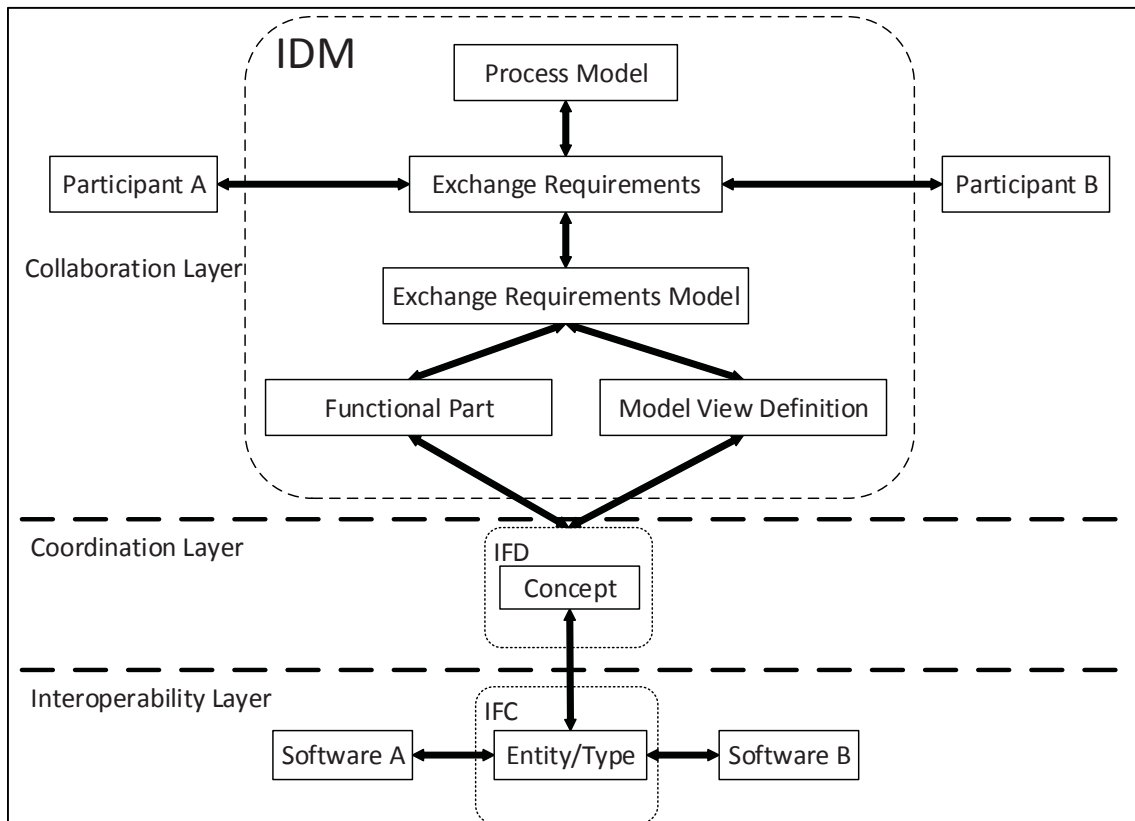


Figure 2 BIM process information exchange technical framework (Zhang et al. 2012)

provides a universal, repeatable and verifiable collaborative methodology for creating information exchanges; IFD establishes the relationship between the functional parts of the IDM and the IFC information. Finally, IFC specifies the data format of the information to be exchanged and lays the foundation for the data exchange between. The structured information exchange framework allows preservation of meaning within different design tools.

The development of the BIM Maturity Level by the UK government encourage the use of these open standards. The levels of maturity in the model vary from 0 to 3 to enable concise description and understanding of the process, tools and techniques that are being used in the project (Martin 2012). Level 3, the highest on the scale, requires a collaborative process compliant with IFC/IFD standards. The next sections will give more details about the three factors that enable an open process and how they promote interoperability and produce reliable data.

3.1 Terminology and definitions of building information

Since construction is a global industry, terminology dictionaries need to accommodate different names for the same things. A dictionary of construction terminology defines the use of a particular name in a consistent manner. Having a controlled vocabulary is essential to support interpretable data exchange between different models from different regions.

3.1.1 International Framework for Dictionaries

The International Framework for Dictionaries (IFD) defined in ISO 12006-3, also known as buildingSMART Data Dictionary (bSDD), is a terminology standard for BIM libraries and ontologies. IFD library is most useful when used in combination with IFC schema and IDM approach dealing with virtual building models. It describes what kind of information is exchanged by providing a mechanism that allows the creation of unique IFD IDs, to connect information from existing databases to IFC data models (Laakso & Kiviniemi 2012).

IFD is an object-oriented database of multi-lingual terms which define concepts (Volk et al. 2014) and enables dissimilar software to connect information about buildings during an exchange of data (Watson 2008). IFD standardise all types of entities, properties and classification inside the IFC schema and allow workflow compatibility to ensure that the element interpretation is correct regardless the difference between parties.

3.1.2 Building Energy Data Exchange Specification Dictionary

An initiative has been in development at the Lawrence Berkeley National Laboratory (LBNL) together with many stakeholders, and funded by the U.S. Department of Energy (DOE). They created the Building Energy Data Exchange Specification (BEDES) dictionary, of common terms and definitions to regulate how the exchange of information on building characteristics and energy use is created. The BEDES dictionary is intended to be used in activities that help stakeholders make energy investments decisions, track building performance, and implement energy efficient policies and programs. Increasing the number of tools and databases that utilize BEDES reduces the cost currently involved in sharing and aggregating data, and at the same time increases interoperability among different systems (Lawrence Berkeley National Laboratory 2015).

3.1.3 OmniClass Construction Classification System

OmniClass is a standard that combines multiple existing classification systems for many subjects into a single unifying system based on ISO 12006-2, Organization of Information About Constructions Works – Part 2: Framework for Classification of Information (Brodt 2011). This standard is a guidance document, and establishes common concepts used in building information exchange (Cemesova 2013). OmniClass consists of 15 tables classifying the built environment and processes used to create it. Classification is hierarchical and has no explicit rules for implementation, as a result is difficult to extent in a consistent way and can be implemented in different ways. Thus, IFD along with OmniClass enables users to access and view data using an unambiguous classification.

3.1.4 Construction-Operation Building information exchange

COBie specification denotes how information may be captured during design and construction and provided to facility operators (East 2007). According to Suermann (2009), COBie's objective is to "create both an IFC reference standard supporting the direct software information exchange and a spreadsheet that can be used to capture COBie data for both renovation and capital projects". This method provides a spreadsheet of the same exact information available in the IFC file in a way that is easier to human to understand. It eliminates the need to create and transfer boxes full of paper construction documents, and the need for post hoc as-built data capture (East 2007). In 2009 the COBie team released the Facility Management Handover Model View Definition. This model view definition identifies all the objects in IFC file necessary to support COBie and the relationship between these objects.

3.2 Industry Foundation Classes

The Industry Foundation Classes (IFC) data schema has been in development since 1994, and the main goal of this schema is to enable interoperability and data integration between building information software applications (Laakso & Kiviniemi 2012). IFC4 is the latest version of the ISO 16739 standard and is considered to be 6 times more efficient than its predecessor IFC2x3 (Liebich 2013). IFC4 has brought significantly improvements in energy and performance analysis, environmental impact values, integration of ifcXML and mvdXML into specification and improved documentation (Liebich 2013). IFC4 covers both EXPRESS and XML schema and links to IFD.

The IFC schema is widely recognized as the common data exchange format for information exchange within the AEC/FM industry. It provides a comprehensive data model that enables sharing of geometry and properties of building elements. It comprises information covering the many

disciplines that contribute to a building throughout its life- cycle: from conception, through design, construction and operation to refurbishment or demolition.

A key point in this paper is to define the exchange requirements necessary for a specific analysis using the IFC data model. IFC supports all business requirements at all project stages. This is relevant where the whole project information needs to be shared or exchanged, but most of the applications have interest in a limited area (subschema) of this complex model. The need is generally to support one or more exchange requirements over one or more life-cycle stages. Hence the exchange of information must be tailored according to domain specific Model Views Definition (MVD) (Eastman et al. 2009). MVD defines the process for determining the appropriate exchange requirements from the IFC schema for any particular use, representing them in an Information Delivery Manual (IDM) (Belsky et al. 2015).

3.3 IDM-MVD Framework

IDM-MVD framework can be seen as an integrated approach for the capture of processes and exchange requirements, and the mapping of these using the IFC schema (Table 1). IDM along with MVD explains the exchange scenario in plain text for human readability, as well as in a computer interpretable way to enable implementation of automatic checks and validations in computer applications (National Institute of Building Sciences buildingSMART alliance 2012).

Table 1 Deliverables from IDM and MVD methodologies

Information Delivery Manual - IDM	Model View Definition – MVD
Process Map	MVD Overview/Description
Exchange Requirements	MVD Diagrams
Functional Parts	Concept Implementation Guidance
Exchange Concepts	Binding to the IFC Schema

3.3.1 Information Delivery Manual

An Information Delivery Manual (IDM) is intended to be a reference for processes and data required by BIM. It should specify where the process fits; why it is relevant; who are the actors creating, consuming and benefiting from the information; what is the information; and how should software solutions support this information (Laakso & Kiviniemi 2012).

The major parts of an IDM include process map, exchange requirements, functional parts and concepts. The process map provides a visual representation of the logical and sequential flow of information required, consumed and produced. The exchange requirements provide a complete schema for the exchange of information for a particular process, at a particular stage of a project. Functional parts are individual parts of information describing the requirements of the IFC data model. Concepts provide a detailed technical specification on the information that should be exchanged as a result of an action. They are specifically designed to be reusable within many exchange requirements (See et al. 2012). The IDM methodology provide documentation and acknowledge the functionality of specific MVDs (Laakso & Kiviniemi 2012).

3.3.2 Model View Definition

A Model View Definition (MVD) defines a subset of the IFC schema that is needed to satisfy one or many exchange requirements defined in one or more IDMs. It is important to understand that these requirements come from the end user and the primary role of MVD is to ensure that IFC implementation support those requirements (See et al. 2012).

The information tailored by one MVD are composed of different information items at different levels of detail. MVD also prescribes implementation bindings using IFC model schema. The IFC bindings are intended to implement a set of standard export and import exchange capabilities for commercial software products, which will in turn increase interoperability among them. This set of information are identified as Exchange Concepts. A MVD is created by choosing a group of concepts and defining their relationship. MVD makes extensive uses of definitions and configurations in order to define an exchange concept. Definitions capture a range of possibilities and configurations capture how those possibilities are used in a specific case. For example comparing the MVD configurations of read and write certified software, will reveal the type of data that can be successfully exchanged

between these two software products. Technically a concept is independent from any MVD and it can be re-used in different applications.

The buildingSMART group has developed an important tool called the ifcDoc tool. It improves the consistent and computer interpretable definition of MVD as true subsets of the IFC specification with enhanced definition of concepts. The tool is based on the mvdXML specification and can be applied to all IFC releases. After the development of a MVD for a specific process, it needs to be submitted to buildingSMART group for revision and acceptance before it becomes official.

MVD specifically indicates what data is needed from the BIM data model for operation performance analysis. This set of data can then be transformed into quantifiable performance metrics and compared with actual measurements from the building. The following Section 4 introduces a BIM-based framework that improves data sharing and performance assessment throughout buildings life-cycle.

4 Requirements for a BIM-based life-cycle performance evaluation framework

The BIM-based performance evaluation framework proposed describes the data exchange requirements necessary to model building performance descriptions in IFC. The framework also allows building performance to be described throughout the BLC, enabling the maintenance of design intent. It accounts for the processes that define and analyse a building's performance over time. These processes are defined using the IDM methodology and implemented to IFC schema through the MVD methodology.

This framework is based on the IDM-MVD approach. The first step is to capture the stakeholder's requirements and translate it to an exchange requirement using the IDM process. The documentation of this process uses the templates and instruction provided in the IDM methodology. The terms in the IDM were defined by standardised terminology such as OmniClass and IFD in order to provide a common language between industry activities. The IDM define the exchange requirements with the appropriate level of detail and format specificity suitable for the development of the MVD. On the other hand, the MVD will bind these requirements in the IFC schema. These exchange requirements represent the data exchange between stakeholders. For example, a building operator would like to exchange the zones of the building and HVAC systems, in this case the MVD would capture the specific data for the exchange.

The next step in the process of development of the MVD is to group the exchange requirements to form Exchange Concepts (EC), such as space, zone, etc. For each EC will be one or more MVD concepts which define a way of exchange the data defined in the concept between stakeholders, e.g. building managers, owners, architects, MEP engineers, energy modellers, etc. These MVD concepts are represented in the MVD diagram which shows the group of concepts been used and the relationship between them. The mvdXML schema defines the format and configuration of the diagram. The MVD diagram represent the final version of the MVD and contain the binding of the exchange requirements to the IFC schema. The complete MVD is the core part of the framework but is still in development.

The framework is intended to assist performance assessment during the operational phase of the building life-cycle and can provide feedback to designers (Figure 3). In this case, the idea is that the BIM will capture changes that occur to the building over the life-cycle and is always up to date. Any derived models such as BEPS should be updated as changes are made to the BIM. The assessment is carried out by capturing exchange requirements from all phases of the BLC through the MVD and compare them to improve building performance.

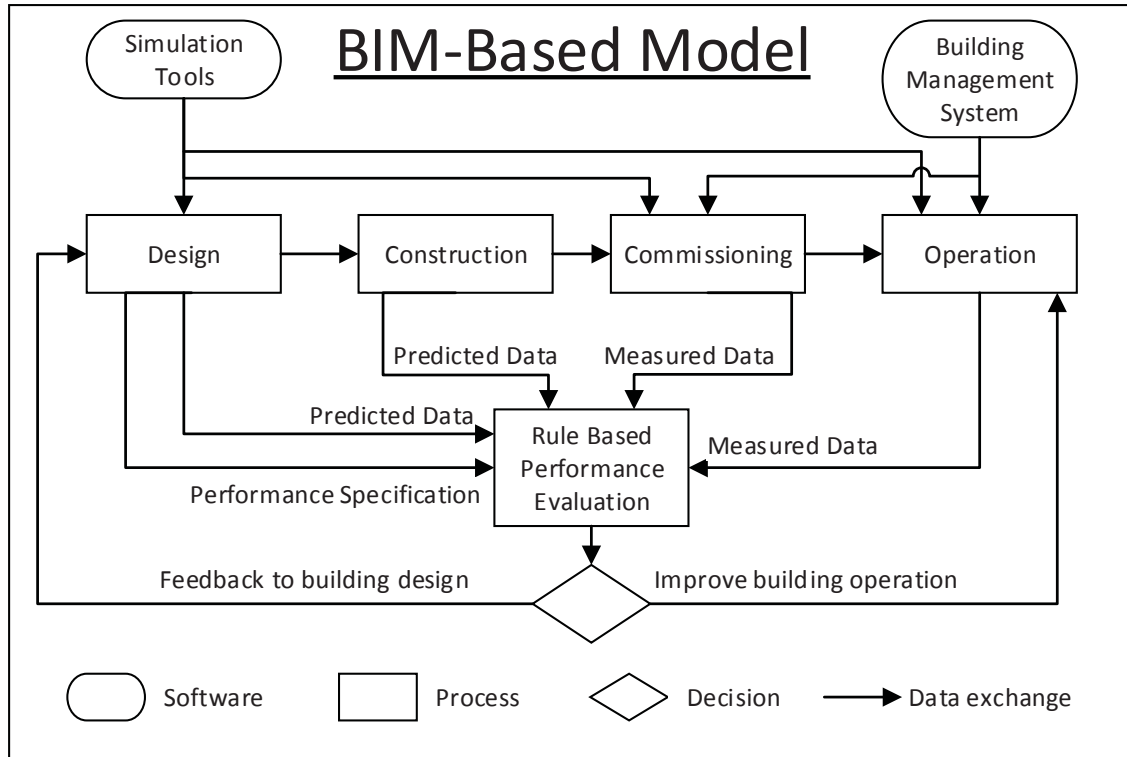


Figure 3 BIM-based file-cycle performance evaluation framework

The comparison process encapsulated rule based performance definitions. These set of rule-based definition apply rules, constraints or conditions to the data that comes from the BMS/EMS and BEPS in order to check building performance, e.g. check the room temperature against a defined set point or setpoint range. These rules may be defined by building managers, or alternatively, as best practices within a design. The rule based evaluation accounts for changes that affect the environmental and energy performance of the building at all stages of the building life-cycle.

One of the set of exchange requirements comes from an energy simulation tool. These tools can provide abundant and detailed information about a building's intended operation. The simulation tools predict the energy performance of the building and generate performance benchmarks for use throughout the life-cycle of the building. Such performance benchmarks can reflect legislative code requirements that representing the minimum amount of energy required to meet basic functions requirements of the building. The second set of specification requirements may come from the actual energy use, which originate from building sensors via the BMS. The BMS allows building operators to control relevant zones and equipment within the building. The use of BIM in this process is fundamental to accurately capture and maintain building information data.

By providing a check mechanism of predicted performance and measured performance, and adjusting optimum operation using the framework calibrates the BIM to better represent the real scenario. Such calibrated model could now be employed to test changes to the design or operation of a building to improve its performance.

5 Conclusion and future work

A BIM-based life-cycle performance evaluation framework has been proposed in this paper to improve building performance analysis and enable building optimum operation. The BIM

environment is used to store, retrieve and control data associated with building's energy usage due to its interoperability between various domains. The paper goes on to describe the IDM-MVD methodology that provide a structured framework for the definition and exchange of building data for building performance analysis.

The BIM-based framework aims to federate all the actions realised on a building across its life-cycle, to gather all information from heterogeneous sources and convert to a common data format, to extract views of information for a specific industry process and to improve interoperability and data integration. The deliverable from this paper is an IFC compliant framework for the assessment of buildings during operation. The authors found out that technical documentation for creating MVD is still missing. This type of documentation needs to be provided to MVD' developers in order to spread adoption of this methodology.

In conclusion, this framework is expected to provide more feedback from actual building performance results to design-phase energy modelling to enable building optimum operation throughout life-cycle. The next step in this research include the development of a MVD based on the framework proposed in this paper. Testing and validation of the optimum building concept will be applied in a case study. After completion the MVD will be submitted to buildingSMART group for acceptance and publication as an official MVD for performance and energy analysis

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