Development of an Information Delivery Manual for Early Stage BIM-based Energy Performance Assessment and Code Compliance as a Part of DGNB Pre-Certification

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Abstract

The evolvement of integrated practices utilizing Building Performance Simulations has made it possible to address the growing needs of the building design. Furthermore, including a sustainability rating system in the early stages ensures a superior environmental performance and a common goal for all parties involved. However, the persistent lack of early collaboration and process standardization prevent reaching the full potential of BIM-based performance evaluation. By following buildingSMART's methodology for development of Information Delivery Manual/Model View Definition, this paper presents a framework for BIM-based energy performance assessment and code compliance, as required by the Danish Building Regulations and the DGNB rating system. Standardization of the information exchange would increase efficiency and reduce manual data input, duplication of work and errors due to miscommunication.

Introduction

The growing need for reduction of CO_2 emissions and energy resource consumption has made optimal performance the highest priority in building design. Senciuc, et al. (2015) define sustainable design as a complex system of elements linked by interdependencies, which requires a focus on the entire building life-cycle and a high level of cooperation from the very beginning. According to Aksamija (2012), a supreme building performance is a result of obeying of multiple requirements and a constant improvement of a multidisciplinary, research-based and data-driven design process, relying on building performance simulations and predictions. It is also crucial that those above are applied as early as possible when decisions can be easily altered, alternative design proposals can be evaluated, and any associated potential losses, gains or effects on the building's life-cycle can be identified (Jalaei and Jrade, 2014).

The advancements in Building Performance Simulations (BPS) make it possible to contribute to the identification of optimal design solutions. Results from energy performance analysis, for instance, are essential to green building certification, but the latter takes into consideration a much wider range of aspects, related to the entire building life-cycle. That by itself ensures the comprehensiveness of the design solution, but at the same time increases the complexity of the process. Including a rating system also supports an integrated practice and sets a common objective for the entire team, which has to integrate various types of expertise. (Petrova et al., 2016)

The demands for building performance and digital information exchange between project stakeholders are constantly becoming bigger. In that relation, Building Information Modelling (BIM) has taken the spotlight as the industry's best collaborative practice. BIM allows integration of multidisciplinary information within the same building model and presents a potential for interoperability with various analysis tools (Zanni, et al., 2013). Being empowered by that, integrated design practices aim for implementation of multidisciplinary technical input, stakeholder feedback, and rating systems much earlier, which ensures an ongoing quality management process and fulfillment of the stated requirements.

Considering that information flows connecting interdisciplinary processes are the core of BIM, their type, volume and complexity should not be underestimated. However, Stipo (2015) states that the slow transition from linear to iterative design practices creates a mismatch with the core incentives of BIM. Vallero and Brasier (2008) argue that the contemporary design process needs to surpass the traditional one by adopting a holistic standpoint and focusing on the long-term benefits. Isikdag (2015) lists the necessary to achieve that future transformation as *'focus on enabling an (i) integrated environment of (ii) distributed information which is always (iii) up to date and open for (iv) derivation of new information.* That also means that the created information must be available and applicable at all stages, which also implies no losses, duplication of activities facilitating performance assessment (e.g. repetitive input of the same parameters, building geometry data, etc.) or backtracking.

The multiplicity of the design iterations is essential to the identification of optimal solutions and the improvement of the workflows. Considering that the different disciplines may have varying requirements for the building information models' level of abstraction, a precise definition of their information needs is necessary to prevent 'conflicts of data interest'. Nevertheless, the linear design process is characterized by manual inputs, remodeling to fit the disciplinary purpose, and requires massive data buildups at the beginning, only to usually suffer later losses (Akin, 2014).

For those reasons, a considerable research effort, aiming for seamless integration of BIM and building performance assessment in the (early) sustainable design process has been made in the last decade (Schlueter and Thesseling, 2009); (Underwood and Isikdag, 2010); (Kubba, 2012); (Kensek and Noble, 2014); (Yalcinkaya and Singh, 2015). The development of standards such as gbXML and Industry Foundation Classes (IFC) has become a major factor in research related to data exchange for building simulations. (Wu and Issa, 2013); (Cidik, 2014); (Abrishami, et al., 2015); (Cemesova, et al., 2015); (Hu, et al., 2016). The realization that a successful integration of sustainable design and performance assessment within the BIM environment would eliminate numerous issues, improve building quality, performance, and team productivity, and reduce effort and manual input, has made achievements in the area a highest priority. (Moakher and Pimplikar, 2012); (Jalaei, Jrade and Nassiri, 2015); (Greenwood and Gledson, 2015); (Ilhan and Yaman, 2016).

Background

In the European Union (EU), the high demands towards building performance have led to tight regulations, governed by the Energy Performance of Buildings Directive (EPBD) (2002/91/EC and recast 2010/31/ EU). EPBD requires the application of minimum energy performance requirements for all new and existing buildings (The European Parliament and Council, 2010). However, those requirements are further defined on a national level.

In Denmark, building owners must submit a calculation of the building's energy demand and document compliance with the Building Regulations (BR15) at the time of applying for building permit. Documentation must be according to DS418:2011 Calculation of Heat Loss from Buildings, and SBi Directive 213 concerning the Energy Demand of Buildings. The obligatory calculation must be performed in agreement with ISO 13790 and by the use of Be15 simulation program and guidelines (Aggerholm & Grau, 2011); (Danish Building Research Institute, 2008). Additionally, the stronger recognition of sustainability practices has led to establishment and implementation of nationally tailored green building certification strategies, based on the German Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) system (Birgisdottir, et al., 2010).

However, despite the significant results in nationwide BIM implementation, integrated practices are still not commonly adopted (Bolpagni, 2013). Major issues related to lack of early collaboration and process standardization prevent reaching the full potential of BIM-based building performance assessment. That also applies to DGNB certification, which usually runs in parallel, rather than being integrated into the multidisciplinary design process. Moreover, meeting performance targets is often associated with manual data inputs, retroactive modifications of parameters and poor interoperability between tools. A common practice is also performing analyses after the completion of the design, which makes late changes hard and costly to implement. That enhances the already prevailing inefficiency, miscommunication, duplication of work, errors and consequently loss of money, time and effort for the parties involved.

The above–mentioned issues stem partly from the fact that collaborative sustainable building design, and hence information delivery and management of data from heterogeneous sources lack a proper definition and formalization. Technical problems, such as geometric misrepresentations, loss of information during data transfer, confusions associated with data re-input and information deficiency further complicate the process. The lack of process standardization also serves as the biggest barrier to exploring the benefits and utilizing the full potential of the available simulation tools, and hinder the implementation of performance feedback and the facilitation of integrated design (Garcia, 2014); (Wu & Issa, 2013); (Jalaei & Jrade, 2014).

Despite the numerous process standardization efforts and initiatives led by organizations such as buildingSMART, a standard methodology for implementation of guidance concerning criteria requirements in the design process does not exist. Such would be especially valuable during the early design stages, where it can crucially influence the decision-making and hence the building performance.

Use case and objectives

The ultimate objective of the study is to develop a new standardized methodology, which would allow a much more efficient and optimized DGNB rating and ISO 13790 code compliance check during the Conceptual Design stage of a project, as defined by Heiselberg (2007). In other words, it would eliminate the fragmentation of processes, by combining them into a single, integrated, holistic process, which utilizes all benefits that the BIM environment has to offer.

From a technical perspective, increasing the use of BIM, and integrating tools used for analysis and assessment would also lead to a significant reduction of manual data input, a decrease of the amount of subprocesses, lower chance for miscommunication and hence shorter the execution time frame and lower project development cost.

However, for technical interoperability solutions to be developed, first an in-depth understanding of all actors and their responsibilities, information exchanges they are involved in, and requirements they have has to be obtained. It is essential that an equally comprehensive knowledge and understanding of both the design process and the technical issues is present, because the problem cannot be solved by skillsets related to only IT or only the building design process.

Methods

The research methods encompass a review of information management practices in Denmark based on interviews, as well as a comprehensive academic literature review, software vendor reports, and relevant codes and regulations. A comparison between the linear and iterative design processes has also been made.

By following buildingSMART's methodology for Information Delivery Manual (IDM)/Model View Definition (MVD) development, the paper goes through an assessment of all actors, their roles, and processes with their involvement. All exchanges and exchange requirements related to life-cycle assessment (LCA) for DGNB pre-certification and BR15 compliance check calculations for non-residential buildings are then defined and classified. Mapping to IFC is showcased with a chosen set of exchange requirements. The paper also presents observations on a part of the MVD development process and the results of it.

A well-defined process will help gain an in-depth understanding of the information management requirements and will serve as a basis for the development of technical solutions for process automation. Moreover, the developed methodology may serve as a basis for application to other rating systems and performance assessment methods.

Simulation

It is important to note that the Danish calculation program Be15 should be used as a compliance check tool and not as one intended for energy design. Considering its mandatory use, it is clear that Be15 requires and provides information, which is essential for the performance of additional assessments (Petrova et al., 2016).

As this paper is process- oriented, the following section aims for clarification of the processes and information needs related to the simulations. The definition of activities and input data related to energy frame compliance calculations and LCA is of high importance, as it is the currency in the information transactions between the professional actors during the building design process.

Energy Performance Assessment according to ISO 13790

The calculations performed with the simulation program are based on use-related values serving as input parameters. They include:

- Location and orientation of the building
- Building envelope
- Heating system and hot water supply
- Heat-accumulating properties of the building
- HVAC systems, including natural ventilation and planned indoor climate
- Solar radiation and solar screening
- Solar energy collectors and PVs, heat pumps, boilers, district heating, heat recovery, etc. may also be considered. (Aggerholm & Grau, 2008)

The compliance check results reflect the total energy performance and demand. Non-compliance requires further design iterations and modification of design parameters. Despite Denmark being the first country to implement prescriptive measures related to building energy performance and the use of Be15 being required in every project, issues related to inefficiencies of the processes still persist. The spreadsheet-based format of Be15 contributes to the inefficiency, as manual information input is unavoidable. That by itself compromises the effectiveness of the BIM—based approach, but the most major issues seem to be related to lack of common understanding between the multidisciplinary parties. (Petrova et al., 2016)

DGNB pre-certification

Contrary to Be15 calculations, DGNB certification is not mandatory, so it is entirely up to the building owner to require it. That also means that performance targets corresponding to the requirements for pre-/certification have to be implemented in the project planning and development from the very beginning. However, current practices usually involve DGNB auditors/ consultants at a stage, too late to achieve best results based on their guidance. Rating systems are often used for evaluation of the completed building design, instead of as an aid for creating of design proposals and guidelines for completion of the project's sustainable goals. A pre-certification raises the probability of achieving the building's performance objectives and makes the obtaining of a final certificate after completion much easier (Petrova et al., 2016).

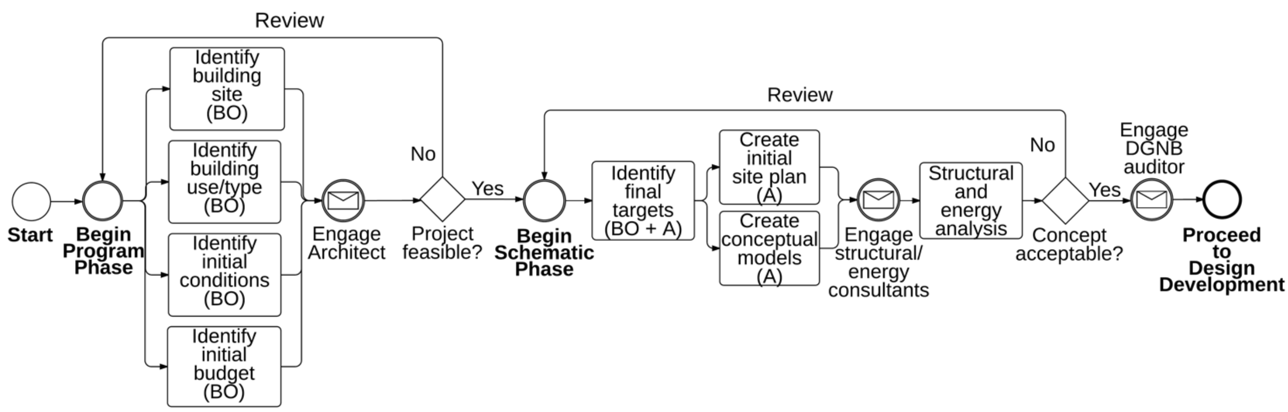

Figure 1: Linear 'as is' process diagram, Petrova et al., (2016)

Life-cycle assessment (LCA)

DGNB evaluation encompasses 40 different criteria within six key aspects: environmental, economic, sociocultural and functional, technology, processes, and site. Even though they have a different weight based on the type of building evaluated, DGNB is one of the most concerned with life-cycle assessment (LCA)- 13,5% of the total score (DK-GBC, 2014). The US Environmental Protection Agency (EPA) clearly underlines the importance of LCA as a criterion, as it evaluates materials and energy use throughout their entire lifetime. Therefore, to demonstrate the proposed sustainable design workflow, this study focuses on LCA as a chosen criterion. DGNB LCA input data comprises two main categories:

1. Building materials:
   - Environmental Product Declarations ISO 14025/DS 15804
   - ESUCO database (EU)
   - Ökobau.dat database (Germany)
2. Energy consumption:
   - Be15 calculations
   - Primary energy factors defined by GBC-DK

To achieve the best outcome, the design process requires the simultaneous input of the above-mentioned and iterative exploration of the interdependence between performance and design parameters from a life-cycle perspective. Despite its enormous potential, the integration of decision support information exchange related to building code compliance and DGNB certification as early as possible in the design process has not yet been explored. That is partly because the involved actors would need to change their traditional approach and find a way to work together dynamically in the same collaborative workflow.

Results

To achieve the stated objectives, this section starts with an overview of the identified common practice within the industry (Figure 1). It will serve as a basis for further analyses on how the existing issues can be resolved.

General description of the linear 'as is' workflow

The use of BIM in the Danish AEC industry is rapidly growing, and Autodesk Revit is the preferred tool. Despite having been through positive changes, the collaborative process engaging multidisciplinary actors in the early design stages is still rather chaotic, especially in the traditional contract agreements. Nowadays, some architectural and engineering consultants cooperate from the very beginning and including an energy expert happens much more often than it used to a decade ago. However, as identified by Petrova et al., (2016), this practice is far from being commonly adopted and depends very much on the organization's scale and scope of work.

The implementation of sustainability principles in building design has almost gained a mandatory status, but DGNB rating is far from being a standard practice. Considering that a BIM-based approach implementing early-stage energy performance assessment and green building certification is significantly different from the traditional linear one, it is clear that the solution has to be tailored accordingly (Petrova et al., 2016).

Figure 1 presents a simplified 'as is' process diagram, with the most significant characteristics of the early stages. The work is divided into phases and delivered in a linear sequence. To present the current practice objectively, the workflow also includes interactions that are not common, but still present is some cases.

Definition of actors and their roles

For a most effective outcome, the design process would have to include representatives from all stakeholder groups from the earliest stages. Their input is of course equally important, but for the process analyses in this study, only the actors directly associated with conceptual building design and performance assessment have been mapped, namely: Building Owner (BO), Architect (A), HVAC Engineer, and DGNB Auditor.

Process mapping of the proposed 'to be' workflow

The results (Figure 2) represent a comprehensive process map using standard Business Process Modeling Notations

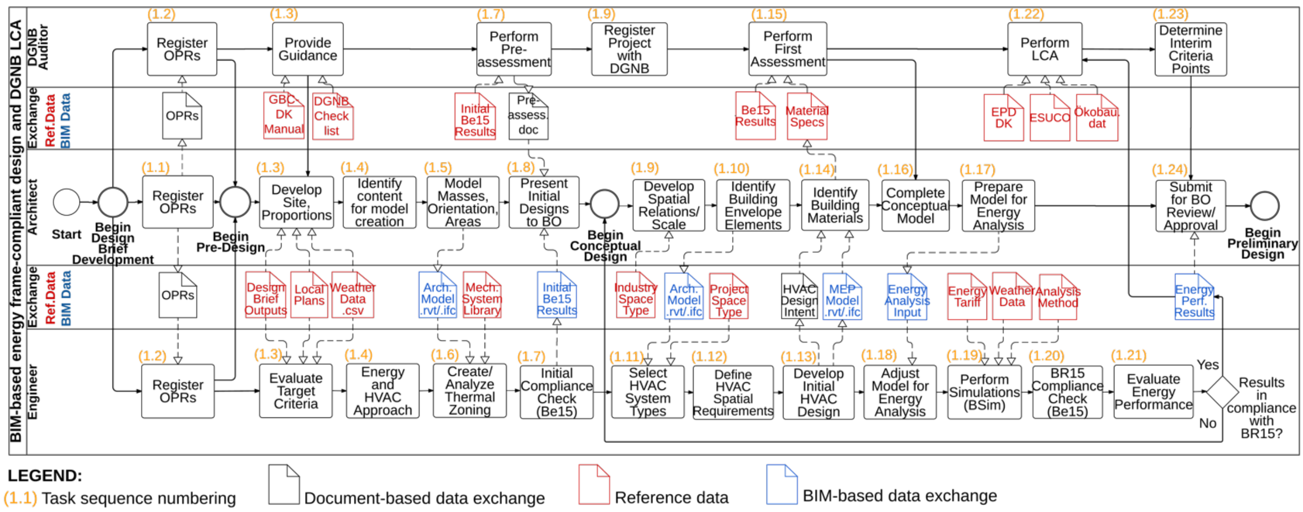

Figure 2: Process map of proposed integrated 'to be' workflow

(BPMN) and defining the integrated process in a way that would facilitate efficient collaboration and information exchange in the crucial early stages when simulation results are most influential.

Despite not being required, the process diagram specifies the internal processes of the Architect, HVAC Engineer, and DGNB Auditor. The reason for considering internal processes is related to the precise determination of information needs and exchange requirements. Two additional swimlanes indicate all exchanges according to the type of data objects (document-based, BIM-based, or reference data). For simplification purposes and clearer visual representation, the Building Owner swimlane is excluded from the process map. However, each phase concludes with a decision point, the purpose of which is the Building Owner's approval of the current output and the fulfillment of performance targets, and continuation to the next phase is not possible without it. Full representation of the process map, a specification of processes, data objects, and decision point gateways is presented in Petrova et al., (2016).

Definition of exchange requirements

The purpose of the exchange requirements(ERs) is to define the exchange of sufficient information to support the performance of compliance check calculations and LCA as required by BR15 and DGNB. The ERs assume that the building model developed by the architect (for instance in Revit) includes the information necessary to support the process, relative to the project development phase.

As previously stated, the performance of the assessments requires information concerning energy consumption and material use. Table 2 presents an overview of the required type of information, its properties, type of data for the exchange, and units.

Mapping of Exchange requirements to IFC

In Denmark, an IFC-based exchange is mandatory for publicly aided projects, with an estimated contract value of minimum 5 million DKK excl. VAT. All basic text and 2D project deliverables (drawings, meeting minutes, schedules, etc.), as well as 3D deliverables (such as discipline models), should be uploaded to a project web platform throughout the ongoing design process (Petrova et al., 2016). To ensure consistency of the information exchange and technical interoperability between tools, IFC uses a complex object- oriented schema. It contains a vast majority of attributes and components used in data exchange in all domains, but stakeholders are usually only using the relevant for themselves subset.

Due to the large number of exchange requirements identified in the previous section, Table 1 presents a chosen set, which has been mapped to the IFC data model.

Table 1: Mapping of exchange requirements to IFC

Exchange Requirement	IFC
Project	ifcProject
Site	ifcSite
Building	ifcBuilding
Building Storey	ifcBuilding Storey
Room	ifcSpace
Building Element	ifcBuildingElementType
Wall	ifcWall, ifcMaterial
Window	ifcWindow, ifcMaterial
Linear heat transmission	ifcPropertySingleValue
U- value	ifcPropertySingleValue

Development of a Model View Definition

The exchange requirements serve as a basis for the development of an MVD, which is a subset of IFC. The value of the MVD pertains in it being a foundation for software implementation and verification to whether or not the provided information to a particular need complies with the exchange requirement. The purpose of the IFC mapping in that relation is to provide appropriate entities and their attributes. As soon as all of the previous deliverables have been developed and a full agreement within the developing team has been reached, MVD development can start. However, it is a complex process, which requires an extensive expertise not only in the construction industry and the IFC schema, but also in software application development and data modelling.

Figure 3 shows the initial stages of development of the MVD for the identified exchange requirements by the use of ifcDoc version 11.1(buildingSMART, 2016) and an existing IFC4Addendum2 Baseline specification. Based on the exchange requirements, the tool generates a Model View Definition and the related to it documentation. In that sense, IFC proves to be a rich data model, which is able to meet the information needs of the multidisciplinary process. However, many attributes, entities, and properties are still unsupported. In the current case that applies to many of the use-related input values for performance assessment, which need to be customized/user-defined.

Discussion and Result Analysis

The class diagram shown in Figure 3 provides a quick overview of all data definitions that are within the scope of the MVD, which is extremely valuable both to professionals and software developers. For instance, the solid black objects in the diagram provide knowledge that those entities are non-abstract, and the class can be used with all of its instances.

Table 2: Definition of exchange requirements

Type of Information	Properties	Description/Comments	Data Type	Units
Project	o Project ID	Unique ID of the project	string	n/a
Site	o Site ID	Unique ID of the project	string	n/a
Building incl. Heat accumulating properties	o Building ID	Unique ID of the building	string	n/a
	o Location	Geographic location	latitude, longitude	degrees, minutes, seconds
	o Orientation	According to true north, 0 to 360° in a clockwise direction	rotation	degrees
	o Heated floor area	Gross area, inside face of walls	real number	m^2
	o Heated basement	Gross area, inside face of walls	real number	m^2
	o Heat capacity		real number	WhK/ m^2
	o Hours of operation	Normal usage time	real number	hours/week
	o Heat supply	Source, i.e. boiler, block heating, district heating or electricity	string	n/a
	o Heat supply alternative sources	Contribution from electric panels, stoves and radiators, solar heat, heat pump, solar cells, wind mills (in that order of priority)	string	n/a
	o Supplement to energy frame	Special conditions, e.g. extended hours of operation, extended height, temperature	real number	KWh/m^2year
	o Mechanical cooling	Share of floor area (0 to 1)	real number	n/a
Building envelope				
External walls Roofs Floors	o Identification	Unique ID	string	n/a
	o Construction type	Materials	string	n/a
	o Placement	Relative to Building Storey	real numbers	metric
	o 3D geometry		various	metric
	o Area		real number	m^2
	o U-value		real number	W/ m^2K
Foundations	o Identification		string	n/a
	o Construction type	Materials	string	n/a
	o Placement	Relative to Building Storey	real numbers	metric
	o 3D geometry		various	metric
	o Length		real number	m
	o Loss	Linear heat transmission (ψ), calculated according to DS418	real number	W/mK
Exterior doors Windows	o Identification	Unique ID	string	n/a
	o Construction type	Materials	string	n/a
	o Placement	Relative to Building Storey	real numbers	n/a
	o 3D geometry		various	metric
	o Amount	Number of windows/exterior doors	real number	pieces
	o Orientation	Compass directions (E,W,N,S) or degrees (0 to 360°)	rotation	degrees
	o Inclination		real number	degrees
	o Transmission area		real number	m^2
	o U-value	Transmission coefficient, calculated according to DS418	real number	W/ m^2K
	o Glazing ratio	The glazed area divided by the entire frame area (0.1 to 1)	real number	n/a
	o Solar screening	Factor (-1 to 1)	real number	n/a
	o Shading	Shadow angles Window opening	real number	degrees %
Window joints	o Length		real number	m
	o Loss	Linear heat transmission (ψ)	real number	W/mK

Spatial information				
Zones	o Identification	Unique ID	string	n/a
	o Zone type		enumeration value	n/a
	o Area		real number	m^2
HVAC systems				
Ventilation	o Zones	Areas	real number	m^2
	o Run-time	Run-time of the ventilation system, relative to the building's running hours (0 to 1)	real number	n/a
	o Mechanical ventilation- Winter and Summer	Within operating hours	real number	l/s m^2
	o Temperature efficiency	Factor determined from the outside air temperature increase in the heat exchanger (0 to 1)	real number	n/a
	o Inlet temperature		real number	degrees C
	o Electric heating surfaces	Marked with 0 for yes, 1 for no	real number	n/a
	o Natural ventilation- Winter and Summer	Within operating hours	real number	l/s m^2
	o Infiltration- Winter	Outside operating hours	real number	l/s m^2
	o SEL	Electricity demand for air transport	real number	kJ/m^3
	o Night	Natural and mechanical ventilation during the summer	real number	l/s m^2
Internal heat supply	o Zones	Areas	real number	m^2
	o Persons	Heat contribution per person	real number	W/ m^2
	o Equipment	Within and outside operating hours	real number	W/ m^2
Lighting	o Zones	Areas	real number	m^2
	o Daylight factor		real number	%
	o Daylight operation	None, Manual, Automatic, Continued automatic(U, M, A, K)	string	n/a
Mechanical cooling	o El- and heat demand		real number	kWh
Heat distribution plant	o Supply and return pipes	Lengths	real number	m
	o Loss	Linear heat transmission (ψ)	real number	W/mK
Pumps	o Number		real number	n/a
	o Type and number	According to operation, e.g. constant all year, time-controlled, combined, etc. (A,V, T,K)	string	n/a
	o Nominal pump power		real number	W
Domestic hot water	o Consumption	Average for the building	real number	l/year per m^2
	o Water heaters	Type and heat loss from container	real number	W/K
Supply	o Use case specific	Heat supply from alternative sources	various	various
Materials				
	o Emissions	Global warming, eutrophication, acidification, smog-formation, ozone depletion potentials	various	various

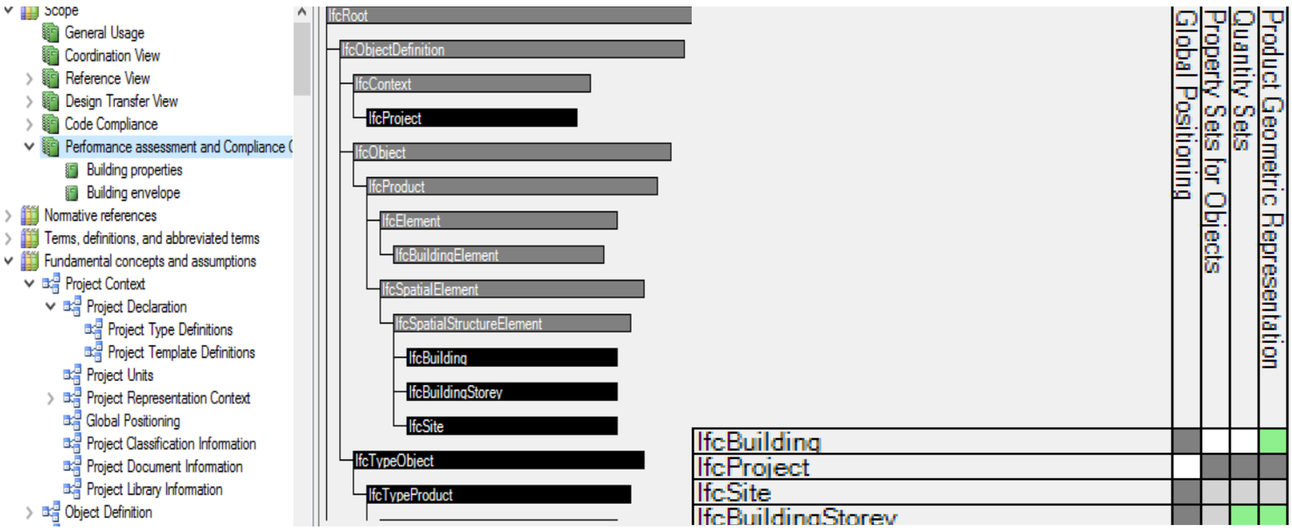

Figure 3: Initial steps of MVD development and documentation in ifcDoc

The grey objects, on the other hand, are abstract data inherited from other definitions. The right side of the figure is an example of documentation of exchanges and shows where each of the requirements is used.

Considering the minimum data requirements identified in the current case, a precise mapping, development, and presentation of the full MVD would require a much bigger effort and a very deep insight into the opportunities that the IFC schema provides.

And while the latter is a matter of end-user development need and resolvable in a relatively short-term, some of the issues identified during process mapping require a fundamental change.

In a linear process, the BO gives the start of the process by defining the business case and the initial owner project requirements (OPRs). The identification of the OPRs is of fundamental importance, as they serve as a basis for further project development.

Thus, it is crucial that the BO as an entity/organization is capable of taking important decisions and formulating them in a proper way. Considering that an Architect is not a part of the process yet might result in neglecting unrecognised needs. Sustainability and energy performance targets are usually not specified at this point, which means their following definition and implementation in the design strategy may have a significant impact on the project economy.

The next stage includes the involvement of the Architect, who after the appraisal of the OPRs develops design proposals. In a usual setting, the Architect is solely responsible for the development of the schematic design.

Therefore, decisions for, for instance, façade appearance and spatial arrangement, which would directly affect the building performance are usually based on the point of view of a single discipline and are taken without the necessary input of the relevant professionals.

The proposed reinvented process aims for the inclusion of the vast benefits of sustainability rating and BPS, as early as the idea generation and programming phase. The significance of the approach is reflected in the opportunity for reduction of energy consumption and environmental impact, without counting only on advanced technologies and tools, but through the efficient collaboration of all parties involved. The involvement of the DGNB Auditor from the very beginning in the role of a sustainability coordinator ensures assistance in making the appropriate technical choices, which means that the probability of meeting the project targets is very high. Approaching the issues from a sociotechnical perspective, where the collaborative processes, the technology and the policies receive equal attention ensures a multilayered perspective and reduces the risk of a one-dimensional solution.

Finally, it is important to note that even though a potential for integration of processes and tools within the BIM environment may be present, it is important that the information requirements are well- defined, because any software solution will be based on the end user's needs. In that relation, the primary purpose of the MVD is to ensure that IFC supports those needs.

The use of the MVD concepts provides a level of modularity, which makes the development of the MVD itself and the framework much more manageable, with a high degree of flexibility. However, a clear limitation is the risk of duplication of activities related to the development of other MVDs. If similar ones are identified, they have to be joined to create an MVD of a larger scope. In this case, partial similarities have been identified and acknowledged in the work of Pinheiro et al. (2016), the officially approved MVD for Nordic Energy Analysis administrated by Stattsbyg (NOW-001, subset of

CDB-2010), as well as Architectural Design to Building Energy Analysis (GSA-003) and Early Concept Design to Analysis (GSA-006) (buildingSMART, 2013). However, while the aforementioned concentrate on BPS as a main element, the current study further includes sustainability rating and compliance documentation, while using the results from BPS as an input.

The initial MVD development steps, in this case, represent the principle, and very few entities have been selected. The final MVD for early stage BIM-based energy performance assessment and code compliance for DGNB pre-certification will, of course, include all exchange requirements and the relations between them.

To achieve that, future works include:

1. Documentation of missing entities, attributes, and properties in IFC, according to the needs defined by the exchange requirements in the use case.
2. Identify whether the missing entities, attributes, and properties exist in buildingSmart Data Dictionary (bSDD).
3. Test the framework in practice to identify limitations.
4. Expand the scope to other rating systems/tools.
5. Validate the developed MVD.

Conclusion

This paper presented a methodology for BIM-based energy performance assessment and code compliance as required by the Danish Building Regulations and the DGNB sustainability rating system. By the use of buildingSMART's Information Delivery Manual methodology, this paper provides a detailed information exchange specification, which would further serve a basis for process automation and software implementation, and therefore elimination of manual inputs in the sustainable design workflows.

The results show that the already standard for information exchanges in the AEC industry IFC schema has a rich structure and is able to support the process in question to a large extent, but many use case-specific attributes still need to be defined. In addition to that, an entirely new approach to the sustainable design process is required, which does not focus on the advanced tools alone, but rely on the fundamental understanding of how those should be utilized by all actors from the very beginning of the collaborative design process.

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