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Procedia Engineering 180 (2017) 520 – 530

Procedia Engineering

www.elsevier.com/locate/procedia

International High- Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

Sustainability assessment through green BIM for environmental, social and economic efficiency

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Abstract

BIM is representing a shift in the traditional process of building delivery. Its adoption in US reached 71% in 2012 rising from 17% in 2007; moreover, Europe is going to adopt BIM for public contracting as promoted by the European Union Public Procurement Directive. Meanwhile, BIM is widely diffused in UK and Northern Europe, as it includes a more accurate documentation, less rework and shorter project timelines. The use of BIM to provide data for energy performance evaluation and sustainability assessment is defined Green BIM and pioneering design organizations are adopting this approach to enable integrated design, construction and maintenance towards Net Zero Energy buildings. Green BIM includes Building Energy Modelling dealing with project energy performance to identify options optimising building energy efficiency during the life cycle. By allowing revisions during the design phase, project teams can ensure that customers' green ambitions beyond regulation compliance can be realized, together with technical and economic requirements. Thus, BIM can provide information to support the calculation of a number of credit points to define goal levels of sustainability related to rating systems. The aim of the paper is to investigate the opportunity to include the "green dimension" in BIM considering the more diffused rating systems.

Peer-review under responsibility of the organizing committee iHBE 2016

Keywords: BIM; Green BIM; sustainability; rating; BEM

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Peer-review under responsibility of the organizing committee iHBE 2016
doi:10.1016/j.proeng.2017.04.211

1. Introduction

LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Methodology) rating systems are widely adopted and internationally considered as robust rating systems. CESBA (Common European Sustainable Built Environment Assessment) tries to implement the harmonization of the indicators included in the various rating systems to promote a uniform rating and quality of the sustainable assets which now are adopting different criteria/weights in each country. Despite the diffusion of the main reported rating systems (LEED and BREEAM), they are getting more and more complicated and this is mainly due to the increased demand of clients and users, that pushed also for different versions, devoted to different aspects of the building (e.g. new construction, existing buildings, operation, site, core & shell) and of the neighborhood. This complexity and the need of reliable results (since early stages) claim for the integration with existing tools and methods, like Building Information Modeling (BIM). BIM can be considered the most innovative process-oriented methodology in the Architecture, Engineering and Construction (AEC) sector 0. Even if BIM has already been used for many years in the construction sector 0, it has been widely adopted only since few years ago from Governments, local authorities and private companies both for new construction and for existing buildings. BIM, in general, allows for a better and more reliable data storage and elaboration, avoiding data ambiguity, duplicates and misleading information. The plurality of rating systems, actors in the building process, technological solutions for building and services, users' and clients' requirements arise the need for exchanging huge amount of data and, thus, for having a common data exchange protocol. The answer to this need could be given by the Industry Foundation Classes (IFC) protocol, which is currently the most advanced non-proprietary data exchange format for the building sector. IFC provides not only an instrument to exchange information, but also a robust framework and a classification able to manage with the building complexity. LEED, BREEAM, CESBA, as well as other rating systems, are no more just a certification to be achieved at the end of the construction, but complex systems to be applied starting from the early design stages to building operation. Their strong connection with design tools boosts for a solid integration with BIM 0. Using IFC, in combination with defined procedures and tools, will allow for a better data extraction and elaboration, providing more reliable results with less effort. The aim of the paper is to investigate the opportunity to include the "green dimension" in BIM considering the more diffused rating systems. This inclusion could give designers a reliable and quick forecast of the sustainability rating throughout all the design stage, allowing architects and engineers to compare alternative design options having the rating score automatically computed. Moreover, storing sustainability rating system data in the Asset Information Model allow for faster update of the rating in case of major maintenance operations or replacements. This paper, with the help of some examples, provides the framework for a practical implementation of the connection among BIM models and rating systems through IFC.

2. Research methodology

2.1. Theoretical framework

The framework of the work and the main steps to be performed are described, accordingly to define the context of the research together with potential and limitations of the proposed approach which wants to include and connect the field of sustainability assessment through the BIM process and promote a data-driven procedure to enable design for a sustainable built environment. The idea supporting this research is to provide stakeholders with tools and procedures allowing them to extract rating protocols data from a BIM model in order to forecast the sustainability rating in every step of the design phase and of the operational life of the building. Data should not only be readily available to fulfill rating protocol paperwork in order to achieve the final ranking nevertheless they have also to be readable by a web server to publish a forecast of the sustainability rating 0 when two or more design options are under investigation and evaluation to enable informed choices. The need of effortlessly available data and of more precise and reliable procedures to effectively work with BIM has been highlighted 0. Satisfying this need is not that easy because complexity and variety of both rating systems and BIM software are growing as it is the amount of data to be handled. Data exchange between BIM software and rating systems must, consequently, be based on a standard exchange protocols like IFC or COBie, which essentially is a Model View Definition (MDV) of IFC. Using IFC as a means of information interchange leads to a more interoperable and open access to data 0, which could be used by professionals in different software in different moments of the building life to empower collaborative environment and shared decisions for better results and a more sustainable built environment 00. The feasibility of the presented concept for research will be demonstrated storing a set of criteria coming from rating systems into a BIM model 0 using IFC attributes where available or creating dedicated property sets when needed, this will be done for three different rating systems 0 (e.g. LEED, BREEAM and CESBA) and also for different building phases (e.g. project, construction, operation) or components (e.g. core & shell, operation and maintenance). This could be done in a real life project only if precise objectives are defined in the pre-design phase 0 and fully described in BIM guidelines. An example has been developed to explain potential and weaknesses of using IFC as the collector of rating system data. A chosen criterion shared by the three rating system under analysis, i.e. daylight, has been used for its significance in indoor space quality, energy saving (electricity and thermal energy) and technological implications and has been selected to carry out some preliminary tests and to demonstrate the feasibility of the objective of the proposed research. The main vision containing this concept is to extend the BIM process to include the green dimension of the project 0, encompass the starting requirement of the project in a structured way customizing and leading the design in term of energy, environmental and social efficiency 0 by the addition and verification of the indicators of the rating systems 00 in the shared virtual environment able to manage and enable improving process through the lifespan of the asset.

2.2. Workflow

The workflow of this research is outlined in Fig.1, starting from the preliminary analysis of sustainability rating systems and of the IFC standard it could produce a constantly updated rating report, based on rating system report structure created from data stored in the BIM model. Main steps of the research are highlighted by letters and described in the following.

Main steps to be completed are outlined in Fig.1:

- A1) rating system data need definition;
- A2) rating system report structure analysis;
- B) IFC standard analysis in order to define which rating data can be directly stored in a IFC project and which need the creation of custom property sets;
- C) creation of BIM guidelines for sustainability analysis;
- D) creation of a web service able to automatically extract data from IFC files stored in a BIM Server;
- E) creation of an html report template according to rating report structure;
- F) creation of a web app that fill the report template with data extracted from the BIM model stored in the BIM server and compute the sustainability rating of the project.

2.3. Case study protocols

In particular, the first step A1 requires a comparison of main rating protocols. Widely used and well known LEED, BREEAM rating systems and the novel CESBA protocol aiming at unify the approach to sustainability assessment through a shared framework and indicators have been analyzed in this research.

It has been decided to include different typologies of each rating systems, as follows:

- LEED new construction and refurbishment (thereafter LEED NC 0);
- BREEAM new construction (thereafter BREEAM NC 0);
- BREEAM refurbishment (BREEAM REF 0), CESBA new construction (thereafter CESBA NC 0);
- CESBA refurbishment (thereafter CESBA REF 0) and CESBA heritage (thereafter CESBA HER 0).

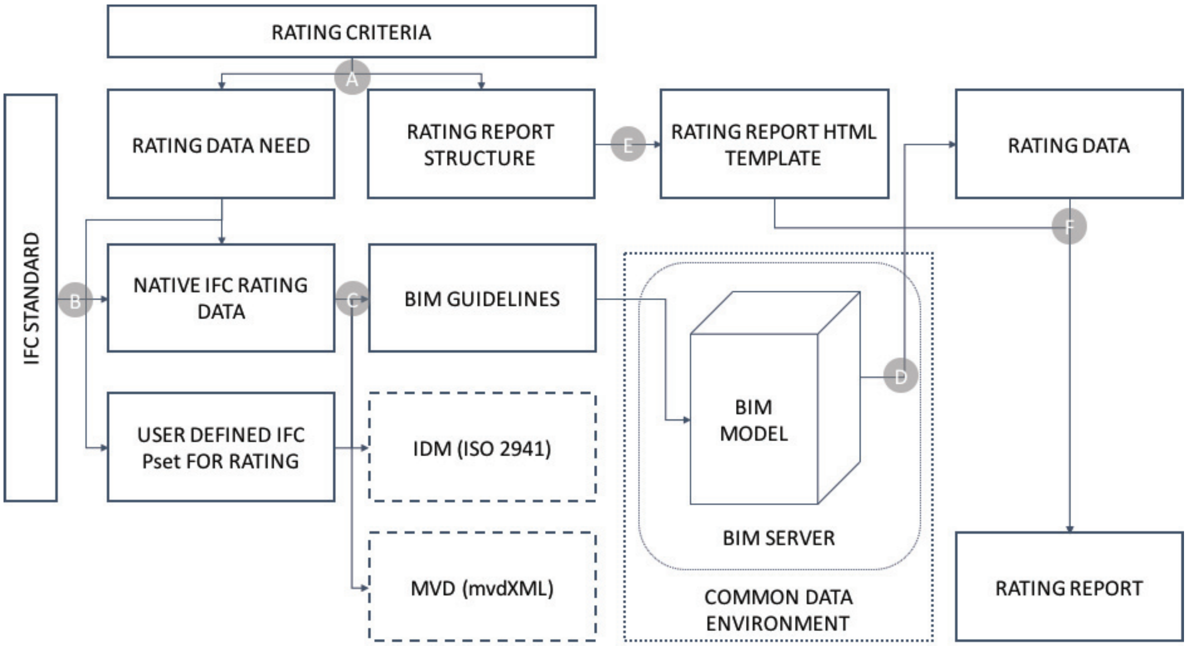

Fig.1. Outline of the research workflow. Main steps of the research are highlighted by letters.

3. State of the art

A brief resume of the state of the art of the development of IFC data model is reported easing to summarize main potentials and opportunities provided by adopting an interoperable exchange protocol. In addition to this, an analysis of three sustainability rating protocols has been carried out and a correlation between sustainability criteria and IFC data model has been given.

3.1. Industry Foundation Classes data model

To effectively enforce BIM processes, the quality of communication among different participants in the building process needs great enhancement with respect to traditional building processes. If the information required is available when it is needed and the quality of information is satisfactory, the building process will be significantly improved 0. Therefore, it is crucial to ensure interoperability among both actors and tools.

Interoperability among information systems concerns the need to transfer data among applications, preventing re-creation or re-input of data and enabling efficient use of information. It offers potential for considerable savings and financial gain 0. In fact, insufficient interoperability among information technology tools costs the US capital facilities industry USD 15.8 billion annually, especially because of redundant data entry, redundant IT systems and IT staff, inefficient business processes, and delays indirectly resulting from these inefficiencies 0. This means that software non-interoperability costs on average 3.1% of total project budgets 0.

With respect to the interoperability issue, buildingSMART defined a structure to support an efficient exchange of information, as shown in Table 1. This structure was then adopted as standard through ISO 16739 0, ISO 12006 0 and ISO 29481 0. IFC specifies how information is to be exchanged, being a standardized neutral data format to describe, exchange and share information. It is an object-oriented data model of buildings, specifying physical items or abstract ideas and their relationships (decomposing, assigning, connecting, associating, and defining). In fact, IFC is a relational data representation, based on a top-down approach, written in EXPRESS language 0.

Table 1. Pillars for an efficient exchange of information.

Pillars	Questions to be answered	Technical answers
The format for information exchange must be shared and unique	How to exchange	Industry Foundation Classes (IFC) as a common exchange language
The information exchange has to be based on a common, standardized understanding	What is exchanged	International Framework for Dictionaries (IFD) as a formalized way for representing a vocabulary
The orchestration of the exchanges has to be specified	When it is exchanged	Information Delivery Manual (IDM) as a formalized way to express and represent processes and data exchanges

The structure of the IFC data model (Fig.2) is divided into four layers (i.e. domain, interoperability, core, and resource), hierarchically related (referencing can only occur downwards in the hierarchy). Data in the resource layer must be independent and reference no classes above it. The other layers, however, can all reference data from the resource layer as well as all other layers below them. References within the same layer are allowed only for the resource layer 0. The resource layer holds the resource schema that contains basic definitions intended for describing objects in the above layers.

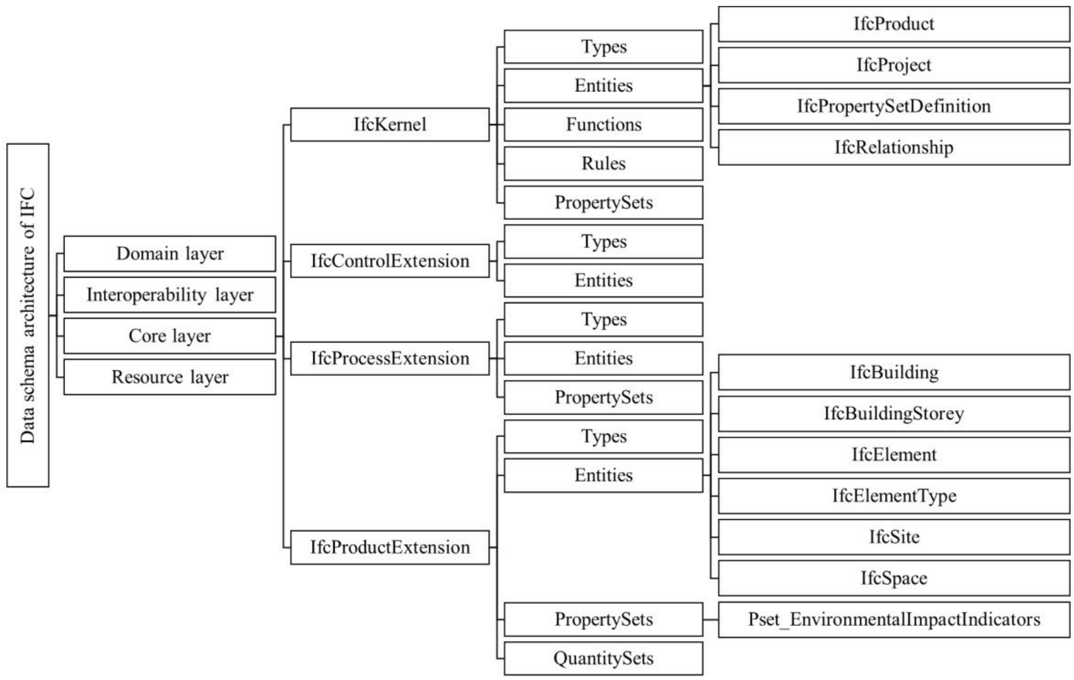

Fig.2. IFC data model.

The core layer consists of the kernel and extension modules. The kernel determines the model structure and decomposition, providing basic concepts regarding objects, relationships, type definitions, attributes and roles. Among them, *IfcProduct* is an abstract representation of any object that relates to a geometric or spatial context; it includes physical building elements (as *IfcWall*, *IfcBeam*, *IfcDoor*, *IfcWindow*, *IfcStair*) and spatial items (as *IfcSite*, *IfcBuilding*, *IfcBuildingStorey*, *IfcSpace*), but also non-physical items, that relate to a geometric or spatial contexts (as *IfcGrid*, *IfcAnnotation*).

Core extensions are specializations of classes defined in the kernel. *IfcElement* is a subtype of *IfcProduct* and, because of IFC hierarchical structure, inherits its properties (i.e. *ObjectPlacement* and *Representation*).

The interoperability layer provides the interface for domain models, including schemas containing entity definitions that are specific to a general product, process or resource specialization used across several disciplines.

The domain layer includes schemas containing entity definitions that are specializations of products, processes or resources specific to a certain discipline 0 0.

IFD specifies what the exchanged information means, allowing the creation of dictionaries or ontologies, to connect information from existing databases to IFC data models 0.

Information Delivery Manual (IDM) specifies which and when the information has to be exchanged 0. IDM is essentially a methodology for identifying and describing the processes and related information within a construction project. IDM methodology maps the business processes related to a particular data exchange between agents or their applications. Those processes are recorded as Process Maps represented in Business Process Modeling Notation (BPMN) and describe the activities and actors involved, as well as the information and its sequence in the process. Moreover, it defines the required data as exchange requirements listed in a tabular form. Therefore, IDM represents a standardized method for defining: a) who needs the information extracted from a BIM model; b) at which point in time this information is needed; c) which minimal amount of data has to be exchanged 0.

MVD is used for specifying how information pointed out by IDM is to be mapped to IFC classes. MVD defines a subset of the IFC schema, which is needed to satisfy one or many Exchange Requirements (ER) of the AEC industry, defined in the IDM 0. Moreover, MDV provides implementation guidance or implementation agreements for all IFC concepts (i.e. classes, attributes, relationships, property sets, quantity definitions) used within the subset of the IFC schema. Thereby it represents the software requirement specification for the implementation of an IFC interface to satisfy the ER. Whereas the general ER is independent of a particular IFC release, the realization within the MVD is specific to an IFC release.

3.2. Rating systems

The rating systems are used in the AEC sector to promote sustainability through a quality certification of the buildings assessed checking lists of criteria in which points are gained by the compliance with specific parameters defining the measure of the requirement. Even though the single indicator is regulated by an assessment area it is surely connected with others requirements and consequently more advanced visualization techniques 0 are beneficial to understand and to weight these kind of unrevealed relationships ad interconnected outcomes. LEED and BREEAM are international tools of the first generation (started 10-15 years ago) and their application leads to improve performance by multiple and interdisciplinary point of views (e.g. energy, comfort, environmental, pollution, transport, management, materials). Each rating system has a number of criteria (Fig. 3) structured into areas.

The CESBA protocol on the other hand tries to overcome the fact that all the different rating systems diffused in the world share a number of similar indicators, however the areas of interest in which they are categorized have different name, declination and connections and the same indicator can have a different definition or parameters on which is based the assessment. The CESBA protocol aims to resume and harmonize the multivariate worldwide panorama, of the rating systems to promote a standardized evaluation in which the same building has not different level of quality if evaluated in two different protocols. At the same time the need of simplification of the tool to boost applicability and suitability in a wide range of building condition. The first step performed in this research has been a rough screening of the criteria listed in the rating protocols under analysis. Rating systems have different criteria, distributed as in Fig.3, which shows that LEED and BREEAM have almost the double of the criteria respect to CESBA; this is due mainly to the definition of the criteria themselves: specific instead of generic. An example is given by the lighting assessment, which has three different criteria in the BREEAM (i.e. daylight, view and lighting) and only one in the CESBA protocol. Results of this screening have been organized in two different charts, to highlight: (1) the distribution of the criteria of the different rating systems into the main IFC objects categories; and (2) the distribution of the criteria of the IFC objects into each single rating system. The *IfcBuildingStorey*, despite that it is part of the hierarchical structure of IFC, has not be used, as authors founded more useful to associate criteria to the space, rather than to the story.

Fig.4 shows that the majority of the requirements is associated to *site* and *building objects*. Then *spaces* and *elements* have almost the same number of requirements. The last object is the *project*, which mainly contains criteria associated to design, construction and operation processes (i.e. presence of innovations, accredited professionals, enhanced management) not associated to single elements or parts of the building.

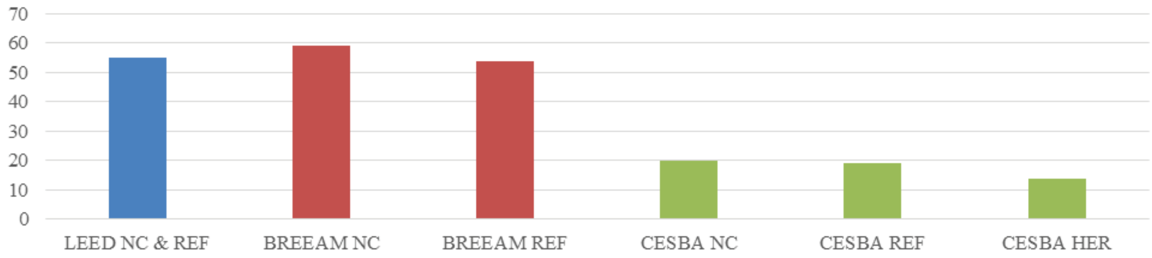

Fig.3. Number of criteria in the rating systems under analysis.

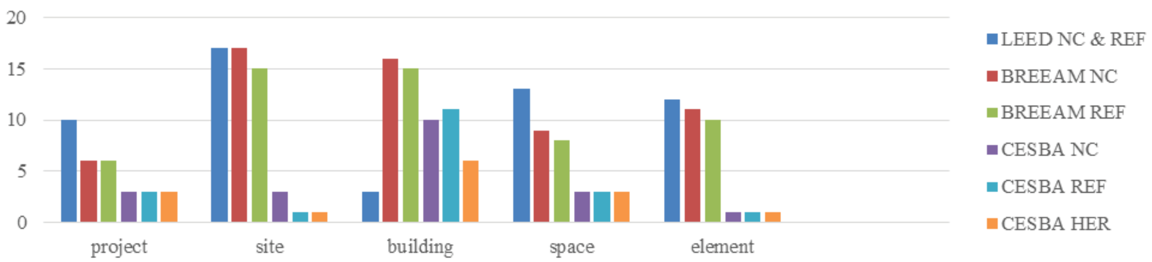

Fig.4. Distribution of the criteria of the different rating systems into the main IFC objects classes.

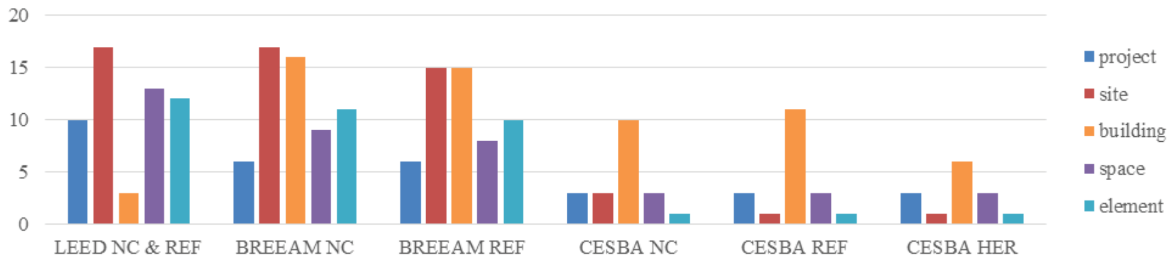

Fig.5. Distribution of the criteria of the IFC objects into each single rating system.

Fig.5 highlights that LEED gives a great importance to *site*, *spaces* and *elements*, as well as BREEAM does; on the opposite, CESBA pays great attention to the *building* level (i.e. more than half of the requirements).

These charts are relevant, as they show where to set more effort in the mapping of the IFC attributes to be associated to rating system criteria.

4. BIM for rating system management

Managing rating systems criteria within a BIM model implies a double level of complexity: as first, there is the problem of defining all the right attributes to fulfill the criteria calculation procedures and then the new attributes must comply with the current IFC schema. In addition to this, not all the attributes necessary to the calculation and to satisfy the criteria are already included in the IFC property sets, so some of them (especially the output) must be created.

An example related to the daylight requirement, with the aim of showing the main steps to be followed to define the right attributes and to export them into an IFC model is proposed. Autodesk Revit 2016, Solibri Model Viewer (to visualize the IFC file and related attributes) and the IFC 2x4 documentation 0 have been used to produce the following pictures and schemes.

4.1. Example of the analysis: Daylighting assessment

The daylight criterion involves, for all the three rating systems: (1) the calculation of the illuminance (E) of the working surface in a space at a specific date and time; or (2) the calculation of the daylight factor (D), which should be in a given range (e.g. > 2% and < = 5%) in most of the frequently used spaces (e.g. > 80% of the used surface). The final expected result is the share of spaces with an E or D compliant with the given conditions.

This involves the use of many attributes, few of them already available in IFC. In Table 2 there is the list of the IFC parameters related to daylighting.

Table 2. Parameters mapping of the IFC attributes related to daylighting.

IFC parameter	Parameter description	Property set	IFC object connected
Illuminance	Average illuminance of the space	5.4.5.17 Pset_SpaceLightingRequirements	IfcSpace
Various	Spaces geometry, area, volume and position	Several Pset according to spaces shape	IfcSpace
Various	Spaces bounding elements geometry and position	Several Pset according to spaces shape	IfcElement
VisibleTransmittance	Visible transmittance	8.10.5.8 Pset_MaterialOptical	IfcMaterial
SolarTransmittance	Solar transmittance	8.10.5.8 Pset_MaterialOptical	IfcMaterial
ThermalIrTransmittance	Thermal Ir transmittance	8.10.5.8 Pset_MaterialOptical	IfcMaterial
ThermalIrEmissivityBack	Thermal Ir transmittance	8.10.5.8 Pset_MaterialOptical	IfcMaterial
ThermalIrEmissivityFront	Thermal Ir emissivity	8.10.5.8 Pset_MaterialOptical	IfcMaterial
VisibleReflectanceBack	Thermal Ir emissivity	8.10.5.8 Pset_MaterialOptical	IfcMaterial
VisibleReflectanceFront	Visible reflectance	8.10.5.8 Pset_MaterialOptical	IfcMaterial
SolarReflectanceBack	Visible reflectance	8.10.5.8 Pset_MaterialOptical	IfcMaterial
SolarReflectanceFront	Solar reflectance	8.10.5.8 Pset_MaterialOptical	IfcMaterial

The attributes listed in Table 2 are related to *elements* and *spaces*. Geometry is fully described in IFC, as well as material properties of the elements. In Table 3 the output needed to calculate the daylight criteria are listed.

Table 3. Output required by the rating systems to calculate the daylight criteria.

Parameter	Condition	Rating system	Type
Percentage of spaces with a correct daylight illuminance level (E)	>75% of the spaces with >25fc and <500fc	LEED	Output
Percentage of spaces with a correct daylight factor (D)	Specific conditions according to latitude and function (e.g. >80%)	BREEAM	Output
Percentage of spaces with an average illuminance for a defined number of hours	Specific conditions according to latitude and function (e.g. >300 lux for 2000 hours/year)	BREEAM (alternative)	Output
Daylight factor (D)	2%>D≥5% (offices)	CESBA	Output

The attributes listed in Table 3 are not natively present in IFC. All of them are a number expressed in percentage and related to the whole building. The suggestion is to create an additional property set, named *Pset_RatingResult* and associated to the *IfcBuilding*, in which inserting the three parameters (as a percentage). In Table 4 the parameters needed to calculate the output of Table 3 are listed. Parameters in Table 4 are not natively present in IFC, even if some geometric criteria can be checked thanks to the geometry provided by IFC (e.g. room depth and sky view); nevertheless, there is no possibility to store the results of the prerequisite in IFC native attributes. Authors suggests to insert them into a dedicated property set related to *IfcSpace*. The main problem is due to the fact that IFC natively has only the average illuminance of a space (namely Illuminance), but the rating systems require the illuminance at a given time date, for a defined number of hours, on just the working surfaces of a room, etc. The IFC parameters must be used according to the description contained in the IFC4 Documentation 0 and no other interpretations could be considered valid. So it comes the need of adding additional IFC property sets to define the right attributes.

Table 4. Parameters required by the rating systems to calculate the output.

Parameter	Description	Rating system	Type
Daylight illuminance level >25fc and <500fc	For each used space, the illuminance level must be calculated at a given time/date	LEED	Input
Areas with illuminance levels below or above the range (not compliant)	For each space, compliant and uncompliant area must be calculated	LEED	Input
Average daylight factor (D) of each space	For each space, the daylight factor must be calculated	BREEAM	Input
Illuminance on the work surface	Needed for daylight factor calculation	BREEAM	Input
External horizontal illuminance	Needed for daylight factor calculation	BREEAM	Input
Uniformity ratio of daylight factor in each space	Prerequisite, each space must have daylight uniform (with given conditions)	BREEAM	Input
Sky view	Prerequisite, at least 80% of the room must have view of sky with given condition	BREEAM	Input
Room depth	Prerequisite, each room must have a depth compliant with a given formula	BREEAM	Input
Average illuminance of the space	For each used space, the average illuminance level must be calculated, defining also the minimum level and the number of hours	BREEAM (alternative)	Input
Illuminance on the work surface (E_P)	This is required to calculate the daylight factor of each room	CESBA	Input
External horizontal illuminance (E_{hz})	This is required to calculate the daylight factor of each room	CESBA	Input

5. Results

The presence of the two main property sets related to daylighting (*Pset_SpaceLightingRequirements* and *Pset_MaterialOptical*) demonstrates that IFC can be (partially) used to store and manage data related to the daylighting criterion of the rating systems analyzed. In addition to this, geometry (of the spaces, of the main elements and of the surroundings, if relevant) is governed by a dedicated series of property sets. On the opposite, not all the required parameters (most of them, including input and output) can be stored in the native IFC model. There is the possibility to create additional property sets, so to cover the whole criteria. This test needs to be considered as a starting point of this research, aiming to demonstrate the feasibility of using an IFC model to store and manage rating systems data. In addition to this, there is the need to implement the missing parameters into IFC, so to validate them with a case study.

6. Conclusion

The framework of the research has been shown together with some preliminary examples that allows understanding the potential of this interoperable approach to sustainability rating of buildings according to main international protocols (LEED, BREAM, CESBA). Having a tool able to calculate and manage criteria since the early design stages allows for a better and more sustainable design based on the three pillars of environment, economic and social key issues, with the possibility of dynamically assess multiple scenarios, getting better results during building construction and operation; same could be done in case of a refurbishment or major maintenance operations. Using IFC standard to exchange data from a BIM model assures that these are correctly transferred from one software to another and thus from professional (architects, engineers and consultants) to another but this first step of the research demonstrated that even IFC 2x4 property sets are inadequate for computing sustainability rating and for storing the results. Proprietary property set must be used, thus the need of BIM guidelines for BIM modelers, but, in the long term, it is to be hope that the IFC standard will be expanded to manage all the data required by sustainability rating. Future developments of this research include the creation of web services and web app depicted in Fig.1 and further application to case studies, hence to test their reliability and robustness.

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