LINKING IFCS AND BIM TO SUSTAINABILITY ASSESSMENT OF BUILDINGS

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ABSTRACT

BIM (Building Information Modelling) is a process involving the generation and management of digital information related to a construction project. The resulting building information model becomes a shared knowledge resource to support decision-making about the facility from earliest conceptual stages, through design and construction then through its operational life before its eventual demolition.

Information exchange with BIM is made using a common format which is the IFC (Industry Foundation Classes). IFCs are supporting different types of information (i.e. Architecture design, HVAC description, Thermal analysis, etc.) and therefore the main asset of the BIM approach is to be able to couple together different key players around the same model and the same data.

Among the possible applications of BIM, the one related to sustainability analysis is of paramount importance. On that subject, SBA (Sustainable Building Alliance - http://www.sballiance.org/) produced a set of core metrics aiming to support operators of building rating tools and certification by the promotion of shared indicators for building performance assessment and rating.

An obvious need emerged for the coupling of this SBA set of core metrics with BIM. Indeed, much of the information required to perform sustainability analysis (e.g. Quantity Take Off, gross area, total numbers of building components, ...) exist, in most cases, in the BIM. On the other side of the process, after having performed a sustainable analysis, there is also a need to store the result in the BIM in order to share them with other stakeholders.

The research presented in this paper addresses this particular point of explaining how the SBA metrics can be mapped to Industry Foundation Class structures. The mapping exercise reveals some gaps and recommendations are done to bridge these gaps in order to allow BIM/CAD tools to efficiently provide input data for LCA tools.

Keywords: BIM, IFC, LCA, sustainability analysis, sustainable buildings

1. INTRODUCTION

The Construction Industry is currently facing an overwhelming number of challenges. In addition to challenges common to all industrial sectors of the 21st century such as globalization, economic slowdown and the need to reduce carbon footprint, the construction sector adjoins intrinsic weaknesses. Indeed, this sector is highly fragmented with a wide variety of professional stakeholders (e.g. architects, engineers, contractors, vendors …) and non-professional stakeholders (owners, users, real estate agents …) interested by the same project but usually pursuing divergent goals. Successful initiatives to improve quality and productivity in this sector using innovation are still rare due to the lack of a lead position in the value chain for the adoption of new technology and practice along with a cultural state of mind that leaves the construction sector lagging behind other industries in applying innovation to improve its work processes.

In that context, the use of Information Modelling combined with simulation capabilities appears to be extremely useful in addressing these complex and multidisciplinary issues. Various disciplines (technical performances of the envelope, comfort conditions, health and safety, cost analysis …) can be integrated in an interdisciplinary and holistic approach supporting a "global optimum" search that allows designers to confront options in order to identify and handle conflicts.

Environmental dimensions of building materials and components (e.g. carbon footprint, energy performance …) can also be integrated and combined with simulation packages thus allowing predicting the effects of using different materials / components in various conditions. This will produce significant advantages to the designer by allowing taking into account the environmental impact of the building over its lifecycle. Many factors can then be considered such as the use of potentially lower carbon footprint materials and their energy performances along with trade-offs associated with the cost implication, the use of renewable energies …

The objective of the research presented in this paper is produce and validate a mapping between a BIM/IFC and sustainable analysis metrics and, in particular, the core metrics produced by the Sustainable Building Alliance (SBA).

2. BIM AND INTEROPERABILITY

There are several definitions for the notion of BIM. The Acronym BIM is sometimes turned into "Building Information Model" or "Building Information Modelling", one representing more the concept and the other the approach. On Wikipedia, the following definition is given to BIM:

"Building information modelling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle, including the processes of construction and facility operation. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities. Dynamic information of the building, such as sensor measurements and control signals from the building systems, can also be incorporated within BIM to support analysis of building operation and maintenance."

This definition presents several facets of the notion of BIM, among others, the most important ones are:

- It covers the whole life cycle of a building project;
- It creates a single information node that simplifies updates and synchronization mechanism among actors of the same construction project.
- It is a structured collection of building and construction objects including physical components, spaces, processes, actors involved, and relationships between these objects. All of these objects may be enriched by shared or specific properties. As a consequence, quantities or values stored in these properties can be extracted and reused as the source of information to perform calculations, analysis or simulations.

Concerning application in the field of sustainable assessment, some of very prominent benefits of BIM Modelling are:

- BIM contains the data of a building that can be analysed from different environmental analysis point of views with different analysis tools (even if the data only was general geometries, quantities and qualities).
- BIM can include data about the environmental properties of the building parts and building products. That could be used as part of the analysis. This kind of data would typically be produced by the manufacturer of a specific product or material. The data is entered to the BIM by the designer when specific products are chosen during the design process (some of the products are only decided during construction).
- The results of the analyses could be inserted back to a BIM and stored there. They would be compactly available for decision making in a single source. Problematic in this approach is data updating and version management. When something in the model is changed the environmental metric (=stored analysis result) and the other content of the model are no more coherent.

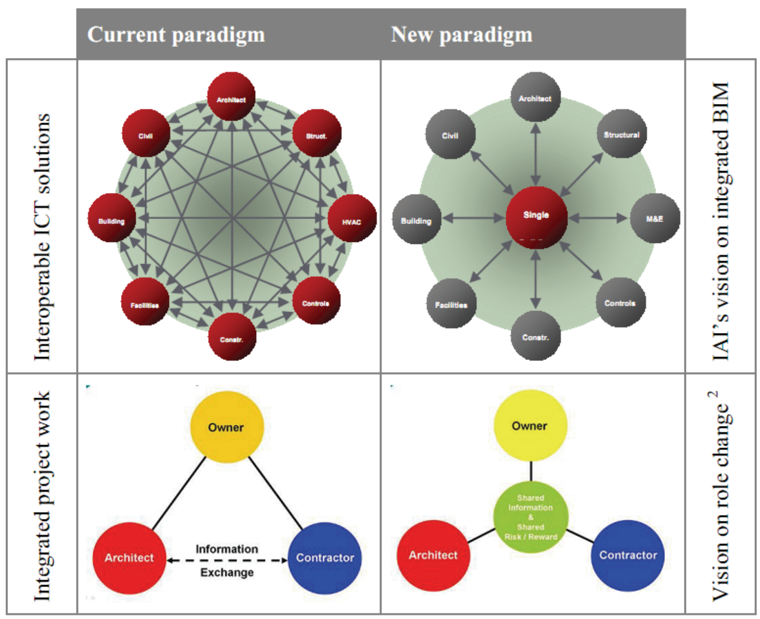

Figure 1: Integrated project work and integrated ICT (or the need for interoperability)

The concept of BIM is easy to understand but hard to turn into tangible reality in a current working environment as there is a strong need for an interoperable exchange format, rich enough to allow all users / stakeholders working simultaneously around the same digital model to enrich and retrieve data from the same single model. If we just focus on the current study related to Sustainable metrics, there is at least one relevant language, namely the IFC, designed to support such exchanges. This exchange language is presented more in details in the next paragraph.

3. MAPPING OF SBA METRICS AND INDUSTRY FOUNDATION CLASSES (IFC)

3.1 SBA Core Indicators – What is Being Analysed?

SBA core indicators consist of 10 individual indicators, in 6 sub-categories of 3 main categories. Resource depletion meters the use of non-renewable primary energy and water consumption. In total cost of building operations these two form the majority of expenses, thus have great impact in facility management and interest of building owners.

Indoor environment quality includes thermal comfort and indoor air quality. Thermal comfort meters the minimum and maximum temperatures for summer and winter settings where indoor air quality emphasizes the concentration of CO_2 during the occupied period and formaldehyde concentration in indoor air. Indoor environment quality impacts health and is an interest for building users.

Building emissions consist of global warming potential and assesses the amount of CO_2 a building produces per unit. Solid wastes production is calculated in tonnes of waste, and includes hazardous, non-hazardous, inert and nuclear waste. Both these indicators impact environment on national and global levels and therefore are important factors in decision making.

3.2 Mapping of SBA Metrics and Industry Foundation Classes (IFC)

3.2.1. IFC Overview

IFCs were originally developed to describe building components in an objectified way. Since the beginning a lot of improvement has been made but the integration of sustainable/environmental notions is quite new as it has been done in the last release. In this latest version (IFC 2x4) several enhancement have been done (the corresponding two property sets are described in details later in this paper). Nevertheless, all notion related to sustainability are not already taken into account as we will see later on.

IFCs are developed and managed by buildingSMART (http://www.buildingsmart.com), which brings together architects, engineers, constructors, product manufacturers and facilities managers, along with software vendors and progressive construction customers. One of the main goals of buildingSMART (through its Model Support Group) is to develop and maintain open international standards for Building Information Modelling (Open BIM). Thus a major output buildingSMART is a common data schema that makes it possible to hold and exchange relevant data between different software applications. The data schema comprises interdisciplinary building information as used throughout its lifecycle. This format (IFC) is registered by ISO as ISO/PAS 16739 and is currently in the process of becoming an official International Standard ISO/IS 16739. IFC can be used to exchange and share BIM data between heterogeneous applications developed by different vendors without the necessity to support numerous native formats. As it is an open format, it does not belong to a single vendor and is therefore neutral and independent of a particular vendor's schedule and development direction.

IFCs specifications are written using the EXPRESS data definition language, defined as ISO10303-11 by the ISO TC184/SC4 committee. It has the advantage of being compact and well suited to include data validation rules within the data specification. The IFC exchange file structure (*.ifc files) is the so called "STEP physical file" format, defined as ISO10303-21 by the same ISO TC184/SC4 committee. It is an ASCII file format used to exchange IFC between different applications.

In addition to the IFC-EXPRESS specification an ifcXML specification is published as well (since the IFC2x release). The ifcXML specification is provided as an XML schema. The ifcXML exchange file structure (*.ifcXML files) is the XML document structure. The XML schema is automatically created from the IFC-EXPRESS source using the "XML representation of EXPRESS schemas and data" (ISO10303-28). This ensures that both IFC-EXPRESS and ifcXML handle the same data consistently and that the *.ifc and *.ifcXML data files can be converted bi-directionally.

3.2.2 Link with Product Libraries - Property Sets

There is a high demand from manufacturers for solutions allowing better integration of their product libraries in application tools (such as design tools), and supporting automated information exchange and sharing. Several initiatives have been launched to improve the situation by developing semantic links between product libraries and product data models, as well as infrastructures to better support access to product information from design or procurement tools. Generally speaking this raises the problem of convergence between classifications and product modelling.

In the construction domain, for instance, IFC-based implementation of product libraries have good prospect for meeting the industry requirements. Indeed, while IFC classes represent generic categories of element (e.g. wall, beam, space) with very few attributes associated with a class to transfer information relevant to a manufacturer, IFCs incorporate a mechanism called Property Sets (Psets) which allow information publishers to dynamically allocate new properties to an object they wish to describe. Since there are numerous alphanumeric attribute definitions depending on discipline, life-cycle stage, building regulation and region, there will never be a complete set of internationally standardized attributes. Therefore, IFC defined property sets intent to standardize a basic set of properties, whereas other property sets can be regionally defined, or agreed upon in projects. The current drawback, however, is that there is no specification of the semantics of Pset information outside that published in the IFC distribution (PSD - Property Set Definition - Schema for the definition of property sets and properties).

As an example, below is the list of properties defined in the Pset attached to the common entity *IfcBoilerType*:

- PressureRating
- OperatingMode
- Material
- HeatTransferSurfaceArea
- NominalPartLoadRatio
- WaterInletTemperatureRange
- WaterStorageCapacity
- PressureRating
- OperatingMode
- Material
- HeatTransferSurfaceArea
- NominalPartLoadRatio
- WaterInletTemperatureRange
- WaterStorageCapacity
- IsWaterStorageHeater
- Weight
- PartialLoadEfficiencyCurves
- NominalEfficiency
- HeatOutput
- OutletTemperatureRange
- NominalEnergyConsumption.

3.2.3 Pset_EnvironmentalImpactIndicators and Pset_EnvironmentalImpactValues

IFC 2x4 defines Environmental impact indicators as the following:

"Environmental impact indicators are related to a given "functional unit" (ISO 14040 concept). An example of functional unit is a "Double glazing window with PVC frame" and the unit to consider is "one square meter of opening elements filled by this product". Indicators values are valid for the whole life cycle or only a specific phase (see LifeCyclePhase property). Values of all the indicators are expressed per year according to the expected service life. The first five properties capture the characteristics of the functional unit. The following properties are related to environmental indicators. There is a consensus agreement international for the five one. Last ones are not yet fully and formally agreed at the international level".

The Environmental impact values (Pset_EnvironmentalImpactValues) are obtained by multiplying the indicator value per unit by the relevant quantity of the element.

3.2.4 How do SBA Metrics Fit Into IFC?

Table 1 establishes a mapping between SBA core metrics and the environmental property sets proposal in IFC 2x4. There are already some gaps identified at that level. As said previously, even if the new 2x4 version provides a better support of sustainable/environmental notions, there is still room for improvement. For example, the notion of Life cycle stage still applies at the project level (via the use of the "ifcContext" entity) as it should be also available at the product level when coupled with the SBA core indicators. Another gap is the lack of support of some SBA core indicators like the Indoor Environmental Quality indicators. This point is detailed below.

IFC and IEQ

As defined by SBA, the notion of "IEQ" (Indoor Environmental Quality) counts two major indicators that are namely:

- **The thermal comfort:** For summer and winter settings [% time out of range] of minimum and maximum temperature
- **The Indoor air quality** (IAQ): The IAQ is composed of two metrics:

- The Concentration of CO_2 [ppm] during the occupied period;
- Formaldehyde concentration [$\mu g/m^3$].

It is worth noticing here that these indicators are defined for the ”Use stage” and are considered as ”not relevant” for the 2 other stages considered by SBA (”Before use stage” and ”End of life stage”).

IEQ and IAQ: Looking at the existing and already defined Property Sets in the IFC, there are no specific Pset dedicated to these indicators (something like ”Pset_IEQ_space”) and looking at IAQ leads to the same conclusion: no specific already pre-defined structure to express and convey such information or measurement.

Thermal Comfort

In the IFC2x4, several Property sets are already dealing with the notion of Thermal comfort. (From the Core Data Schema):

- **Pset_SpaceThermalDesign:** Space or zone HVAC design requirements. It’s a new property set corresponding to the previous ”Pset_SpaceHvacInformation”;
- **Pset_SpaceThermalLoad**: The space thermal load defines all thermal losses and gains occurring within a space or zone. The thermal load source attribute defines an enumeration of possible sources of the thermal load. The maximum, minimum, time series and app;
- **Pset_SpaceThermalLoadPHistory**: The space thermal load IfcSpaceThermalLoadProperties defines actual measured thermal losses and gains occurring within a space or zone. The thermal load source attribute defines an enumeration of possible sources of the thermal load;
- **Pset_SpaceThermalPHistory**: Thermal and air flow conditions of a space or zone;
- **Pset_SpaceThermalRequirements**: Properties related to the comfort requirements for thermal and other thermal related performances of spaces that apply to the occurrences of IfcSpace or IfcZone. This includes the required design temperature, humidity, and air conditioning;
- **Pset_ThermalLoadAggregate**: The aggregated thermal loads experienced by one or many spaces, zones, or buildings. This aggregate thermal load information is typically addressed by a system or plant;
- **Pset_ThermalLoadDesignCriteria**: Building thermal load design data that are used for calculating thermal loads in a space or building. It’s a new property set corresponding to the previous ”Pset_LoadDesignCriteria”.

This table demonstrates that the proposal made for including environmental property sets in IFC 2x4 standard is completely in line and coherent with SBA metrics calculation. This also shows the need to extend the IFC model with property sets related to IAQ (Indoor Air Quality).

Table 1: IFC 2x4 environmental property set suitability for SBA Environmental metrics calculation

SBA metric	**IFC 2x4 corresponding property** (for the whole life cycle or only for a given phase)	**Comments**
IEQ:	See the details in the paragraph above.	Only notions related to thermal comfort are well covered. IAQ is not already taken into account explicitly.
Global warming potential (GWP)	ClimateChange: Quantity of greenhouse gases emitted	in kg eq CO_2/m^2
Use of non-renewable primary energy	NonRenewableEnergyConsumption: Quantity of non-renewable energy used	in kWh/m^2
Water consumption	WaterConsumption: Quantity of water used expressed	in m^3/time unit
Hazardous waste	HasardousWaste: Quantity of hazardous waste generated	in t/m^2
Non hazardous waste	NonHasardousWaste: Quantity of non-hazardous waste generated	in t/m^2
Inert waste	InertWaste: Quantity of inert waste generated	in t/m^2
Nuclear waste	RadioactiveWaste: Quantity of radioactive waste generated	in t/m^2

Finally, a simplified scheme containing the list of building elements, services and appliances to be taken into account in the calculation of the sustainability indicators as structured in Nibel et al. (2012) is shown in Table 2. This list does not apply to the Indoor Environment Quality indicators.

Table 2: List of Building Elements, Services and Appliances to be taken into account in indicator calculation.

List of Building elements, Services and appliances to be taken into account in indicator calculation	GWP	Energy Consumption	Water Consumption	Waste	IFC Entities	IFC PSET
				* derived from energy provision		
Building products/ Elements						
Roof					IfcRoof	Pset_RoofCommon
Load bearing structure					IfcBuildingEleme nts	
Exterior and basement walls including windows					IfcWall	Pset_WallCommon
Internal walls					IfcWall	Pset_WallCommon
Floor slabs					IfcSlab	Pset_SlabCommon
Foundation					IfcSlab	Pset_SlabCommon
Floor finishes/Coverings					IfcCovering	Pset_CoveringFloor ing
Refrigeration/Coolants					IfcDistributionEl ement	
Decorative wall finishes/coatings (e.g. wallpaper, paints)						
Doors					IfcDoor	
Heating/Cooling/Lighting Equipment and any power generating equipment (e.g. wind turbines/PV/solar heating)					IfcDistributionEl ement	
Internal transport (Lifts, Escalators)					Building equipment	
Water and sewerage systems					IfcDistributionEl ement	
Electrical distribution systems					IfcDistributionEl ement	
Urinals					IfcDistributionEl ement	
WCs					IfcDistributionEl ement	
Taps (internal and external)					IfcDistributionEl ement	
Baths					IfcDistributionEl ement	
Showers					IfcDistributionEl ement	
Building services and appliances						
Heating				*	IfcDistributionEl ement	
Cooling or air conditioning				*	IfcDistributionEl ement	
Ventilation				*	IfcDistributionEl ement	

Heating for provision of domestic hot water				*	IfcDistributionElement	
Lighting				*	IfcDistributionElement	
Internal transports (e.g. lifts, escalators)				*	Building system	
Computers and IT equipment				*	IfcElectricalDomain	
Refrigerators				*	IfcElectricalDomain	
Washing machines				*	IfcElectricalDomain	
Dishwashers				*	IfcElectricalDomain	
Dryers				*	IfcElectricalDomain	
Other 'small power' devices				*	IfcElectricalDomain	
Urinals						
WCs						
Taps (internal and external)						
Baths						
Showers						
Grey water/rainwater systems						
Water softeners (where present)						
Waste disposal units (where present)						
List of Building elements, Services and appliances to be taken into account in indicator calculation	**GWP**	**Energy Consumption**	**Water Consumption**	**Waste**	**IFC Entities**	**IFC PSET**
				* derived from energy provision		
Building products/Elements						
Roof					IfcRoof	Pset_RoofCommon
Load bearing structure					IfcBuildingElements	
Exterior and basement walls including windows					IfcWall	Pset_WallCommon
Internal walls					IfcWall	Pset_WallCommon
Floor slabs					IfcSlab	Pset_SlabCommon
Foundation					IfcSlab	Pset_SlabCommon
Floor finishes/Coverings					IfcCovering	Pset_CoveringFlooring
Refrigeration/Coolants					IfcDistributionElement	
Decorative wall finishes/coatings (e.g. wallpaper, paints)						
Doors					IfcDoor	
Heating/Cooling/Lighting Equipment and any power generating equipment (e.g. wind turbines/PV/solar heating)					IfcDistributionElement	
Internal transport (Lifts, Escalators)					Building equipment	

Water and sewerage systems					**IfcDistributionElement**	
Electrical distribution systems					**IfcDistributionElement**	
Urinals					**IfcDistributionElement**	
WCs					**IfcDistributionElement**	
Taps (internal and external)					**IfcDistributionElement**	
Baths					**IfcDistributionElement**	
Showers					**IfcDistributionElement**	
Building services and appliances						
Heating				*	**IfcDistributionElement**	
Cooling or air conditioning				*	**IfcDistributionElement**	
Ventilation				*	**IfcDistributionElement**	
Heating for provision of domestic hot water				*	**IfcDistributionElement**	
Lighting				*	**IfcDistributionElement**	
Internal transports (e.g. lifts, escalators)				*	**Building system**	
Computers and IT equipment				*	***IfcElectricalDomain***	
Refrigerators				*	***IfcElectricalDomain***	
Washing machines				*	***IfcElectricalDomain***	
Dishwashers				*	***IfcElectricalDomain***	
Dryers				*	***IfcElectricalDomain***	
Other 'small power' devices				*	***IfcElectricalDomain***	
Urinals						
WCs						
Taps (internal and external)						
Baths						
Showers						
Grey water/rainwater systems						
Water softeners (where present)						
Waste disposal units (where present)						

4. CONCLUSION: BENEFITS, GAPS AND EXPRESSION OF FUTURE NEEDS AGAINST BIM CAPABILITIES TO SUPPORT SBA CORE INDICATORS

The paper presents the research work conducted to map the SBA core metrics for sustainability analysis with the IFC model. This mapping exercise showed that even though most of the indicators can be calculated using information contained in the IFC model, there is still some gaps in particular related to

IAQ (Indoor Air Quality). Bridging these gaps by introducing specific p-sets to the IFC model is necessary to allow BIM/CAD tools to efficiently provide input data for LCA tools.

This can explain why the analysis of current software solutions conducted in the research but not presented in this paper showed that there is currently no single tool that supports the whole functionalities of performing, using IFC as input data, a comprehensive sustainable assessment taking into account all SBA indicators.

This shows as a consequence that performing a sustainability assessment with existing tools remains a complex process that may require the use of different software tools and even so, the assessment of all the indicators isn't possible. This consideration reinforces if necessary the importance of the notion of interoperability and beyond it the importance of an open BIM based on an open exchange format.

Also, in all cases, the simulation results and possible conclusions remain in the simulation software. A feedback into the design software using IFC isn't supported. Changes in design due to performance criteria have to be done manually in the design software, the model has to be exported and simulated again.

This research has shown that the functionalities to perform a sustainable assessment using IFC are available even if some extensions are needed. Nevertheless, only and calculation aspects are tackled and there is a definite need to support a process driven approach allowing to high level information exchange regarding sustainable buildings assessment practices. In that context, this research will be pursued in particular to establish a link between IFC/BIM and manufacturers' product catalogues in order to ease the assessment of building sustainability taking into account the real components and systems that will be used.

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