The Building Information Model and the IFC standard: analysis of the characteristics necessary for the acoustic and energy simulation of buildings

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Abstract

The new European Directive 2014/24 / EU requires for all member States the use of BIM procedures in the construction of public buildings. The countries belonging to the European Union shall be obliged to transpose the Directive and adapt their procedures to that effect. The paper analyzes the IFC format, the only recognized by the European Directive Standards for BIM procedures, in order to assess its use for simulations of buildings. IFC, described by the ISO 16739 (2013), is today a standard that describes the topology of the constructive elements of the building and what belongs to it overall. The format includes geometrical information on the room and on all building components, including details of the type for performance (transmittance, fire resistance, sound insulation), in other words it is an independent object file for the software producers to which, according to the European Directive, it will be compulsory to refer in the near future, during the different stages of the life of a building from the design phase, to management and possible demolition at the end of life. The present study aims at carrying out a first analysis on the IFC data format, which will be further deepened in successive phases. The study will compare the information and data contained in it, with those in other formats already used for energy simulations of buildings such the gbXML (Green Building XML), highlighting the missing required information and proposing the inclusion of new data for energetic and acoustic simulation. More generally the attention is focused on the building physics simulation software which is implemented to exploit the BIM model potential enabling interoperability.

1. The introduction at concept BIM and at IFC data format

The IFC initiative began in 1994, when an industry consortium invested in the development of a set of C ++ classes that can support the development of integrated applications. Twelve US companies joined the consortium: these companies that were included initially are called the consortium "Industry Alliance for Interoperability". In September 1995 the Alliance opened up membership to all interested parties, and in 1997 changed its name to "International Alliance for Interoperability". The new alliance was reconstituted as a non-profit organization, with the aim of developing and promoting the " Industry Foundation Class "(IFC) as a neutral data model for the building product that were useful to gather information throughout the life cycle of a building /facility. Since 2005 the Alliance has been carrying out its activities through its national chapters called SMART building. The above data relate to 2015, the first analysis in 2016 lead to consider a significant increase not only in the number of applications but also in the precision of procedure management based on the experience gained in the meantime by the contracting authorities.

Conducting a project with BIM methodology is now necessary and a mandatory condition to achieve a "good design". But what really "good design" means? What are the goals and uses of a BIM model? The technical literature on the topic BIM shows different uses, but very little about how a BIM model can be considered a plausible model for the analysis and simulation of energy and/or acoustic building performance.

Today, it is generally recognized that BIM / IFC standards is capable to centralize the project information throughout its life cycle, information that can potentially serve to all disciplines and sub-disciplines and ensure an integrated and coordinated project. However, to support the work of the operators and at the same time the interoperability many conditions must be met and many problems have to be solved. One of the basic problems is modeling (model quality), linked to the purpose for which the model was made (quantity and quality of the current information in the model) and how this information can be interpreted by the model software.

For energy and acoustics analysis, in the market there are many applications, reliable and mature, but most of them do not directly support the IFC data model. Usually they use a proprietary data scheme, specifically designed to represent the analytical models. This creates a number of challenges in the field of BIM / IFC:

A. Appropriate models. The models for energy - acoustics analysis and simulation require explicit definition of the spaces (rooms and zones) and of their use, the clear specification of the exterior walls, the correct specifications of openings, etc. In an IFC model that should be represented not only visually but at semantic level.

B. Appropriate geometry. The analysis / simulation requires that both thermal and acoustic spaces (zones and rooms) are completely bounded by objects with known physical properties (thermal, acoustic..) taking into account how they are connected with adjacent spaces. This requires a direct connection between the perimeters of the spaces in the model, the objects correspondences along the boundary, the sub-division into homogeneous parts (homogeneous by the analysis criteria) of walls and slabs, checking that there are no gaps along the perimeter or, on the contrary, objects overlapping

C. Integration with non-BIM data. The correct integration of the necessary external data from external non-BIM sources, such as climate data, used and unused times etc. of the spaces, data that must be appropriately associated with the BIM / IFC objects

D. Correct definition of BIM-IFC objects. The model must contain details of the physical properties of objects regardless of the detailed graphical representation level, because this is required by the analysis / simulation tools to determine correctly their properties (e.g. total weight, thermal resistance, U values, etc.)

E. Proximity information. i.e. option to manage information of topology and proximity. This is a kind of information supported by the IFC scheme, but not common for the CAD tools used typically to create BIM. Unfortunately, the energy-acoustics analysis / simulation tools require such an information, therefore if it is missing there is the need to be re-defined from building geometry.

F. Output Editing. The capabilities to edit the output, that is, how "added" information should be properly associated / integrated into the BIM data to enable management, visualization and evaluation of results.

Many of the problems require an extension of the IFC model scheme to an advanced model able to contain the necessary information for the energy-acoustics analysis and simulation. In this work we will focus attention on the characteristics of the building (geometry and physical properties of building components).

2. IFC format and other formats for interoperability

We consider two data formats used to facilitate this interoperability: the first gbXML format, developed by Green Building Studio and the second IFC format, developed by building SMART.

In this paragraph will describe the IFC2x3 format, IFC4 and other formats such as gbXML considering the main frame (wall, floor, slab, roof, windows and door) and their physical properties associated with these components. We will also assess the interaction between the different components such as nodes and joints fundamental for the energetic and acoustic analysis. As mentioned before the IFC format is only part of the BIM processes that actually are designed to manage and contract the procurement procedures and the building management.

2.1 IFC format

Industry Foundation Classes, or IFC, is the official international standard for open BIM and is registered within the International Standardization Organization (ISO). The IFC adopts the "topdown" approach, which creates a complex, hierarchical scheme, developed in a large data file [7].

Additionally building SMART developed a standard for the information flow in an integrated project called Information Delivery Manual (IDM).

The IFC format (Industry Foundation Classes) as mentioned in the introduction is designed to be an interoperability format between different applications, so as to allow its use in different stages of the construction process in the perspective of greater industrialization of the construction sector (building component, building structure , management, disposal). The data structure, very complex, of the IFC format, includes these fundamental concepts. The scheme, as found on the building site SMART [13] is shown in figure 1.

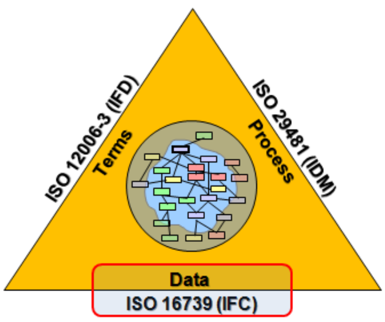

Fig. 1 –Example of structure data organization [19]

The ISO 16739 [11] specifies a conceptual data scheme and an exchange file format for Building Information Model (BIM) data. The conceptual scheme is defined in the EXPRESS data specification language. The standard exchange file format for exchanging and sharing data according to the conceptual scheme is using the Clear text encoding of the exchange structure. Alternative exchange file formats can be used if they conform to the conceptual scheme. Currently there are two types of IFC format, IFC2x3 and IFC 4. In the following the schemes of data formats found on the website [13] are shown in the figures 2,3,4,5.

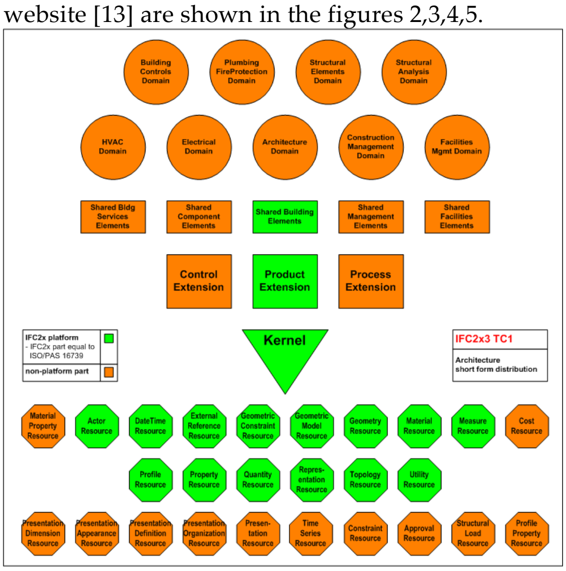

Fig. 2 –Example of structure data, IFC 2x3 format [19]

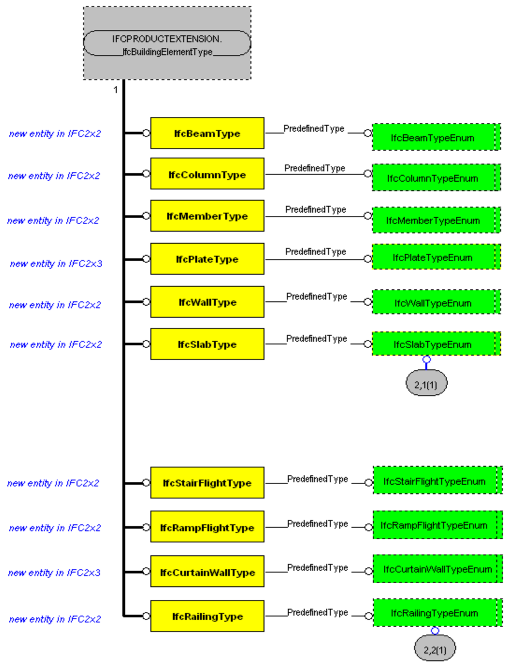

Fig. 3 –Example of structure data, IFC 2x3 format [19]

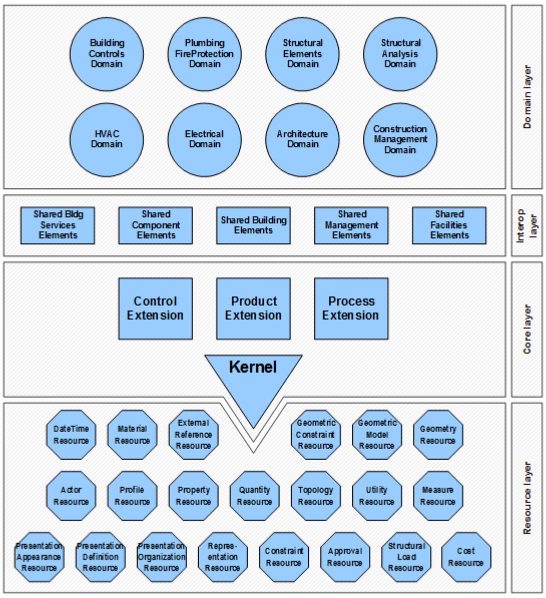

Fig. 4 –Example of structure data, IFC 4 format [19]

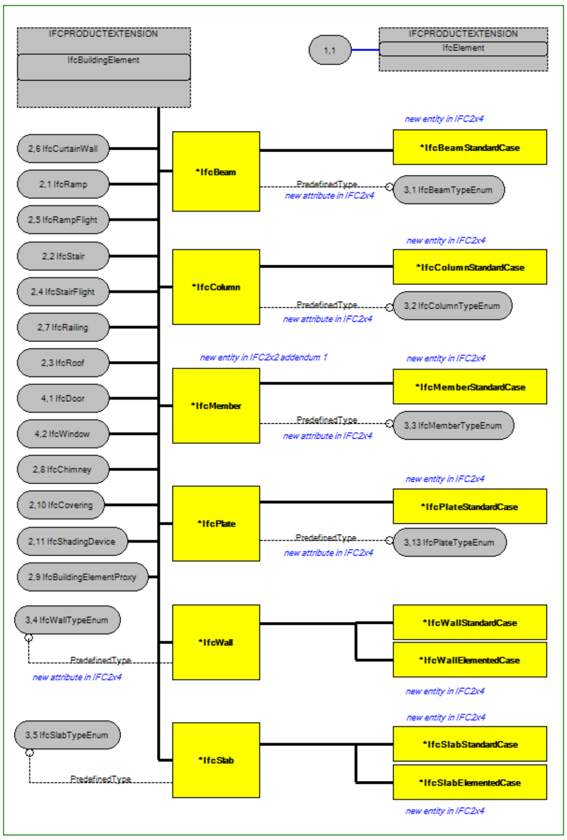

Fig. 5 –Example of structure data, IFC 4 format [19]

2.2 gbXML format

The Green Building XML scheme, or "gbXML", was developed to facilitate the transfer of building information stored in CAD-based building information models, enabling interoperability between disparate building design and engineering analysis software tools [20]. This is all in the name of helping architects, engineers, and energy modelers to design more energy efficient buildings. Today, gbXML has the support of industry and a wide adoption by leading Building Information Modeling (BIM) vendors. In 2009, gbXML was spun off from Green Building Studio to become a stand-alone entity. Today, this development gbXML , is funded by organizations such as the U.S. Department of Energy (DOE), the National Renewable Energy Lab (NREL), software houses and others. Within the standard it uses geometrical and non geometrical information available from the model and saves it in a text format under predefined labels. The information is divided into three different categories: ShellGeometry, SpaceBoundary and Surface. Software tools employing gbXML do not always use all three categories in order to retrieve geometry. Most of them implement ShellGeometry and SpaceBoundary since in combination they represent geometry more accurately [3].

2.3 Features of IFC format

The characteristics of the IFC format are manifold, these range from the description of the geometry of the building, to information on individual building components and various accessories [7]. In this section the main classes that describe the geometric-dimensional information, the building components and their positioning will be detailed [8,9,10,11,12].

As an example of geometry information representation, figure 6 shows how the IFC scheme represents the coordinates and dimensions of an IfcWall object. IfcWall is a subtype of IfcBuildingElement.

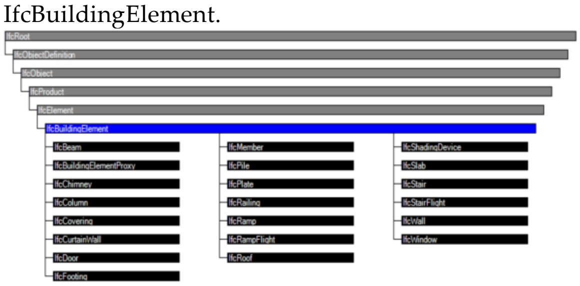

Fig. 6 –Example of IFC 4 format, Building Element - Entity inheritance [19]

IfcBuildingElement is a subtype of IfcElement, which generalizes all components that make up an AEC product such as a wall, window or door.
IfcElement is a subtype of IfcProduct. IfcProduct has two attributes named ObjectPlacement and Representation. ObjectPlacement defines the starting point of IfcWall. It can be given by an absolute value relative to the world coordinate system by IfcGridPlacement; by a relative value, relative to the object placement of another product by IfcLocalPlacement; by grid reference i.e. by the virtual intersection and reference direction given by two axes of a design grid through IfcGridPlacement.
The figure 7 gives and shows an example of how IfcWall is represented as IfcProductRepresentation to elaborate the relational and organized data (representation of IFC).

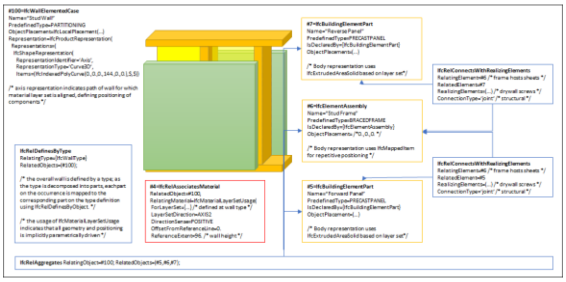

Fig. 7 – Example of IFC 4, format Building Element - object Wall elemented case [19]

For example, the default properties / template of a wall are shown in Table 1 below.

Table 1 – IfcWall Property Sets for Objects

Predefined Type	PsetName
IfcWallType	Pset_WallCommon
IfcWallType	Pset_ConcreteElementGeneral
IfcWallType	Pset_PrecastConcreteElementFabrication
IfcWallType	Pset_PrecastConcreteElementGeneral
IfcWallType	Pset_ReinforcementBarPitchOfWall
IfcWallType	Pset_EnvironmentalImpactIndicators
IfcWallType	Pset_EnvironmentalImpactValues
IfcWallType	Pset_Condition
IfcWallType	Pset_ManufacturerOccurrence
IfcWallType	Pset_ManufacturerTypeInformation
IfcWallType	Pset_ServiceLife
IfcWallType	Pset_Warranty

The IfcProductRepresentation defines a representation of a product, including its geometric or topological representation. It has two attributes: IfcProductDefinitionShape and IfcMaterialDefinitionRepresentation. The IfcProductDefinitionShape defines all shape relevant information about an IfcProduct. It allows for multiple geometric shape representations of the same product. The IfcRepresentation defines the general concept of representing product properties. IfcPlacement locates a geometric item with respect to the coordinate system of its geometric context. It has two attributes called Location and Dim, where Location refers to the geometric position of a reference point, such as the center of a circle, of the item to be located, Dim refers to the space dimensionality of this class and is a IfcDimensionCount object, derived from the dimensionality of the location. IfcPlacement has three subtypes: IfcAxis1Placement, which defines the direction and location in three dimensional space of a single axis; IfcAxis2Placement2D is used to locate and originate an object in two dimensional space and to define a placement coordinate system; finally IfcAxis2Placement3D is used to locate and originate an object in three dimensional space and to define a placement coordinate system.
These are just some of the information data encoded in the data structure of the IFC format

2.4 Characteristics gbXML format

As mentioned before, gbXML has been developed based on XML, which incorporates data information representation but not the relationships among the data. All the geometry information imported from CAD tools are represented by the "Campus" element. The global child element "Surface" represents all the surfaces in the geometry. There are several attributes defined in "Surface" such as "id" and "surfaceType". Every "Surface" element has two representations of geometry: "PlanarGeometry" and "RectangularGeometry". Both of them carry the same geometry information. The purpose of this is to double-check whether the translation of geometry from the CAD software is correct or not. Every "RectangularGeometry" has four "CartesianPoint" elements which represent a surface. Every "CartesianPoint" has a three dimensional representation, by three coordinates (x,y,z).

3. The characteristics necessary for energetic and acoustic analyses

The physical, geometrical, environmental, characteristics, that are necessary for the simulation of the performance of a building, through the use of BIM are many.

The tools that let use the geometrical data or more generally the data of the building from a three-dimensional model, modify and complete the information on the building, on climate, or on different environmental aspects with the need for energy simulations are numerous [1,2,5,6]. Several of them allow to import gbXML and IFC formats automatically or in a semi-automatic way to simplify the input of geometrical data and sometimes of those related to the physical properties of building components. A very important aspect when working with different data formats, is the congruence of geometric information data, which is not always guaranteed, taking into account the input mode required by the software or by the calculation model used for energy simulation [3]. This fundamental aspect, if not considered, can spearhead to results affected by errors [3].

In the following the main features needed by each application are described:

3.1 For Energy simulation

The characteristics that mainly are found missing, in the IFC [21] data format, as the energy simulation is concerned are mainly related to the environmental forcers as, for example, the temperature trend is that is monthly or hourly scheduled as a function of the type of simulation to be performed. Currently calculation standards [14,15,16,17,18] require for energy aspects the knowledge of different physical quantities, factors, or procedures not included in the IFC format. For instance, the UNI EN ISO 13790 [14] lays down the simplification of the calculation of geometry, the subdivision of the whole building into zones according to the type of energy service considered (this means that different areas can share the same space or part of space). Such aspects are not managed, in a comprehensive manner by the IFC, at present. For energy simulation, the IFC format should include the following key figures:

• data relating to environmental inputs (external temperature, solar radiation, vapor pressure, etc.);

• detailed physical characteristics for dynamic calculations (such as the data required by Energy Plus)

• data relating to the building intended use, in particular, the usage profiles;

• data on the energetic zones to apply to the building;

• data on energy consumption the building in the case of energy audits;

• data relating to the characteristics of the energy generation systems (for example heat output power supplied by generators at part loads).

What reported is the main information needed for the energy simulation that are missing; they result from the analysis performed in this study, which will be further developed in successive stages.

3.2 For Acoustic simulation

The simulation of the passive acoustic performance, which can be performed according to the standard EN 12354 [13] requires the distinct knowledge of the individual building components performance, as measured in the laboratory, and the knowledge of the interaction among these components once installed (junctions) . The geometrical identification of the rooms [6], by means of the various components in fact involves obtaining very different performance results with respect to those measured in laboratory for each individual components. Currently IFC has proved lacking as regards the data required for the calculation of passive acoustic aspects.

As regards the acoustics it is evident that the building element performance is not a direct outcome from those of the individual components, in particular as sound insulation and insulation against impact noise are concerned.

It is consequently necessary that the IFC format includes all of the parameters that depend on the junction of more elements or by constraint conditions, in particular:

• Kij - parameter that accounts for the lateral vibration transmission;

• resonance frequency under load for materials for floating floors;

• Delta R due to the coatings that depends on the characteristics of air gap and on the mass of the rear structure;

• for noise transmission from plant operation the possibility (as for the thermal aspects) of including reference data in the dynamic input (sound power released in the structures) is not permitted;

• for the acoustic insulation of the facade it should be noted that the performance depends on geometric and architectural parameters for the same structural components (ratio opaque surface / transparent surface, depth of the rearward room and the façade form factor ΔL_{fs}).

In addition as regards both thermal aspects and acoustic aspects there is the performance problem related to the dynamic data input (Lden like solar radiation, with a value of the annual figure but not of the daily or hourly figure).

4. Conclusion

In the present work the characteristics of the BIM IFC standards have been shown highlighting the limitations and procedures that the use of them involves to run the simulations of the energy and acoustic performance of buildings.

It has also pointed out that the IFC standard, unlike the gbXML standard, is born for procedural, contractual and management purposes of buildings. In order to use the IFC format for yhe prediction of energy and acoustic performance, without having to resort to tools in an unidirectional way or to ensure interoperability it is still necessary a lot of development work, combining the contractual and managerial aspects, the physical and environmental data of buildings.

5. Nomenclature

Symbols

BIM	Building Information Model
BEM	Building Energy Model
BPS	Building Performance Application
IFC	Industrial Foundation Class
gbXML	Green Building xml
xml	Extensive Markup Language
CAFM	Computer Aided Facilities Management
COBie	Construction Operations Building Information Exchange
AEC	Architecture Engineering Construction
IDM	Information Delivery Manual
IDF	Data format for Energy Plus software

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[9] ISO 10303-21, Industrial automation systems and integration — Product data representation and exchange — Part 21: Implementation methods: Clear text encoding of the exchange structure

[10] ISO 10303-28, Industrial automation systems and integration — Product data representation and exchange — Part 28: Implementation methods: XML representations of EXPRESS schemas and data, using XML schemas

[11] ISO 16739:2013, ndustry Foundation Classes (IFC) for data sharing in the construction and facility management industries

[12] ISO 15686-4:2014, Building Construction -- Service Life Planning - Part 4: Service Life Planning using Building Information Modelling

[13] EN 12354, Building acoustics Estimation of acoustic performance of building from the performance of elements.

[14] EN ISO 13790 - Energy performance of buildings Calculation of energy use for space heating and cooling

[15] EN 13788 - Hygrothermal performance of building components and building elements Internal surface temperature to avoid critical surface humidity and interstitial condensation Calculation methods

[16] EN ISO 6946 - Building components and building elements Thermal resistance and thermal transmittance. Calculation method [12] EN ISO 13786 – Thermal performance of building components Dynamic thermal characteristics. Calculation methods

[17] EN ISO 7730 - Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (ISO 7730:2005)

[18] EN 15251 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

Online resource

[19]Building SMART – Internationa home of open BIM http://buildingsmart.org/

[20]gbXML – Industry supported schema for sharing building information between disparate building design software tools. http://www.gbxml.org/index.html

[21] Anafyo - http://www.anafyo.com