The Building Information Model and the IFC Standard: Analysis of the Characteristics Necessary for the Acoustic and Energy Simulation of Buildings

Costantino Carlo Mastino – University of Cagliari – mastino@unica.it
Roberto Baccoli – University of Cagliari – rbaccoli@unica.it
Andrea Frattolillo – University of Cagliari – andrea.frattolillo@unica.it
Martino Marini – University of Sassari – marini@uniss.it
Antonino Di Bella – University of Padova – antonino.dibella@unipd.it
Valerio Da Pos – Cadline Software srl – valerio@cadlinesw.com

Abstract

The new European Directive 2014/24/EU requires the use of BIM procedures in the construction of public buildings for all member States. 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 one recognized by the European Directive Standards for BIM procedures, to assess its use for simulations of buildings. IFC, described by the ISO 16739:2013 standard (ISO, 2013), is 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 rooms and on all building components, including details of the type of 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 the possible demolition at the end of its life. The present study aims at carrying out a first analysis on the IFC data format, which will be further studied in-depth in the following 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 as the gbXML (Green Building XML), highlighting the required information missing, 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 to the BIM Concept and to the 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 initially included, are called the consortium "Industry Alliance for Interoperability". In September 1995 the Alliance opened the 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 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 led to the consideration of 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 does "good design" mean? What are the goals and uses of a BIM model? The technical literature on the BIM topic 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 are capable to centralize the project information throughout its life cycle, information that can potentially serve 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 its 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, there are many reliable applications on the market, 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. An IFC model should be represented not only visually but also at semantic level.

B. Appropriate geometry. The analysis/simulation requires for both thermal and acoustic spaces (zones and rooms) to be 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 subdivision in 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 the objects regardless of the detailed graphical representation level, because this is required by the analysis/simulation tools to determine their properties correctly (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 typically used to create BIM. Unfortunately, the energy-acoustics analysis/simulation tools require such 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 our attention on the characteristics of the building (geometry and physical properties of the building components).

2. IFC Format and Other Formats for Interoperability

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

In this paragraph we 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 the 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 are actually 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 with the International Standardization Organization (ISO). The IFC adopts the "top-down" approach, which creates a complex, hierarchical scheme, developed in a large data file (Dong et al., 2007).

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 a greater industrialization of the construction sector (building components, building structure, management, disposal). The very complex data structure of the IFC format includes these fundamental concepts. The scheme, as found on the building site SMART (BuildingSMART, 2016) is shown in Fig. 1. The ISO 16739 standard (ISO, 2013) specifies a conceptual data scheme and an exchange file format for Building Information Model (BIM) data.

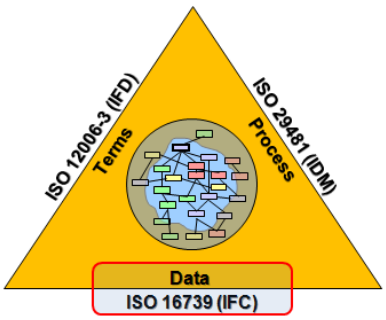

Fig. 1 –Example of data structure organization

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 uses 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 formats: IFC2x3 and IFC 4. In the following the schemes of data formats found on the website (BuildingSMART, 2016) are shown in Fig. 2, 3, 4, and 5.

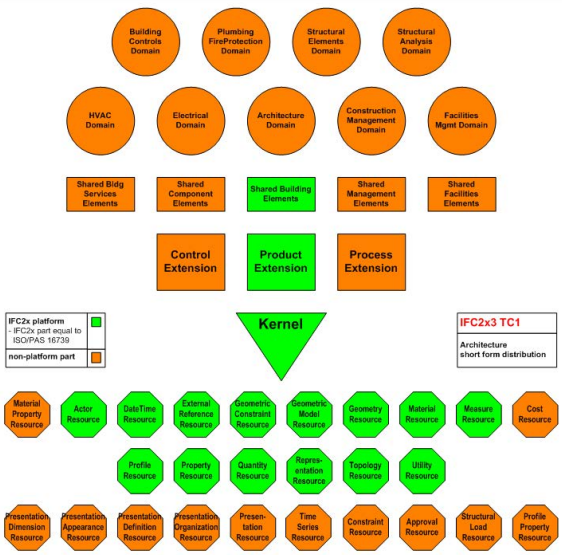

Fig. 2 – Architecture diagram, IFC 2x3 format (BuildingSMART, 2016)

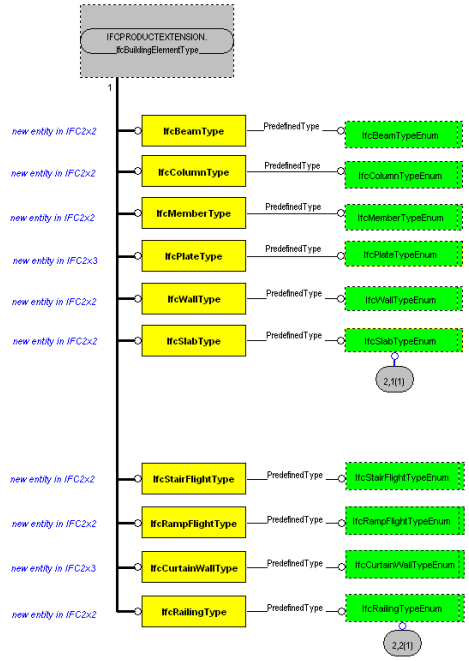

Fig. 3 – Example of data structure IFC 2x3 for building elements

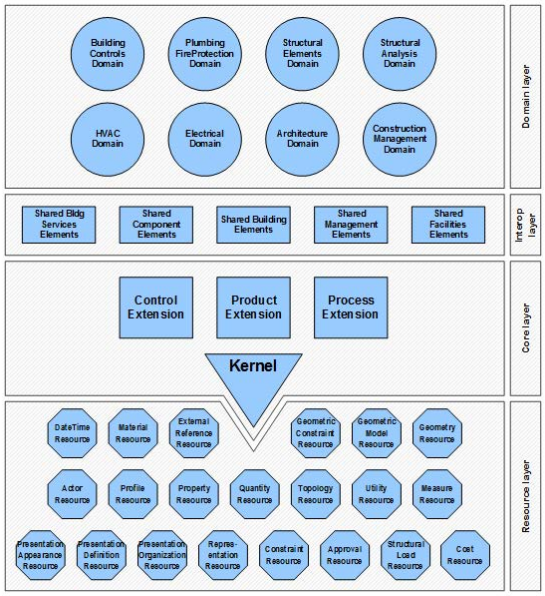

Fig. 4 – Data schema architecture with conceptual layer, IFC 4 format (BuildingSMART, 2016)

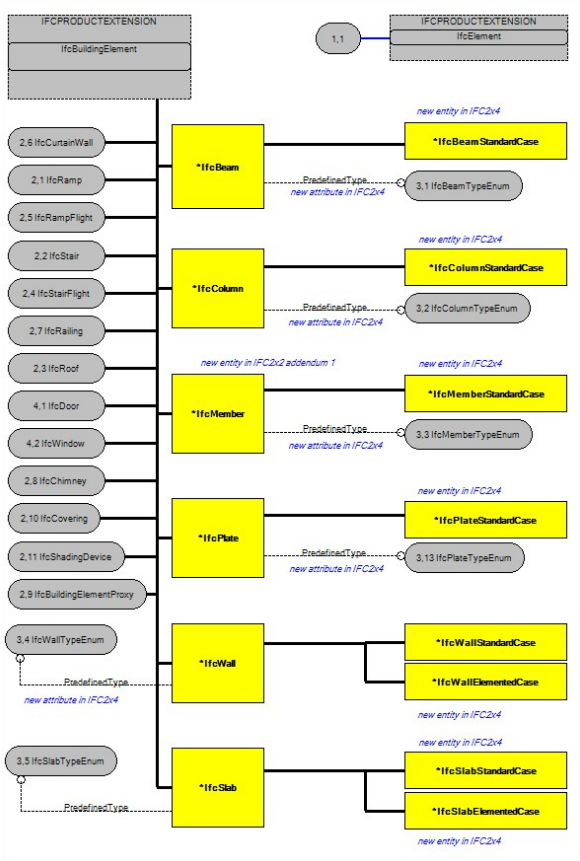

Fig. 5 – Example of data structure, IFC 4 format for building elements (BuildingSMART, 2016).

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 (gbXML, 2016). 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 the industry and has been widely adopted by leading Building Information Modeling (BIM) vendors. In 2009, gbXML was spun off from Green Building Studio to become a standalone entity. Today, the developed 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 (Ivanova et al., 2015) .

2.3 Features of the IFC Format

The characteristics of the IFC format are manifold, they range from the description of the geometry of the building, to information on individual building components, and various accessories (Marini et al., 2015). In this section the main classes that describe the geometric-dimensional information, the building components and their positioning will be detailed (ISO, 2004; ISO, 2016; ISO, 2007; ISO, 2013; ISO, 2014).

As an example of geometry information representation, Fig. 6 (BuildingSMART, 2016) shows how the IFC scheme represents the coordinates and dimensions of an IfcWall object. IfcWall is a subtype of IfcBuildingElement.

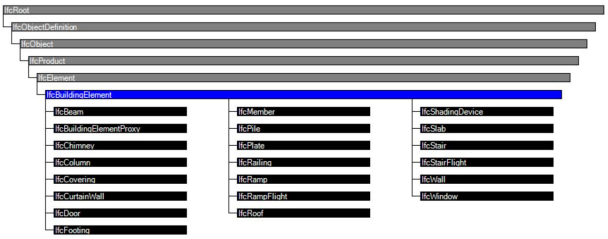

Fig. 6 – Example of IFC 4 format, Building Element - Entity inheritance

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. Fig. 7 gives and shows an example of how IfcWall is represented as IfcProductRepresentation to elaborate the relational and organized data (representation of IFC).

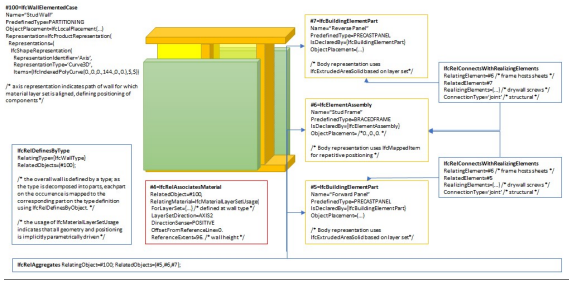

Fig. 7 – Example of IFC 4, format Building Element - object Wall elemented case

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

Table 1 – IfcWall Property Sets for Objects

Predefined Type	
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 the 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 an IfcDimensionCount object, derived from the dimensionality of the location. IfcPlacement has three subtypes: IfcAxis1Placement, which defines the direction and location in the three dimensional space of a single axis; IfcAxis2Placement2D is used to locate and originate an object in a two dimensional space, and to define a placement coordinate system; finally IfcAxis2Placement3D is used to

locate and originate an object in a 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 gbXML Format Characteristics

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 is 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 allow for the use of the geometrical data or more generally of the data of the building from a three-dimensional model, to modify and complete the information on the building, on climate, or on different environmental aspects with the need for energy simulations are numerous (Maile et al., 2007, Bazjanac, 2008, Chiaia et al., 2015, Pinheiro et al., 2016, Marini et al., 2015). 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 the building components. A very important aspect when working with different data formats, is the congruence of geometric information data, which is not always guaranteed, by taking into account the input mode required by the software or by the calculation model used for energy simulation (Ivanova et al., 2015). This fundamental aspect, if not considered, can spearhead results affected by errors (Ivanova et al., 2015).

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

3.1 For Energy Simulation

The characteristics mainly missing in the IFC (Anafyo, 2016) data format as far as the energy simulation is concerned are related to the environmental forcers as, for example, the temperature trend, be it monthly or hourly scheduled, as a function of the type of simulation to be performed. Currently, calculation standards (CEN, 2008; CEN, 2012; CEN, 2007a; CEN, 2007b; CEN, 2005; CEN, 2007c) require for energy aspects the knowledge of different physical quantities, factors, or procedures not included in the IFC format. For instance, the EN ISO 13790:2008 standard (CEN, 2008) 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's intended use, in particular, the usage profiles;
- data on the energetic zones to apply to the building;
- data on energy consumption of the building in 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).

We reported the main information needed for the

energy simulation that is 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 EN 12354:2000 standard (CEN, 2000) requires a distinct knowledge of the individual building component performance, as measured in the laboratory, and the knowledge of the interaction among these components once installed (junctions). The geometrical identification of the rooms (Marini et al., 2015), by means of the various components involves very different performance results with respect to those measured in the laboratory for each individual component. Currently, IFC lacks the data required for the calculation of passive acoustic aspects.

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

It is consequently necessary for the IFC format to include 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

The present work shows the characteristics of the BIM IFC standards, highlighting the limitations and procedures that their use involves in generating energy and acoustic building performance simulations.

It also points out that the IFC standard, unlike the gbXML standard, is born for procedural, contractual, and managerial purposes. In order to use the IFC format for the prediction of energy and acoustic performance without having to resort to tools in an unidirectional way or to ensure interoperability, a lot of development work is still needed to combine the building contractual and managerial aspects, as well as their physical and environmental data.

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

References

Anafyo. 2016. http://www.anafyo.com

Bazjanac, V. 2008. "IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulation". In: *Proceedings of the CIB-W78 25 International Conference on Information Technology in Construction*. Santiago, Chile.

Building SMART. 2016. International home of open BIM. http://buildingsmart.org/

CEN. 2000. *EN 12354:2000, Building acoustics Estimation of acoustic performance of building from the performance of elements*. Brussels, Belgium: CEN.

CEN. 2005. *EN ISO 7730:2005 - 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.* Brussels, Belgium: CEN.

CEN. 2007a. *EN ISO 6946:2007 - Building components and building elements Thermal resistance and thermal transmittance. Calculation method.* Brussels, Belgium: CEN.

CEN. 2007b. *EN ISO 13786:2007 – Thermal performance of building components Dynamic thermal characteristics*. Calculation methods. Brussels, Belgium: CEN.

CEN. 2007c. *EN 15251:2007 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. Brussels, Belgium: CEN.

CEN. 2008. *EN ISO 13790:2008 - Energy performance of buildings Calculation of energy use for space heating and cooling*. Brussels, Belgium: CEN.

CEN. 2012. *EN ISO 13788:2012 - Hygrothermal performance of building components and building elements Internal surface temperature to avoid critical surface humidity and interstitial condensation Calculation methods*. Brussels, Belgium: CEN.

Chiaia, B., S. Davardoust, A. Osello, N. Aste, M. Mazzon. 2015. "BIM and Interoperability for energy simulations". In: *Proceedings of BSA 2015*. Bolzano, Italy: BUPRESS.

Dong, B., K.P. Lam, Y.C. Huang, G.M. Dobbs. 2007. "A Comparative Study of the IFC and gbXML Informational Infrastructures for Data Exchange in Computational Design Support Environments". In: *Proceedings of BS 2007*. Beijing: IBPSA.

gbXM. 2016. Industry supported schema for sharing building information between disparate building design software tools. http://www.gbxml.org/index.html

ISO. 2004. *ISO 10303-11:2004, Industrial automation systems and integration — Product data representtation and exchange — Part 11: description methods: The EXPRESS Language Reference Manual*. Geneve, Switzerland: ISO.

ISO. 2007. *ISO 10303-28:2007, Industrial automation systems and integration — Product data representtation and exchange — Part 28: Implementation methods: XML representations of EXPRESS schemas and data, using XML schemas*. Geneve, Switzerland: ISO.

ISO. 2013. *ISO 16739:2013, Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries*. Geneve, Switzerland: ISO.

ISO. 2014. *ISO 15686-4:2014, Building Construction – Service Life Planning - Part 4: Service Life Planning using Building Information Modelling*. Geneve, Switzerland: ISO.

ISO. 2016. *ISO 10303-21:2016, Industrial automation systems and integration — Product data representtation and exchange — Part 21: Implementation methods: Clear text encoding of the exchange structure*. Geneve, Switzerland: ISO.

Ivanova, I., K. Kiesel, A. Mahdavi. 2015. "BIM-generated data models for EnergyPlus- A comparison of gbXML and IFC Formates". In: *Proceedings of BSA 2015*. Bolzano, Italy: BUPRESS.

Maile, T., M. Fischer, V. Bazjanac. 2007. "Building Energy Performance Simulation Tools -a Life-Cycle and Interoperable Perspective". *CIFE Working Paper #WP107*. Stanford, U.S.A.: Stanford University.

Marini, M., R. Baccoli, C.C. Mastino, V. Da Pos, Z. Tòth. 2015. "A new computational model: G.E.A.R. Graphical Expert Analytical Relations". In: *Proceedings of BSA 2015*. Bolzano, Italy: BUPRESS.

Pinheiro, S., J. O'Donnell, R. Wimmer, V. Bazjanac, S. Muhic, T. Maile, J. Frisch, C. Van Treeck. 2016. "Model View Definition For Advanced Building Energy Performance Simulation". In: *Proceedings of BauSIM 2016*. Dresden, Germany.