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"BIM AND PLANT SYSTEMS: A SPECIFIC ASSESSMENT"

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Abstract

It is now known that the use of Building Information Modeling (BIM) procedures offers many benefits in the design and management of buildings. According to recent legislative enactments the BIM procedures will become mandatory for Public Works as from 2019. There are several advantages by using BIM procedures, among them the following can be highlighted: gaining a clear overview of the building plant system, evaluating the spatial coherence of the plant networks, the evaluation of the interferences to keep the system do not interfere with the functionality or the aesthetics of built environments. The present work analyzes the BIM procedures with particular reference to air conditioning systems in existing buildings, to their performance and management characteristics. The objective consists of analyzing the different BIM procedures and critically comparing the information provided by the IFC standard published by the European Institution Building SMART International, recognised as a standard by ISO, with the main reference standards for building installations and facilities design.

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1. Introduction

Building Information Modeling (BIM) can be defined as a virtual 3D building model which integrates with a database of the building elements. Using BIM tools entails the definition of a virtual model including graphic information and data about materials and components of the building [1]. The development or detail level is a concept adopted to describe information richness of the BIM model, it is defined by the amount of information about the building [2]. Application of BIM to most aspects of building design and operation has been explored in depth since its appearance as a comprehensive term for the processing of data describing a building [3].

A target of BIM application can be found in performance assessment and simulation, being energy management a growing trend within building areas. Instead, BIM application to building performance management during operation is restricted to the advantage of process optimisation, information querying and retrieval [4].

BIM can play a key role in analysing and determining energy consumption in existing buildings, as it has an relevant effect on the accuracy of estimates. Since BIM is a tool to estimate accurately building information it can be used to predict the energy results of retrofit measures by creating models of existing buildings, setting alternatives, comparing building performance for such alternatives [5]. BIM is capable of facing complex challenges in refurbishment projects, and can play a role in determining optimization requirements [6].

Moreover, BIM is more cost and time effective to assess the sustainability of refurbishment projects and can contribute to economic development. Environmental problems arising from the building sector demand for specific tools to help reduce finite resource consumption and carbon footprint. Life Cycle Assessment, widely used tool to quantify the environmental impacts of the building sector, can integrate with BIM to simplify data acquisition and to provide an effective feedback [7].

Within this framework of different powers of BIM the issues concerning the completeness of data and their use cannot be neglected [8],[9],[10]. In the paper the problems found in BIM application to building installations are investigated with special attention to data format and their interoperability [11]

Nomenclature

BIM Building Information Modelling
IFC   Industry Foundation Classes
BPM Building Performance Modelling

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2. BIM formats and definitions

Building Information Modeling (BIM) is starting to spread increasingly at international level since it allows time-and-money savings during the building comprehensive lifecycle. The BIM data format named Industry Foundation Classes, IFC, is a standard format which is open to the BIM data that are exchanged and shared among the software applications used by the participants to building sector or facility management [12]. Such a standard format includes definitions that cover all the data required by buildings over their lifecycle. The version IFC 4.0 broadens further and describes data definitions for the resources of each framework over its lifecycle. The classes of format IFC 4.0 specify a data collection scheme as well as an exchange structure. As described with BuldingSMART Europa [13], the data collection scheme is defined according to:
- EXPRESS language for data specification, defined in ISO 10303-11,
- Scheme XML (XSD), defined in the recommendation concerning the scheme XML W3C.

The definition of the EXPRESS scheme is the source and the definition of the scheme XML is generated with the EXPRESS scheme on the basis of the mapping rules specified in in ISO 10303-28. Formats of swapfiles for data exchange and sharing are set out according to the conceptual framework:
- Clear text encoding of the exchange structure, as defined in ISO 10303-21,
- Extensible Markup Language (XML), defined in the recommendation W3C XML.

Alternative formats of swapfile can be used if they are consistent with data collection schemes. Version 4.0 of IFC includes data collection schemes, represented as an EXPRESS scheme and a XML scheme, and reference data,

represented as definitions of property names, quantities, formal and informative descriptions. A subset of the data collection scheme and of the reference data is defined as MVD (Model View Definition). A peculiar MVD is defined in order to support one or more workflows known and recognized in the sectors of construction industry and facility management. Each workflow identifies the requirements for data exchange in software applications (Figure 1). The corresponding software applications have to identify the definition of the model with which they are consistent. The purpose of the present work consists of analyzing information included into the IFC scheme as regards the air conditioning systems, with which a building is equipped, pointing out its characteristics and deficiencies.
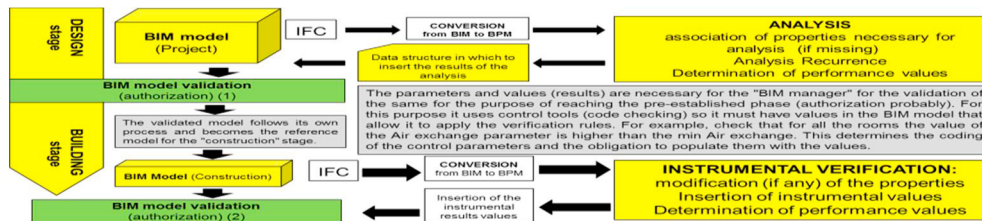

Fig. 1. Flow diagram for BIM operation

3.The standard format IFC and the plant systems

The IFC standard consists of a scheme which defines data types, as well as common concepts denoting the use of data types in specific scenarios. In the following such common concepts are dealt with and they are applied to entities that own a specific use (plumbing, HVAC…). Furthermore these concepts form the basis of BIM views, which are additional specifications fitting the scope and the rules of the scheme to targeted domains within the building sector. Each concept model draws up a graphical development of entities and attributes, with constraints and parameters set for specific attributes and request types. Several entities within this scheme relate to such conceptual models and fit them to a special use on the basis of specific parameters. For instance the concept model "Doors" defines the connectivity of the distribution system as mechanical, electrical and hydraulic systems are concerned; a tube segment is an application of the concept 'Doors', having a door as input and a door as output. In case of plant systems the IFC 4.0 format defines, among the different domains contained within, two specific domains just for plant systems. The former named "IfcHvacDomain" for air conditioning systems and the latter named "IfcPlumbingFireProtectionDomain" for the hydraulic systems designed to fire services. The entities managed with these domains are schematic in figures 2 and 3.
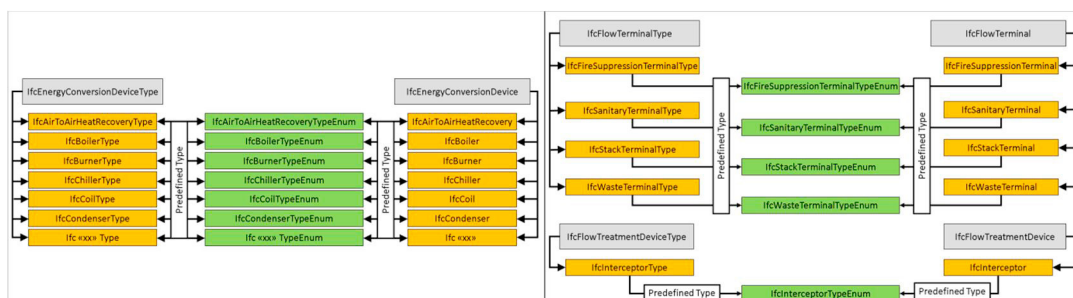

Fig. 2. Example of some data types for HVAC systems in IfcHvacDomain and IfcPlumbingFireProtectionDomain
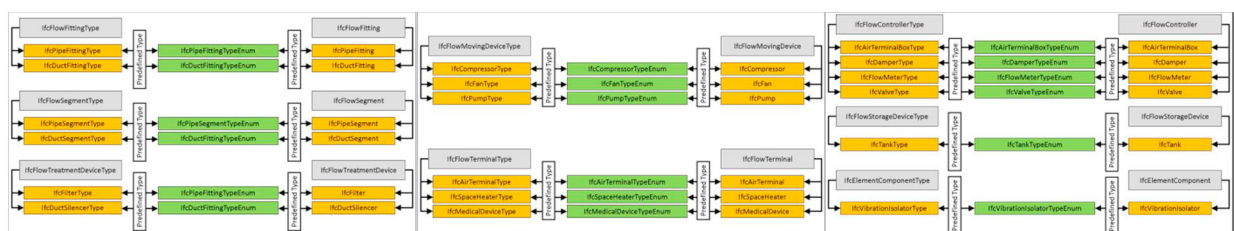

Fig. 3. Data types for HVAC systems Definition of the scheme IfcHvacDomain

The scheme IfcHvacDomain defines the concepts of basic object which are required to get the interoperability in the heating, ventilation and air conditioning (HVAC) domain. It extends the concepts defined with the scheme IfcSharedBldgServiceElements. The range of the scheme IfcHvacDomain is defined as:

• Segments, junctions and connections forming the distribution systems through piping and ducts customarily used in building services, such as air conditioning plants, ventilation and exhaust air systems, as well as water heating, vapor, drinking water, waste, natural gas, LPG systems, etc.

• Facilities customarily used in building services, as boilers, chillers, fans and pumps, the vibration dampers associated to such components.

• Devices for heating flow and terminal control, such as vents and distribution grids, modulators of air flow rate, valves and louvers.

The following elements, at present, are considered beyond the scope of the IfcHvacDomain scheme:

• Special industrial and institutional facilities as those used for electricity production and distribution, etc.

• Provisions to process specifically hazardous material such as chemical or biological agents,

• System controls and sequencing systems concerning the above facilities in addition to what has been set out in the scheme of IfcBuildingControls domain.

3.1 Definition of the scheme IfcPlumbingFireProtectionDomain

The scheme IfcPlumbingFireProtectionDomain is a part of the Domain Layer of IFC model. It extends the ideas concerning construction service as outlined in the scheme IfcSharedBldgServicesElements, and points out concepts in the field of hydraulics and fire protection. The aim of IfcPlumbingFireProtectionDomain, in conjunction with other schemes linked to laid down services to the buildings, is the provision of plumbing and fire protection to buildings. In the case of plumbing, the scope includes supply of services that are external to the building, from it up to the final manhole where a connection to the public network for sewerage /drainage is made. Special exceptions in support of the control requirements of building code have been made as shown in the following. In the case of fire safety, the scope includes all the services from the point where it is connected to a fire fighters service or the point where the water network manager provides the supply (water meter). In detail, the IfcPlumbing-FireProtectionDomain scheme supports concepts which includes the types:

• sanitary appliances for personal and public hygiene,

• traps along gas pipelines to prevent any backflow and odor transmission,

• interceptor to capture unwanted solid and liquid material and to prevent their passage into drainage ducts,

• unit for waste disposal,

• terminal ventilation and piping for rainwater at the maximum elevation,

• manual and automatic terminals that can be activated to put out the fire,

• fire hydrants that provide a water source to the hoses in case of fire or for other needs requiring a temporary water supply.

3.2 Managed units and data collection schemes for each domain

The data collection schemes that are specific of each domain include final specializations of entities as shown in the list hereinafter:

• 1 IfcArchitectureDomain
• 2 IfcBuildingControlsDomain
• 3 IfcConstructionMgmtDomain
• 4 IfcElectricalDomain
• 5 IfcHvacDomain
• 6 IfcPlumbingFireProtectionDomain
• 7 IfcStructuralAnalysisDomain
• 8 IfcStructuralElementsDomain

Entities defined in this level are autonomous, on their own, and cannot be referred with no other level. The specific level of the domain sets up the definitions on the basis of the sector discipline. Domains called "7.5

IfcHvacDomain" are of interest to us as the installation field is concerned. Such domains include the 66 entities that are nowadays encoded into data format IFC 4.0: they are listed respectively in table 1 for the scope of HVAC systems and per in table 2 for the scope of fire-fighting systems.

Table 1 – Main plant entities managed with ifcHvacDomain

n.	Entities	n.	Entities	n.	Entities	n.	Entities
1	IfcAirTerminal	10	IfcCooledBeam	19	IfcFan	28	IfcPumpType
2	IfcAirTerminalBox	11	IfcCoolingTower	20	IfcFilter	29	IfcSpaceHeater
3	IfcAirToAirHeatRecovery	12	IfcDamper	21	IfcFlowMeter	30	IfcTank
4	IfcBoiler	13	IfcDuctFitting	22	IfcHeatExchanger	31	IfcTubeBundle
5	IfcBurner	14	IfcDuctSegment	23	IfcHumidifier	32	IfcUnitaryEquipment
6	IfcChiller	15	IfcDuctSilencer	24	IfcMedicalDevice	33	IfcValve
7	IfcCoil	16	IfcEngine	25	IfcPipeFitting	34	IfcVibrationIsolator
8	IfcCompressor	17	IfcEvaporativeCooler	26	IfcPipeSegment	35	IfcAirTerminalBoxType
9	IfcCondenser	18	IfcEvaporator	27	IfcPump	36	IfcAirTerminalType

Table 2 – Plant entities managed with IfcPlumbingFireProtectionDomain

n.	Entities
1	IfcFireSuppressionTerminal
2	IfcFireSuppressionTerminalType
3	IfcInterceptor
4	IfcInterceptorType
5	IfcSanitaryTerminal
6	IfcSanitaryTerminalType
7	IfcStackTerminal
8	IfcStackTerminalType
9	IfcWasteTerminal
10	IfcWasteTerminalType

3.3 Property Sets and Type

All the plant entities defined in IFC 4.0 are characterized by a set of data defined in turn as Property Sets for Objects [13]; some of them are common to many entities, some other are specific to the described entity. Task of Property Sets is to describe how data sets (usually referred to as a name, a value and unit of measurement or data type) are associated with objects or object types. For instance the generation systems "IfcEngine" defined in point 7.5.3.31 of IFC 4.0 scheme in buildingSMART [13] and described with the Property Sets reported in table 3.

Table 3 – Property Sets for ifcEngine Objects

PredefinedType	PsetName	Properties
-	Pset_EngineTypeCommon	-
-	Pset_SoundGeneration	-
-	Pset_ElectricalDeviceCommon	-
-	Pset_EnvironmentalImpactIndicators	-
-	Pset_EnvironmentalImpactValues	-
-	Pset_Condition	-

-	Pset_ManufacturerOccurrence	-
-	Pset_ManufacturerTypeInformation	-
-	Pset_ServiceLife	-
-	Pset_Warranty	-

In addition to property sets entities are described by the Type i.e. entity types or links with entity types. For instance the "IfcEngineType" type describes the kind of thermal generator, while the "IfcDistribution-FlowElementType" type describes the system type the generator is linked with. By way of example the types the object ifcEngine are linked with are reported in table 4.

Table 4 – Object Typing applied to ifcEngine entity

HasType	RelatingType	TypeName
-	IfcEngineType	-
-	IfcDistributionFlowElementType	-
-	IfcDistributionElementType	-

4. Variables and performance of plant systems

Inside the Property Sets, as can be deduced from the name list in Table 3, the different data concerning the performance of the set of installations are set out, usually in terms of physical properties of components but not only those. Indeed there is information concerning the noise of the specific component, warranty, maintenance, environmental aspects.

4.1 Energy

With regard to environmental aspects, a lot of information are contained within Property Sets. For instance in the Pset_EngineTypeCommon shown in Table 5 in the case of a generation system, references to the energy carrier used with such a system are given. This Property Set in turn makes reference to the enumeration set "PEnum_EngineEnergySource" which sets out the list of different energy carriers, as shown in Table 6.

Table 5 – Variables in "Pset_EngineTypeCommon" Property Set

Name	Type	Description
Reference	P_SINGLEVALUE / IfcIdentifier *	Reference ID for this specified type in this project (e.g. type 'A-1'), Also referred to as "construction type". It should be provided as an alternative to the name of the "object type", if the software does not support object types.
Status	P_ENUMERATEDVALUE / IfcLabel / PEnum_ElementStatus*	Status of the element, predominately used in renovation or retrofitting projects. The status can be assigned to as "New" - element designed as new addition, "Existing" - element exists and remains, "Demolish" - element existed but is to be demolished, "Temporary" - element will exists only temporary (like a temporary support structure).
EnergySource	P_ENUMERATEDVALUE / IfcLabel / PEnum_EngineEnergySource	The source of energy.

Table 6 – Variables in the "PEnum_EngineEnergySource" enumeration set

Name	Description
DIESEL	Diesel
GASOLINE	Gasoline
NATURALGAS	Natural Gas
PROPANE	Propane
BIODIESEL	Biodiesel
SEWAGEGAS	Sewage Gas
HYDROGEN	Hydrogen
BIFUEL	Bifuel
OTHER	(other) Value is not listed.

UNKNOWN	Unknown	
UNSET	(unset) Value has not been specified.	

Many properties are alike in all the air-conditioning subsystems (emission, regulation, distribution, storage and generation), some other are typical of the specific subsystem. However many data needed by the energy calculations are missing as, for instance, many of the properties required by UNI, EN, ISO standards, in detail the old UNI EN ISO 13790 [14] o the new ISO 52016 [15].

4.2 Acoustics

With regard to the noise generated by building facilities, the IFC format essentially provides for two data sets, entitled respectively "Pset_SoundAttenuation" [http://www.buildingsmart-tech.org/ifc/IFC4/Add2/html/link/-ifclabel.htm] and "Pset_ SoundGeneration" ; inside such PSets frequency values concerning the attenuation of the emitted sound power are recalled in tabular form. In tables 7 and 8 the variables covered with the two PSets are given in full.

Table 7 – Variable set Pset_SoundAttenuation

Name	Type	Description
SoundScale	P_ENUMERATEDVALUE / IfcLabel / PEnum_SoundScale	Sound Scale -The reference sound scale. DBA: Decibels in an A-weighted scale DBB: Decibels in an B-weighted scale DBC: Decibels in an C-weighted scale NC: Noise criteria NR: Noise rating
SoundFrequency	P_LISTVALUE / IfcFrequencyMeasure	Sound Frequency - List of nominal sound frequencies, correlated to the SoundPressure time series values (IfcTimeSeries.ListValues)
SoundPressure	P_REFERENCEVALUE / IfcTimeSeries / IfcSoundPressureMeasure	Sound Pressure - A time series of sound pressure values measured in decibels at a reference pressure of 20 microPascals for the referenced octave band frequency. Each value in IfcTimeSeries.ListValues is correlated to the sound frequency at the same position within SoundFrequencies.

Table 8 – Variable set Pset_ SoundGeneration

Name	Type	Description
SoundCurve	P_TABLEVALUE / IfcFrequencyMeasure / IfcSoundPowerMeasure	Sound Curve - Table of sound frequencies and sound power measured in decibels at a reference power of 1 picowatt(10^{-12} watt) for the referenced octave band frequency.

The variables found within the IFC format, in addition to stand in as nameplate rating of plant components, can be used into calculation models for predictions aimed at the design phase, They are described in the standards from UNI EN 12354 [16] series with special reference to part 5.

4.3 Remarks and proposal

From the analysis carried out on the IFC data format, which is recognized by ISO 16739 [17] as BIM format, it has been found that various data concerning the performance of the building installations and the single components of them are not represented in this format. This aspect, which could be read as a shortage not relevant to the main purpose of construction management to which BIM is mainly addressed, plays a fundamental role in the informed choice of components by the operators and in the assessment of the potential of each component, at least in the opinion of the authors.

The proposal, which we intend to put forward with this work, is to insert some new Psets within the above standard that describing the performance of each single installations component. It would prevent each manufacturer from putting on the marked plant components with customized Psets, thus making it difficult to compare them for the choice made by the designers, as well as allowing the use of these data for analysis or design calculations. The standardization of the performance parameters, would allow in any case, since the IFC format is an open format, to all manufacturers of components or systems, to add, besides the usual parameters, the performance features of their

own products as already happens for the building components. In conclusion, the new Psets which are intended to be introduced into the IFC standard for plant systems and which will be the subject of a further study, should carry all the variables provided with the different rules intended for performance evaluation by the national (Italian) (such as UNI TS 11300) and / or international standards such as UNI EN ISO 13790 [14] or the more recent ISO 52016 [15]. At an early analysis the quantity of variables giving rise to the performance of the different plant systems, just according to the aforementioned standards, may seem very extensive and one might think that this could overload the BIM model. Actually, it has been ascertained by various tests, carried out with the use of Authoring Tool software, that the such data modify the size of the model to an irrelevant extent, sometimes undetectable if compared to the amount of data that the BIM has to manage for 3D representation.

5. Conclusions

In conclusion, in the work the IFC data format has been analyzed, focusing the attention on building installations, in particular to HVAC systems. These have been found to be described in the above data format by 66 types of entities and by numerous sets of descriptive parameters, many of which are common to the different entities described. With regard to the variables needed to express the energy and acoustic performance, the present analysis highlighted the lack of data in the data structure concerning various parameters provided for in the existing design standards. Such lacks could be balanced out into the IFC format to make possible its use also for purposes related to the performance calculation or to improve the mere performance comparison among the same entities.

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