Application of BIM Model Checking in building acoustic design

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Abstract
Building Information Modelling (BIM) is a process with an increasing diffusion in the construction market that leads to considerable savings in realization times and building management costs. Within the BIM methodology, a key role is played by Model Checking for the validation of the projects not only during the design stage, but also during all the phases of the building process. The control of geometric interferences in the Building Performance Modelling (BPM) can be easily applied in the evaluation of the acoustic performance of a building using standardized methods. The purpose of this paper is to analyse the information contained in BIM data structure that can be used to design or to evaluate compliance with acoustic classes or, in general, the acoustic performances of a building.

Keywords: BIM, Building Acoustic Design, Building Performance Modelling.

1 Introduction

The use of the Building Information Modelling (BIM) methodology has now passed the initial phase of development to become a consolidated reference for buildings, especially those of considerable complexity or articulation [1,2].
Despite the widespread diffusion of these methodologies and their adoption within building codes and construction protocols [3] (Figure 1), there are still many aspects that have not been fully investigated and the potential not explored is considerable.
According the United States National Institute of Building Sciences (NIBS) “A BIM is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward” [4]. It is, therefore, a methodology based on the digitization of the entire building process for data sharing [5]. This exchange process is meant to be continuous and updated from the conception and design of the building to its construction and management over the course of life up to its disposal “from the cradle to the grave”.
One of the fundamental aspects of Building Information Modelling is to represent the building geometrically and graphically through the creation of a three-dimensional model to be associated in the different phases of the building's life. The essential information (functional, performance, management or more generally relating to the building at different levels and for different purposes) are always accessible, consultable and updatable.
BIM was originally proposed with the aim of achieving an economic saving in the building management phase. However, the advantage that can be obtained when trying to use the BIM model for the Building Performance Model (BPM) to estimate the performance of the building during the design phase was immediately evident [6-12]. The BIM model identifies the real model, or its digital representation, in which

the digital content (geometric and informative) varies according to the purpose and the phase in which the model is made available for its use.
Traditional modelling processes for energy simulation (Building Energy Model, BEM) or other physical aspects such as acoustic requirements simulation (Building Acoustic Model, BAM) are generally complex, time-consuming and specifically prepared for simulation application used. This involves high costs, long times, geometric simplifications and errors. In essence, these typical processes reproduce the data already existing under other aspects, that is the models usually made for the architectural and structural part. This results in high costs, long lead times, geometric approximations and potential modelling errors. In practice, these processes reproduce the already existing data, that is the models usually created for the architectural part, with other purposes. The risk of "translation errors" between models is often high, also considering that they are developed by different operators and at different times.
It is evident that the use of a standardized information coding process can significantly reduce these risks, also through control and validation processes.
The advantages of these processes, automatic or semi-automatic, can be summarized in four factors:

1) reduction of time and costs required to develop a physical simulation model of the building;
2) rapid generation of design alternatives;
3) improvement of the accuracy of Building Performance Modelling Simulation (BPMS);
4) building construction process with significantly higher performance.

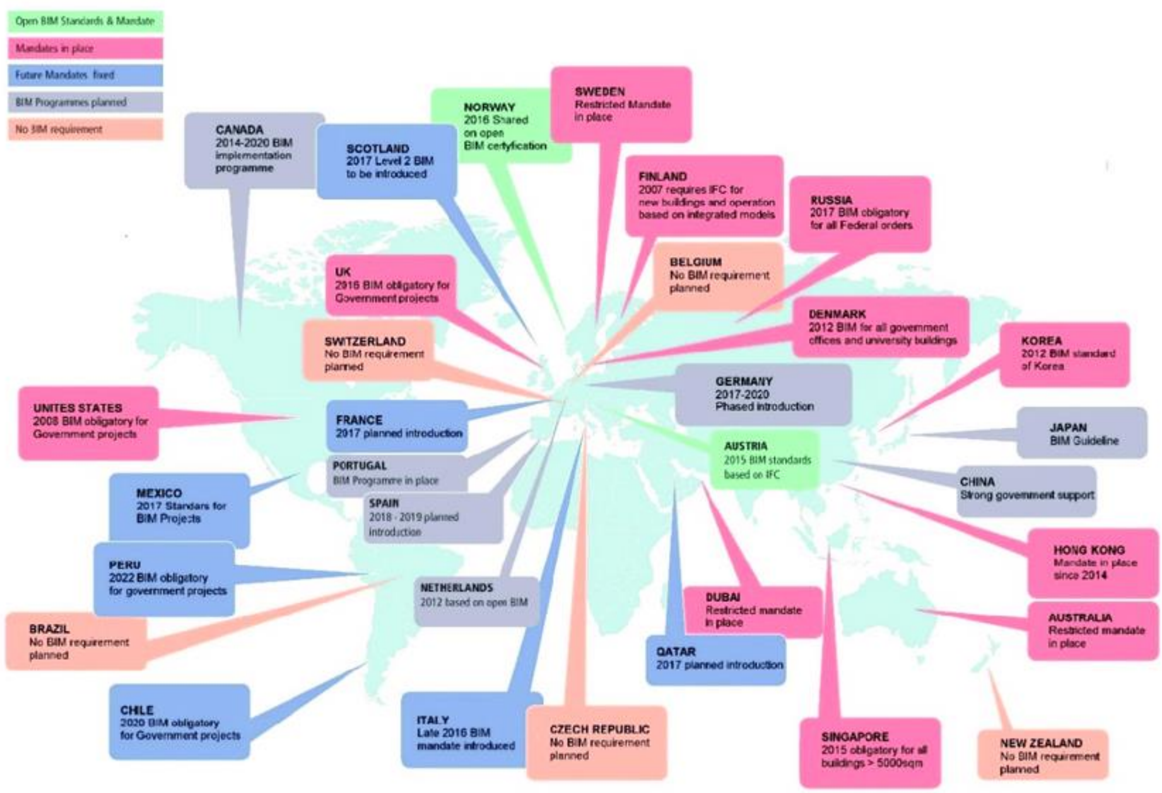

Figure 1 – Overview of global BIM adoption [3].

This paper examines a particular methodological aspect of the acoustic design of buildings with the support of the BIM methodology, described in its general aspects in previous works [13-16].

2 Opportunities and limits of BIM oriented acoustic models

BIM is a data format model that applies to a database of elements, each containing specific information that is uniquely defined.
From a general point of view, BIM is just one of the possible digital representations of a building model. What makes a method successful is the ability to share this digital and informative representation among all the participants in the compressive building process of its geometric, physical and functional characteristics, based on open standards to ensure interoperability. However, one of the biggest limitations in using BIM for acoustic modeling lies precisely in the definition of the properties of the elements used in the model.
There are many building-proprietary data models. The IFC (Industry Foundation Classes) model [17] promotes a representation format of the open BIM model and throughout the building's life cycle. IFC format is recognized from the International Standards Organization as ISO 16739 [5]. A Model View Definition (MVD) defines a subset of the IFC schema needed to satisfy one or more Architecture, Engineering, and Construction (AEC) industry exchange requirements. Together with the subset of the IFC schema, a set of implementation instructions and validation rules, called MVD concepts. The method for publishing the associated concepts and rules is mvdXML. An application of the concept of MVD takes, for example, extrapolation from the IFC data model of the geometrical and performance information, aimed at acoustic prediction calculation or evaluation of acoustic performance on site.
From this point of view, the BIM methodology is optimal for defining automatic or semi-automatic procedures for the generation of buildings acoustic models, especially for the prediction of noise levels with the methods of the ISO 12354 series standards.
In this case, in fact, the correct definition of the geometric properties of the environment and their relationship with the structures and systems is essential to identify the acoustic criticalities in the building project. However, the calculation methods require information on building elements and their interaction which are not fully contained in the ICF data model.
The set of all the properties that can be assigned to an object of an IFC data model is called “Pset” (IfcPropertySet). The properties contained in this set (or set) can be of two types:

- predefined;
- additional/customized (i.e. defined by the user).

The default properties are those that follow the standard; they are automatically generated by the authoring software that was used to model the building design and are listed in the specifications of each entity of the 3D model. In addition to the predefined properties, it is also possible to define custom properties, i.e. those added to the model directly by the user. These properties follow a non-standard nomenclature but chosen in a conventional way among the different actors involved in the building process.
The current version of IFC (4.3) provides seven Pset code results in IFC Documentation under the search entry "Acoustic Rating" and two Psets under the search entry "Sound". These Pset are correlated to specific performance levels that must be traced back to standardized parameters for the characterization of building elements and systems serving the buildings (Table 1).
Other properties can be defined in relation to the noise generated by the systems, mainly HVAC, also in relation to the resulting sound pressure levels (both in the prediction phase and verification on site). However, some critical aspects for the prediction of passive acoustic requirements are not fully defined, which depend on the physical interaction between different building elements (eg: the vibration reduction index, K_{ij}) or even geometric between the environments (eg: sound insulation, D_{nT}). Some of these problems of lack of completeness of the input data derive from the difficulty of implementing "dynamically" information on the acoustic properties of building elements. For example, a concrete element can be either a wall or a slab, depending on how it is used, without changing its properties. However, the acoustic reference parameters change, also in relation to the sound source considered (airborne or impact noise). Other problems derive from the fact that in the first versions of IFC the only acoustic parameter considered was the acoustic absorption of the element surface. This has long conditioned the data structure, limiting the possibility of having other predefined properties in the Psets.

Table 1 – IFC 4.3 Pset referred to specific acoustic performance levels.

IFC 4.3 Acoustic Properties Set	IFC Name	Definition
Pset_RoofCommon	AcousticRating	It is provided according to the national building code. It indicates the sound transmission resistance of this object by an index ratio (instead of providing full sound absorption values).
Pset_CurtainWallCommon		
Pset_WallCommon		
Pset_PlateCommon		
Pset_SlabCommon		
Pset_CoveringCommon		
Pset_WindowCommon		
Pset_DoorCommon		
Pset_SoundAttenuation	SoundFrequency	Common definition to capture sound pressure at a point on behalf of a device typically used within the context of building services and flow distribution systems. To indicate sound values from an instance of IfcDistributionFlowElement at a particular location, IfcAnnotation instance(s) should be assigned to the IfcDistributionFlowElement through the IfcRelAssignsToProduct relationship. The IfcAnnotation should specify ObjectType of 'Sound' and geometric representation of 'Annotation Point' consisting of a single IfcPoint subtype as described at IfcAnnotation. This property set is instantiated multiple times on an object for each frequency band.
Pset_SoundGeneration		Common definition to capture the properties of sound typically used within the context of building services and flow distribution systems. This property set is instantiated multiple times on an object for each frequency band.

Despite these limitations, BIM methodologies remain the ideal tool to limit the uncertainties in the definition of a BAM, especially for geometric aspects.

3 BIM Model Checking in building acoustic design

Within the BIM methodology, a key role is played by Model Checking, a set of tools aimed to verify and validate projects not only during the design phase, but also during all the phases of the process, in order to guarantee completeness, transmissibility and congruence of all data and information. In the Information Documentation (ID) and in the Information Management Plan (IMP) the rules set must be specified, that is the set of control rules that are applied to the model, which are divided into three verification phases:

- rules for regulatory verification (BIM Validation);
- information interference management rules (Clash detection);
- rules for managing information inconsistencies (Code checking).

The application of a specific set of rules optimized for the acoustic design allows an effective control of the main criticalities that may occur in the transition from the architectural project to the performance evaluation and, therefore, to the construction of the building.

3.1 BIM Validation

By managing an appropriate set of parametric rules, BIM Validation analyses and determines the level of quality and consistency of a BIM model. This is an essential step to ensure that there are no modelling errors as overlapping objects and more generally that the model is constructed in accordance with the requirements specified in the Industry Standard (IS), depending on the purpose of the modelling. Within a BIM model it is possible to detect two types of errors: modelling and design. Finally, it allows to validate the relative Level of Development (LoD) of the objects specified in the IS.

The concept of LoD has evolved over time, and refers to the level of development necessary in relation to the contents of the elements of the model; the choice to use the definition “level of development” instead of “level of detail” is motivated by the fact that an element, although it may appear visually detailed, could in reality be generic.

BIM LoD is an Industry Standard that defines how the 3D geometry of the building model can achieve different levels of refinement, is used as a measure of the service level required. These development models are purpose built for various stages of design, 3D visualization, quantities control, scheduling, estimations, on-site production control and fabrication.

There are different LoD hierarchy systems but all are generally object-oriented than design-oriented, more focused on the level of object refinement at a geometric and informative level than on the global project cycle. This latter aspect sometimes obliges to introduce sublevels in order to adapt work variations [18] (Figure 2).

The LoD Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high level of clarity, the content and reliability of BIMs at various stages in the design and construction process. The LoD Framework addresses various issues faced by AEC professionals by providing an industry-developed standard to describe the state of development of various systems within a BIM. This standard enables consistency in communication and execution by facilitating the detailed definition of BIM milestones and deliverables.

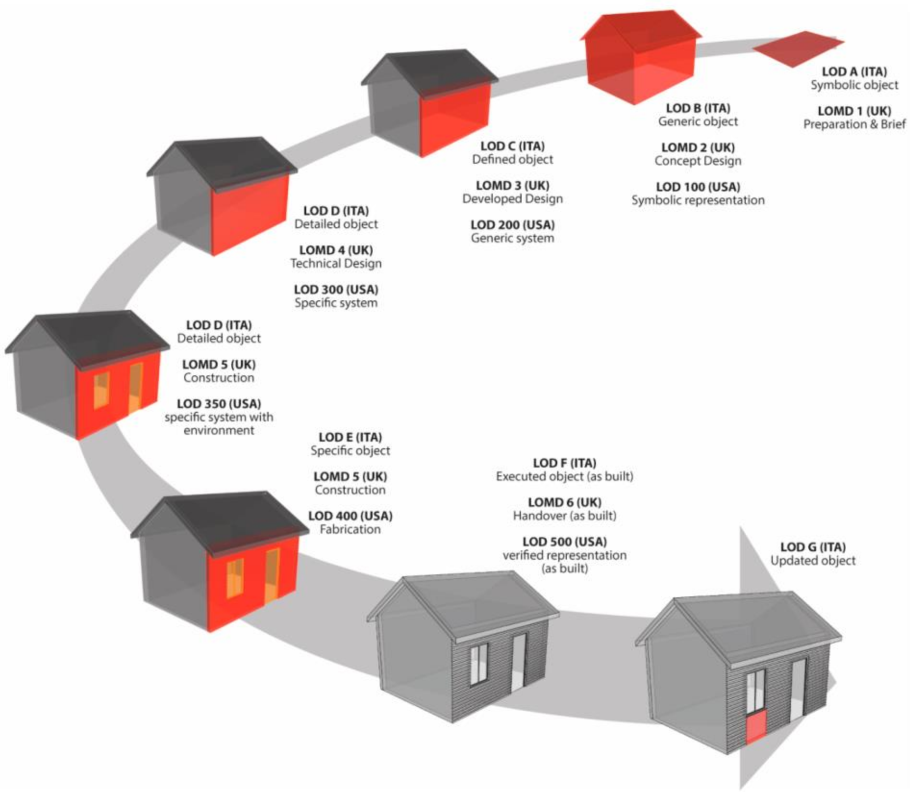

Figure 2 – Level of detail (LoD)’s progression according different national references with relative comparison [18].

In order to correctly transfer the design information to the BPM for the predictive evaluation of the acoustic performance of a building, the BIM LoD must be at least at level “300” (equivalent to “4” or “D”, according to the different classifications). In this way, it is possible to interact correctly with the BIM model to ensure that the results of the calculation process (for example according to the methods of the ISO 12354 series standards) can “re-enter” in the design process by providing the validation of the construction choices or indicating the necessary changes to meet the design objectives. The following level “350” (equivalent “5” or “D”) can contain the detailed information deriving from the acoustic predictive calculation that help to define the specific system in relation to its environment and, therefore, all the information necessary for the subsequent phases of construction.

3.2 Clash Detection

It consists in the control of geometric interferences in the single model and between models belonging to different disciplines, born as an analysis of geometric and spatial coherence, and is today one of the most widespread tools in BIM. For example, it allows to determine interference between the model for the design of service equipment (Mechanical, Electrical and Plumbing, MEP) and the architectural model. To date, there are several BIM coordinator tools in which, after correctly setting the rule set (with minimum tolerance between elements), the interference control can be carried out in an automated way, firstly to the individual disciplinary models and then to the merged models. From the acoustic point of view, this process can be useful for identifying acoustic bridges, preventing installation errors of resilient systems, and favouring the optimization of the path of MEP distribution networks.

3.3 Code Checking

It is the checking phase of the BIM model with respect to the information requirements necessary to assess its compliance with the standards and project objectives. The construction process is normally governed by numerous local, national and international laws or requirements and the information within them can be translated into parametric rules. For example, the acoustic requirements of rooms and building elements can be verified at this level for both predictive (ISO 12354 series) and field verification (ISO 16283 series) purposes.
One of the possible developments of this phase is to provide all the elements for determining the acoustic class of a building or housing unit, if applicable in a specific national context.

4 Conclusions

The implementation of acoustic assessment procedures (both predictive and on-site verification) within BIM procedures currently requires some adaptations to remedy the lack of a specific exchange architecture for all the information necessary for the complete acoustic characterization of the building.
Despite these limitations, the use of the methods already available can lead to significant improvements in terms of reliability and time savings in the development of simulation models, management of survey data and verification of performance parameters.
To ensure a successful process that develops the BPM criteria for BPM it is still necessary to undertake a thorough analysis of the acoustic issues before the start of the project.
Furthermore, it is of fundamental importance that all the information necessary for the acoustic model is provided, both from the geometric and performance point of view for the building elements to be used.
A significant step forward could be achieved through the development of software tools for BPM already optimized to communicate with BIM models.
Finally, it should be emphasized that, regardless of the tools used, it is necessary to keep the BIM criteria as a "living document" throughout the project, the construction process and the verification at the end of

construction, so that future projects can benefit from the experiences learned. through a complete documentation of the entire process and the results obtained.

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