Development of an architectural acoustic study through a complete Open BIM workflow

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Abstract
Over the last few years, the BIM (Building Information Modelling) methodology has represented the digital transformation of the AEC sector and has established itself as a standard for the development of construction projects from initial design to execution and maintenance. When the processes that enable collaboration between BIM professionals are carried out through open formats which ensure the accessibility and durability of the project, regardless of the tools used to develop the digital models, we call it Open BIM. This paper reflects an example of an Open BIM workflow where different specialized applications (e.g., architectural design, analytical modelling, acoustic simulation) are involved in order to develop an architectural acoustic study and generate all the required documentation for its verification based on the EN ISO 12354 standard and the European building codes.

Keywords: BIM, IFC, software, interoperability, simulation.

1 Introduction

BIM methodology involves the digitalisation of building models beyond CAD-based design where only project plans are made digital. As a result, information is centralised and problems of interpretation are avoided. The BIM implantation through open standards, known as Open BIM, extends its benefits by improving the accessibility, usability, management and sustainability of digital data [1].

One of the main advantages of using Open BIM applications in the development of architectural projects is their capacity to transmit information to each other. Sometimes this exchange is needed because architectural modelling tools do not have the capacity to perform an analysis or their calculation methodology is not recognised by an official organisation [2]. Such is the case of the acoustic study, where there are usually no advanced calculation tools within BIM architectural design-oriented applications, due to the differences between the data models. In this paper we will show the necessary steps to perform the acoustic calculations from an architectural BIM model without losing information or duplicating efforts.

2 Workflow

In the workflow we are going to propose in this paper, the data is shared through files based on open standards and using the collaborative workspace BIMserver.center where all the applications we are going to show can be linked. Therefore, the first step consists in the creation of a new project from the BIMserver.center website and the constitution of a work team [3].

Once the BIM project has been established, the beginning of the workflow focuses on the development of an architectural model employing an Open BIM application. In this case, we are going to use CYPE Architecture as it is a free program that allows the user to connect with BIMserver.center projects. This software permits us to model the geometry of the building from an architectural approach by defining and introducing elements such as walls, floor slabs, roofs, doors and windows [4].

After finishing the architectural design, it is possible to export the result to BIMserver.center in order to complete the project through new contributions from other specialized tools. Some examples are the structural calculation, the building installations, the thermal study or the acoustic calculation. In the context of this paper, we will focus on the following steps necessary to perform the last of these.

The main digital data file generated by CYPE Architecture and exported to BIMserver.center is the IFC. The open standard IFC (ISO 16739-1:2018) [5], Industry Foundation Classes, supports the exchange of information related to BIM models between applications which work with this technology. However, although the IFC is considered the universal format in the Open BIM world, it has some gaps that are evident when working on some specific disciplines. As a consequence, concepts such as BEM, Building Energy Model, have emerged with the aim of providing BIM-derived models usually defined in a different format from IFC, which are more suitable for the analysis to be carried out. This also happens in the field of architectural acoustics, where it is necessary to generate an analytical model that allows the calculation application to successfully determine the geometric parameters required to carry out the study of acoustic transmissions between spaces. Consequently, before starting with the acoustic simulation tool, in order to obtain an accurate analytical model, we must go through an intermediate software that allows us to define it.

The Open BIM Analytical Model application provides an analytical geometric model for thermal and acoustic analysis based on a BIM model defined through the IFC standard [6]. The output of this program is a JSON file with all the components that characterize the analytical model, such as spaces, surfaces, edges and joints. In addition, it includes the relationships between these entities (e.g., belonging to rooms, surface boundaries, connecting links).

When the analytical model is exported to the BIMserver.center project, it will already contain the required data to perform the acoustic simulation in the following application. The Open BIM tool that we will use for the analysis is AcouBAT by CYPE which allows us to evaluate the acoustic insulation and conditioning of the spaces that compose the building [7]. Like the other workflow programs, the results can be exported to BIMserver.center and be shared with the rest of the work team.

Finally, once the acoustic study is completed, it is possible to use other Open BIM tools to generate additional documentation. In this case, we will use Open BIM Layout to design the drawings of the acoustic study. This application allows us to obtain drawings of the different BIM models that form part of the BIMserver.center project [8].

Figure 1 – Acoustic workflow diagram.

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3 Architectural BIM model

The case study that we are going to use as an example of the workflow is a residential building of 12 dwellings and 1069.89 m2. The architectural modelling process has been carried out using CYPE Architecture.

The first step in the development of the architectural BIM model is the introduction of the vertical and horizontal partitions, as well as the doors and windows they contain. A correct definition of these components is essential to easily achieve an accurate analytical model required for the acoustical calculation in the following stages of the workflow. In this context, it is important to correctly configure the category of the elements because it will determine the relationships between spaces.

Table 1 – Categories of architectural partitions.

Vertical partitions categories	Horizontal partitions categories	Adjacencies
External façade	External floor slab / Roof	Outside
Party wall	-	Adjacent building
Internal partition	Internal floor slab	Space
Basement wall	Screed	Soil

As CYPE Architecture only provides an architectural description of the spaces, acoustical characterization of the elements will not be required for the moment. However, assigning the same typology to elements which share the same properties will greatly simplify the association of their acoustical features in the subsequent stages of the flow.
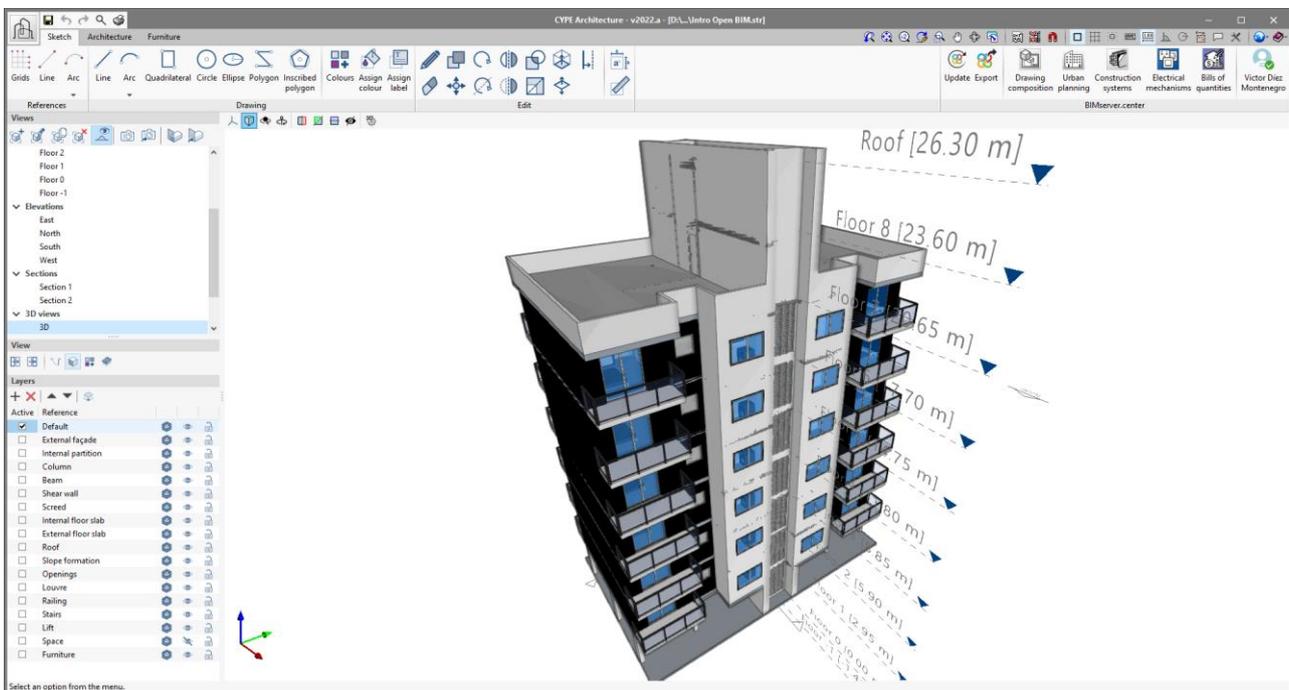

Figure 2 – Design of the architectural model in CYPE Architecture.

Once the modelling of the building geometry has been finished, the next step is the introduction of the spaces. It is important that the surfaces that conform the 3D boundaries of the spaces be coplanar to the faces of the partitions that define them, so that the analytical model can be generated correctly in the next stage of

the flow. If not, we will find failures in the calculation of areas and volumes, as well as in the association of the space boundaries with the construction elements.

As in the case of the partitions, it is also possible to assign a typology to the spaces and this must be consistent, since the acoustic requirements will be established later according to this classification.

Table 2 – Wall and space types of the architectural model.

Wall type	Category	Thickness	Space type
EF15	External façade	0.15 m	Balcony
EF25C2	External façade	0.25 m	Bedroom
P15	External façade	0.15 m	Gallery
IP9	Internal partition	0.09 m	Kitchen
IP15	Internal partition	0.15 m	Living room
IP25	Internal partition	0.25 m	Bathroom
EF25C1	External façade	0.25 m	Lift
			Shaft
			Circulation
			Stairs
			Garage
			Others

Finally, additional architectural elements such as stairs, elevators, furniture and sanitary equipment are introduced to complete the model.

4 Acoustic model

One of the main objectives when developing the model for the acoustic analysis is to take advantage of as much information as possible from the architectural model relevant to this task. To this end, we have imported the architectural design created with CYPE Architecture into the Open BIM Analytical Model tool. Thanks to the utility included in this programme, the analytical model can be achieved quickly from IFC files. However, once the process is finished, we must check the result and fix it if necessary.
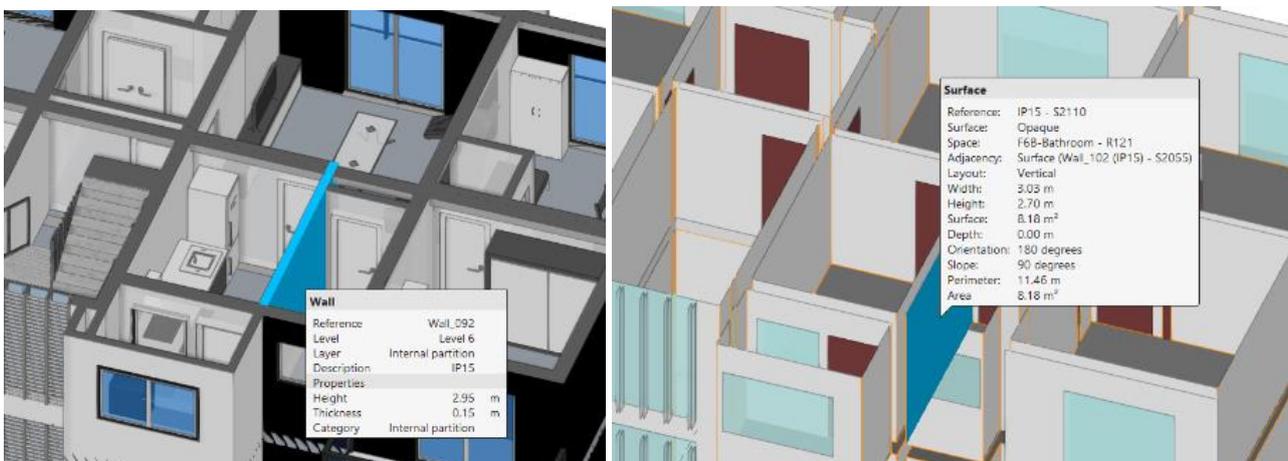
Figure 3 – Elements of the analytical model derived from the architectural model.
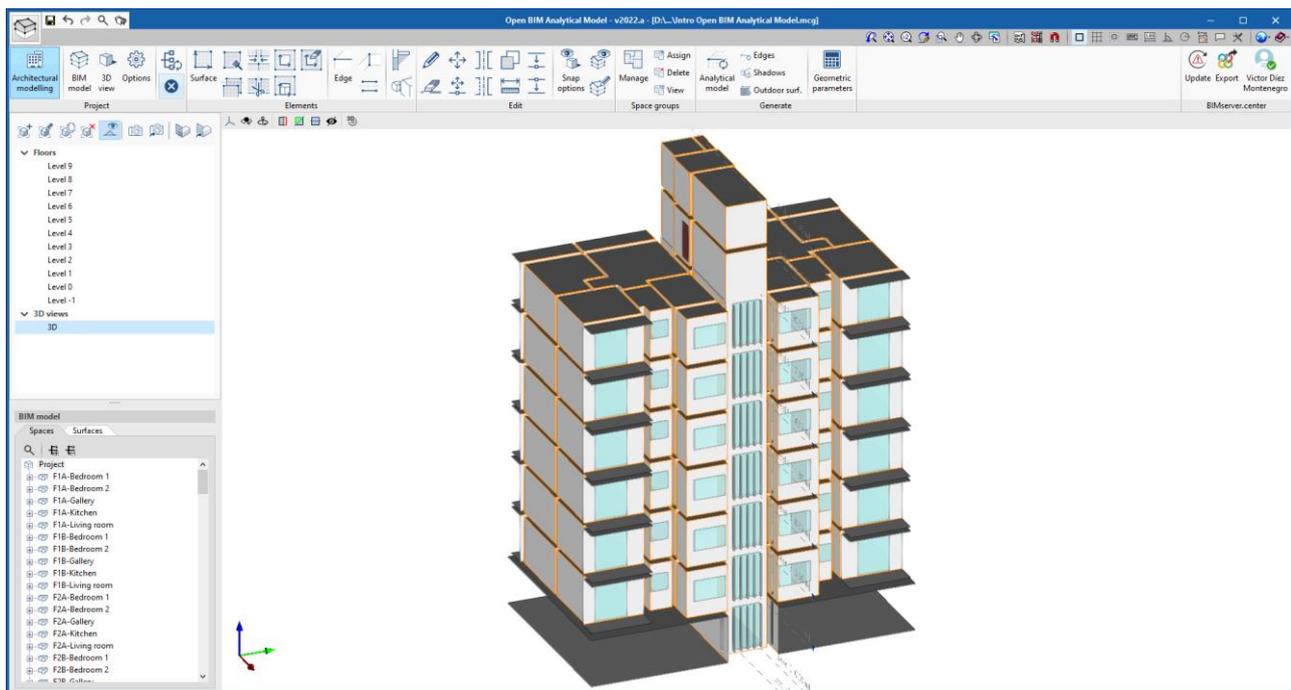
Figure 4 – Analytical model generation in Open BIM Analytical Model.

Before exporting the analytical model and starting with the acoustic simulation tool, in this application we must also specify the groups of spaces according to their use unit. This allows us to differentiate between dwellings and avoid the calculation of acoustic insulation between rooms in the same dwelling later on.

In the AcouBAT by CYPE acoustic analysis tool, we have to set the general calculation parameters and characterise the acoustic properties of the components from the analytical model. The insulation and acoustic conditioning requirements are applied to the spaces of the analytical model which, in fact, come from the architectural model. For this purpose, we must previously define typologies of acoustic spaces that will contain the limit values in order to assign them to the spaces of the analytical model that have been incorporated by the application. AcouBAT by CYPE includes some default acoustic typologies corresponding to the main international standards. Table 4 shows the relationship between the architectural spaces and the acoustic space types of some European standards.

Table 3 – Relationship between types of architectural spaces and types of acoustic spaces.

Architectural space types	Acoustic space types			
	Spain [9]	France [10]	Portugal [11][12]	Italy [13]
Balcony	-	-	-	-
Bedroom	Protegido (Dormitorio)	Pièce principale	Quartos ou zonas de estar dos fogos	Abitato (residenza o assimilabili)
Gallery	-	-	-	-
Kitchen	Habitable	Cuisine	Quartos ou zonas de estar dos fogos	Abitato (residenza o assimilabili)
Living room	Protegido (Estancia)	Pièce principale	Quartos ou zonas de estar dos fogos	Abitato (residenza o assimilabili)
Bathroom	Habitable	Sale d'eau	Quartos ou zonas de estar dos fogos	Abitato (residenza o assimilabili)
Lift	-	-	-	-
Shaft	-	-	-	-
Circulation	Habitable (Zona	Circulation	Caminho de circulação	Abitato (residenza o

	común)	commune	horizontal	assimilabili)
Stairs	Habitable (Escalera)	Escalier	Caminho de circulação vertical	Abitato (residenza o assimilabili)
Garage	De actividad	Garage	Garagem	Solo emittente
Others	De instalaciones	Local technique	Outros	Solo emittente

Table 4 – Assignment of acoustic requirements to the geometrical data of a space.

Geometric data	
Reference	F2B-Bedroom 2
Type	Bedroom
Area	12.24 m^2
Volume between the floor and suspended ceiling	33.06 m^3
Location	
Acoustic requirements (Portugal)	
Reference	Quartos ou zonas de estar dos fogos
Airborne sound insulation against outdoor sound, $D_{2m,nT,w}$	30 dB
Equipment noise (continuous), L_{nTA}	27 dB
Equipment noise (intermittent), L_{nTA}	32 dB
Equipment noise (emergency), L_{nTA}	40 dB
Internal airborne sound insulation, $D_{nT,w}$	50 dB (Quartos ou zonas de estar dos fogos)
	40 dB (Caminho de circulação vertical)
	48 dB (Caminho de circulação horizontal)
	50 dB (Garagem)
	58 dB (De actividad)
	48 dB (Outros)
Impact noise insulation, $L'_{nT,w}$	60 dB (Quartos ou zonas de estar dos fogos)
	60 dB (Caminho de circulação horizontal)
	50 dB (De actividad)
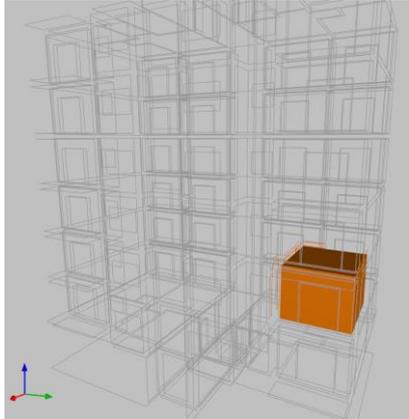
In a similar way to the spaces, the acoustic characterisation of the model partitions must be defined. For this purpose, AcouBAT by CYPE incorporates the acoustic performance database of the French national organisation CSTB (Scientific and Technical Centre for Building) [14], which contains more than 2,400 products and 3,000 acoustic measurements. The values of these measurements are in one-third octave bands in the range 100 - 5000 Hz and, in some cases, in the range 50 - 5000 Hz.

For each partition type, which was defined in the architectural model, it is possible to assign several products from the database to constitute its acoustic properties for the calculation.

Table 5 – Assignment of acoustic characteristics to the geometrical data of a wall

Geometric data		Acoustic characteristics	
Type	EF25C1	**Base element**	
Thickness	0.25 m		
		CSTB Product	Hollow concrete blocks - 150 mm in thickness - with 15 mm cement mortar on one side
		Class	Masonry in hollow concrete block
		Mass	180.00 kg/m²
		Thickness	0.160 m
		Rw (C;Ctr;C50-3150;Ctr,50-3150)	48 (-1;-3;-1;-4) dB
		STC	48 dB
		Internal lining	
		CSTB Product	13+80 expanded elastified polystyrene based interior lining fixed with glue
		Class	Glued lining complexes
		Mass	15.00 kg/m²
		Thickness	0.100 m
		Δ(Rw + C) heavy wall	12 dB
		Δ(Rw + Ctr) heavy wall	9 dB
		Δ(Rw + C) heavy floor	12 dB
		Δ(Rw + C) direct	13 dB
		Δ(Rw + Ctr) direct	9 dB
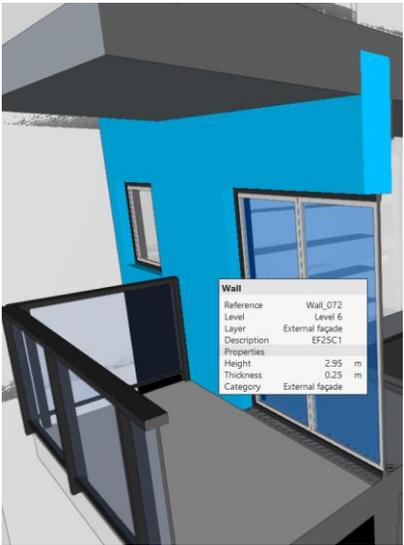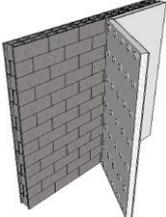
5 Simulation and results

After the acoustic characterisation of the BIM model, the acoustic simulation is carried out in the same application, AcouBAT by CYPE. This tool is used to perform the following calculations based on the method specified in the EN 12354 standards:

- Airborne and impact sound insulation [15] [16] [17]
- Absorption area and reverberation time in rooms [18]
- Sound pressure levels [19]

After finishing the analysis, we get a histogram as a calculation summary where we can appreciate the percentage of spaces that are within the limits defined by us.
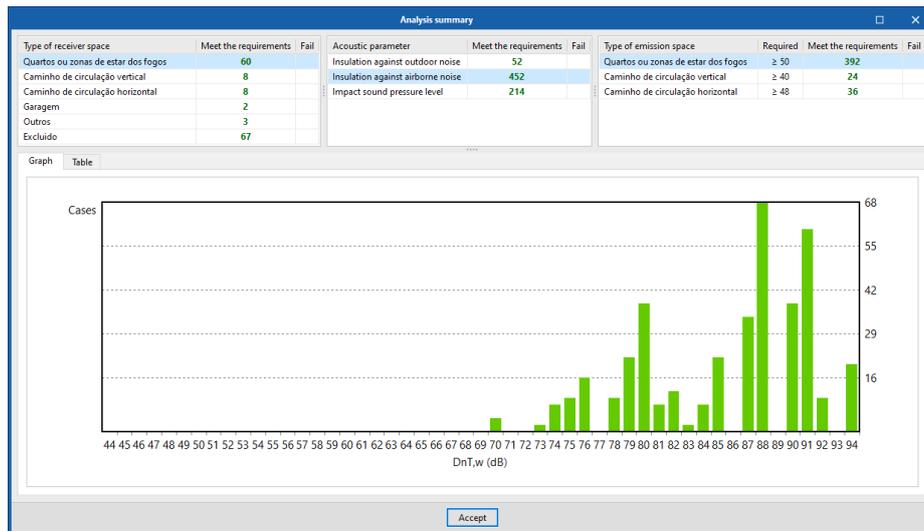
Figure 5 – Overall summary of the acoustic analysis (histogram).

Then, we inspect each receiving space of the model in order to fix those that do not meet the requirements. Regarding the acoustic insulation, we can get results for each of the direct, lateral and indirect transmissions. All these results are displayed according to the acoustic index chosen in the general project specifications and, for each calculation, we can also view the values obtained in one-third octave bands in the range 100 - 5000 Hz or in 50 - 5000 Hz if the products used contain this additional information.
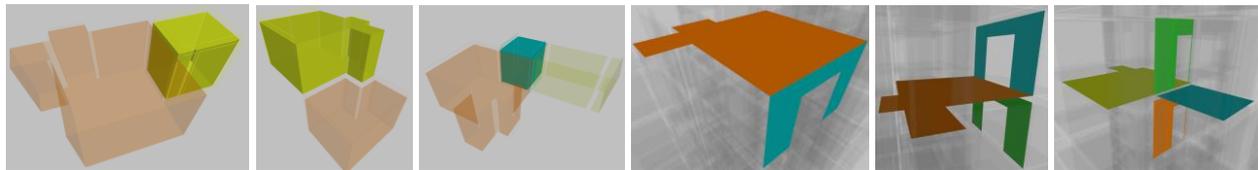
Figure 6 – Analysis of spaces and junctions.
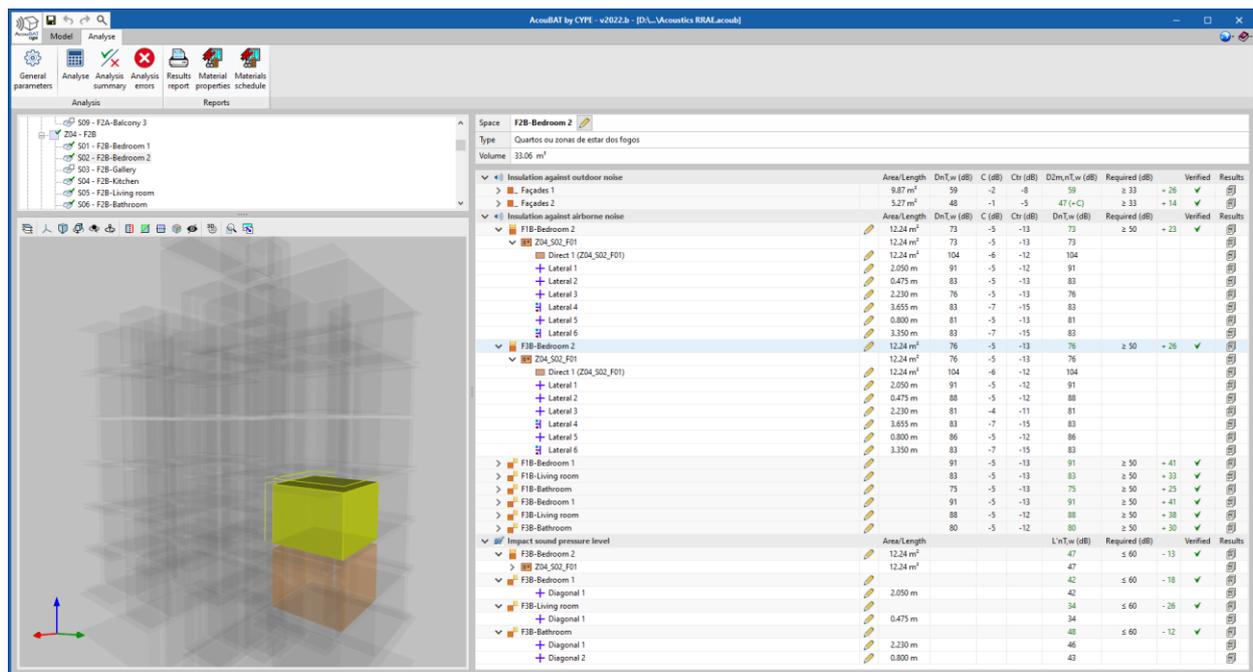
Figure 7 – Results of the space " F2B-Bedroom 2".

If a modification to the calculation model is required, we must determine in which application it should be carried out, depending on the corresponding step of the workflow. The tools that have been used are able to update their models so that a change in the architectural design programme, CYPE Architecture, can be easily reflected in AcouBAT by CYPE.

Finally, to complete the graphic documentation, we use the Open BIM Layout tool which helps us to design drawings from the 3D models we have created.
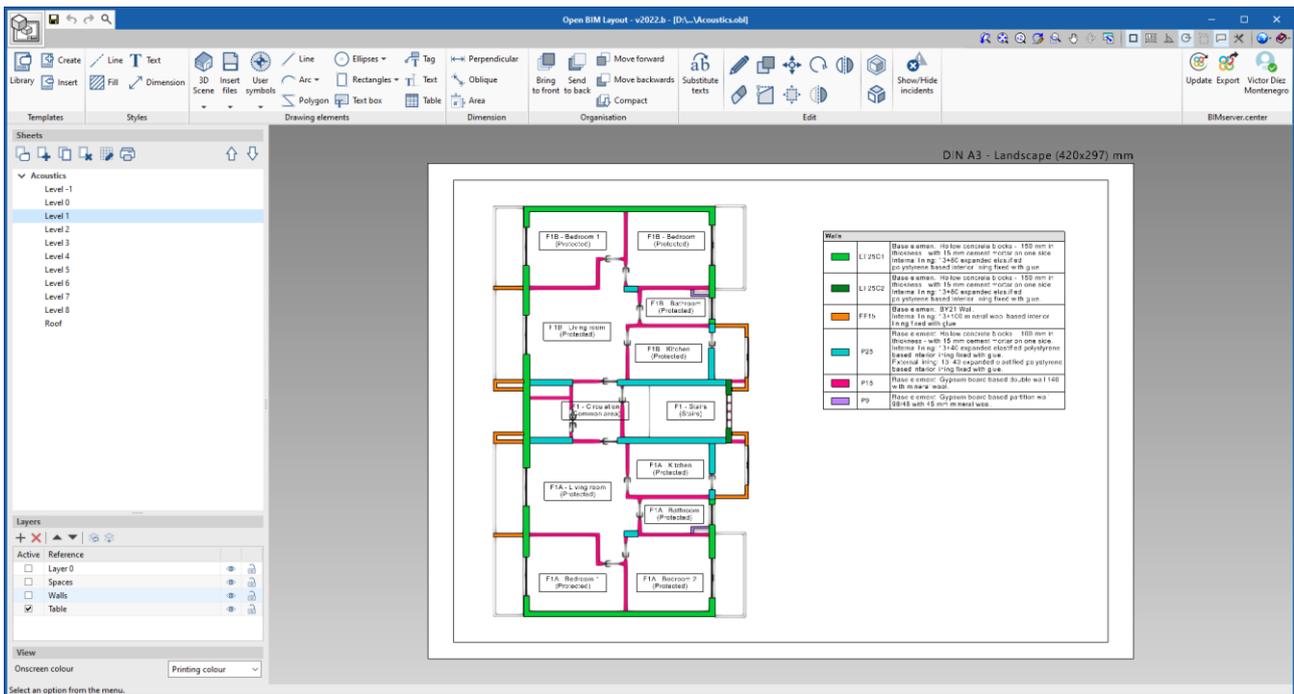
Figure 8 – Drawing of the relationship between the walls and the construction systems chosen.

6   Conclusions

The aim of this paper has been to demonstrate that it is possible and effective to carry out an acoustic study from an architectural design model without the need to remodelling for this purpose and following the Open BIM approach. In this respect, it has been proven that the objective can be achieved, although it is important to note that following a suitable workflow considerably reduces the effort required. This also happens with the accuracy of the models created in each tool, in this study we have indicated some of the key points that must be considered in order to produce an adequate model that facilitates its subsequent reading in the upcoming applications.

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