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# BIM-based framework for indoor acoustic conditioning in early stages of design

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## ABSTRACT

**Indoor acoustic performance is a critical factor for user comfort and it is linked to a healthy indoor environment. In this sense, designing a healthy indoor environment is included in the Declaration on Occupational Health for All of the World Health Organization. Thus, building projects should take into account indoor acoustic considerations in the early stages of design since it is often more expensive and difficult to achieve acoustic standards in subsequent stages. In this context, the Building Information Modelling (BIM) methodology offers an improvement opportunity to designers who want to consider acoustic conditions from the initial phase of the building projects. BIM, as a methodology, involves a process to generate and manage data on the properties and characteristics of the construction project during the building life cycle. The BIM model is a digital representation of all the physical and functional characteristics of a building, a database of reliable information which can be consulted throughout the service life of a construction, from design to demolition. The aim of this study is to propose a framework using BIM methodology for decision making at early stages of design. For this purpose, a software tool implemented in BIM has been developed that allows us to estimate and take into account the main acoustic parameters (absorption, insulation) during the design of the project.**

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## 1. INTRODUCTION

Nowadays, people spent the most part of a day in indoor environment (about 80-90%) [1]. Therefore, indoor conditions of buildings become an important factor in the occupant/user lives. Within these indoor conditions, the environment quality of spaces in buildings are highly conditioned by the indoor acoustic behavior [2, 3]. In this regard, the acoustic performance is conditioned not only by outside noise sources but also those inner building sources and other adjacent spaces [4, 5]. So, these inner sources should also be controlled in order to guarantee the comfort of the user.

Despite of the fact that the acoustic behavior of the building has a high impact on its occupants, it is not often taken into account from the early stages of the project (except in buildings where acoustic requirements are particularly important, such as theatre or auditorium). In general, the analysis of the acoustic performance of spaces is evaluated in an advance stage of the construction projects, where generally the geometry and configurations of the spaces are fixed. Thus, achieving the minimum acoustic requirements at this stage of the project is more complicated and costly than if it had been managed at an early stage [6, 7].

Moreover, acoustic simulations are often carried out with a specific software (Odeon, Catt-Acoustic, Ease, Soundplane, etc.) different from or not integrated within the software used to design the building. In conventional building projects, this process involves additional work and is time-consuming [6]. In this sense, Building Information Modelling (BIM) is a new methodology that has been developed in recent years, replacing the traditional methodology based on Computer-Aided Design (CAD) and improving the project management [8] and it aims to overcome those problems.

BIM, as a methodology, involves a process to generate and manage data related to properties and characteristics of the construction project during the building life cycle. These data do not only refer to geometric or visual properties, but also includes information about material properties, geographic information, etc. The BIM model becomes a digital representation of all physical and functional characteristics of a building, a database of reliable information which can be consulted throughout the service life of a construction, from design to demolition [9]. The use of a single model concentrating all the project information and data offers a global vision and better coordination of the process. Consequently, BIM methodology has a great potential and its implementation is accelerating a fast technological transformation in Architecture, Engineering and Construction industry (AEC).

In addition, the possibility of implementing BIM in construction projects provides an exceptional opportunity to evaluate acoustic performance from an initial phase. BIM helps to visualize different scenarios during the design and construction process. Therefore, BIM has the potential to improve the design process and to supports architects, engineers and builders making decision in the acoustic field [6, 10].

In this study, a software tool was developed in order to propose a framework using BIM methodology for decision making at the early stages of the design. This software is a first approach to an estimation framework model of airborne sound insulation between horizontal indoor spaces and the reverberation time (in accordance to the Spanish requirements CTE DB-HR [11] and ISO 12354-1:2017 standard [12] ). This framework enables designers to explore design alternatives in order to achieve a high level of acoustic performance in early stage of design.

## 2. BIM FRAMEWORK PROPOSED METHOD: METHODOLOGY.

### 2.1. BIM-based framework indoor acoustic performance

A framework integrated in BIM is developed as a tool to enable an indoor acoustic optimization in the design process of buildings. This tool allows different agents to collaborate across the process of performance-based design. The information stored in the parametric BIM model is used to simulate the acoustic behavior of the interior space. The framework was developed on Autodesk Revit [13] (a software BIM tool) and visual programming software (Dynamo version 2.0.2) [14]. Fig. 1 shows an example of the operating mode of the proposed performance simulation tools using Dynamo software.

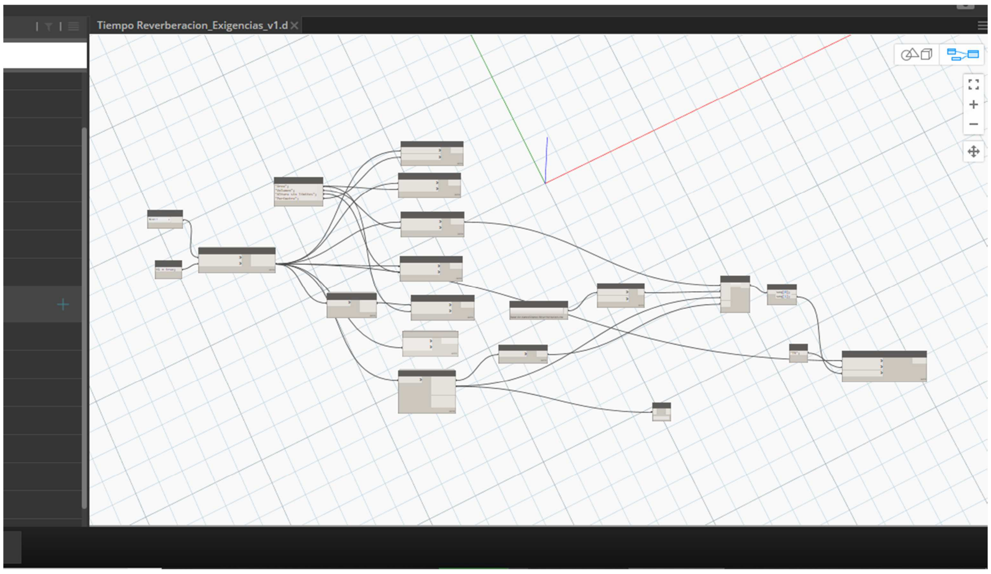


*Fig. 1. Example of visual programming software of the proposed performance simulation tool.*

Dynamo nodes and Python scripting were used in this study to create a simulation package for calculation of the reverberation time and the airborne sound insulation between rooms. As a part of the tool workflow, the Reverberation Time Simulation (RTS) package is developed to parametrically interact with Autodesk Revit in order to calculate the Reverberation Time value of each indoor spaced. Furthermore, the Airborne Sound Insulation Simulation (ASIS) package for parametric acoustic simulation between adjacent spaces were implemented.

Both, RTS and ASIS packages, implement an automatic workflow that enables to simulate the acoustic performance accordingly to the parametric changes made into the BIM model. Designers can explore possible alternatives for optimizing acoustic performance based on the executions of the acoustic simulation.

The geometry data, project information and acoustic properties of the construction materials stored in the model were used in the initial nodes of the workflow to create the acoustic simulation model. As a first approach, the created acoustic simulation package is only applicable to spaces contained on the same floor for the sake of simplicity. The building floor level is require as a user input by the developed package. The other variables (geometric and non-geometric) are extracted from the BIM model. Fig. 2 shows the diagram of the acoustic simulation process.

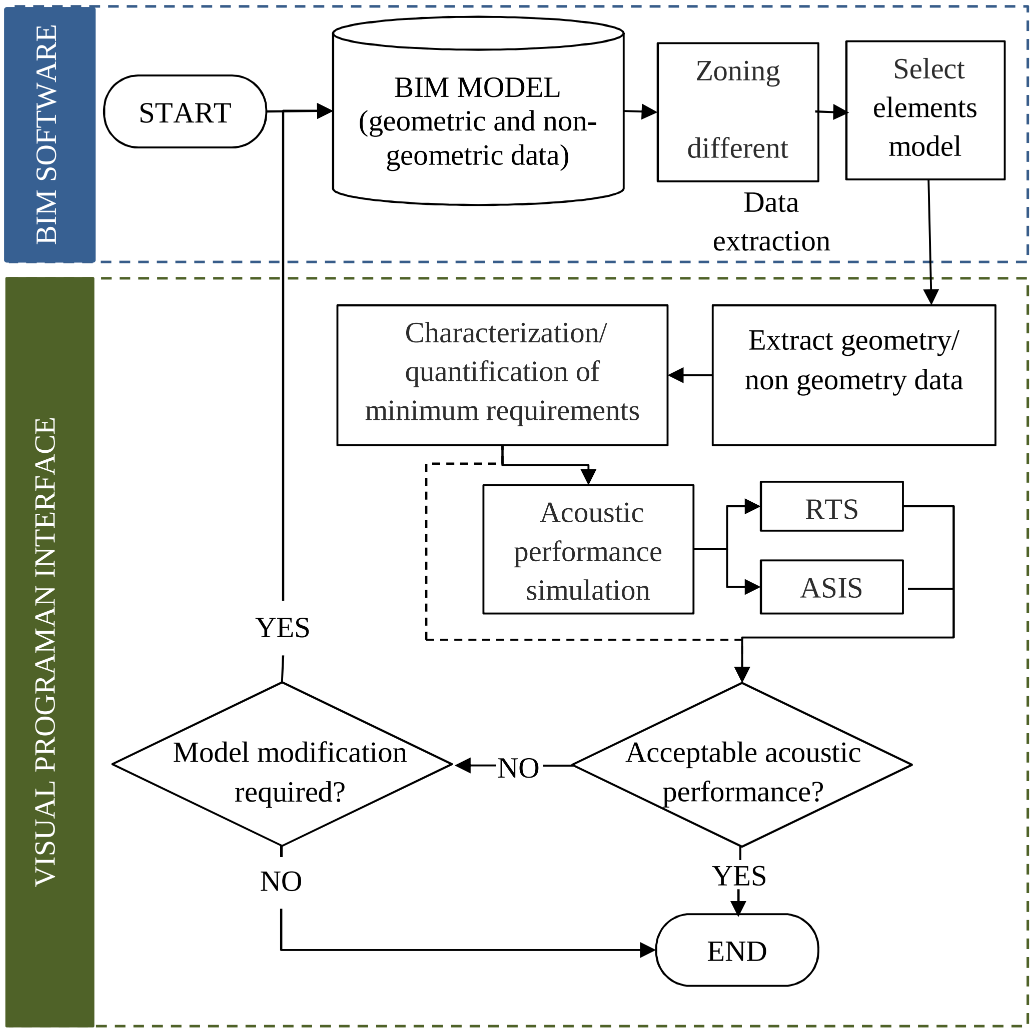


*Fig. 2. Diagram of the acoustic simulation process and developed software.*

## 2.2. Indoor acoustic analysis

The acoustic performance includes the estimation of both, reverberation time and the airborne sound insulation. On the one hand, the reverberation time, $T$, of the room is calculated using Equation 1:

$$T = \frac{0.161 * V}{A} \quad (1)$$

where $V$ is the room volume (m$^3$), $A$ is the total sound absorption of the room. Total sound absorption is calculated as in Equation 2:

$$A = \sum_{i=1}^{n} \propto_{m,i} S_i + \sum_{j=1}^{N} A_{O,m,j} + 4\overline{m_m}\, V \quad (2)$$

where:

$\propto_{m,i}$ average acoustic absorption coefficient of each facing, for the third octave bands centered on the frequencies of 500, 1000 and 2000 Hz.

$S_i$ facing area with coefficient of absorption $\propto_{m,i}$ (m$^2$).

$A_{O,m,j}$ equivalent average acoustic absorption area of each different absorbent fixed furniture (m$^2$).

$V$ volume of the room (m$^3$)

$\overline{m_m}$ average sound absorption coefficient in air, for frequencies of 500, 1000 and 2000 Hz

On the other hand, the simplified model described in the EN 12354-1 standard has been implemented in order to calculate the the airborne sound insulation between adjacent rooms (Equation 3).

$$D_{nT,A} = R'_A + 10log\left(\frac{0.32V}{S_s}\right) \quad (3)$$

Where:

$D_{nT,A}$ Standardized A-weighted sound pressure level difference within rooms,

$V$ Receiver room volume,

$S_s$ area of the separation element,

$R'_A$ A-weighted apparent acoustic reduction global index. The $R'_A$ was calculated as in Equation 4:

$$R'_A = 10log\left(10^{-0.1R_{Dd,A}} + \sum_{F=f=1}^{n} 10^{-0.1R_{Ff,A}} + \sum_{f=1}^{n} 10^{-0.1R_{Df,A}} + \sum_{F=1}^{n} 10^{-0.1R_{Fd,A}} + \frac{A_0}{S_S}\sum_{ai=ei,si}^{n} 10^{-0.1D_{n,ai,A}}\right) \quad (4)$$

Where:

$R_{Dd,A}$ A-weighted sound reduction index for direct transmission

$R_{Ff,A}$ A-weighted flanking sound reduction index for transmission path Ff

$R_{Df,A}$ A-weighted flanking sound reduction index for transmission path Df

$R_{Fd,A}$ A-weighted flanking sound reduction index for transmission path Fd

$n$ stands for the number of flanking elements

The sound flanking reduction index for each path was calculated using the following Equation 5:

$$R_{Df,A} = \frac{R_{i,A} + R_{j,A}}{2} + \Delta R_{ij,A} + K_{ij} + 10\log\frac{S_s}{l_0\, l_f} \quad (5)$$

Where:

$R_{iA}$ and $R_{j,A}$ are the A-weighted sound reduction index for the dividing or separating element and flanking elements, respectively.

$S_s$ is the separating element surface area.

$l_{i,j}$ is the junction length between the separating element and flanking element.

$K_{ij}$ is the vibration reduction index for the T junction.

$\Delta R_{ij,A}$ sound reduction index improvement by additional layers added to the separating element in the source room and/or receiving room

## 2.3. Overview of the propose BIM-workflow

The process of assessment the acoustic performance and obtaining feedback for taking a design decision was established in six consecutive phases. The process proposed in this section is shown in Fig. 3. In the first phase the BIM model is created. The design of the building and the construction elements are developed, as well as the setting up of the project information, materials and construction systems. The designer can create, modify or import from an external data base the acoustic properties of the building materials. This information would be then add into a list.

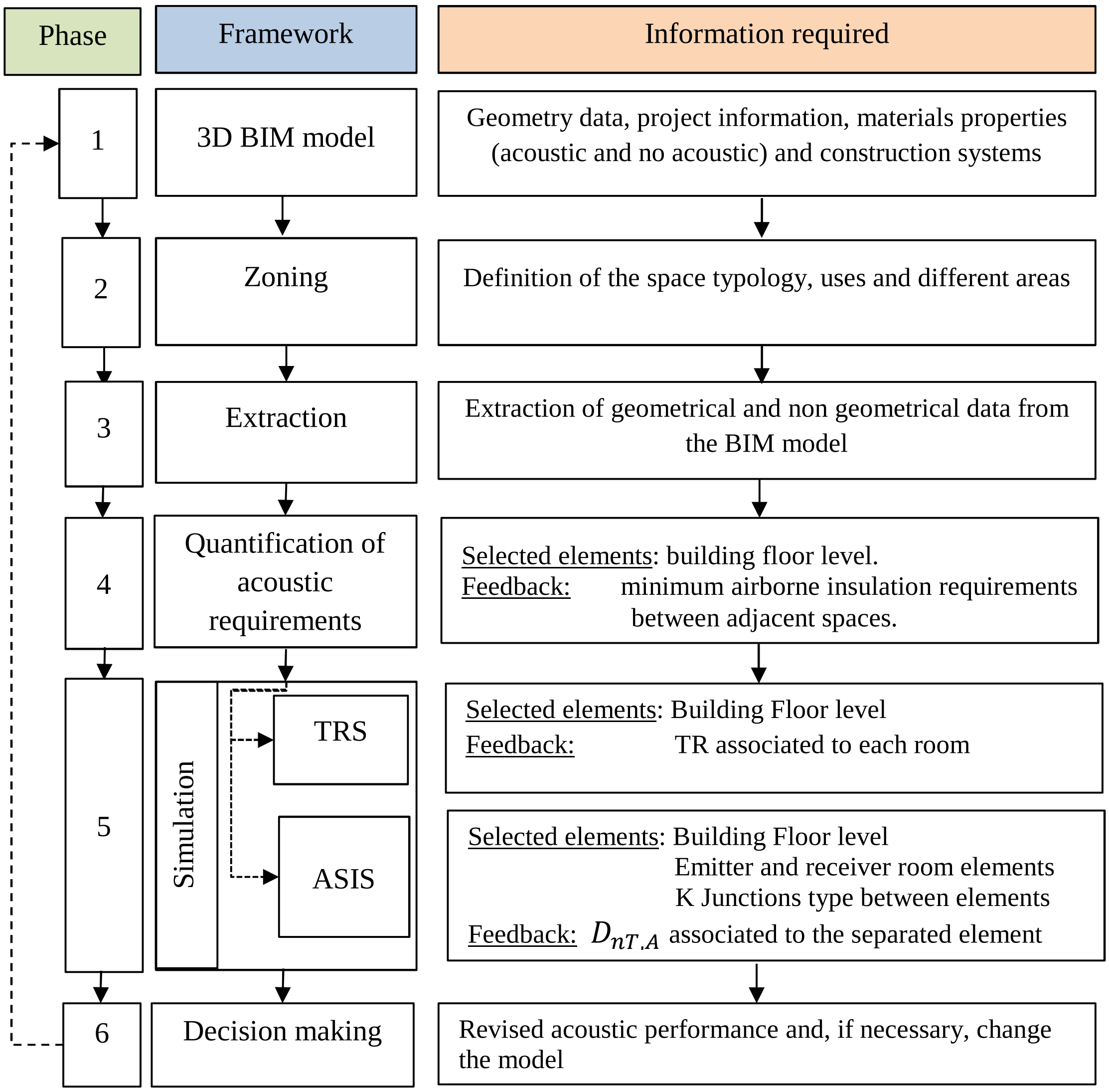


*Fig. 3. Diagram of the proposed workflow process*

In the second phase the zoning of the building is carried out. The typology of the areas is established according to their use. The designer defines the characteristics of each space (use, type of space, etc.). These variables are defined in a Revit interface and it is used to establish the relationships between adjacent spaces. All these data are used in the acoustic simulation.

In the third phase, the geometric (enclosure dimensions, volume, etc.) and non-geometric data (absorption coefficients, etc.) are extracted from the BIM model through the visual application of programming. In the fourth phase, the model calculates the characterization and quantification of the acoustic requirements according to the regulations using the prescribed construction elements. In the fifth phase, the simulation of the two programmed packages is carried out:

1) the RTS package: this package performs the automatic calculation of reverberation time, depending on the spaces previously defined by the designer. Absorption coefficients are introduced manually or selected from a database.

2) the ASIS package: This package calculates the airborne acoustic insulation between two adjoining areas on the same level of the building model. Through the visual programming interface the elements of the model necessary for the calculation are selected.

In the last phase, a visualization of the obtained results is shown in the BIM model. The feedback allows the designers to evaluate the results and to make decisions. At this phase, the designers can proceed in two ways: (1) if the acoustic performance is acceptable, so the process will end; (2) if the acoustic performance is not acceptable, the designer can modified the model in the Revit interface (improving the geometry of the space or acoustic material properties) and then re-evaluate the acoustic performance using this proposed tool.

## 3. CASE STUDY FOR THE PROPOSED METHOD.

A case of study was implemented to test the proposed framework. The BIM model of a building was designed to check out both, the RTS and the ASIS packages. Fig. 4 shows a floor plan of the building that carried out the analysis. In the first phase, the geometry of the building was modelled and the construction systems were selected according to the construction specifications of the project. In the second phase, the floor areas were defined by their uses (installation facilities, protected room, habitable room, etc.).

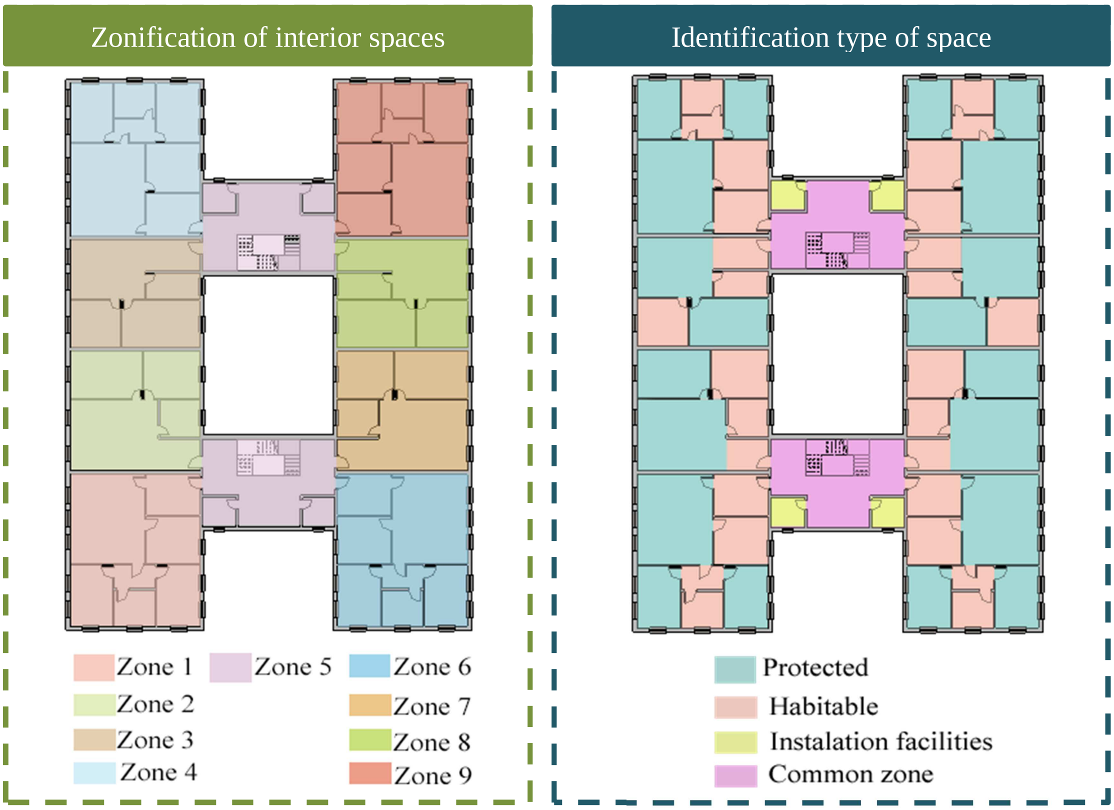


*Fig. 4a. Zonification. 4b. Visualization of different type of space level building model*

In the next phase the geometric and non-geometric data were extracted from the BIM model. The data are used as an input to determine the characterization and quantification of the minimum requirements established for each elements. Fig. 5 shows the data obtained at the end of this phase.

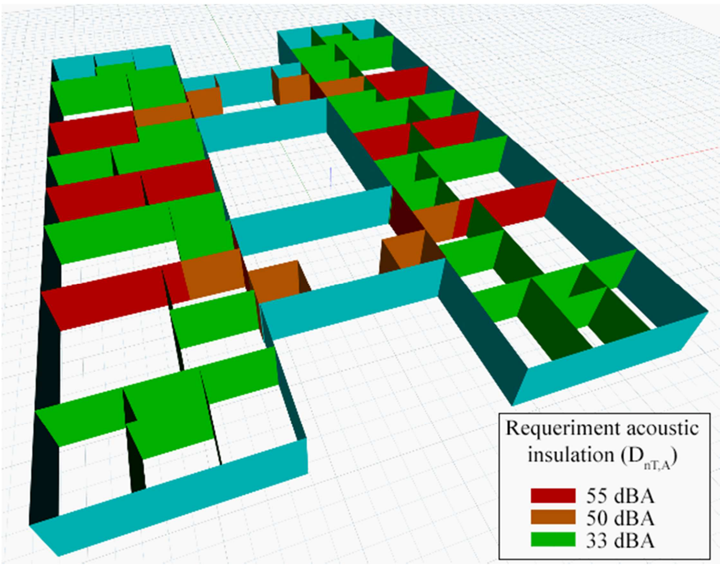


*Fig. 5. Visualization of the requirements of acoustic insulation to airborne noise between rooms*

In the next step the reverberation time was calculated. This process is automatic, the program identifies the areas defined by the user and performs the analysis. The Fig. 6 shows the schedule of the results obtained after the analysis.

Nivel 1 | Schedule RT simulation

<Schedule RT simulation>

| A | B | C | D | E |
|---|---|---|---|---|
| Level | Name | Area | Volume | RT |
| Nivel 1 | Hall | 12.26 m² | 33.10 m³ | 0.70716 |
| Nivel 1 | Living room | 38.08 m² | 102.82 m³ | 1.057371 |
| Nivel 1 | Bedroom | 14.42 m² | 38.92 m³ | 0.74776 |
| Nivel 1 | Bath | 8.25 m² | 22.27 m³ | 0.608503 |
| Nivel 1 | Bedroom | 14.21 m² | 38.38 m³ | 0.743116 |
| Nivel 1 | Corridor | 5.07 m² | 13.69 m³ | 0.481127 |
| Nivel 1 | Kitchen | 14.06 m² | 37.96 m³ | 0.748114 |
| Nivel 1 | Kitchen | 15.12 m² | 40.82 m³ | 0.767786 |
| Nivel 1 | Bedroom | 19.28 m² | 52.05 m³ | 0.829078 |
| Nivel 1 | Living room | 34.68 m² | 93.64 m³ | 1.032801 |
| Nivel 1 | Bath | 8.16 m² | 22.02 m³ | 0.613033 |
| Nivel 1 | Living room | 25.48 m² | 68.80 m³ | 0.933337 |
| Nivel 1 | Kitchen | 12.97 m² | 35.03 m³ | 0.726105 |
| Nivel 1 | Bedroom | 20.04 m² | 54.11 m³ | 0.832534 |

*Fig. 6.Time reverberation results from RTS package*

Hereafter, the airborne noise isolation between areas was calculated. Through the interface of the program, the necessary elements for the calculation were selected. Fig. 7 shows an example of an element selection in the BIM model. Figure 8 shows the data obtained after the analysis.

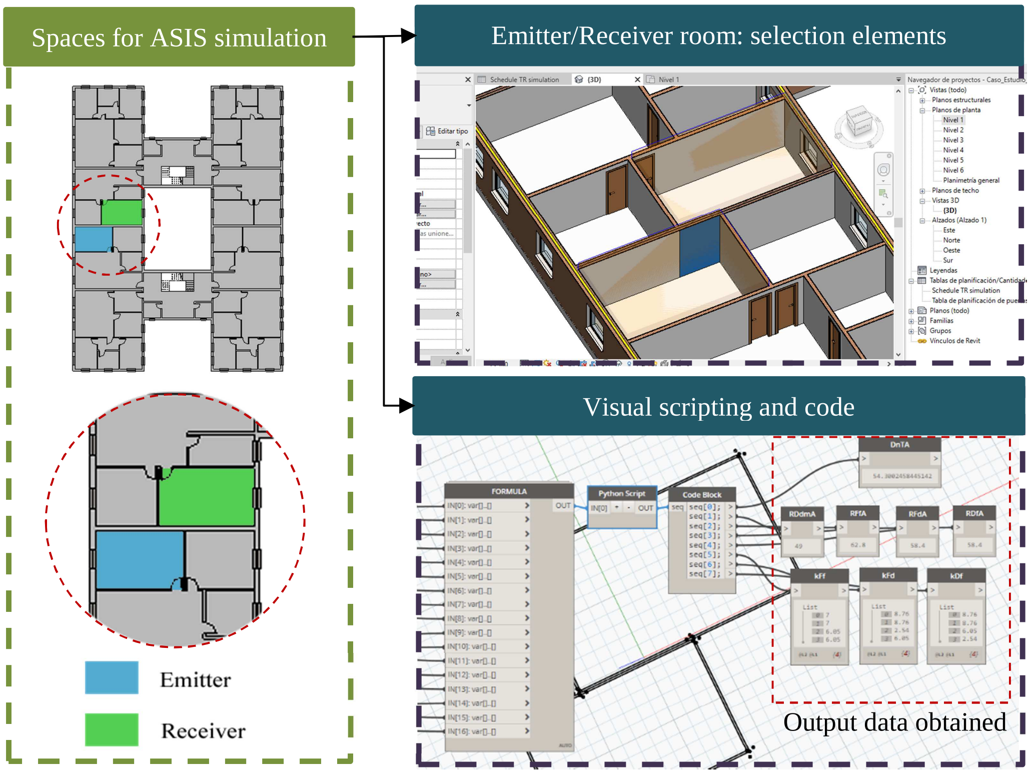


*Fig. 7. Process for element selection to perform ASIS simulation.*

Finally, to test the obtained data from our proposed method, a simulation was carried out with the official software provided by the Spanish government (DB-HR software for Technical Code for Building Construction) to verify the results obtained. A variety of construction solutions and materials were tested in this process and the comparison shows that the obtained results from our scheme are similar to that provided by the official software with a difference range less than 1 %.

## 4. CONCLUSION

The use of the BIM methodology together with the visual programming provides an essential tool for the use of the multiple data contained in the models. In this article we have proposed a framework for supporting a decision making process for designers and involved agents. It allows some basic acoustic parameters (reverberation time and airborne acoustic insulation) to be calculated in a first approach. Also, the tool provides an automatic check to the requirements and quantification of the building elements.

The main advantages obtained by this proposal are: 1) reduced calculation time (reintroducing data is not necessary), 2) the results are visualized in the same design interface, 3) as the framework is integrated in the BIM software, errors due to the input of data from one software to another are avoided, 4) to evaluate a new solution, it is only necessary to change the construction element in the 3D model, 5) the results obtained are similar to other software applications.

The authors think that this tool can contribute to get a better visualization of the analysis without exporting or regenerating the model in a different software. The system reduces the time required for the additional work and the possible errors that could result from this re-process. The visualization of the results in the same design environment of the projects provides a more global vision, allowing an optimization in the decision making process.

With regard to the results obtained in the case of study, the BIM methodology has been shown applicability to the field of acoustics during the early stages of design. Similar results are obtained using other tested calculation software.

Future lines of research will include the improvement of the BIM-based framework, adapting it to more complex geometries. Expansion of the calculation packages (impact noise and vertical transmissions and external noise), upgrading of the database of building materials and construction elements will be also be accomplished in future research work.

## 5. ACKNOWLEDGEMENTS

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