BIM-based Simulation for Analysis of Reverberation Time

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Abstract

The acoustic condition of indoor spaces is one of the significant indoor environmental factors affecting building occupants’ perception and performance. Acoustic analysis of spaces is currently involved in creating a geometric model of a building and infusing it with physical properties (such as absorption coefficients of surface material). This paper aims to evaluate acoustic conditions of building spaces by calculating reverberation time (RT), using the (geometric and physical) information stored by the building designer in the Building Information Model (BIM). We have developed a program to identify rooms, calculate RT for each room using Sabine’s formula by retrieving necessary information from BIM and an external acoustics material database (openMAT). Our system also adds the calculated RT values as new attributes to the BIM and visually represents RT values based on seven octave-band frequencies on color-coded floor sheets within the BIM model. The results of the study indicate that BIM combined with acoustical simulation will bridge the gap between the two domains.

Introduction

Building Information Modelling (BIM) facilitates the integration of data analysis for architects, engineers, and construction professionals, by providing an information-centric platform. Acoustic specialists and experts have recently put an effort to adopt BIM software tools into their projects. Data are usually retrieved from a BIM model and are used in acoustical simulation software such as EASE, Odean, and CATT-Acoustics (Kim & Coffeen, 2013). However, interoperability issues between the BIM software and acoustical analysis software limit the applications in practice. One possible solution to this problem can be performing acoustical simulations locally in the BIM software. The integration can increase productivity by facilitating feedback loops between the architect and acoustic engineer. More importantly, the coordination among the architectural and acoustic models will keep both models up-to-date with impacts from the other discipline changes at various levels of development (LODs) of the model.

The current practice of transferring geometric and non-geometric data from BIM and plugging into acoustic simulation software (and vice versa) is time-consuming, error-prone, and the accuracy of acoustic analysis results will depend on the expertise of the user. The process is also unidirectional (i.e., from BIM to the acoustic software); hence, the simulation outputs cannot be easily retrieved back to the BIM.

In this paper, we will investigate/implement: (1) extraction of geometry data from the BIM software; (2) enriching BIM with acoustic-related data (absorption coefficients) via an external open format database; (3) calculation of reverberation time; and (4) visualization of the simulation results in the BIM software. The main objectives of the study include: supporting acoustic simulation as a BIM use, improving interoperability and decreasing the time for acoustical analysis; creating bi-directional feedback loops between architectural and acoustical models of a building.

Works done

Wong and Fan (2013) evaluated the use of BIM for sustainable designs. They studied functions, benefits and sustainable achievements of BIM inherency and BIM-based analysis tools and concluded that the lack of interoperability among BIM and other software tools could potentially limit the application of BIM in the architectural, engineering and construction industry.

Over the last decade, there have been several attempts to integrate acoustic analysis into BIM-related software during the conceptual design phase. A previous study on code compliance in France used BIM effectively with the help of the European Enriched Virtual Environments project (EVE). EVE is a developed program, which supports the different aspects of a building’s performance, including environmental noise and indoor noise compliance against French Building Code for the Buildings and Construction (B&C). The simulation module of EVE includes acoustic simulation codes which originate from a software called ACOUBAT-Son (Maïssa et al., 2002). Parminder (2015) tried to bridge the gap between standards for classroom acoustics and real-time practice of acoustical design of classrooms using BIM, acoustic simulation and multi-criteria decision modelling (MCDM). The author calculated values of early decay time (EDT), reverberation time (RT), and sound pressure levels (SPL) for classrooms, by importing data from an Industry Foundation Classes (IFC) model.
Some BIM software products have acoustic simulation capabilities. However, they are most useful with respect to the noise generated from mechanical, electrical and piping (MEP) systems. Kim et al. (2013) used Autodesk Revit in conjunction with acoustic simulation software of EASE, and Autodesk Ecotect to analyze noise levels, RT, and binaural impulse response of an auditorium while examining the performance, productivity of the project design and efficiency of collaboration between architects and acousticians. They conclude that the interoperability between BIM and acoustic simulation is of importance to successful acoustic performance in the building design. Another interesting aspect of their study was the comparison between interoperability of EASE and Ecotect with Revit. They reported that while EASE was capable of conducting more sophisticated simulations, Ecotect was more compatible with Revit. According to this study, EASE has its disadvantages including the time consuming and complicated process of rebuilding a 3D model.

Tan et al. (2017) took advantage of IFC 4 and Revit API to extract geometric data for a concert hall. They then assigned absorption coefficients to indoor decorated materials through a plug-in. Finally, an acoustic simulation was conducted using commercial finite element solver COMSOL. The authors focused on the effects of geometry and influence of a sound source. They calculated RT for the concert hall with different layout alternatives and various source types of sound and compared the results. However, they did not return the calculated properties and simulation results back to the BIM. In another study with Autodesk Revit, Wu and Clayton (2015) retrieved geometric data using the DirectX toolkit and Revit API. They conducted simulation via C# and manually added the non-geometric data to their simulation. While they color-coded floor sheets with their simulation outputs, the results (RT values) were not stored back in the BIM. This study interestingly mentions that even though Ecotect was developed by Autodesk, they did not add the functionality of importing non-geometric metadata such as materials and their absorption coefficients. Other researchers have also reported Ecotect to be a tool to ‘document results in a visual manner’, rather than adding numerical outputs as ‘attributes’ of BIM elements (Thuesen, Kirkegaard, & Jensen, 2010).

The review of the previous literature suggests that the industry lacks interoperability between BIM and acoustic simulation tools. Most studies used Autodesk Revit for 3D modelling, in combination with different external simulation platforms (including Ecotect, EVE, EASE, etc.) to analyse the models. While some return the analysis outputs and calculated factors back to the model and some do not; none of the previous studies stores back the simulation results as attributes of BIM elements.

Methods
In response to the gaps reported in the literature, the present study aims to develop a fully BIM-based process to improve the evaluation of indoor acoustic performance of buildings by calculating the RT of rooms on each floor based on seven octave-band frequencies of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. We selected Autodesk Revit (as the most common BIM modelling software in the literature), and aim to return calculated RT values and store it back in the model, as attributes of rooms.

RT calculation
In this study, the calculations are based on Sabine’s formula of reverberation time (Kinsler, 2000). The equation is:

\[
RT_{60} = \frac{0.161 V}{\sum S \alpha}
\]

where:

- \(RT_{60}\): reverberation time (sec)
- \(V\): volume of a room (m\(^3\))
- \(S\): surface area of material (m\(^2\))
- \(\alpha\): absorption coefficient

The range of absorption coefficients is from 0 to 1. The coefficient would be 0 when none of the sounds is absorbed, and it would be 1 when all of it is absorbed. Sabine’s equation used in this study assumes a diffuse sound field for calculating the reverberation time. There are other equations for non-uniform absorption distribution in a room, but Sabine’s equation is the most popular and suitable for prediction a reverberation time for a general purpose.

Acoustic material open database
An acoustic material database is necessary to find absorption coefficients of the finish material of all surfaces inside rooms. Today, researchers and acoustic consultants have access to many acoustic simulation programs. These applications can be commercial or open-source. The interoperability between different programs is practically non-existent since they rely on internally developed database formats. Therefore, OpenMAT database project was initiated to support a detailed description of materials and to provide acoustic professionals with an exchangeable database usable in acoustical simulation software (Schröder et al., 2013). OpenMAT can store both numerical data and meta-information of the material in an open Extensible Markup Language (XML) format. The available data are absorption coefficients, scattering coefficients, the price of material, URL, a photo of materials texture, and etc. Moreover, OpenMAT has both C++ and Python library for external coding.

3D Model preparation
A Revit model of a building passed to an acoustic engineer from an architect needs some pre-processing before the RT simulation. The preparation process includes steps such as:

- Making sure that walls and ceilings are joined
- Double checking rooms defined in the architectural model
- Checking rooms’ constraints and changing the “limit offset” of the rooms based on the thickness of the ceiling if needed.

Additionally, since the simulation is conducted through a process developed in Dynamo in this study, some additional steps are needed to set up required libraries. Our code uses the following dependencies: Bakery (2018.4.301), Clockwork for Dynamo 2.x (2.1.0), RevitPython (1.0.0), and Spring Nodes (132.2.8). Dynamo is a node-based programming tool, which can be accessed through either Revit or Dynamo Studio. In this study, Dynamo is used in conjunction with OpenMAT database to calculate RT for rooms on each floor of a building through its Revit models.

**RT calculation module**

Our analysis process (and the program developed in Dynamo based on it) consists of 10 major components (also known as “blocks”), each of which is composed of smaller sub-processes. Figure 1 illustrates the process and the relations among the blocks. Sub-processes in each block is explained in the following.

**Figure 1: Process of RT calculation and assignment**

1. **Calculation of Rooms’ area:** All ‘Room Elements’ from the ‘Room Category’ are called from the Revit model. The extrusion of their base boundary is then intersected with a plane made from the room’s bottom closed curve. This process will produce ‘surfaces’ which their area can be measured. These will be then calculated as the area of rooms.

2. **Floor & Ceiling area calculation:** Our assumption is that both the ‘Floor’ and ‘Ceiling’ have the same areas. On the basis of this simple assumption, a list of areas retrieved from the previous block is duplicated and transposed to create material-area matrix for floors and ceilings (block 5).

3. **Detecting Floor’s finish material:** ‘Floor Elements’ are filtered among all elements of each ‘Floor’. Then, the floor’s finish is extracted using a custom node. The ‘Material’ of the floor’s finish is then passed to the next node block.

4. **Finding Ceiling’s finish material:** The exact same procedure as block 3 is repeated for ‘Ceiling Elements’ this time. The main difference is that the finish is at the bottom layer for ceilings, and the finish is the top layer of the element for floors.

5. **Floor & Ceiling (Material–Area) Matrix:** Our assumption is that all rooms in the same level are similar in terms of floor and ceiling finish materials. Although this is a limiting assumption and must be resolved in future versions of the system, it allows us to easily combine Floor’s (and Ceiling’s) finish materials and replicate them for as many rooms as exist on that floor to create a ‘Material Matrix’ of floor & ceiling for each level of the building. This matrix is then combined with the area matrix received from Block 2 is and transposed to create the ‘Floor & Ceiling (Material - Area) Matrix’.

6. **Wall’s Finishes (Material–Area) Matrix:** This block is similar to the previous one, but for Wall elements except that wall finishes dimensions do not exactly match the dimensions of walls since their start and end points are from the top of the floor’s finish to the bottom of the ceiling’s Finish. Based on the above assumption, and using two python scripts, Wall Finishes’ ‘Material’ and ‘Area’ are calculated. They are then combined and transposed to create the ‘Wall’s Finishes (Material - Area) Matrix’.

7. **Calculating volume of Rooms:** All ‘Room Elements’ from the ‘Room Category’ are called and solid shapes are generated from their geometry. The volumes of these solids are retrieved, multiplied by the constant value 0.161, and passed on to the next block to be used in the numerator of Sabine’s RT formula.

8. **Parsing OpenMat database for absorption coefficients:** The openMAT database is called from its path and is parsed using ElemenTree3 node to retrieve all the ‘Material Names’ accompanied by their 7 ‘Absorption Coefficients’ and form a matrix that we call ‘Material & Absorption Coefficients’. The result is passed on to the next major block to be used in the calculation of the RT for each of the rooms.

9. **Matching Materials and calculating RT:** This block consists of two nodes: the core node running a python code, and a ‘watch’ node. The python code receives as input, the matrices of: ‘Material & Absorption Coefficients’, ‘Floor & Ceiling (Material - Area)’, ‘Wall Finishes (Material - Area)’, and Sabine’s RT ‘Numerator’ and calculates as the output the reverberation times per room on each floor. The Python code searches for the finish materials of the model in the ‘Material & Absorption Coefficients’
Matrix’ which was passed from Block 8, and uses the associated coefficients to calculate the RTs.

10. Assigning values to parameters RT: This is a combination of seven blocks. In each block, one set of calculated RTs are picked and assigned to room’s parameter Reverberation Time \(i\) (an integer from 1 to 7, representing the 7 octave-band frequencies).

**Visualization module**

This module visualizes the results back in BIM. It is composed of two major components.

1. Creating views: this component consists of 7 blocks, each is creating a view (to represent one of the RT) per each floor. It works by replicating existing views of floors and renaming them (by adding “\_RTi” to the end of the view name. These views will go through the color-coding method and will represent RT of rooms on a floor for one of the 7 octave-band frequencies calculated.

2. Colouring each level: This component color-codes the seven replica floor plan views. All rooms are geometrically extruded as solids, and ‘color weights’ are assigned to them based on the range from the highest and lowest RTs of the rooms.

**Case study**

In order to validate and verify the developed system and examine the practicality and efficiency of this process in action, an educational space at Concordia University in Montréal was studied. Autodesk Revit 2019 was selected as the BIM software to analyse the model of John Molson School of Business at Concordia. This building has 17 floors and 37,000 gross square meters of area. The building was opened in 2009 and is LEED Silver certified. We analysed the Revit model of the building and compared the outputs versus RT values manually calculated in Microsoft Excel, to verify the outputs of the developed system.

**Results and discussion**

Absorption coefficients were extracted from the database of Physikalisch Technische Bundesanstalt (PTB). All minor surfaces such as doors, windows, partitions and furniture are ignored because the information was not available in the BIM model. The future study, however, should include the neglected components with the detailed model. We selected a colour code, covering shades of red (from dark, i.e. high, to light, i.e. low, RT values). Figure 2 presents examples of visualization for the simulation results.

![Figure 2: JMSB Building and its digital model](image)

The comparison of our results versus the results calculated manually in MS EXCEL shows a very close conformation for the results generated by the developed software system. The average difference between calculated and simulated RTs across the octave band frequencies from 125Hz to 8kHz is 0.23% with the standard deviation of 1%.

On the other hand, the RT values calculated were compared against the suggested values from ANSI/ASA S12.60-2010 for evaluation of the building’s acoustical performance. The standard recommends reverberation time of 0.6 seconds for classrooms with enclosed volume up to 283 m\(^3\), and 0.7 seconds for larger classrooms. Almost half of the RTs calculated for classrooms in JMSB building were above this range.

While the approach used in our study is similar to previous works with respect to the use of Revit as the BIM authoring software and choosing RT as the building acoustic performance factor, this study contributes to this field by:

- Calculating of RT within the Revit environment and avoiding the use of IFC exports (and the interruptions associated with it),
- Accessing to both geometric and non-geometric parameters without regenerating the 3D model,
- Using an open acoustic material database which can be completed and shared with others on the fly,
Creating a bidirectional path and a closed feedback loop between architectural and acoustical models.

Conclusion
Improving productivity and efficiency of shared information among the acoustic professionals and architects was the main objective of this study. This paper pointed out the information technology gap between the two fields and suggested one solution for bridging part of it. We calculated the reverberation time of rooms using an external acoustic material database, a Revit 3D model, and the analysis process that we developed, without involving any additional third-party application. On the one hand, this resolve interoperability issues reported in the previous works (by keeping the entire process in the same software environment) and on the other hand, storing the simulation outputs back in association with room elements enriches the BIM model. Creating closed feedback loops in BIM (as a process) is shown to be in line with the goals of achieving higher levels of BIM maturity in architecture, engineering and construction organizations.

The limitations of this study range from scope (to the calculation of reverberation time), to assumptions and algorithmic limitations. The future versions of the system can be extended to simulation and calculation of factors such as sound level and structure-borne noise. Additionally, the system must be tested by models with a higher level of detail. Future works can study other forms of construction and building types. Moreover, each of the four simplifying assumptions mentioned in the methods section, adds limitations to the system that must be improved in future developments. Integrating OpenMat databases in BIM-based simulations requires better semantic integration. This can, for example, include developing and using “Material Universal ID” system, rather than searching material by their names. An alternative solution (which will need the software vendor initiatives) can be to enrich Revit material database with more detailed material properties. Another important improvement which is currently underway is including absorptions by furniture, windows and doors for RT simulation results; RT values for a vacant building (as calculated in this paper) are expected to be higher than the values for a furnished one.

Despite its limitations, this study successfully accomplished the defined objectives to bridge the gap between BIM authoring software and acoustical simulation, and consequently architects and acousticians.

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References