ENGR 6991 Project and Report III

BIM-Acoustic Final Report

Dr. Mazdak Nik-Bakht
Dr. Joonhee Lee

Kaveh Erfani
40067302
Sara Mahabadipour
40059331

Date
December 6th, 2018

Table of Contents

Table of Figures

Table of Tables

Introduction

Building Information Modeling (BIM) software facilitates the integration of data analysis for architects, engineers, and construction (AEC) professionals by providing a central information platform. ArchiCAD, Tekla Tools, Bently Applications, Revit products are good examples of a few BIM software used by the AEC industry. Acoustical specialists and experts have recently put an effort to adapt BIM tools into their projects. The data is usually retrieved from a BIM model and is then used in acoustical simulation software such as EASE, Odean, CATT-Acoustics and Autodesk Ecotect Analysis. However, the interoperability between the BIM software and acoustical analysis software is very limited.

Motivation

This paper is to demonstrate how an acoustician could use BIM models and external acoustical databases to conduct acoustical simulations without the use of acoustical simulation software. The goal is to show the possibility of creating a feedback loop between architectural design and acoustical analysis in a BIM software environment. This could dramatically increase productivity and coordination among architects and their fellow acoustician colleagues.

Problem Statement

Geometric and non-geometric data from Building Information Models (BIM) need to be manually reconstructed in acoustic simulation software to examine building acoustic performance. This process 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); meaning that simulation outputs can't be easily retrieved back to the BIM. The paper will investigate: 1) extraction of geometry data from the BIM software; 2) enriching the BIM with data regarding acoustic absorption coefficients, via an external database; 3) calculation of reverberation time and 4) visualization of the simulation results in the BIM software.

Previous Studies

Over the last century, many studies and tests have been conducted on the prediction of building's acoustic performance. Reverberation Time (RT) is the most commonly selected acoustic factor for prediction due to the simplicity of its formula. The most famous Reverberation Time prediction formulas were proposed by Sabine and Eyring.

The rapid growth of computer science resulted in the development of computer simulation. Building acoustic simulation had only begun to become more efficient and available by late 1960. Computer models have been developed to study the effects of different factors of the acoustic performance of buildings. Over the last decade, several attempts have been made to integrate acoustic analysis into BIM-related software during the conceptual design phase.

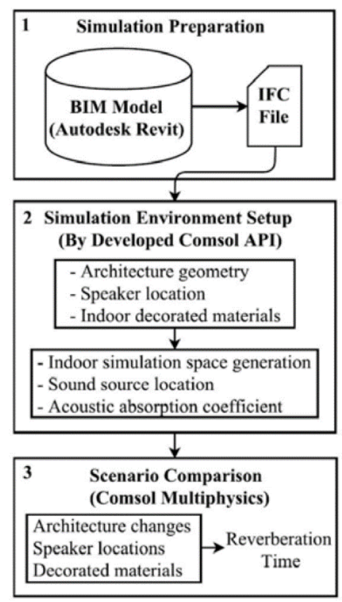

Figure 1 - Flowchart of Tan, Fang, Zhou, Wang, Cheng's Study Method

Y. Tan , Y. Fang , T. Zhou , Q. Wang, and J.C.P. Cheng had used an Autodesk Revit Model to retrieve its IFC file. They mentioned in their "Improve Indoor Acoustics Performance by Using Building Information Modeling" that they had to reconstruct the model's non-geometric data in COMSOL Multiphysics using the COMSOL API. The acoustic simulation was conducted in COMSOL and the results were never returned to the Revit Model. Therefore, their studies lacked a closed feedback loop to further enrich the BIM model.

Also, Chengde Wu, Mark. J. Clayton used an Autodesk Revit Model to retrieve their model's geometric data using a developed C# Program and Revit API. They conducted their simulation in the developed C# Program and could never return back their results to the BIM model. It is obvious that the industry lacks the interoperability among BIM and acoustic simulation software.

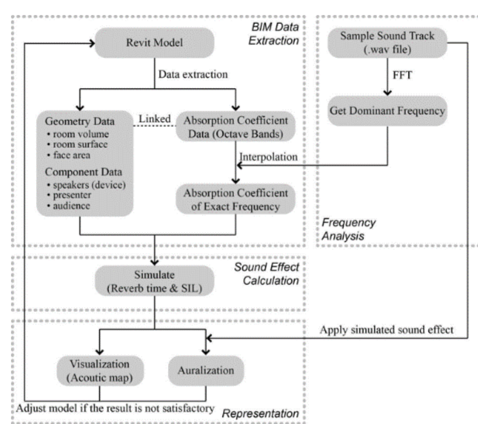

Figure 2 - Flowchart of Wu and Clayton's Study Method

Similarities of both studies is that they both used Autodesk Revit, and both have calculated the Reverberation Time.

Methodology

The approach of this study is a BIM-based which proposes a process to improve the indoor acoustic performance of buildings by calculating the Reverberation Time of rooms on each floor based on seven frequencies of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz.

Sabine’s Reverberation Time Formula

In this study, the calculations are based on Sabine’s formula of Reverberation Time. The original formula is:

$$RT_{60} = \frac{24\,(\ln 10)\ V}{c_{20}\, S_a}$$

RT60: Reverberation Time to drop 60 dB

V: The volume of the room

c20: The speed of sound at 20°C which is 343 m/s

Sa: is the total absorption

One square meter of a surface with an absorption coefficient of 0.75 would be considered 0.75 Sabine’s since Sabine’s unit has the same dimension as area. The range of absorption coefficient is 0 to 1. The coefficient would be 0 when none of the sounds is absorbed, and it would 1 when all of it is absorbed. The formula is further simplified to:

$$RT_{60} \cong \frac{0.161\mathrm{s/m}\ V}{S_a}$$

RT60: Reverberation Time to drop 60 dB
V: The volume of the room
a: Absorption coefficient of the material
S: Surface Area

OpenMAT: Acoustic Material 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 applications. These applications could be commercial or open-source. Although all applications use similar material data, interoperability among different applications is practically non-existent since they rely on internally developed database formats. Therefore, the openMAT database project was founded to support a detailed description of materials and to provide acoustic professionals with an exchangeable database usable in acoustical simulation software. The openMAT could store both numerical data and meta-information on the material in an open Extensible Markup Language (XML) database format. The available data could be absorption coefficients, scattering coefficients, the price of material, URL, a photo of materials texture, and etc. "The XML schema applied in openMAT is defined by an XML Schema Definition (XSD) file in compliance with the W3C recommendations" (openmat.info, 2018). Also, it is worth to mention that the openMAT has both a C++ and Python library which could be very handy for external coding.

Revit File Prepration

First, a Revit model of a building is chosen and its floors are separately extracted and saved as new Revit models (i.e. if a 7 story building is chosen, then 7 Revit files must be created, each having one specific floor only). Then, 7 project parameters are defined in the Revit models as:

- Reverberation Time 1
- Reverberation Time 2
- Reverberation Time 3
- Reverberation Time 4
- Reverberation Time 5
- Reverberation Time 6
- Reverberation Time 7

They are all parameters of Revit's Room element, and their type should be set as 'Number'.

Dynamo

Dynamo is a node-based programming tool which could be accessed either through Revit or through the installation of the Dynamo Studio. Any of the Dynamo and the Dynamo Studio would be more than sufficient. In this study, the Dynamo is used to calculate the reverberation times of rooms on a floor using the openMAT database, and Revit models. The Dynamo programs produced by the end of this study are:

1. RT Calculation.dyn
2. Creating 7 Views.dyn
3. Color-coding Level1_RT1.dyn
4. Color-coding Level1_RT2.dyn
5. Color-coding Level1_RT3.dyn
6. Color-coding Level1_RT4.dyn
7. Color-coding Level1_RT5.dyn
8. Color-coding Level1_RT6.dyn
9. Color-coding Level1_RT7.dyn

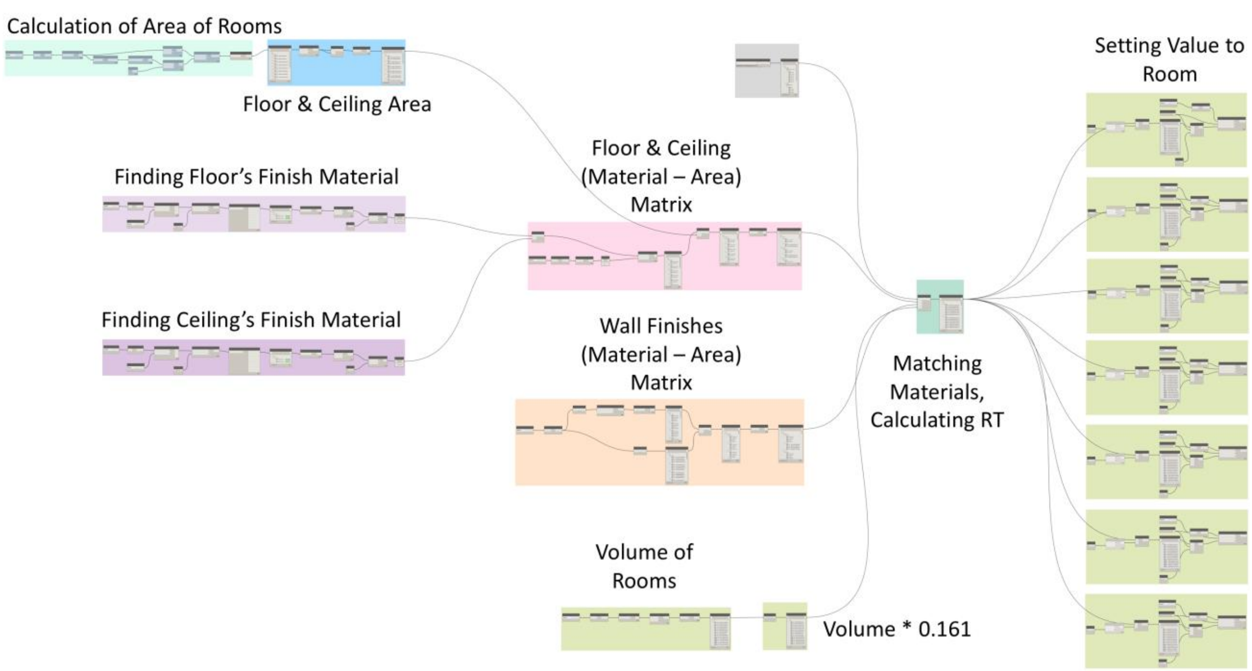

Figure 3 - RT Calculation.dyn Program's Major Blocks

RT Calculation.dyn Program

This program consists of 17 major blocks which will be discussed:

1. Calculation of Area of Rooms

   All of 'the Room Elements' from 'the Room Category' is called and 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' could be measured. These will be the calculated area of rooms.

2. Floor & Ceiling Area

   Assumption: Both the 'Floor' and 'Ceiling' have simar area.

   Based on the above assumption, list of areas retrieved from the last block is duplicated and transposed to create the Floor & Ceiling Area Matrix.

3. Finding Floor's Finish Material

   All 'Elements' of 'Level 1' are filtered to select the 'Floor' of 'Level 1'. Then, Floor's finish is extracted using a custom node. The 'Material' of the floor's finish is then selected to be passed to the next node block. This will be done by selecting the item with an index of 0 since the Finish is the top layer.

4. Finding Ceiling's Finish Material

   All 'Elements' of 'Level 2' are filtered to select the 'Floor' of 'Level 2' which is basically that story's 'Ceiling'. Then, Floor's finish is extracted using a custom node. The 'Material' of the floor's finish is then selected to be passed to the next node block. This will be done by selecting the item with an index of 1 since the Finish is the bottom layer.

5. Floor & Ceiling (Material - Area) Matrix

   Assumption: Floor's Finish Material is the same for all rooms.

   Assumption: Ceiling's Finish Material is the same for all rooms.

   Based on the above assumptions, Floor's Finish Mateiral and Ceiling's Finish Material are combined and repeated as many rooms as exist on the floor to create 'The Material Matrix of Floor & Ceiling'. The area matrix is also received from the 'Floor & Ceiling

Area' block. They are combined and transposed to create the 'Floor & Ceiling (Material - Area) Matrix'.

6. Wall's Finishes (Material - Area) Matrix

   Assumption: Wall Finishes do not exactly match the dimension of walls as their start and stop point 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, both the Wall Finishes' 'Materia' and 'Area' have been calculated. They are combined and transposed to create 'the Wall's Finishes (Material - Area) Matrix'.

7. Volume of Rooms

   All of 'the Room Elements' from 'the Room Category' is called and from their geometry, solid shapes were generated. The volume of those solids was retrieved and passed on to the next major block to calculated the numerator of Sabine's RT Formula.

8. 0.161 * Volume of Rooms (Numerator)

   The volume of rooms received is multiplied by the constant number of 0.161 to form the numerator of Sabine's RT Formula. The result is passed on to the next major block to be used for calculation of RT of rooms.

9. Parsining Absorption Coefficients of All Finishing Materials Existing in the XML Database (OpenMAT)

   The openMAT database's file path is selected to be used by the ElemenTree3 node to pars all the 'Material Names' accompanied by their '7 Absorption Coefficients' to form the matrix of 'Material & Absorption Coefficients'. The result is passed on to the next major block to be used in the calculation of the RT of rooms.

10. Matching Materials, and Calculating Reverberation Time

    This block consists of two nodes which are a python code and a watch node. The main node would be the python code which was the most complicated part of this study which was achieved by Dr. Nik-Bakht's great help. Four matrixes of 'Material & Absorption Coefficients', 'Floor & Ceiling (Material - Area)', 'Wall Finishes (Material - Area)', and

‘Numerator’ have been connected to this block as inputs to calculate 7 Reverberation Times per room on the floor. The Python code searches for the existing materials of the project in the ‘Material & Absorption Coefficients Matrix’ which was parsed from the openMAT database and uses those coefficients to calculate the reverberation times.

11. Setting Value to Reverberation Time 1 Parameter

First set of calculated reverberation times are picked and assigned to room’s ‘Reverberation Time 1’ parameter. Similarly, the second, third, fourth, fifth, sixth, and seventh set of calculated RTs are assigned to Reverberation Time 2, 3, 4, 5, 6, and 7 respectively.

12. Setting Value to Reverberation Time 2 Parameter
13. Setting Value to Reverberation Time 3 Parameter
14. Setting Value to Reverberation Time 4 Parameter
15. Setting Value to Reverberation Time 5 Parameter
16. Setting Value to Reverberation Time 6 Parameter
17. Setting Value to Reverberation Time 7 Parameter

Creating 7 Views.dyn Program

This program consists of 7 major blocks which all have similar functionality.

1. Creating Level1_RT1 View
2. Creating Level1_RT2 View
3. Creating Level1_RT3 View
4. Creating Level1_RT4 View
5. Creating Level1_RT5 View
6. Creating Level1_RT6 View
7. Creating Level1_RT7 View

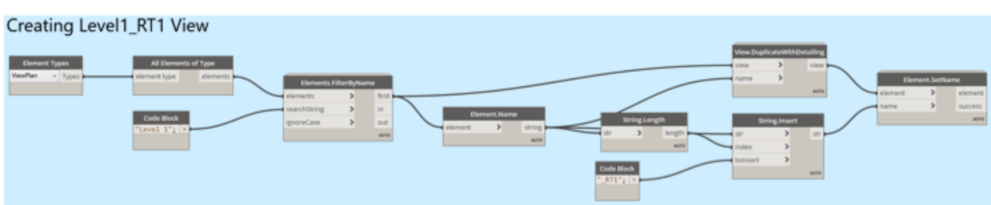

Figure 4 - 7 Similar Major Blocks of Creating Level1_RTx View

The function of these major blocks is to duplicate the Floor Plan: Level 1 of the Revit model and add the _RTx to the name of the view. These views will go through the color-coding method and will visually represent the reverberation times of rooms. Each view will represent reverberation times of rooms based on one frequency (out of the 7 frequencies calculated).

Color-coding Level1_RTx.dyn Programs

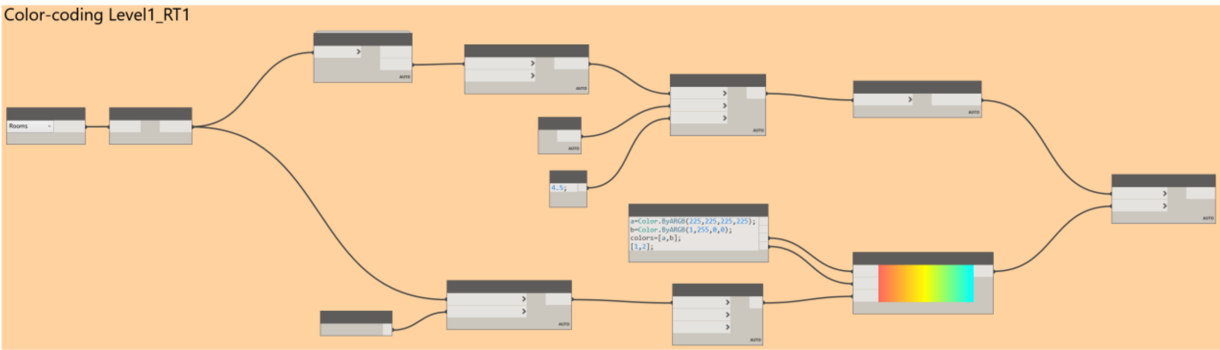

Figure 5 - 7 Similar Files of Color-coding Level1_RTx

This dynamo program is created 7 times; each for color-coding an specific duplicated view of Floor Plan: Level 1. All rooms are geometrically extruded as solid shapes, and color weights are assigned to them which are calculated using the highest and lowest reverberation times of the rooms.

Case Study

A case study with an educational space at Concordia University in Montreal is carried out to validate the developed system and examine the practicality and efficiency of this process in action.

Autodesk Revit 2019 is selected as a BIM software to analyze the model of Concordia University's School of Business, the John Molson building. The Dynamo Studio is highly interoperable with Revit and is used to analyze the model and run a simulation to calculate the reverberation time (RT) of rooms on a selected floor. Data from the simulation is then compared with data calculated by hand using Microsoft Excel to check and ensure the credibility of the program's calculation procedure.

Figure 6 - (left) Real picture of John Molson Building, (Right) 3D Revit Model with LOD of 250 of John Molson Building

The reverberation time (RT) is calculated 7 times based on 7 different frequencies. The data generated by Dynamo will be stored in the Revit model and the results will be represented on 7 copies of the original floor sheet. The rooms are color-coded based on their reverberation time.

Results

Absorption coefficients are taken from the appendix of an educational book which could be found in the reference. However, we decided to reduce them by some factors to reduce the reverberation times of rooms after consulting with Dr. Lee.

Table 1 - Modified Absorption Coefficients

Frequency	Concrete	Glass	Plaster
125	0.14	0.7	0.07
250	0.14	0.35	0.07
500	0.21	0.28	0.14
1000	0.21	0.21	0.14
2000	0.28	0.21	0.14
4000	0.35	0.21	0.35
8000	0.35	0.21	0.35

Table 2 - Original Absorption Coefficients

Frequency	Concrete	Glass	Plaster
125	0.02	0.1	0.01
250	0.02	0.05	0.01
500	0.03	0.04	0.02
1000	0.03	0.03	0.02
2000	0.04	0.03	0.02
4000	0.05	0.03	0.05
8000	0.05	0.03	0.05

Table 3 - Results Calculated Using Microsoft Excel

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
ROOM	RT	RT	RT	RT	RT	RT	RT
1	0.709548	1.081934	0.868032	0.947854	0.855116	0.522213	0.522213
2	0.482542	0.695329	0.499736	0.533555	0.502899	0.261154	0.261154
3	0.483282	0.697124	0.501752	0.535884	0.504968	0.262583	0.262583
4	0.483282	0.697124	0.501752	0.535884	0.504968	0.262583	0.262583
5	0.483282	0.697124	0.501752	0.535884	0.504968	0.262583	0.262583
6	0.483282	0.697124	0.501752	0.535884	0.504968	0.262583	0.262583
7	0.521081	0.768691	0.572738	0.616384	0.57591	0.31109	0.31109
8	1.314969	1.314969	0.71094	0.71094	0.657484	0.309543	0.309543
9	2.0859	2.0859	1.104567	1.104567	1.04295	0.469569	0.469569
10	1.887307	1.887307	1.057838	1.057838	0.943654	0.481384	0.481384
11	1.8861	1.8861	1.057045	1.057045	0.94305	0.480956	0.480956
12	0.986215	1.30842	0.903839	0.946564	0.848188	0.473917	0.473917
13	1.004942	1.342049	0.929474	0.974766	0.876943	0.486934	0.486934
14	1.50885	1.50885	0.800048	0.800048	0.754425	0.340618	0.340618
15	0.434266	0.661812	0.510878	0.555843	0.522581	0.285809	0.285809

Room Schedule							
A	B	C	D	E	F	G	H
Name	Reverberation Time 1	Reverberation Time 2	Reverberation Time 3	Reverberation Time 4	Reverberation Time 5	Reverberation Time 6	Reverberation Time 7
Room	0.709493	1.081862	0.867982	0.947802	0.855074	0.522186	0.522186
Room	0.481909	0.694484	0.499195	0.532995	0.502359	0.260907	0.260907
Room	0.483013	0.696779	0.50157	0.535703	0.504764	0.262531	0.262531
Room	0.483013	0.696779	0.50157	0.535703	0.504764	0.262531	0.262531
Room	0.483105	0.696951	0.501735	0.535888	0.504929	0.262639	0.262639
Room	0.483013	0.696779	0.50157	0.535703	0.504764	0.262531	0.262531
Room	0.520522	0.767682	0.571887	0.615426	0.574941	0.310606	0.310606
Room	1.313794	1.313794	0.710282	0.710282	0.656897	0.309244	0.309244
Room	1.510272	1.510272	0.82655	0.82655	0.755136	0.365153	0.365153
Room	1.886987	1.886987	1.05767	1.05767	0.943493	0.481314	0.481314
Room	1.885458	1.885458	1.05671	1.05671	0.942729	0.480817	0.480817
Room	1.010381	1.351275	0.938046	0.984146	0.884544	0.492728	0.492728
Room	1.00482	1.341865	0.929299	0.974577	0.876807	0.486808	0.486808
Room	1.281059	1.281059	0.691184	0.691184	0.640529	0.300216	0.300216
Room	0.434099	0.661556	0.510642	0.555583	0.522377	0.28564	0.28564

Figure 7 - Reverberation Times Calculated by Dynamo

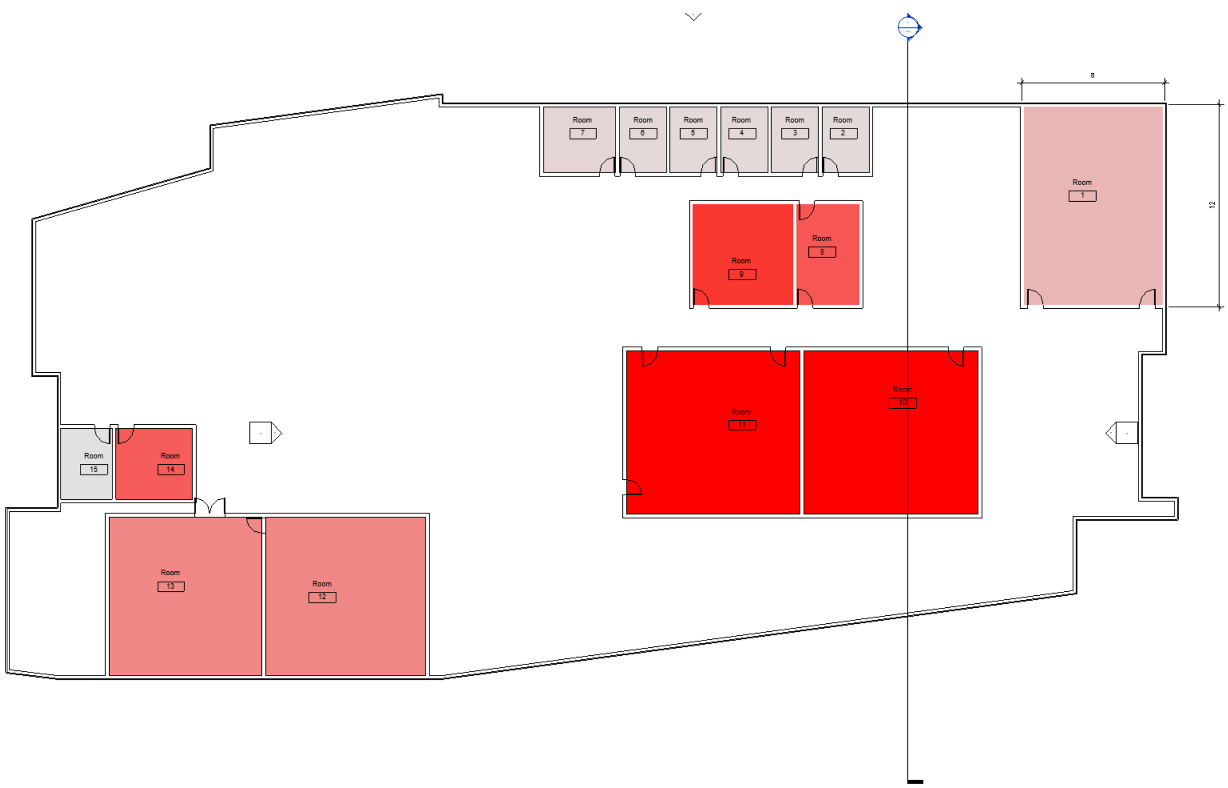

Figure 8 - Example of Visual Representation

Discussion

The approach used in this study is similar to the previous studies with respect to choosing Revit as the BIM software and choosing Reverberation Time as a factor of building's acoustic performance to investigate. However, this paper has major differences in areas which could be significant to the end user, such as:

1. Calculation of reverberation time within the Revit environment
2. Rejecting manipulation of IFC file to further complicate the process of interoperability
3. The model not being reconstructed
4. Geometric and Non-Geometric data not being imported
5. Use of an external acoustic material database (openMAT)
6. Eliminating the unidirectional method and introducing a closed feedback loop

Conclusion

Maximizing the productivity and efficiency among the acoustic professionals and architects by introducing and increasing interoperability among the acoustic simulation software and BIM applications should be of the highest priorities of the developer communities. This study shows how big of a gap has the information technology industry to fill between the two fields of science. Improving the building's acoustic performance using BIM tools has many benefits for the communities of both industries. A simple example of such improvement was shown in this paper by calculating the reverberation time of rooms using an external acoustic material database, a Revit model of a building using very little programing. Creating a closed feedback loop in a BIM application environment is shown to be in line with the goals of enriching BIM models.

Future work includes developing the dynamo program, 1) to recognize different materials of finishes of room's floor and ceiling, 2) to group the dynamo programs into one, 3) to predict a more advanced version of Reverberation Time, 4) to add this functionality to other BIM tools.

References

1. Acoustic Material Database. (2018). Retrieved from http://www.openmat.info/
2. Sound Insulation. (2015, January 29). Sabine's Formula & Modern Architectural Acoustics. Retrieved from https://www.thermaxxjackets.com/sabine-modern-architectural/
3. Chengde Wu, Mark J Clayton. (October 2013). BIM-Based Acoustic Simulation Framework. Retrived from https://www.researchgate.net/publication/304625903_BIM-Based_Acoustic_Simulation_Framework
4. Y. Tan , Y. Fang , T. Zhou , Q. Wang, and J.C.P. Cheng. (2017). Improve Indoor Acoustics Performance by Using Building Information Modeling. Retrieved from http://www.iaarc.org/publications/fulltext/ISARC2017-Paper133.pdf