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Sound insulation design methodology: case study on a music rehearsal room

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ABSTRACT

This paper describes the procedure to determine the acoustic insulation requirements of a musical rehearsal room in the basement of a house in a residential area.

An airborne sound insulation design methodology is proposed as a guide to follow in projects of similar characteristics, as the current normative publications cover only partial steps of the process. Improvement suggestions on this methodology and future development lines are also shown.

The methodology is applied to a case study which consists of the following steps: recording musical instruments in sound-proof chamber, determining their acoustic power, measuring the acoustic insulation of the room, modelling it using specific prediction tools and proposing solutions according to the fulfilment of the established objectives.

1. INTRODUCTION

A common problem for musicians is the impossibility of practicing their instrument in their own home without disturbing the neighbours and/or breaching the current regulations. The sound levels produced by instruments are often too high for the sound insulation typical of most settlements.

Most normative standards related with acoustic insulation offer directions to follow on the in-situ or laboratory tests for “partitions” [1], “building elements” [2] and “façades” [3]. There's not a standardized methodology for the design of the acoustic insulation of a specific case like this, apart from some recommendations for general rooms like the Technical Code of Building (Spain) [4], or for recording studios like Philip Newell's book “Recording Studio Design” [5]. They are usually focused on the insulation of one or various partitions, or in the acoustic treatments of the room. In some cases, like dorms or recording booths, some examples of very specific materials and solutions that work on those situations are presented, but in general the design methodology is responsibility of the engineer in charge of providing solutions, much more in demanding projects like the one exposed in this article.

An acoustic insulation design methodology is presented, applied to a room with high insulation requirements due to its purpose and its location. The scope of the proposal covers the phases of design and evaluation of different solutions, leaving out the verification of them. The results obtained in the on-field measurements, the simulations carried out to address the design, the problems encountered and suggestions for their solution, as well as future lines of development are discussed.

2. METHODOLOGY DEVELOPMENT

This methodology consists on several steps that will allow an optimized adjustment of the design of insulation solutions. The fundamental workflow is to obtain enough data from the real case to adapt the solutions as much as possible. Therefore, measurements are made, and then used as input data in simulation models. These models are adjusted with the real data offering guarantees in later phases of insulation estimation for different solutions that can't be easily implemented in reality. The stages of this methodological proposal are the following ones, and will be detailed each in following sections:

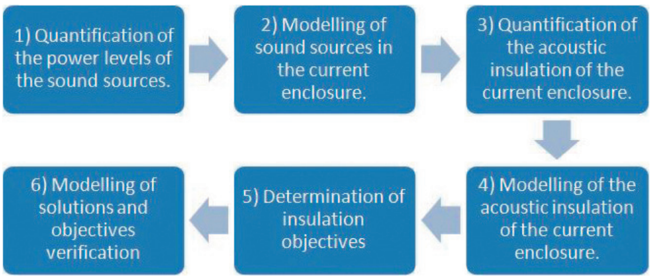


Figure 1. *Methodology stages.*

2.1. *Quantification of the Power Levels of the Sound Sources*

The first step is to calculate the acoustic power levels (L_w) of each sound source.

Those sound sources will be three of the most used musical instruments all over the world: bass-guitar, guitar and drums. The reasons to choose them are mainly two: they can reach really high volumes (drums by themselves, bass-guitar and guitar with help of amplifiers) and they constitute the most common base of any loud music band (rock, metal, etc.), being surely present in the future use of the rehearsal room. We are interested in developing a solution that works with the loudest instruments, so that any kind of other instruments can be safely played inside the room afterwards.

The first sound source will be actually the bass-guitar amplifier, followed by the guitar amplifier, continuing with the acoustic drum kit and finishing with the three of them together being considered as one source. The process followed to obtain the acoustic power levels is the one defined by the standard ISO 3744 [6]. A sound proof chamber with reflective floor and absorptive walls and ceiling has been used for the measurements. The sources were displayed on the floor in the centre of the chamber, and the microphones forming a semi-sphere around them. A graphical representation is shown in *Figure 2*:

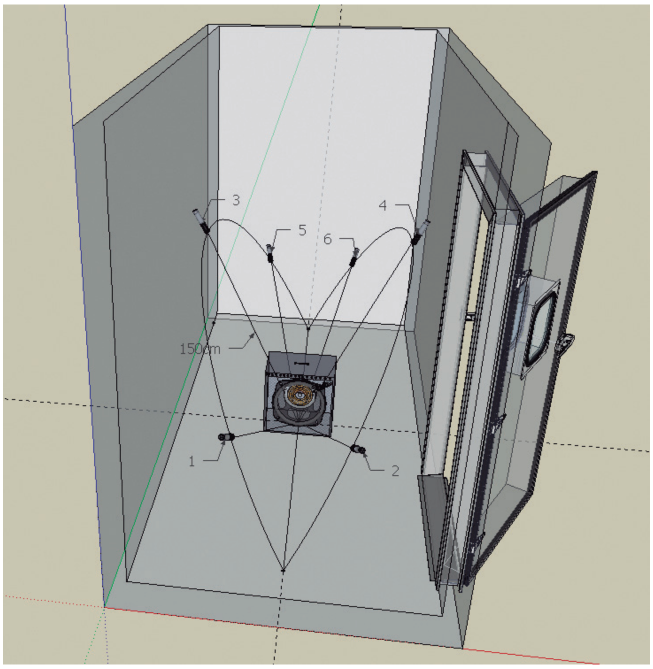


Figure 2. *Sound proof chamber model with source and microphone positions.*

The measurement procedure will be carried out by first recording a cycle of operation of the source with the two available microphones in positions 1 and 2 (measure A), repeating the same process for positions 3 and 4 (measure B), and finally for positions 5 and 6 (measure C).

It is important at this point to define the concept of cycle of operation in our case. In order to vary as little as possible the differences between the measurements belonging to different pairs of positions, a repetitive musical fragment was composed and interpreted by the three instruments in an iterative way for 20 seconds in each one of the measurements, trying also to maintain the same intensity.

Note that these sources may have variable power; in the case of the amplifiers, varying the output volume control, and in the case of the acoustic drum set, hitting harder or softer. For this reason, and given our interests, the test was carried out at the maximum volume of normal use, that is, setting the volume control of the amplifiers as high as possible without causing distortion, and playing the drums with energy.

After finishing the measurements in all the microphone positions planned for each source, it is possible to calculate the acoustic power levels from the measured sound pressure levels (SPL) with help of the formulas stated in [6]. Now we have developed a L_w comparative spectrum of the tested sources (Figure 3).

Beginning with the bass amplifier, it is easy to observe a clear descent of the power level as the frequency increases. In the case of the guitar amplifier the power levels are distributed in a much flatter frequency spectrum. Something remarkable about the drums experiment is that the values of the power level aren't lower than 102 dB in any of the frequency bands. Its L_w spectrum is high and almost flat in the whole range of frequencies. It's important to mention that the drums can produce even higher levels at low frequencies than the bass amplifier used.

In the fourth experiment, considering the three sources together as a single one, we obtain a considerable high power level. This data will be used in the following chapter to calculate the SPL level inside the room.

The data collected shows an omnidirectional behaviour of the source, although more microphone positions could be used in order to determine better the directionality.

It is possible to calculate the sound power level of an acoustic source by different procedures, following the standards [7 - 10]. It is very useful to know the sound power levels of the sources because they are independent of the room, and they are useful to predict the SPL levels that those sources will generate in any room.

2.2. *Modelling of the Sound Sources in the Current Enclosure*

A room sound field simulation tool will be employed to predict the sound pressure level that would be generated in the room by the three instruments without producing such levels on-field. This will avoid problems with the neighbours, as well as the difficulties of bringing the sources on site. From the L_w data collected previously it is possible to simulate these sources and determine the response of the room to their sound. In this case the tool EASE [11] is used.

The model should be compared and calibrated with the data collected in the insulation measurement (described in the next chapter). First, adjusting the surfaces' materials until we reach the most similar reverberation time possible. Then, modelling the omnidirectional test source used for the on-field measurements and applying a correction adjustment in each band to make the difference between the average results of the simulation and the average of the measured SPL levels smaller than 2 dB. Finally, it is possible to generate SPL distribution maps (*Figure 4*) introducing the source that represents the musical instruments in the model (in two different positions and with the correction adjustment applied) and to know the level predicted in each microphone position. The average SPL values will be calculated and used to create a source spectrum (*Figure 5*).

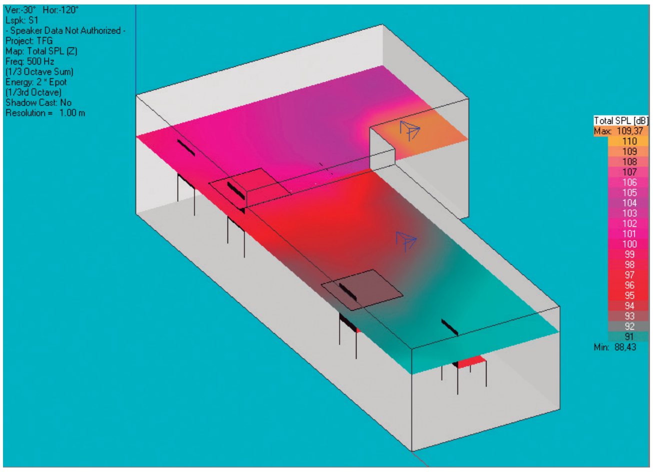
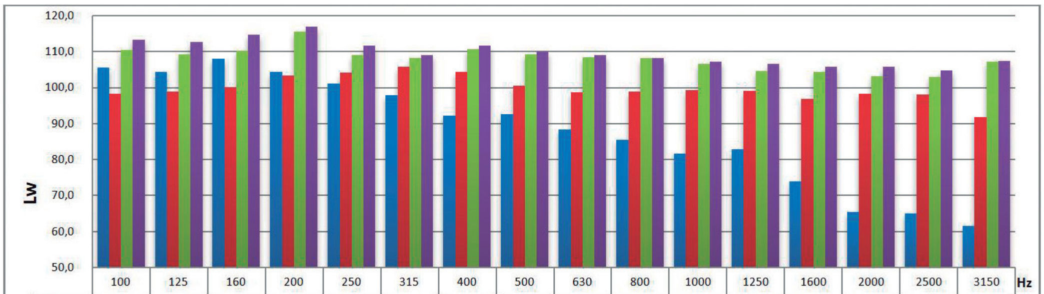


Figure 4. *SPL map with source in A point.*



	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	Hz
BASS	105,6	104,3	108,0	104,4	101,1	97,8	92,2	92,7	88,4	85,5	81,7	82,9	74,0	65,5	65,0	61,6	
GUITAR	98,2	99,0	100,2	103,4	104,3	105,7	104,4	100,5	98,7	99,0	99,3	99,1	96,8	98,4	98,1	91,9	
DRUMS	110,5	109,2	110,2	115,5	109,0	108,1	110,7	109,2	108,4	108,3	106,6	104,6	104,5	103,1	102,9	107,2	
ALL	113,2	112,7	114,7	117,0	111,7	109,0	111,7	110,1	109,0	108,3	107,2	106,6	105,9	105,9	104,7	107,4	

Figure 3. *Acoustic power levels (L_w) of each source.*

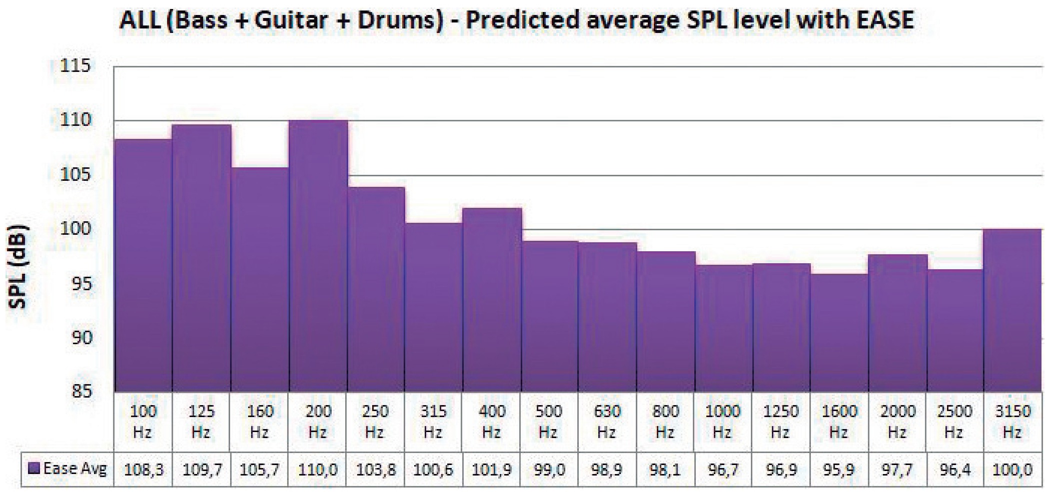


Figure 5. *Predicted average SPL level generated by the musical instruments in the room.*

Different software solutions than EASE may be used for this same task, as CATT-Acoustic, for example.

In this way, we have determined the level that is going to exist in the future use of the rehearsal room without generating it on-site. This level will be used in the insulation design and is more specific in frequency and level than using only a test source. It is important to note that we have made the assumption that the source representing the instruments is omnidirectional and aggregates the three instruments as one, placed in two different locations. As a future improvement line, this process can be repeated separating the three sources and taking into account their directionality.

2.3. *Quantification of the Acoustic Insulation of the Current Enclosure*

In order to design suitable solutions, it is necessary to know first the current insulation of the enclosure. The space that is being planned to be converted into a rehearsal room is part of the basement of a house that is attached to two more houses, one per side. We will call it "Basement" and it can be seen in orange colour in *Figure 6*.

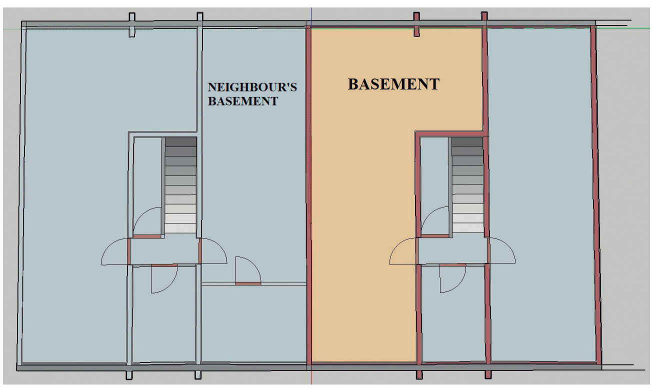


Figure 6. *Basement level plan.*

One of the walls of the room is shared with the adjacent house's basement. This wall does not differ in composition with the rest of the walls that separate the different rooms of the basement (12,5 cm of clay bricks with a 2 cm concrete cover on each side). This wall that separates both basements will be the most critical partition, as our principal objective is to ensure a lower level reception in the closest room of the neighbour's house than the maximum allowed by the local law. Additionally, the transmission vertically to the same house's living room will be studied, in order to achieve as well a low received level there as a secondary objective through the study of the insulation of the ceiling.

Once we have reached a valid solution for the wall, it is intended to apply it to the rest of the walls, building an integral isolation of the room.

The measurements are performed in the room setting the microphone/sound source positions and following the process described in the standard [12].

We will need to perform measurements of the emission level in the source room (Basement), the received level in the receiver rooms (Living Room and Neighbour's Basement), the level of background noise in the receiver rooms and the reverberation time in the receiver rooms. A total of 6 microphone positions are set in each room along with 2 source positions in the source room. This sums up a total of 12 combinations in each transmission path. For measuring the reverberation time the sound source should be moved to each receiver room and 4 microphone positions will be used. Additionally, we'll perform a reverberation time measurement in the source room for further data (calibrating the EASE model in previous section, for example).

The insulation level of each wall will be calculated via the next formula:

$$R' = L_1 - L_2 + 10\log\left(\frac{S}{A}\right)[dB]$$

Formula 1. *Apparent sound reduction index.*

where L_1 is the frequency-band level of emission in the source room in dB, L_2 is the frequency-band level measured in the receiver room in dB, S is the surface of the wall in m² and A is the equivalent sound absorption area of the receiving room in m². To calculate A, the formula of the reverberation time proposed by Sabine is used:

$$T60 = 0{,}161\left(\frac{V}{A}\right)[seg]$$

Formula 2. *Sabine's reverberation time*

where V is the volume of the receiver room in m³.

The results are shown in Figure 7.

The acoustic insulation of the critical transmission path, which is the wall separating both houses (Basement – Neighbour's Basement) will be surely insufficient, as we will see in section 2.5, for an emission noise like the one predicted in the previous section. The acoustic insulation of our secondary objective path, which is the ceiling separating the Basement and the same house's Living Room, presents a not so different R' curve, so it will need additional insulation also.

2.4. Modelling of the Acoustic Insulation of the Current Enclosure

The simulation tools allow us to calculate different solutions that could accomplish the objectives. In this case, the calibrated theoretical simulation tool INSUL [13] will be used, but there are other suitable options like WinFlag [14], for example.

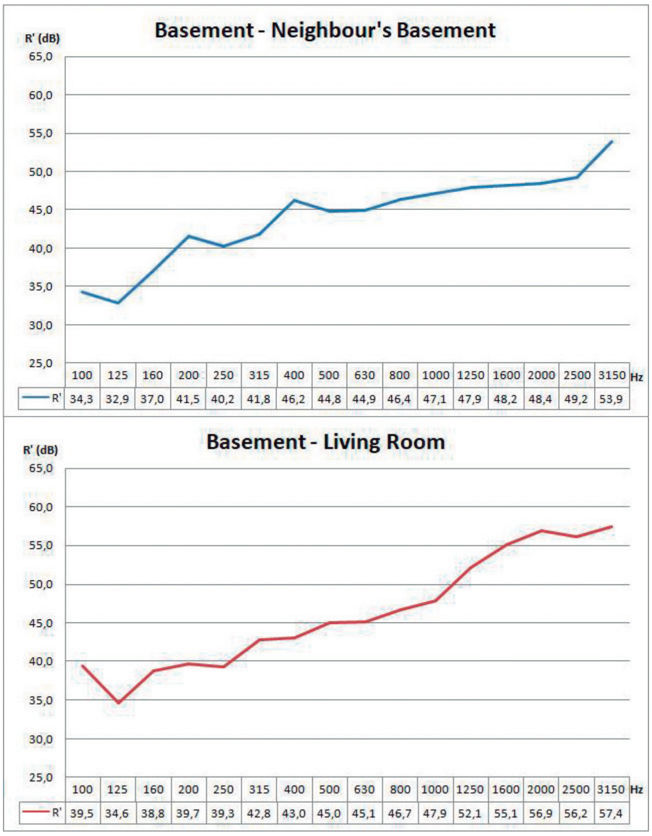


Figure 7. *Current insulation level of the wall and the ceiling.*

First of all, the existing wall and ceiling should be modelled, trying to obtain the most similar insulation values to the ones measured.

The original partitions are modelled setting a 12,5 cm layer of clay bricks with an internal layer of 2 cm of concrete for the wall, and a 19 cm layer of clay bricks with an internal layer of 2 cm of gypsum for the ceiling. Comparative graphs showing the difference between the values measured and modelled are shown below.

The model has limitations taking into account flanking transmissions and gives higher values in high frequencies

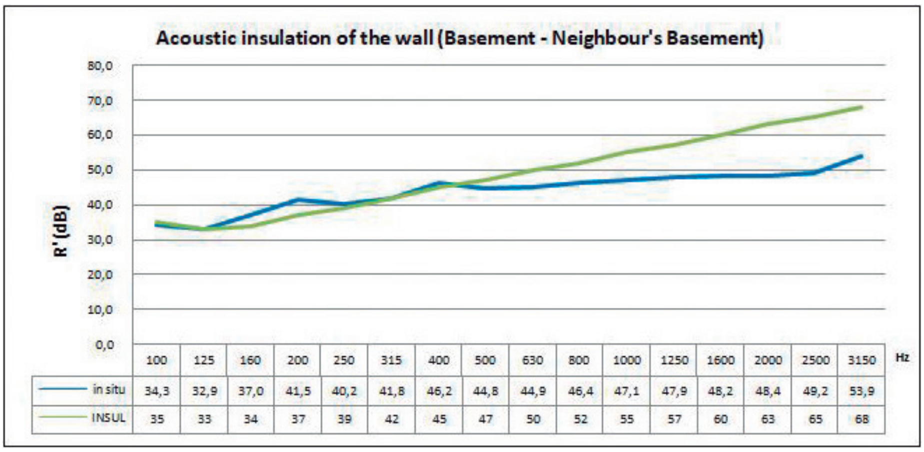
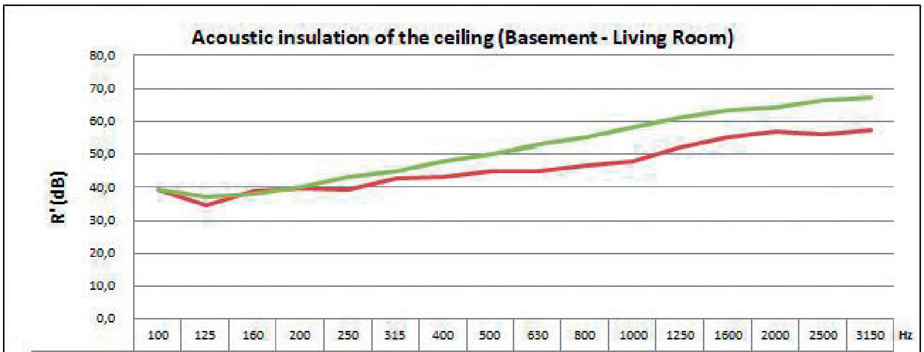


Figure 8. *Wall in-situ/INSUL comparative insulation results graph.*



	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	Hz
in situ	39,5	34,6	38,8	39,7	39,3	42,8	43,0	45,0	45,1	46,7	47,9	52,1	55,1	56,9	56,2	57,4	
INSUL	39	37	38	40	43	45	48	50	53	55	58	61	63	64	66	67	

Figure 9. *Ceiling in-situ/INSUL comparative insulation results graph.*

than the real insulation (the tool used also informs to typically have 3-5 dB uncertainties). The values agree quite well in low and medium frequencies, where we typically have the real insulation problems, in general cases and also in this case.

Flanking transmissions are not specifically studied because it has been checked by on-site measurements that they are not enough critical compared to the direct transmissions in the frequencies of interest, although they can be studied as a future improvement line. Being conscious of the importance of flanking transmissions in high insulation projects, we will extend the solutions designed for the most critical wall to the rest of them, even though only the critical wall is shared with the neighbour's basement. Also, a floating floor will be present, even though there is no more levels below the basement. This, along with the designed solution for the ceiling, will constitute an integral design solution with decoupled partitions that will further ensure that flanking transmissions remain kept to the minimum, and at the same time, provide the same insulation levels on the rest of the rooms of the user's house. It is surely not the most optimized solution if we focus in reaching the objectives in the neighbours's basement, as a specific solution for each one of the walls could be designed along with the development of a detailed flanking transmissions study, yet it is an effective solution.

The models' results using the software available are good enough for this case. There are other software options that can be used and compared in case we observe great deviations with the measured data. Some of them also take into account the flanking transmissions like SONarchitect [15] and Acoubat [16], but they are more data requiring and the time investment that they need is much bigger.

In the process of modelling the existing partitions is important to get as close as possible to the measured data, knowing the limitations of the modelling software, in order to design later valid solutions from these initial models.

2.5. Determination of Insulation Objectives

A fundamental part of the process is to establish the insulation objectives, avoiding in this way to use oversized or insufficient solutions and therefore achieving efficient designs.

For that, it's time to consult the local law's noise limit for transmission to the adjacent house [17], which corresponds to a L_{Aeq} of 35 dBA during the day and 30 dBA during the night. In order to know the maximum level in dB that we can transmit in each octave band, the equivalent NR Curve of these global dBA limits will be used, which corresponds with a NR-30 curve.

Using the *Formula 1* it is possible to calculate the level of sound received (*L2*) in the neighbour's basement and in the living room.

The additional insulation required for each octave can be calculated subtracting the NR-30 curve limit values to the received level values. Then, adding the results to the current insulation levels, the final insulation needed is calculated.

Knowing these final insulation levels that our partitions should reach, now it's possible to start evaluating different solutions with the help of the models created.

2.6. Modelling Solutions

The solutions will be decided with the help of the original partitions' models. The objective levels can be reached through the addition of layers of different

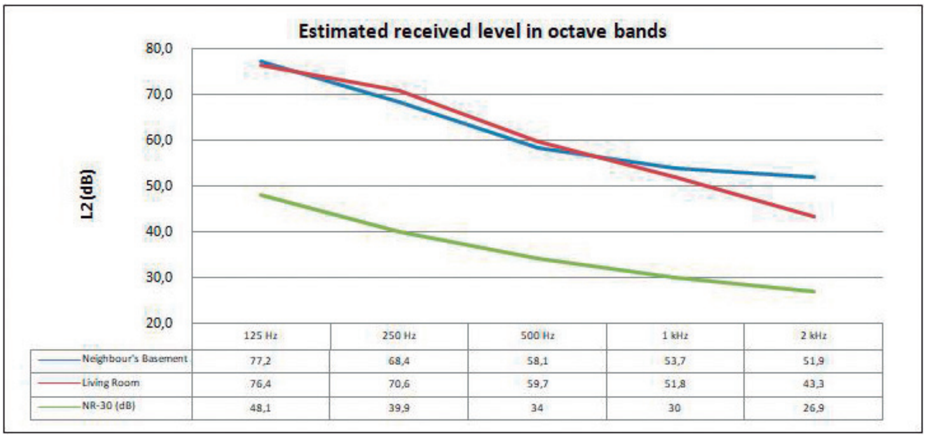


Figure 10. Calculated level in the receiver rooms (L2) vs. objective level.

R final (dB)	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz
Basement - Neigbour's Basement	71,1	76,4	74,9	76,1	77,3
Basement - Living Room	69,0	74,4	74,2	75,7	78,4

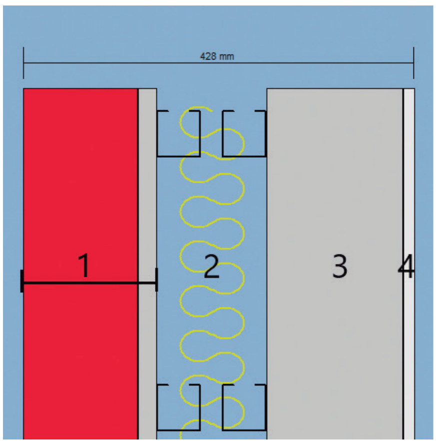
Figure 11. Final insulation levels required.

materials and thicknesses, as well as air chambers. Two limiting factors will be carefully taken into account while designing a solution: the space that the solution needs and the cost of the materials.

The chosen solution for the walls consists of (from the original wall to the room):

- 12 cm air chamber with 7,5 cm fiberglass sheet inside with density of 22 kg/m^3 (installed without adding a rigid union between both walls).
- 15 cm hollow concrete bricks layer with density of 886 kg/m^3.
- Internal layer of 1,3 cm acoustic gypsum board with density of 955 kg/m^3.

Total thickness of the solution: 28,3 cm.



1 - Original wall

2 - Air chamber with fiberglass

3 - Concrete blocks

4 - Acoustic gypsum board

Figure 12. Proposed solution for the walls.

Frequency (Hz)	TL(dB)	TL(dB)
50	60	
63	63	62
80	64	
100	67	
125	67	69
160	72	
200	76	
250	80	78
315	81	
400	86	
500	88	88
630	94	
800	99	
1000	105	103
1250	109	
1600	114	
2000	118	117
2500	123	
3150	128	
4000	131	130
5000	135	

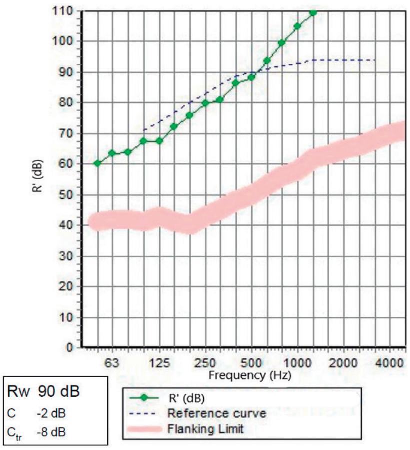


Figure 13. Wall model simulation results.

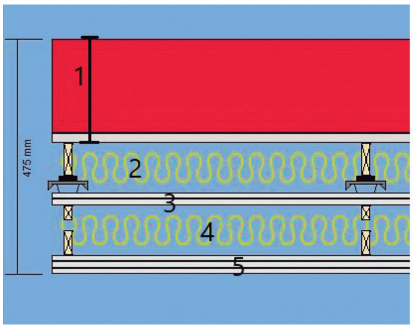
As it can be seen, materials with high density are needed to reach the objectives in low frequency, which are specially high due to the spectrum of the bass guitar and the drums, making necessary the design of elevated mass solutions.

In the case of the ceiling, we need to reach also high insulation levels in low frequency, but it is not possible to build a heavy double ceiling with concrete blocks &/ or clay bricks; the construction of it would be difficult due to the existing ceiling, and would result in a too low rehearsal room ceiling.

A more advanced, less heavy & less thick solution is searched instead. The resulting solution is the following (from the original ceiling to the room):

- 10 cm air chamber with 7,5 cm fiberglass sheet inside with density of 22 kg/m^3.
- Intermediate ceiling made of two layers of acoustic gypsum boards of 1,3 cm each, with density of 955 kg/m^3.
- Another 10 cm air chamber with 7,5 cm fiberglass sheet inside.
- Inner ceiling made of three layers of the previously mentioned acoustic gypsum boards.

Total thickness of the solution: 26,5 cm.



1 - Original ceiling

2 - Air chamber with fiberglass

3 - Intermediate ceiling (two acoustic gypsum boards)

4 - Air chamber with fiberglass

5 - Inner ceiling (three acoustic gypsum boards)

Figure 14. Proposed solution for the ceiling.

The inner ceiling will be supported by the concrete blocks walls, and the intermediate ceiling will be hanging from the original ceiling with special acoustic spring clamps separated each by 120cm.

The rehearsal room area has to be reduced to an area of 16,24 m^2 inside the basement, corresponding to the area in which the original ceiling is 2 metres and 30 cm high. In the rest of the basement, the ceiling is originally only 2 metres high, so it would not be possible to build the solution proposed as the rehearsal room ceiling wouldn't be high enough.

With the values of the final insulation levels provided by these solutions we can check that the received levels in the receiver rooms (*L2*) are below the objective NR-30 curve.

Frequency (Hz)	TL(dB)	TL(dB)
50	44	
63	50	48
80	60	
100	68	
125	72	71
160	81	
200	90	
250	98	94
315	106	
400	113	
500	118	116
630	123	
800	128	
1000	132	130
1250	136	
1600	151	
2000	152	150
2500	147	
3150	152	
4000	159	155
5000	165	

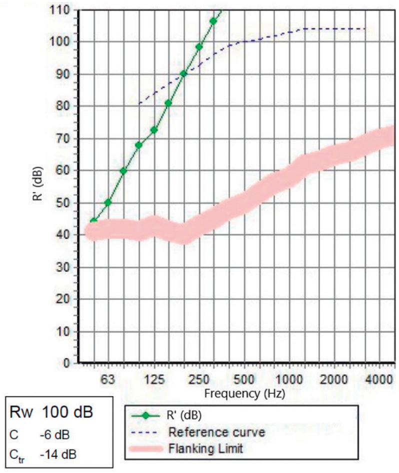


Figure 15. Ceiling model simulation results.

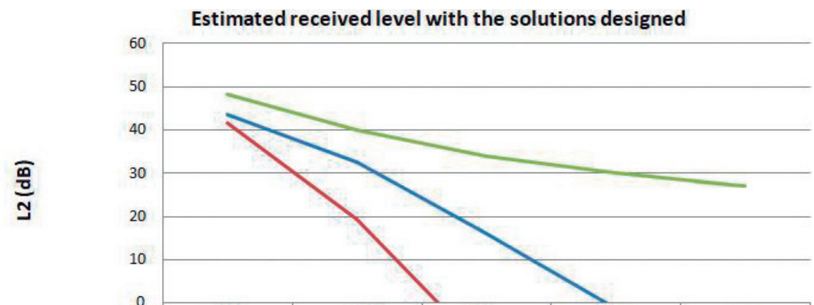
The extremely low and negative values are caused by the previously mentioned optimistic behaviour of the software with the insulation in high frequencies because of the insufficient consideration of flanking transmissions, but we can check that the objectives have been met in the critical frequencies, which are the lowest ones.

An acoustic door should be installed in the new wall created and a floating floor system should be designed as well in order to avoid impact noise and indirect transmissions. An overview of the rehearsal room designed is provided in Figure 17.

The final rehearsal room area is reduced to 11.97 m^2 and approximately 2 metres high. The overview of the project shows us the complexity of designing and building a rehearsal room capable to mitigate enough the noise levels produced by the instruments studied in an area with strict noise regulations.

3. CONCLUSIONS

The established insulation objectives have been satisfied. Nevertheless, the process has made us come to several additional conclusions.



	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz
NR-30 (dB)	48,1	39,9	34	30	26,9
Neighbour's Basement	43,5	32,7	16,0	-1,2	-16,6
Living Room	41,7	19,4	-11,4	-30,5	-50,2

Figure 16. Objectives verification.

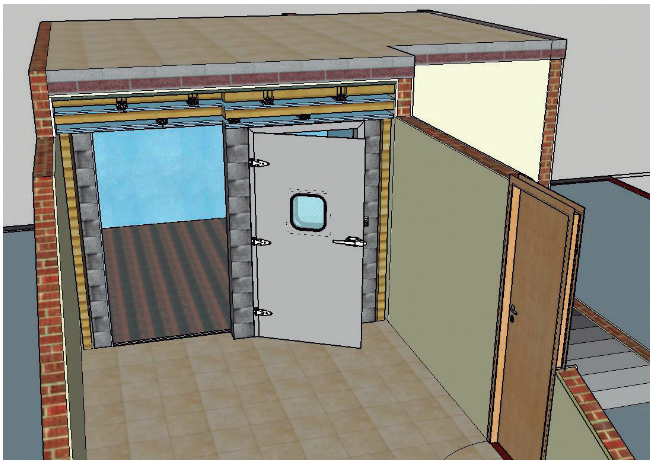


Figure 17. Overview of the rehearsal room.

We should appreciate the importance of on-site measurements (choice of appropriate instrumentation, preparation of measures, coordination with third parties, etc.), as well as the importance of analyzing the room under study (location, dimensions, building materials, adjacent rooms, weak points and limitations). All of this often makes us need to make adaptations of the regulations and standards for their application in real cases.

It is important to characterize the activity and have clearly marked objectives to be achieved in order to avoid oversized or insufficient designs. Being able to estimate the effects of each solution before its installation thanks to the modelling tools is a great advantage, but we would like to remark the importance of the use of simulation tools always in conjunction with fieldwork and on-site measurements in order to check their validity.

The standard insulation of a house is clearly insufficient for activities such as the one analyzed in this case without breaking the legal limits, which are quite strict. That presents us a considerable difficulty to reach the high levels of isolation required in low frequency, requiring solutions with large mass systems and air chambers that needed to be carefully designed because, in real projects, factors such as cost, thickness and weight must be taken into account when choosing materials.

Finally, we appreciate the difficulty that these three common musical instruments can create to insulate a room intended for their use in a house close to others, needing designs of great magnitude and making us conclude that there are no cheap and easy solutions for projects like this.

4. ACKNOWLEDGEMENTS

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