Preliminary study of the acoustic behavior concerning an innovative prototype for indoor modular partitioning

Gonçalo SIMÕES[1]; Jorge PATRÍCIO[2]; Paulina FARIA[3]

[1] FCT-UNL, 2829-516 Caparica, Portugal

[2] LNEC, Av. Do Brasil,101, 1700-066 Lisboa, Portugal

[3] FCT-UNL

ABSTRACT

This paper presents a preliminary acoustic study concerning the development of the first prototype of a patented removable module for interior partitioning. It is a prefabricated, vertical element for division of interior spaces that does not require the use of gutters or technical support. A set of such modules, linearly disposed, will create a division, allowing the personalization of any indoor area, including open office spaces, rooms, among others. The main characteristic that distinguishes this element from the existing solutions available on the market is that its mobility relies exclusively on a set of integrated bearings at the base of each module. Through an incorporated elevation system, the user can lower the module, move it to the desired position and re-elevate it until pressed against the ledge of the ceiling, making it stable. In this sense, and taking into account its acoustic behavior, several tests were made in the LNEC acoustics lab. Airborne sound insulation tests for different typologies of the prototype were conducted, according to the applicable standards EN ISO 354:2003, EN ISO 717-1:2013 and EN ISO 10140-2:2010. Some important conclusions and analysis of the prototype viability were extracted.

Keywords: Sound, Insulation, Interior Partitioning Prototype
I-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

In the last few decades, there has been an increase in the noise level that directly affects citizens' quality of life. Overpopulation and the consequent lack of space are aspects that should be evermore considered when developing solutions that mitigate noise resulting from everyday life. The dynamics that characterizes younger generations drives designers to be more versatile and, at the same time, actively assure the acoustic comfort of the interior of buildings. Combining this aspect with the possibility of defining a temporary space with the desired geometric disposition at any moment constitutes the vision that sustains the object analyzed in this present work, which consists in the first prototype of a removable module for interior partitioning. This solution could be very important in office areas, namely whenever their owners or users decide to redefine the available space distribution to create bigger meeting rooms, some private rooms in open plan offices for the administration or more reserved areas, etc. It represents the first approach, limited to the available resources, of what is intended to be a lightweight, movable element that guarantees structural and mechanical resistance, an acceptable acoustic performance, and above all operational security. The extrapolation of this concept to various identical modules, connected to each other, will result in a non-structural, continuous partitioning element. A more detailed description of this module can be found submitted in the form of the Portuguese patent, nº 106016, available for public consultation in the INPI (7).

Contrary to known classical interior partitioning solutions such as fixed partitions, which separate areas with different functions, a set of modules with the previously mentioned characteristics will allow the occasional maximization of any space. Due to their incorporated mobility systems, these

[1] gnccsimoes@gmail.com
[2] jpatricio@lnec.pt
[3] mpr@fct.unl.pt

modules will be able to occupy any position within a compartment, be it an open-space, a living room, or any other compartment. In addition to these solutions, there are others on the market that can move along a track system, which require assembly beforehand. These solutions differ from the referred module because their movement is restricted to one direction, that of the track system. Regardless of the solutions chosen in interior spatial partitioning, it is fundamental that they present a considerable performance in terms of airborne sound insulation, particularly regarding middle and high frequencies, which is the case of the human voice and noise resulting from most daily activity.
Due to the scope of this present work, no reference has been made to the mechanical systems incorporated in the interior of the prototype. This study is strictly pertaining to questions that are acoustic in nature.

2. PROTOTYPE DESCRIPTION, MATERIALS, AND MODULE TYPOLOGIES

The object tested in this work consists in a light, pre-fabricated partition. It is a self-supporting element, vertically extensible and customizable, both in terms of the internal height of the room and the final coating chosen. After the construction of the steel metallic structure, by means of conventional welding and the incorporation of the mechanical systems that convey the module's mobility and elevation, several materials were chosen and different typologies were established.

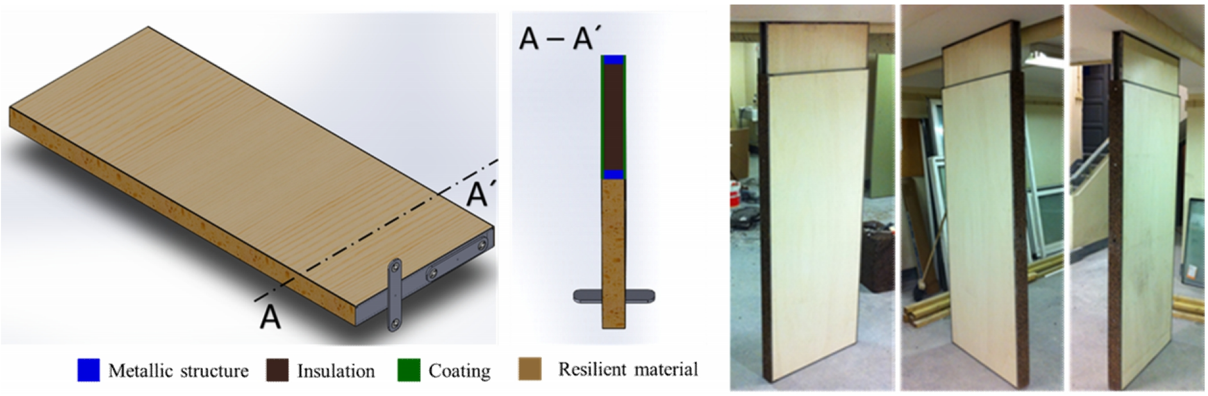

Figure 1 – Components of the module and prototype positioned in the acoustics lab of LNEC.

3 types of coating panels were chosen, namely poplar plywood, OSB, and MDF. Regarding the chosen material for the air gap, only 2 materials were chosen: cork and glass wool. The combination of the previously mentioned materials, when incorporated in the module, resulted in 6 different typologies (IS1, IS2, IS3, IS4, IS5, and IS6). Table 1 illustrates the properties of each material used, and Table 2 illustrates the typologies used in the first 6 airborne sound insulation tests, making performance comparisons possible. It is noteworthy that the module was placed directly on a high density layer, physically reticulated, closed cell polyethylene foam, embossed and screen printed on the upper surface, joined on the underside to a needled fiber to improve soundproofing.

Table 1 – List of materials incorporated in the module

Materials used	Panel type	Approximate Density, kg/m^3
Coating panels	Poplar Plywood	430
	OSB	620
	MDF	780
Insulation	Cork	115
	Glass wool	30
Support	Polyethylene foam	50

Table 2 – Airborne sound insulation tests and typologies of the prototype

Type of test	Test number	Typologies	Incorporated panels	Support thickness, mm
Comparison of tested materials	1	IS1	Poplar Plywood; Cork	5
	2	IS2	OSB; Cork	5
	3	IS3	MDF; Cork	5
	4	IS4	Poplar Plywood; Glass wool	5
	5	IS5	OSB; Glass wool	5
	6	IS6	MDF; Glass wool	5

4 complementary tests were done using the same combination of materials, MDF and Glass Wool, as illustrated in table 3. The first complementary test, (IS7 typology), was done with the objective of understanding the influence of the silicone's drying time. Silicone was used in the space between the sample and the reverberation rooms opening used for airborne sound insulation test. The objective of the second complementary test was to assess the influence on the performance of the sample when it was placed on the support (i. e. representing the floor covering) and directly on the concrete slab of the reverberating room, typology IS8. The mapping of sound pressure level measurements, typology SP1, was crucial to identify zones of the module with the worst sound insulation, which ones were later subjected to corrections by reinforcing the amount of glass wool, with the objective of improving its performance with the optimization test – done with typology IS9.

Table 3 – Airborne sound insulation tests and typologies of the prototype – complementary tests

Type of test	Test Number	Typologies	Incorporated panels	Support thickness, mm
Airborne sound insulation: Influence of drying time	7	IS7	MDF; Glass wool	5
Airborne sound insulation: Irregular floor simulation	8	IS8	MDF; Glass wool	No support
Mapping of sound pressure level measurements	9	SP1	MDF; Glass wool	5
Airborne sound insulation: Optimization	10	IS9	MDF; Glass wool	12

3. Airborne sound insulation tests

3.1 Methodology

The airborne sound insulation tests were done in LNEC's acoustic laboratory with appropriate standards.
Reverberation times were measured with the sample introduced in the opening, according to EN ISO 354 standard (5).
For airborne sound insulation, the measurements were made in accordance with EN ISO 10140-2 standard (2).
After processing the data from the calculations done according to the previously referred standards, the characteristic curve of the sound insulation of the tested element was determined, as well as the corresponding sound reduction index, R_w, following the methodology set by EN ISO 717-1 standard (6).

3.2 Equipment

The equipment used in the sound insulation tests was the Pulse multi-analyzing acquisition system commercialized by Bruel&Kjaer and the sound source type 4224 (Bruel & Kjaer).

3.3 Test conditions

- Area, S, of the test element: 1,895 m^2
- Air temperature in the reverberation rooms: 20 ± 1ºC
- Relative humidity in the reverberation rooms: 79 ± 2%

3.4 Test procedure

After placing the IS1 sample in the opening (Figure 2), with the support positioned, silicone was applied in the existing gap, approximately 4 mm on each surface, and allowed to dry for approximately 20 hours (Figure 3). The use of silicone was due to the necessity of filling the gaps between the opening and the prototype, so that it would remain fixed, and to avoid sound insulation losses.

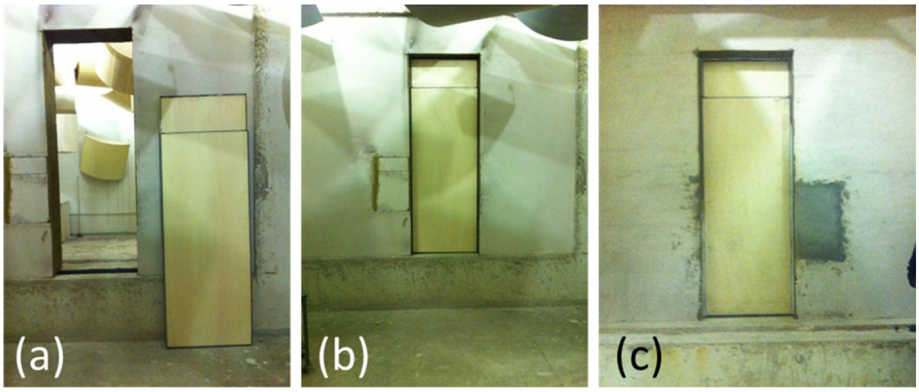

Figure 2 – Left and center: As seen from the emission room; Right: As seen from the receiving room.

Figure 3 – Application of silicone in the gap between the sample and the opening.

The reverberation times in the receiving chamber were measured using the interrupted noise method with three decay measurements done in each of the four microphone positions, for each of the two speaker positions, in order to obtain a representative average. For the purpose frequency bands of one third of octave were, between 100 and 5000 Hz.
The normalized characteristic curve was designed and the sound insulation index R_w, as well as the spectrum adaptation coefficients C; C_{tr} were calculated.
The referred methodology was rigorously applied in the remaining tests. When it was necessary to remove a sample, the silicone was cut on three surfaces (Figure 4), the coating and/or the filling material was replaced - Figure 5 (a) -, the element was placed in the opening, the silicone was reapplied on both sides of the element (on the side facing the emission room and on the side facing the receiving room), and so forth; Figure 5 (b) and Figure 5 (c).

Figure 4 – Cutting of silicone in order to remove the sample from the opening.

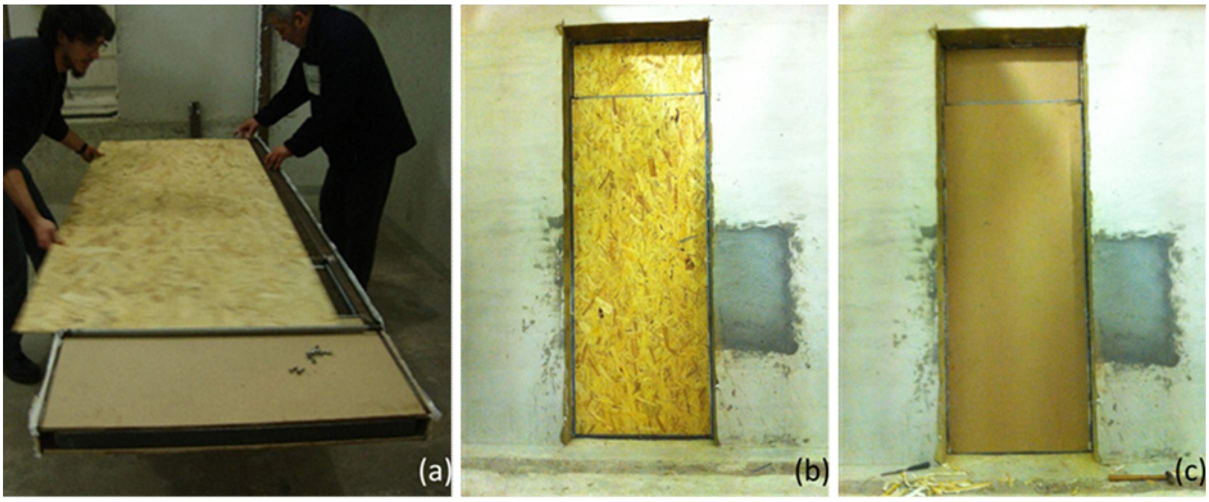

Figure 5 – Changing panels (a) IS5 sample aspect (b) and IS6 sample aspect (c).

4. MAPPING OF THE SOUND PRESSURE LEVEL

4.1 Methodology

After positioning sample SP1 in the test opening, three measurements were taken in the emission room, at the base, in the center, and at the top (at approximately 20 cm distance from the panel). In the receiving room, 9 measurements were taken, distributed evenly (3 by height), as presented in the schematic found in Figure 6. In order to acquire the values, a fast response time was selected previously on the sound level meter’s menu, which corresponds to a fast temporal weighting.

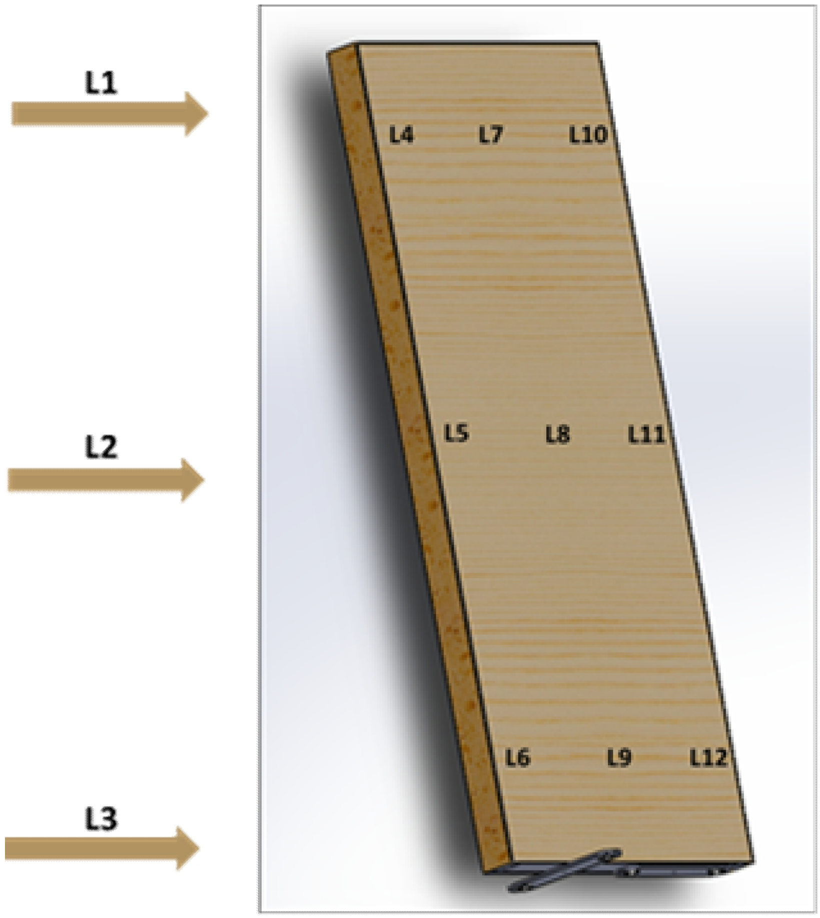

Figure 6 – Schematic of the panel zones where results were gotten.

4.2 Equipment

The equipment used in this sound level measurement tests were the type 4224 sound source by Bruel&Kjaer and the type 2260 sound level meter by Bruel&Kjaer.

4.3 Calculation procedure

In order to correlate the results found in Table 5, the energetic average of sound pressure levels L6, L9, L12 (Base) was calculated. The procedure was repeated for L5, L8, L11 (Center) and finally for L4, L7, and L10 (Top). The first set of results was subtracted from L3, the second set of results was subtracted from L2, and the third set from L1. In this way, it was possible to determine the "generic" sound insulation of the prototype, at each of the three positions: Base, Center, and Top.

5. RESULTS

5.1 Results of the sound insulation tests

The results obtained regarding the airborne sound insulation tests are resumed in Table 4.

Table 4 – Airborne sound insulation tests and typologies of the prototype.

Freq. (Hz)	**IS1** $R_w = 27$ (-2;-5) (dB)	**IS2** $R_w = 30$ (-2;-5) (dB)	**IS3** $R_w = 32$ (-2;-5) (dB)	**IS4** $R_w = 32$ (-2;-7) (dB)	**IS5** $R_w = 36$ (-3;-7) (dB)	**IS6** $R_w = 36$ (-1;-5) (dB)	**IS7** $R_w = 37$ (-2;-6) (dB)	**IS8** $R_w = 35$ (-1;-5) (dB)	**IS9** $R_w = 39$ (-2;-7) (dB)

Figure 7 shows all the comparisons for the results obtained and the analysis done.

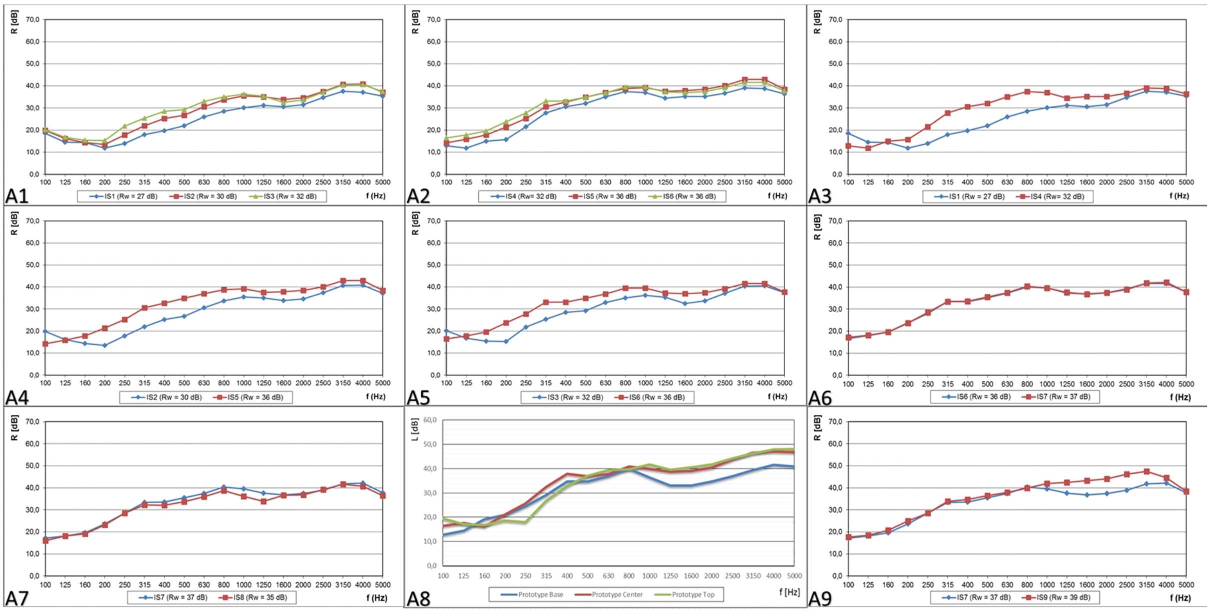

Figure 7 – Performance comparisons of airborne sound insulation between tested typologies.

5.2 Prototype detailed analysis

The results obtained in the process of analyzing the prototype zones where higher transmission losses occur are presented in Table 5, both those measured in the emission room and those in the vicinity of the prototype (Figure 6).

Table 5 – Pressure levels in the emission room and in the vicinity of prototype in the receiving room.

Freq. (Hz)	L1 (dB)	L2 (dB)	L3 (dB)	L4 (dB)	L5 (dB)	L6 (dB)	L7 (dB)	L8 (dB)	L9 (dB)	L10 (dB)	L11 (dB)	L12 (dB)
100	102,9	101,2	101,0	83,1	83,1	88,0	84,3	85,5	89,4	82,7	85,0	86,9
125	101,0	102,2	100,2	82,6	83,4	84,9	84,5	85,5	86,5	84,4	84,3	85,6
160	98,9	98,0	99,0	81,2	81,5	80,1	83,5	82,7	79,9	81,1	81,4	79,7
200	89,6	89,0	90,7	69,5	67,1	68,8	71,6	67,9	69,7	71,4	68,4	70,3
250	87,1	88,1	88,3	70,6	63,4	63,9	69,1	61,7	64,1	67,1	62,0	63,5
315	97,0	95,4	96,3	71,8	64,3	67,7	67,6	62,0	65,0	69,9	61,8	68,0
400	101,2	101,0	102,3	69,3	64,4	67,6	65,3	62,5	65,9	69,3	62,5	68,7
500	102,3	101,7	101,7	63,4	66,4	65,2	67,2	64,0	67,5	64,3	63,9	68,1
630	103,5	101,6	102,6	63,4	64,7	63,2	64,7	63,6	63,8	64,3	63,4	68,3
800	99,6	100,5	100,9	59,7	61,6	57,6	60,6	59,4	60,4	59,6	56,6	63,3
1000	99,2	98,4	98,4	57,2	60,2	59,0	58,7	57,7	62,6	56,1	56,8	63,3
1250	96,6	96,8	96,3	55,4	57,8	59,0	57,4	58,2	62,2	58,1	58,3	65,9
1600	98,4	98,4	98,0	57,8	60,1	62,9	58,6	58,4	64,1	57,2	59,7	66,9
2000	99,1	99,1	99,3	56,8	59,4	62,1	57,2	58,6	64,1	58,3	58,2	66,4
2500	99,4	98,9	99,0	54,3	55,7	59,1	55,3	54,7	62,8	55,8	54,9	63,4
3150	95,2	95,8	95,4	48,7	50,2	54,0	49,3	49,4	56,6	49,2	48,2	57,0
4000	90,8	90,1	89,8	42,3	42,9	46,4	43,2	43,6	47,8	43,3	42,5	49,8
5000	84,4	84,1	84,3	36,4	37,0	39,1	36,1	38,2	39,6	36,8	36,9	47,0
L	112,1	111,5	112,0	88,4	88,6	91,1	89,9	90,2	92,4	88,9	89,5	90,8

6. CONCLUSIONS

The use of poplar plywood, OSB, and MDF coating planks resulted in increasing performance, respectively (verified by graphs A1 e A2 of Figure 7).
The benefits of incorporating mineral wool instead of cork were confirmed (verified by graphs A3, A4 e A5 of Figure 7).
The drying time of the silicone has a reduced influence on performance for the time-span considered (verified by graph A6 of Figure 7).
Regarding the influence of an irregular floor surface, the results of typologies IS7 and IS8 point to differences of up to 2 dB in terms of sound insulation index (verified by graph A7 of Figure 7).
The mapping measurements of sound pressure level showed that the base of the module is the area where there were greater sound losses in the prototype. The graph A8 of Figure 7 illustrates the "generic" sound insulation, in particular each of the three positions analyzed of the module.
The optimization of typology IS9 allowed for an increase in sound insulation of 12 dB compared to the initial typology (IS1), and 2 dB compared to typology IS7 (verified by graph A9 of Figure 7).
As a global conclusion it could be stated that this prototype is a good solution for offices (as well as housing buildings) where versatility in internal disposition of partitions is needed, in order to create/redefine rooms or private spaces for administration, meeting rooms, and other particular activities. The airborne sound insulation obtained with the optimized solution is a good compromise between the required versatility, viability and performance.

ACKNOWLEDGEMENTS

The authors would like to thank all those who have contributed for the development of this work, mainly the intellectual property holders, for having kindly authorized the use of performance data of the specified module (9). The authors would also like to thank LNEC, for making its facilities available for testing.

REFERENCES

[1] - EN ISO 10140-1:2010. Acoustics: Laboratory measurement of sound insulation of building elements. Part 1: Application rules for specific products.
[2] - EN ISO 10140-2:2010. Acoustics: Laboratory measurement of sound insulation of building elements. Part 2: Measurement of airborne sound insulation.
[3] - EN ISO 10140-4:2010. Acoustics: Laboratory measurement of sound insulation of building elements. Part 4: Measurement procedures and requirements.
[4] - EN ISO 10140-5:2010.Acoustics.Laboratory measurement of sound insulation of building elements. Part 5: Requirements for test facilities and equipment.
[5] - EN ISO 354:2007. Acoustics: Measurement of sound absorption in a reverberation room.
[6] - EN ISO 717-1:2013. Acoustics: Rating of sound insulation in buildings and of building elements. Part1: Airborne sound insulation.
[7] - INPI. http://www.marcasepatentes.pt/index.php?section=1.
[8] - Patrício, J. (2010). Acoustics in buildings (in Portuguese). 6ªEdition. Lisbon. Portugal.
[9] - Simões, G., Branco, T., Mergulhão, D., Ferraz, D., Lourenço, R., Cachadinha, N. (2013). National Patent n.º 106016. Lisbon. INPI.