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Acoustic beamforming applications in construction

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ABSTRACT

This work aims to present the application of beamforming techniques for building acoustics. The main purpose for applying this method in building acoustics consists in the qualitative characterization of sound transmission through constructive elements, such as window frames, walls and doors, by checking critical sound transmission and leakage spots. In the present work, tests were performed in buildings by using an omnidirectional sound source and an acoustic camera. Frames, walls and doors were analyzed, seeing that each case addresses distinct goals. Evaluations were also performed with respect to the influence of sound leakage upon the acoustic insulation parameters used as reference in the Brazilian standard ABNT NBR 15575. Investigating the results obtained, it became possible to validate the effectiveness of employing the beamform technique. It is possible to detect constructive failures in advance, preventing future problems, and, in a corrective manner, diagnosing sound leakage spots, allowing faster solutions to provide increased acoustic insulation for a constructive element.

Keywords: Beamforming, Insulation, Transmission

1. INTRODUCTION

Due to the growing concern regarding acoustic comfort in buildings, new technologies must be used to guarantee the sound insulation in a building. One practice which has become increasingly widespread concerning the design of buildings is the development of acoustic projects capable of estimating the insulation levels by using a simulation software.

However, simulations tend to work well in ideal scenarios, disregarding construction difficulties and execution failures, which commonly occur in most construction sites. Because of that, to get the expected results, the construction sector must take all the precautions recommended by the acoustic project.

Despite that, there are many cases in which corrective actions must be taken to solve constructive failures. In such cases, the more accurate the method when diagnosing problems, the more effective solutions tend to be. One of the most advanced procedures in terms of acoustic measurements is the use beamforming techniques. As per reference FONSECA (1), the beamforming method consists in a technique for locating sound sources based on wave beam shaping, coming from a given direction or region in space. The main purpose of applying this method in building acoustics is characterizing sound transmission in a qualitative term, by means of constructive elements such as frames, walls and doors while checking all the critical points for sound transmission and leakages. Furthermore, it becomes possible to spot possible flaws, either in the construction or installation of constructive elements.

Studies addressing the application of such techniques are presented in this work, in order to solve acoustic insulation and sound transmission problems in buildings.

2. MEASUREMENTS CONFIGURATION AND GOALS

The goal of such assessment, as reported in this work is to characterize sound transmission

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regarding constructive elements, as well as the identification of possible sound leakage spots within such elements. To that end, the following test rig was set up:

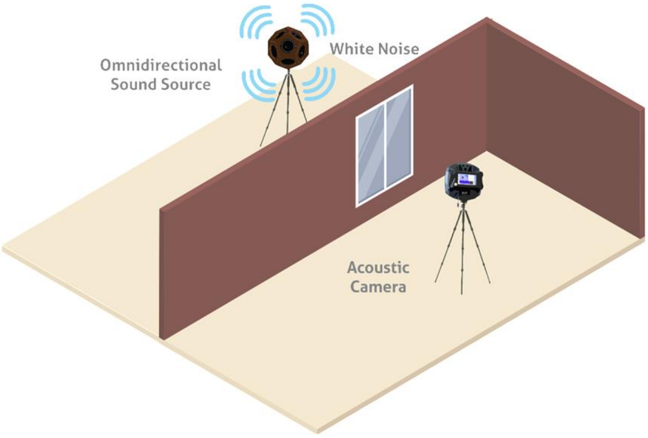

Figure 1 – Assay configuration

The purpose is creating a sound field in the source room as uniform as possible, covering the entire extension of the partition under evaluation. Therefore, it becomes possible to carry out measurements by means of an acoustic camera, capable of locating all the spots where major sound transmissions levels take place within constructive elements.

Tests were carried out to obtain suitable configuration settings by varying sound sources of distinct directivities as well as signal types and frequency ranges while also evaluating background noise influence. The best configuration was found out to consist of an omnidirectional sound source employing white noise as excitation signal, with a frequency range coverage of 3 to 10 kHz.

3. CASE STUDIES

In this section are presented practical case studies regarding the application of beamforming techniques in construction works. Each case had a distinct goal which shall be described under each subsection.

3.1 Checking frame installation

The goal here was to check frame installation standardization at the construction site. To that end, samples were taken from the same frame types on distinct floors. Tests were performed for each of the samples, as shown in Figures 2 and 3.

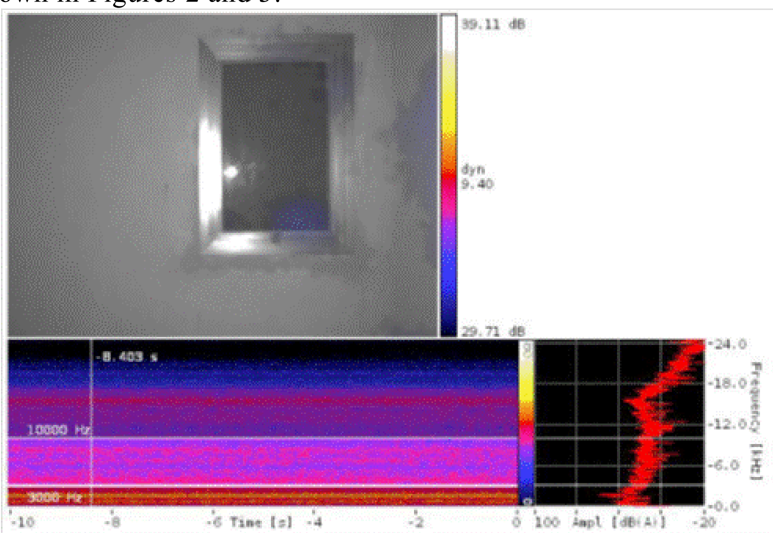

Figure 2 – Results: Framing from the 3rd floor

In this case, as can be seen in Figure 2, there is no observable sound leakage from the frame. Contrary to that, the frame shown in Figure 3, which presents identical composition to the first one, showed some sound leakage pointwise which became predominant at its uppermost edge.

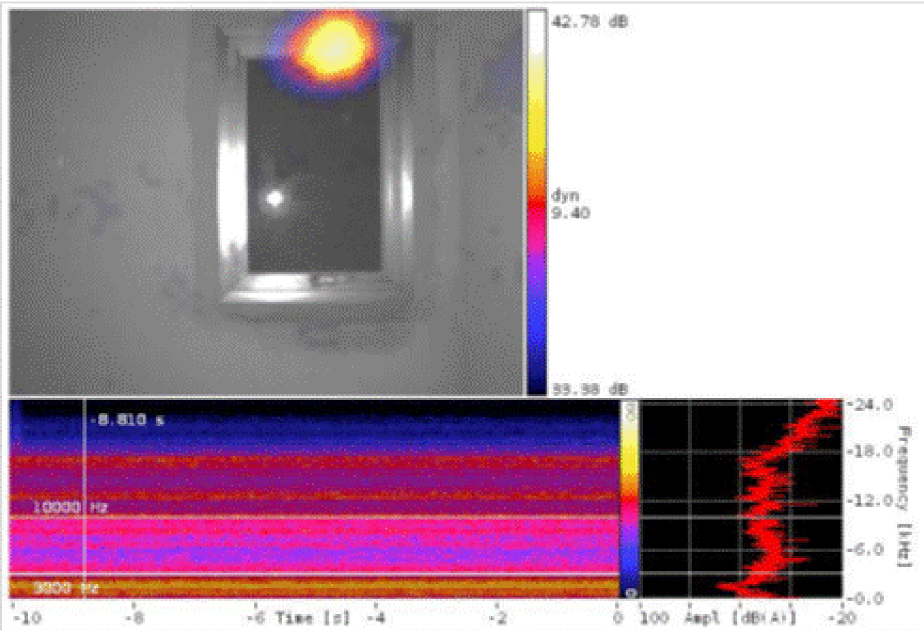

Figure 3 – Results: Framing from 12th floor

After construction workers carried out an inspection to find out the causes for such leakage, it was found out lack of mortar in the framing's upper edge. In situations like that, it would not have been possible to spot this fault from visual inspection alone, given that the framing structure conceals such area. It demonstrates beamforming measurements effectiveness.

Another similar case was carried out over the balcony doors shown in Figure 3.

Figure 4 – Balcony doors

Once again, the study was carried out on samples from the same framing on different floors within the building. The door under test, as shown in Figure 5, had been correctly installed, seeing that the pointwise leakage detected in its upper central portion (panel junction) is due to framing configuration. In Figure 6, which shows the tests for a door from another floor. One can notice a specific sound leakage, which is predominant in the upper portion of the door's left panel.

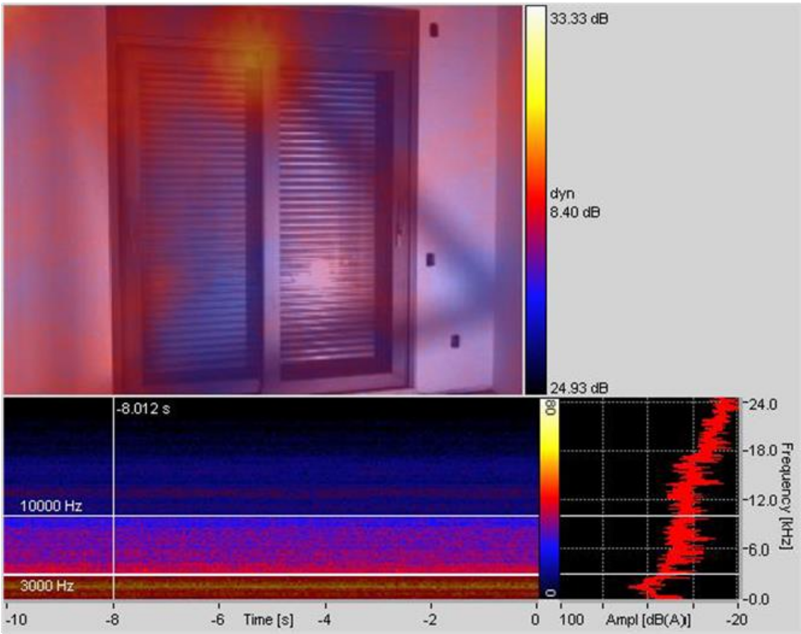

Figure 5 – Results: Balcony Door from 5th floor

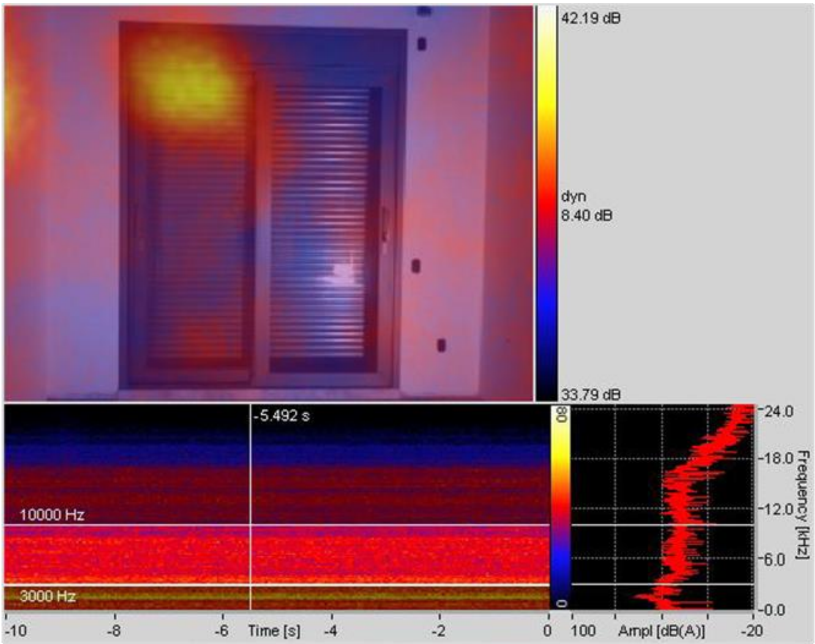

Figure 6 – Results: Balcony Door from 6th floor

By approaching the acoustic camera to the leakage area (Figure 7), it became possible to conclude that sound was being transmitted through an existing gap between glass and sash, due to the lack of a sealing element around its edge, as shown in Figure 8. Thanks to such assessment, the construction team carried out an inspection on all the building's doors, performing repairs as needed.

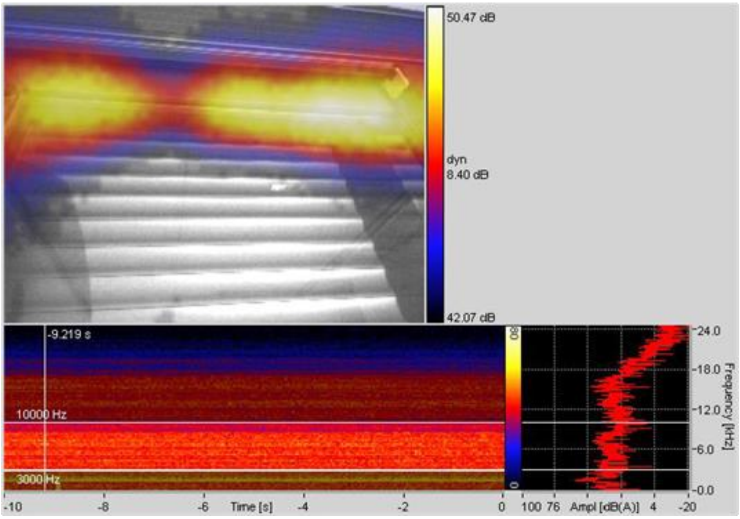

Figure 7 – Results: Door’s left panel in detail

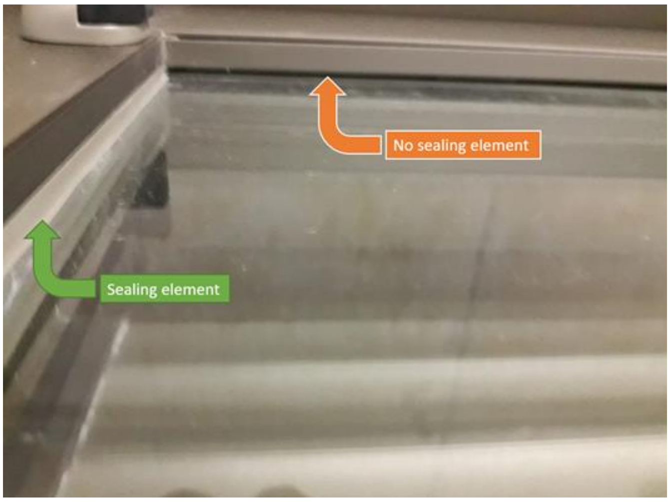

Figure 8 – Lack of sealing element

3.2 Low acoustic insulation levels between office rooms

This specific case is a commercial building whose offices were already occupied. It is an office in which its users complained about the lack of privacy between adjacent rooms due to the low sound insulation level of the partitions used. These partitions were made out of Drywalls and users suspected that their low acoustic performance was linked to constructive failures or the drillings made during the equipment’s installation.

A beamforming assay was then performed by placing the omnidirectional sound source within a source room, while taking measurements from the acoustic camera in the adjacent room, the receiving room. The goal is to determine how sound transmission was taking place in this partition. Test results may be viewed in Figure 9.

Upon assessing the results, it became possible to notice that the predominating sound leakage came from the ceiling and not from the partition itself. After close investigation with those in charge of the construction, a peculiar characteristic of the building's air conditioning system was identified: there were microperforations in the ceiling and the rooms got mutually connected, since the partition height extended up to the ceiling only. Therefore, the sound emitted in one of the rooms would enter the ceiling through these microperforations, reaching the adjacent room through the same path.

Due to the precise diagnosis provided by the beamforming assay, it became possible to act directly upon the core of the problem by improving the sound insulation between rooms.

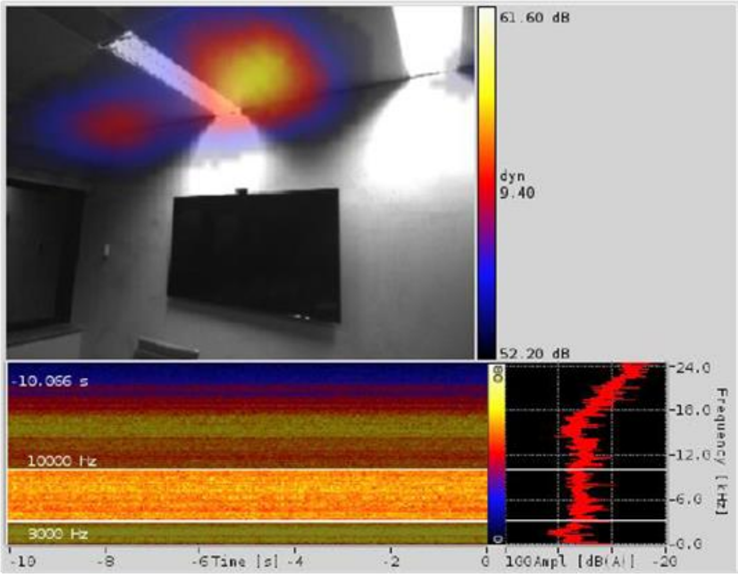

Figure 9 – Results: Ceiling-bound sound transmission

Measurements have also been carried out between one of the meeting rooms and the office reception. In this case, the door was identified as the weaker element, responsible for most of the sound transmission taking place. There was a large gap in this door's upper portion thar would be hard to be noticed visually due to ceiling placement. Nonetheless, it was detected after the beamforming assay had been performed, as shown in Figure 10.

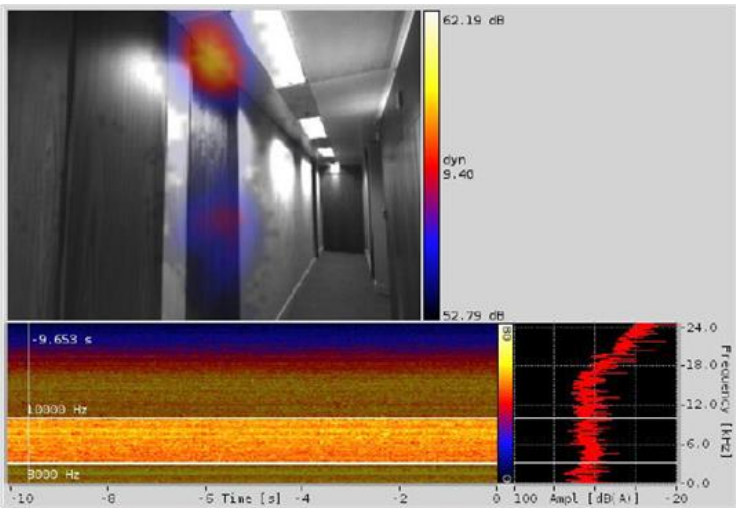

Figure 10 – Results: Door-bound sound transmission

3.3 Sound leakage between walls from distinct units

In this case, the goal consisted in determining the airborne sound insulation of a masonry partition separating bedrooms from different units within a residential building, by determining the Weighted Standardized Level Difference ($D_{nT,w}$) according to ISO 16283-1 standard (3). Such assay is mandatory for new buildings in Brazil, which must follow the limits of acoustic performance regarding constructive elements according to the ABNT NBR 15575 standard (2). In this specific case, the partition should present a value of $D_{nT,w} = 45$ dB.

Simultaneously to this, a beamforming assay was also carried out in order to characterize wall-bound sound transmission.

Initially, the perception was that sound transmission took place smoothly all along the partition. However, upon performing a full-wall scan, pointwise leaks were spotted from the electrical switchboxes, according to the results shown in Figures 11 and 12.

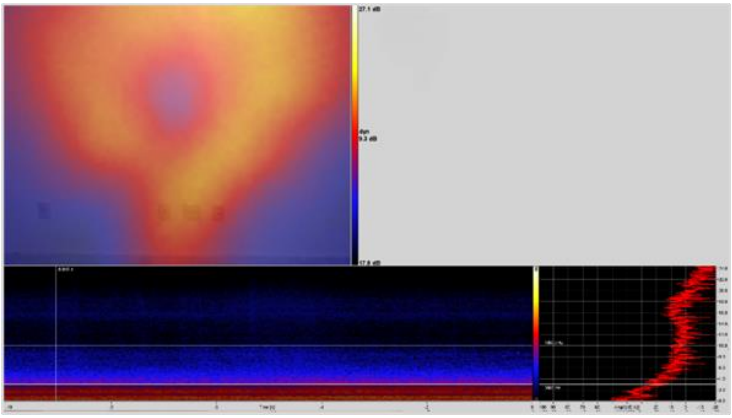

Figure 11 – Results: Wall-bound sound transmission

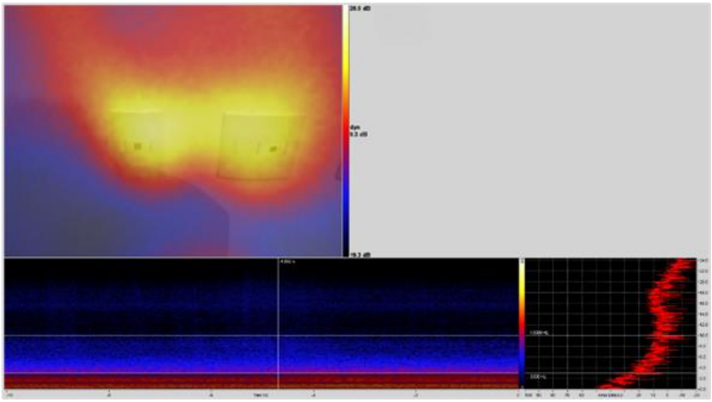

Figure 12 – Results: Sound leakage on electrical switchboxes

Once the source of leakage had been identified, an immediate solution was used: fulfill the referred cavity with burlap. The effectiveness of such quick solution may be verified in Figure 13. By comparing Figures 11 and 13, one can notice that the specific sound leakage from the electrical switchboxes ceased afterwards, leaving just the transmission of sound going through the wall itself.

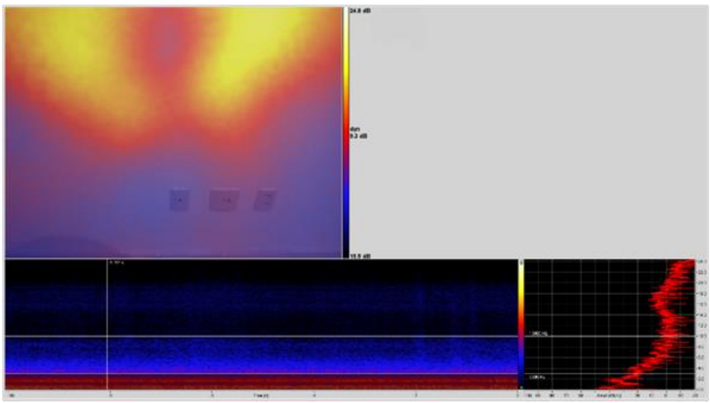

Figure 13 – Results: Wall-bound transmission after leakage isolation

Acoustic insulation measurements were then carried out in order to determine the Weighted Standardized Level Difference ($D_{nT,w}$) for the partition, both with and without insulation fixes at the electrical switchboxes. Figure 14 displays a comparison between both situations.

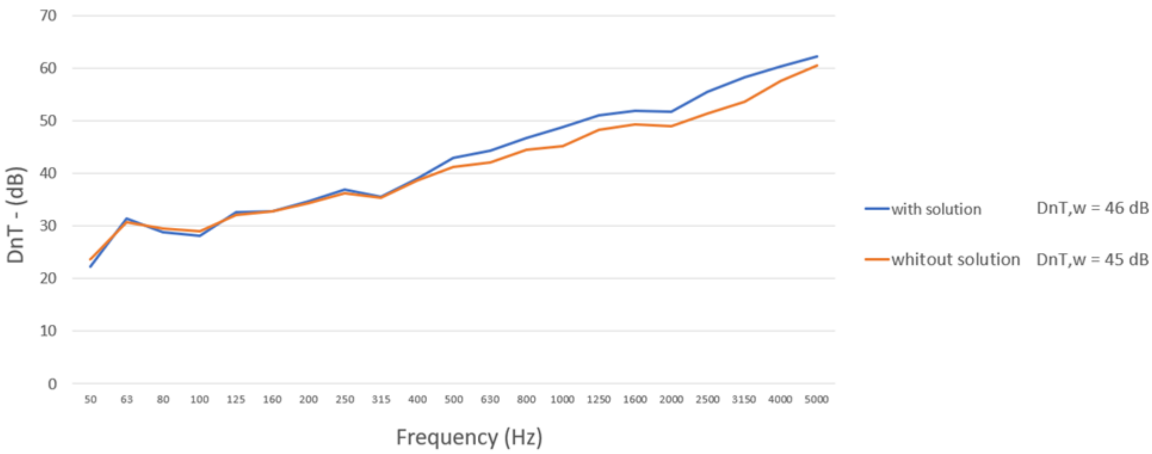

Figure 14 – Measured results for acoustic performance, shown both with and without solutions for the leakage problem.

By assessing these results, it can be observed a 1dB increase in the $D_{nT,w}$ value regarding the partition, after the correction of the sound leakage spot. Such increase is quite significant, especially in those situations when acoustic insulation values are found to be very close to the acoustic performance limit values set out by a specific standard.

3.4 Sound leakage in facade window frames

The standard for building performance in Brazil (2) specifies the acoustic insulation values for building facades, according to the soundscape where these are located. Therefore, considering buildings located in very noisy environments, such standard specifies that the Weighted Standardized Level Difference measured at a distance of 2 meters from the facade must be at least 30 dB ($D_{2m,nT,w} \geq 30$ dB).

The building addressed in the latter case fits the situation described above. In order to check whether this building's facades would meet the minimum performance required by the standard, measurements in accordance to the ISO 16283-3 standard (4) were performed, to obtain the $D_{2m,nT,w}$ value. The results obtained showed that facade did not meet the mandatory requirement ($D_{2m,nT,w} \geq$ 30 dB), having attained $D_{2m,nT,w} \geq 27$ dB.

The main problem faced is that this situation was only detected when the construction work was already concluded. Therefore, any solution found should be replicated for more than 300 existing dormitories in the condominium, something that could generate extra costs, affecting directly the project's economic results.

Given the relevance of finding economically feasible solutions, beamforming measurements were carried out for the facade. Figure 15 shows the environment under test. Our goal was to find the most sensitive region along the facade and help the supplier in finding specific and simple solutions to achieve the minimum and mandatory results at the lowest costs possible.

Figure 15 – Measured room

The facade was made up of masonry; however, there was an area measuring approximately 0.4 m² which had been covered with plasterboards only, to be found below the window line. This is a usual practice which makes it possible for future users to install their air conditioning systems inside bedrooms. Therefore, the first assessments aimed at checking the contributions from each constructive element through transmission means, determining which of these would be more sensitive from an insulation standpoint. Figure 16 shows the results for this study. It becomes clear that sound transmission takes place through the frame mostly.

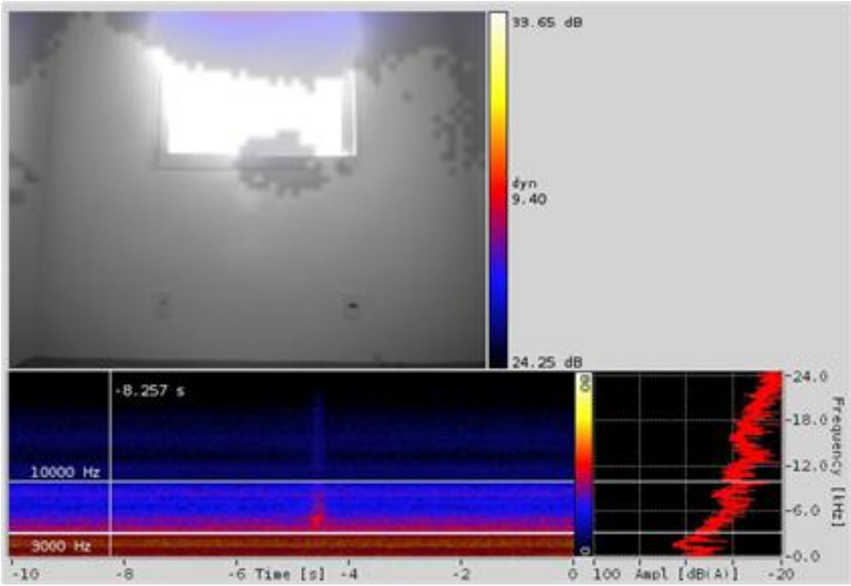

Figure 16 – Result: Initial assessment of sound transmission through window frames

Therefore, we set out to determine which spots over the frame were the most sensitive ones. The results showed that the upper corners had sound leakage due to existing cracks in the window frames. The right corner displayed greater sound transmission range, and, for such a reason, it was the first one upon which solutions were attempted. These results are shown in Figures 17 and 18.

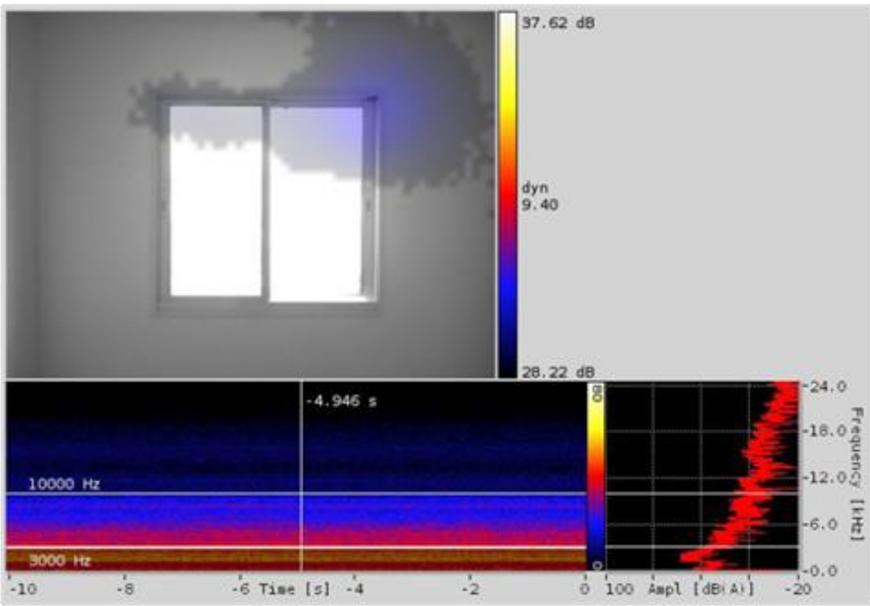

Figure 17 – Results: Sound transmission level assessment through window frames

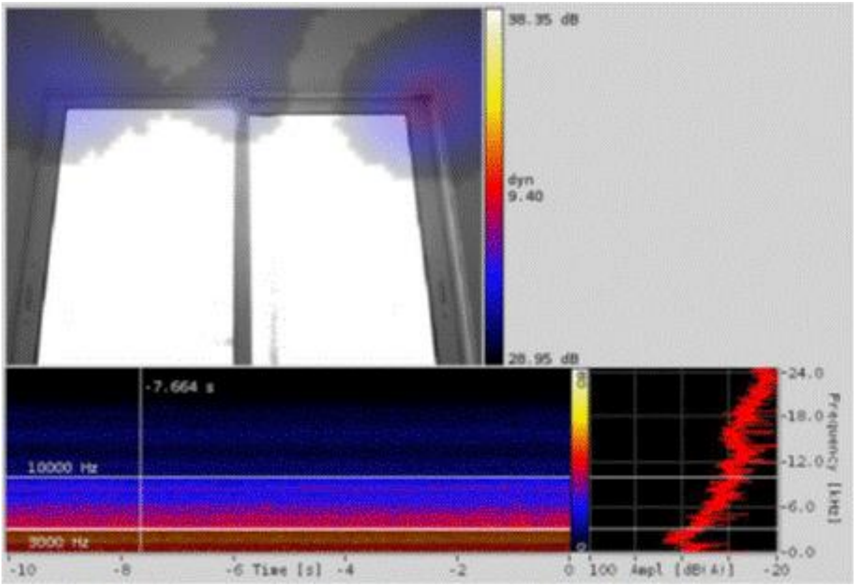

Figure 18 – Results: Approximate assessment of sound transmission by window frame

In order to seal the gap existing in this area, a fixed sealing element was added on the outer side of the frame. Such element sealed the gap existing between rail and window frame, without impairing frame movement. Figure 19 shows the solution already installed.

Figure 19 – Solution employed for sealing of main crevice

In order to check the effectiveness of such solution, another acoustic performance measurement was carried out. Figure 20 shows a comparison of results, both before and after providing a solution.

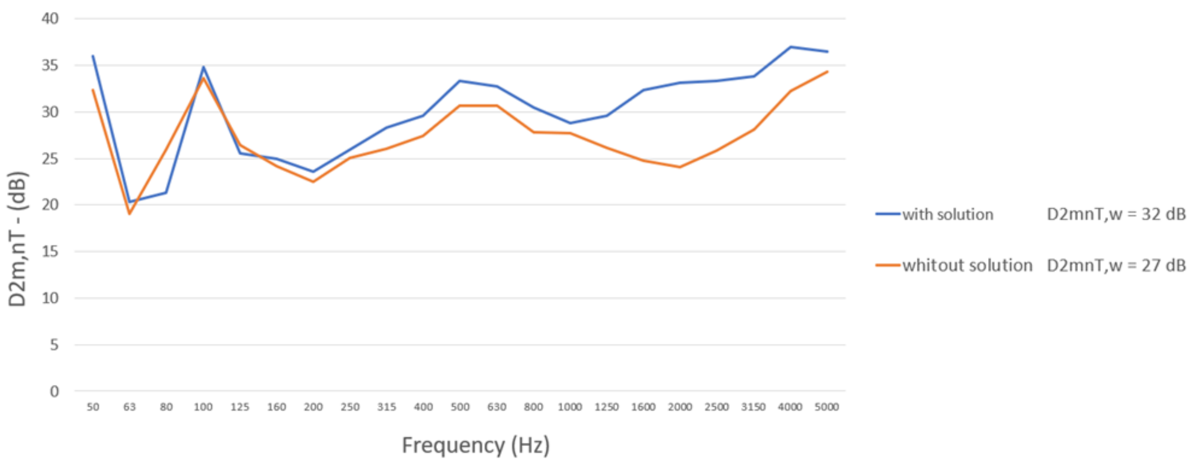

Figure 20 – Measured results for acoustic facade insulation, both before and after a solution was fitted in.

When evaluating the results, one can notice that such solution significantly increased performance by 5 dB, as the value found for $D_{2m,nT,w}$ reached 32 dB. It is also noticeable the improved performance from 1000 Hz upwards, caused by the crevice's sound transmission characteristic.

Therefore, due to the precise diagnosis ensued by the beamforming assays, it became possible to correct a very unfavorable situation, by means of a simple and economically feasible solution.

4. CONCLUSIONS

After having assessed the results obtained under the most diverse situations and with distinct goals, it was showed the relevance of acoustic measurements making use of the beamforming technic. It allows the precise identification of all sound leakage spots, allowing for faster, more effective and cheaper solutions.

5. ACKNOWLEDGEMENTS

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