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Interactions between sound insulation and urban sounds: how to incorporate the user's perception to the application of the Brazilian building performance standard using auralization

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ABSTRACT

The Brazilian building performance standard ABNT NBR 15575, which entered into force in 2013, conditions the facade sound insulation requirements to external sound levels based on a three-class system. After five years of application, it was observed that this requirement has been a great challenge for constructors when trying to understand how does each environmental noise class sounds, and what would be the occupants experience depending on the facade acoustic performance. In this study it is presented an auralization tool aiming to provide simulations of the indoor sound pressure level of typical urban soundscapes of São Paulo. It incorporates the acoustic attenuation due to the propagation path and the facade insulation according to the ABNT NBR 15575 three-class system. In addition to helping constructors and occupants to relate acoustic perception to performance requirements, this auralization tool can be used to contribute in further subjective studies regarding new facade insulation requirements in the future standard revision.

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1. INTRODUCTION

Brazilian construction market is responsible for 6.2 % of brazilian US$ 2.080 trillion GPD and the building construction segment has an added value of US$ 23.4 billion [1]. In this context, since the entry into force of building performance standard ABNT NBR 15575 [2], full attention has been paid to the implications of applying its technical criteria. Since its publication in 2013, this standard is considered a milestone for the building acoustic regulation in Brazil. For the first time, mandatory sound insulation performance was established and, since then, new residential buildings would have to comply with Minimum requirements of sound insulation. The Brazilian ABNT NBR 15575 standard indicates requirements for airborne sound insulation (facades, walls and floors between dwellings) and impact sound levels (floors). In an informative annex, Intermediate and Superior criteria are presented for those cases were higher performance is aimed to be achieved . For all systems, there is a 5 dB step between performance levels that are indicated for ISO 717 descriptors $D_{nt,w}$, $L'_{nT,w}$, $D_{2m,nT,w}$. The facade sound insulation Minimum requirement is determined according to the environmental noise scenario, named as "noise class". The noise class scheme is divided in classes I, II and III, however, the standard is not objectively clear in their descriptions. Instead of using objective criteria to determine the acoustic environment in the building surroundings, a brief soundscape description is informed leading to multiple misinterpretations (see Table 1). For this reason, the Brazilian Acoustic Quality Association (Proacústica) has developed a manual [3] to guide the noise class classification scheme into a more objective procedure, where classes are defined by the incident sound pressure level on the new building facades through software prediction and a noise mapping development.

Table 1: Weighted standardized level difference minimum requirements,$D_{2m,nT,w}$, for dormitories

Noise Class	Building location	$D_{2m,nT,w}$ dB
I	Building located far from sources of intense noise of any nature	≥ 20
II	Building located in areas subject to noise situations not classified in classes I and III	≥ 25
III	Building located in areas with heavy noise from traffic and other natures, which are in accordance with the legislation	≥ 30
Note 1: For external walls of rooms, kitchens, laundries and bathrooms, there are no specific requirements. Note 2: In regions of airports, stadiums, sports venues, highways and railways, specific studies are necessary.		

Such new requirements have been challenging to be comprehended by construction companies and users due to lack of acoustic knowledge. The complexity does not only reside in the perception difference of 5 dB between each requirement level (Minimum, Intermediate and Superior), but also in the assimilation of noise class concepts. An acoustic inexperienced constructor company is not able to opine and realize the meaning of a minimum requirement, neither the perception change of accomplishing a higher performance level 10 dB stricter. The users also lacks knowledge to decide the importance of investing money in a higher acoustic performance dwelling, not only in the perception of the facade insulation but also to consider the relevance of the noise class when the window is open. It is of paramount importance the development of technologies to facilitate the comprehension of such acoustic descriptors and criteria targeting an inexperienced public in Brazil, following the same practice adopted in some countries throughout the world, which approximates the population to mitigation noise researches [4].

2. OBJECTIVE

The objective of this current work is to develop an auralization tool, aiming to bring the user and the constructors companies closer to the acoustic consultant, since sound levels are not trivial to be comprehended only by numbers. The tool contemplates both aspects of the Brazilian standard for residential building: the sound class of the area where the building will be raised, and the sound insulation performance levels (minimum, intermediate and superior) for typical types of sound sources.

3. AURALIZATION TOOL DEVELOPMENT

In order to achieve a complete auralization of the environmental noise in the residential building, the methodology comprises three main steps:

- estimation of the outdoor sound attenuation (from the noise source to the incident sound pressure level on the new building facades);
- estimation of the facade sound insulation;
- filter design.

3.1. Outdoor sound attenuation

As mentioned in Section 1, the absence of objective methodology for determining the noise class of the building emplacement in ABNT NBR 15575-4, a practical guide was elaborated by acousticians in the scope of ProAcústica. This guide was used in the first step of this work to predict the incident sound levels on the building facades. The main guidelines are:

- analysis of the new building surroundings by observation and measurement of the sound sources sound levels;
- sound level simulation of the outdoor propagation on the area;
- acoustic classification of the area according to the incident sound pressure level.

The noise class scheme suggested by ProAcústica can be found in Table 2.

An example of a case study was carried out in a typical residential building in São Paulo - SP, Brazil. The Figure 1 is an overview of the area, which shows the building under study close to a railway. The aim is to evaluate the train noise that reaches the 19th pavement of the residential building. The decision to carry out the study near a railway was taken to facilitate the characterization of the sources, since in this case the sound pressure level of a train passage is far above the other background noise sources (e.g. road noise).

Table 2: ProAcústica guide's recommendations for building classification

Noise Class	Incident noise level at facades L_{Aeq} dB	$D_{2m,nT,w}$ dB
I Building located far from sources of intense noise of any nature	≤60	≥ 20
II Building located in areas subject to noise situations not classified in classes I and II	61-65	≥ 25
III Building located in areas with heavy noise from traffic and other natures, which are in accordance with the legislation	66-70	≥ 30
For incident noise levels above 70dB, a specific study should be performed to estimate the sound insulation of the facade.		

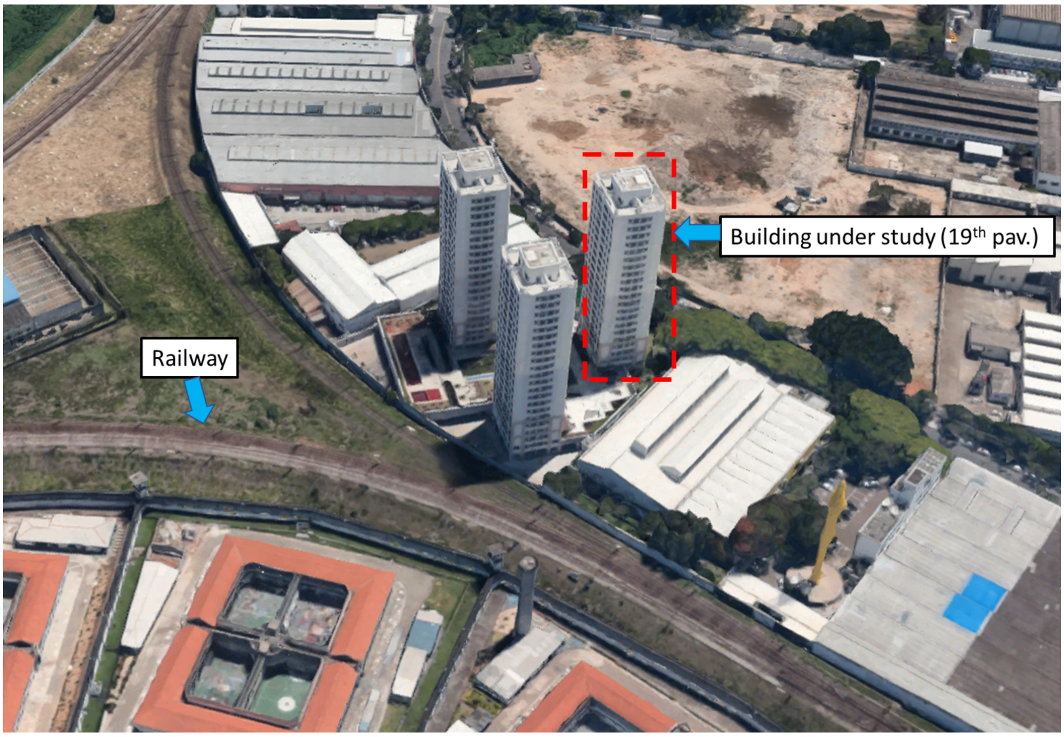

Figure 1: Location of the building and the railway

A commercial software has been used in this step to perform the propagation attenuation from the sound source to the receiver. The CNOSSOS-EU [5] model of sound propagation was chosen, since it has been previously studied as the most precise model to the Brazilian reality according to pilot studies in this same area [6]. A measurement performed as close as possible to the railway allowed the calibration of the source sound power level in the simulation. The noise map of the outdoor sound propagation calculated in the software is shown in Figure 2.

The outdoor sound attenuation (A_{out}) was estimated by a 1/3 octave band frequency transfer function given by the difference between the sound pressure level measured close to the railway (L_{p1}) and the sound pressure level incident on the receiver facade (L_{p2}), as

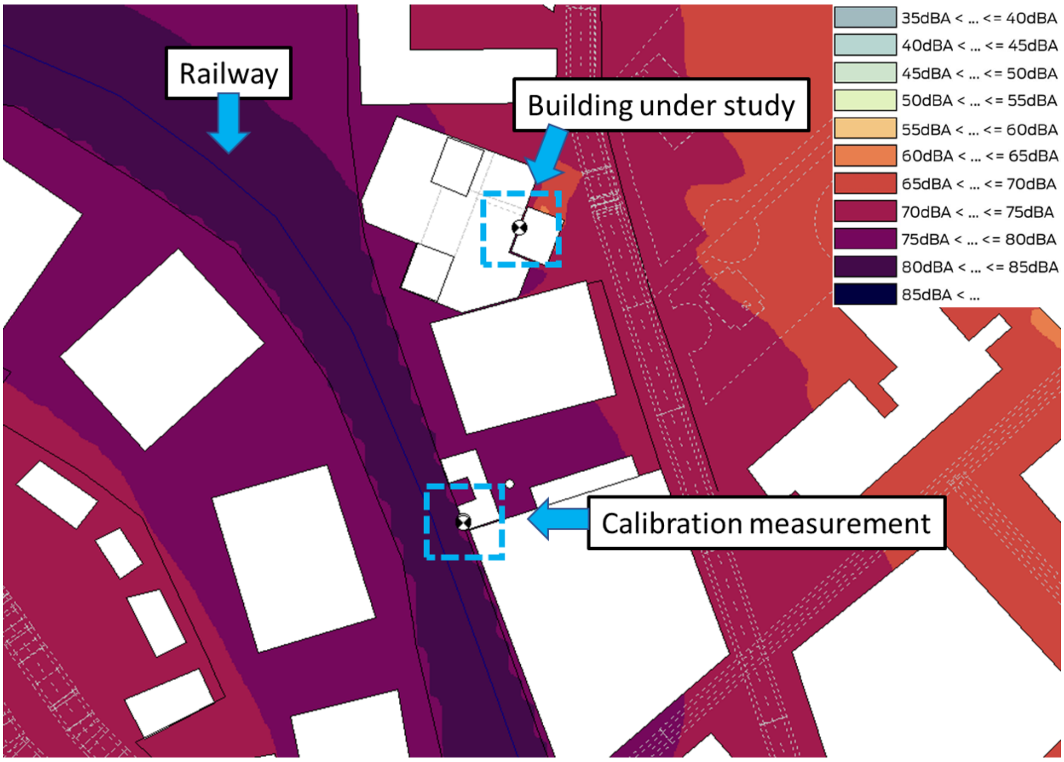

Figure 2: Noise map simulation of the area using CNOSSOS-EU methods

seen in the Equation 1 and Figure 3.

$$A_{out} = L_{p1} - L_{p2} \tag{1}$$

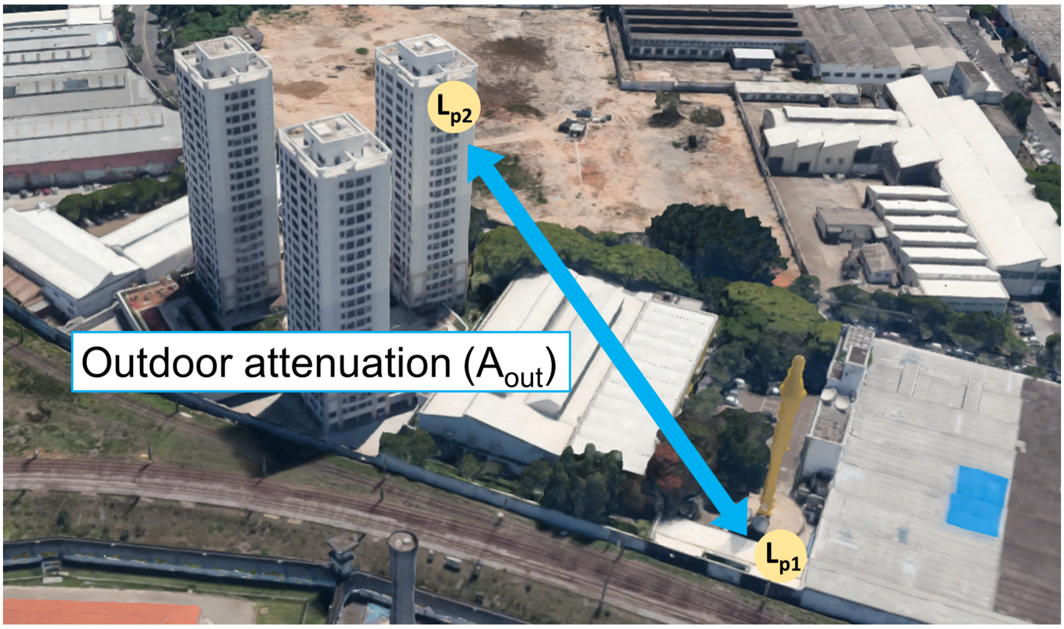

Figure 3: Transfer function of the outdoor acoustic attenuation due to the path propagation

A single train passage was selected from the acquired data to provide the input data and calibration of the railway sound source, which was modelled as a line source. In

Table 3, it is shown the error between the predicted incident sound pressure level on the facade and the actual measurement outside the 19th building pavement, it is seen that all errors are less than 5 dB which is acceptable. Whilst the sound level measurement was carried out in a specific location, a recording equipment and a head simulator saved the audio files into a computer in order to use the data as the raw file to the auralization.

Table 3: Difference between the predicted incident sound pressure level on the facade and the in-situ measurement

Freq. (Hz)	31.5	63	125	205	500	1000	2000	4000	8000
Error (dB)	2.8	1.1	-2	-3.4	-1	1.7	-1.6	-1.0	4.4

3.2. Facade sound insulation

The second step relies on the estimation of the acoustic attenuation due to the facade sound insulation. There are some plausible ways of achieving it. The most precise would be measuring the weighted standardized level difference at 2 m of the facade ($D_{2m,nT}$) for each 1/3 octave band frequency, however this is not always feasible, as in most cases the building is not built yet. Therefore, a mathematical estimation of the insulation can also be a reasonable solution according to the ISO 12354-3 [7] method. The disadvantage of this approach relies on the inaccurate acoustic characterization of the system, once it is important to know the exact physical properties of the walls. The window performance precision can also be a huge setback, since it is more susceptible to workmanship errors during installation, resulting in considerable variations if compared to the laboratory measurements. The estimation may be impracticable if there is no laboratory test at all.

This is an important stage because the user would be allowed to listen to how the various types of windows will affect the insulation depending on the building noise class area, enabling the auralization for typical sound sources of the surroundings.

3.3. Filter design

The third step consists on implementing the digital filters that will be applied in the signals to accomplish the auralization. The objective is to auralize the sound levels of an external sound source inside a residential building after it is digitally filtered accordingly to the estimated outdoor sound attenuation and the facade sound insulation.

A Finite Impulse Response (FIR) filter was designed considering the 1/3 octave band frequencies attenuation of each stage in a range from 50 Hz to 5 kHz. It was chosen a high resolution filter design (8193th order) to achieve an accurate response at low frequency, since there is no concern at the moment in implementing a real-time signal processing. The approximated frequency amplitude for each 1/3 octave band frequency could be produced using the frequency-sampling filter design method, which also leads to stable filters. A zero-phase digital filtering was possible by processing the input data signal both the forward and reverse directions, generating consequently, no phase distortion. As a result, a highly accurate response was acquired [8], which can be seen in the comparison between the desired filter response versus the actual filter response found in Figure 4. This Figure illustrates the attenuation exemplified in Subsection 3.1, also accounting the transmission loss of a facade containing a simple closed window system (R_w = 21 dB) from a Brazilian manufacturer.

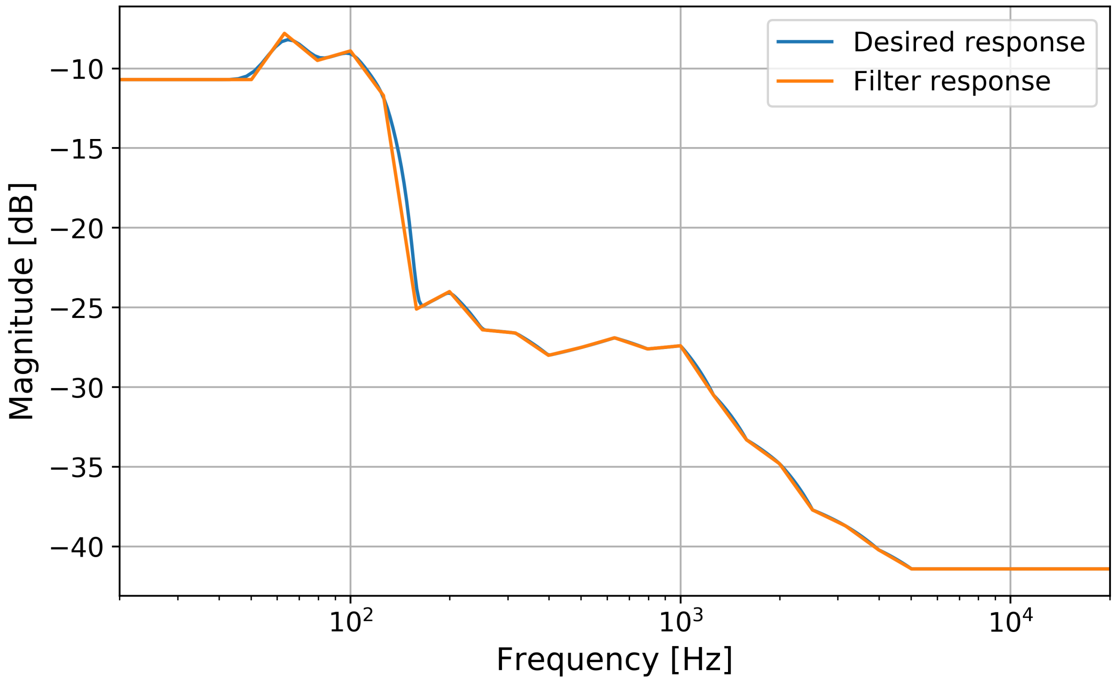

Figure 4: Filter response versus desired response

The full procedure of data acquisition, acoustic modelling and signal processing of the auralization tool is found in Figure 5.

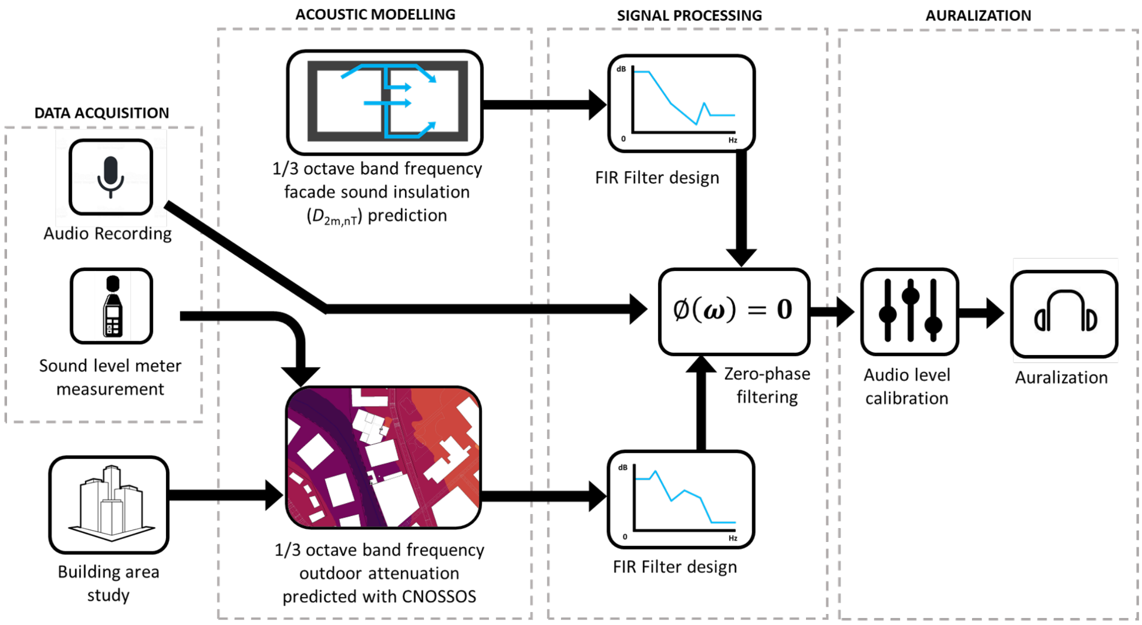

Figure 5: Flow diagram of the auralization tool

4. DISCUSSION AND FUTURE DEVELOPMENTS

Some issues were encountered while trying to validate the auralization tool. The filtered audio of a single train passage was compared to an actual recording of the train inside the room of the building from the Section 3.1 example with windows closed. However, the casement window installed in the dwelling provided a high facade acoustic insulation, which combined to the outdoor acoustic attenuation resulted in a recorded signal extremely close to the background noise from the interior of the building, dramatically interfering in the comparison between the filtered and recorded audio. For this reason, in this paper, it has not been carried out a specific subjective study for the tool validation besides the graphical comparison from Subsection 3.3 and the outdoor propagation in Table 3. The reverberation could also be a relevant difference in the subjective test, since it has not been digitally implemented in the filtered audios yet.

The further steps in the tool improvement will aim to implement the filtering process for each sound path transmission of the building and the acoustic radiance of the elements to the receiving room, generating an approximate immersive experience with the aid of an appropriate HRTF dataset [9]. The equivalent absorption area of the room can also be considered to calculate a reverberation time, and therefore, to acquire a more realistic indoor acoustic field to the auralization.

5. CONCLUSIONS

The implementation of ABNT NBR 15575 has been a challenging process and all professionals related to the construction market, public administration, and the population in general are still adapting to the new acoustic requirements.

There is a need to increase the awareness and commitment of the stakeholders and, at this current development stage, the proposed tool is already useful to approximate the objective requirements to the subjective perception.

The revision of the standard is due to start in 2019, and this preliminary auralization tool enables an adequate filtering and sound level presentation of the signals that can be used as starting point for future research to determine whether subjects perceive the difference between the minimum, intermediate and superior performance and whether these criteria represent a significant improvement in their perception of acoustic comfort in Brazilian dwellings.

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