ACOUSTIC ASSESSMENT OF A CLASSROOM AND REHABILITATION GUIDED BY SIMULATION

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ABSTRACT

The acoustics of spaces whose purpose is the acoustic communication through speech, namely classrooms, is a subject that has not been given the due importance in architectural projects, with consequences in the existence of adverse acoustic conditions, which affect on a daily basis the learning of the students and the well-being of teachers.

One of the lecture rooms of the Faculty of Engineering of the University of Porto (FEUP) was chosen, with a criterion of generality, in which the acoustic conditions were evaluated and compared with those that are known to be necessary for the intended acoustic communication effect. Several measurements were made in the space to investigate the acoustic parameters situation relatively to the appropriate range.

An acoustic model of the amphitheater under study was developed in the EASE software, with which it was possible to obtain simulated results for comparison with the previously measured parameters and to introduce changes in the model to perceive their impact in the real space. In this phase it was possible to use the auralization resources of the software to create perception of how the sound is heard in the built model. This was useful for the phase of rehabilitation of the space because it was possible to judge subjectively the improvement of the sound intelligibility in that space.

Finally, possible solutions are presented in the acoustic domain and using electroacoustic sound reinforcement aiming to provide a better acoustic comfort and communicational effectiveness for the people who use it.

1. INTRODUCTION

In today's society there is still no great concern with the acoustic problems of the daily frequented places, however, if an analysis is done on this subject, we quickly see how harmed we sometimes are due to the poor acoustics of a space, either by the excessive effort to the understanding of speech or by the vocal effort caused on the speaker. Among the most critical cases of this situation are the classroom spaces. Often they do not present favorable acoustic conditions for a good understanding of the words, so impairing student learning [1].

This problem arises from the lack of awareness in the project stage of the space about the acoustic specifications necessary for its purpose. It is known in acoustic science that, if the space is used for communication by means of the word, then the intelligibility of the transmission will only be assured by deliberate attention and should therefore be a factor to be taken into account [2].

Through direct contact with the problem and the perception of its impact it became necessary to intervene.

This problem was identified in some lecture spaces of FEUP from internal reports and studies and above all, through the common experience of students and teachers [3, 4]. In the course of previous studies in some of those spaces, a clear diagnosis of the problem was achieved, through objective and subjective tests, and some pilot interventions were carried out, however, the changes made in the chosen rooms were quite profound and expensive, making it difficult to generalize to the whole school.

A new study was carried out in the Amphitheater B013 of FEUP, one of the more abundant types of lecture rooms that may be encountered at FEUP, in terms of quantity times capacity ranking, to evaluate how far is it from the necessary conditions for the purpose and to present solutions.

Is it possible to evaluate the acoustic conditions of a space not only through experimentation but also by modeling the space using appropriate software. This is a great advantage when it comes to evaluate and simulate changes to the space in an economic way. To do this there are several softwares available, such as, EASE [5], ODEON [6], Olive Tree Lab-Room[7] and CATT [8], among others. In these softwares, auralization might also be available allowing a subjective evaluation of the space through its digital model where it is possible to actually ear a simulated sound as if the person was inside, on a specific spot of the model. This also brings the advantage of having a perception of how sound will be heard after simulating an intervention, saving all the costs of implementing the solution experimentally in the place, which is very important in the case of a preliminary study.

2. METHODOLOGY OF STUDY, ASSESSMENT AND ACOUSTIC DESIGN OF CLASSROOMS

Since the problem under analysis is centered on the evaluation of an existing lecture room, a methodology is proposed for its acoustic enhancement, that, in this case, a corrective one, since the space in study is already constructed. The work addressed in this paper can be separated in two phases, a preliminary phase and an implementation phase. The present paper describes only the first phase which was already accomplished. Thus, the workflow proposed for the preliminary phase consists of the steps presented in figure 1.

For the following implementation phase, where the design will be applied to the space, what is recommended is to intervene with alteration of the acoustic architecture by means of some acoustic materials for passive correction as well as with introduction of a simple speech reinforcement system, composed of microphones, amplifier and one loudspeaker. Finally, the project should finish by taking measurements for verification of the effectiveness of the intervention.

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* Acknowledgments: Support from MIEEC programme of work developed in the scope of the MIEEC master dissertation; Support of Acoustics Laboratory of FEUP - António Costa (M.Eng.).

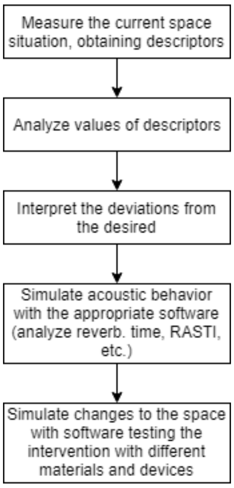

Figure 1: Workflow proposed for the preliminary phase of the acoustic assessment and rehabilitation.

3. CASE STUDY: AMPHITHEATER B013 (FEUP)

3.1. Acoustic evaluation

The acoustic evaluation consisted of an *in loco* data collection for calculation of a set of descriptive acoustic parameters of the space. For the amphitheater B013, composed of 98 seats, of which two pictures are presented in figures 2 and 3, the set of parameters, which were considered important, taking into account that the space has the purpose of speech communication, was composed by: reverberation time, RASTI, definition, clarity, and also background noise [9] [10]. Two types of sound sources besides a RASTI emitter were used to excite the room space, and a couple of measurement microphones, a sound-level meter and a RASTI receiver were employed to record sound and measure, respectively. Some pictures of the equipment used are presented in figure 4. Posteriorly, a specially developed Matlab program was employed to process the recorded signals and obtain not only the values for the definition and clarity but also reverberation times for additional sub-bands not given by the sound-level meter. The impulse responses of the space were also obtained for two distinct locations, in rows 2 and 6, using the same software with additional averaging.

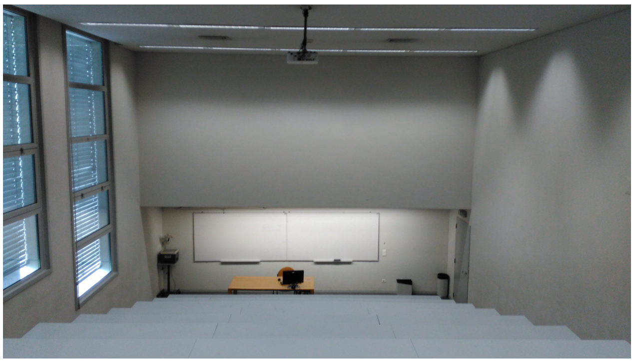

Figure 2: Front of amphitheater B013.

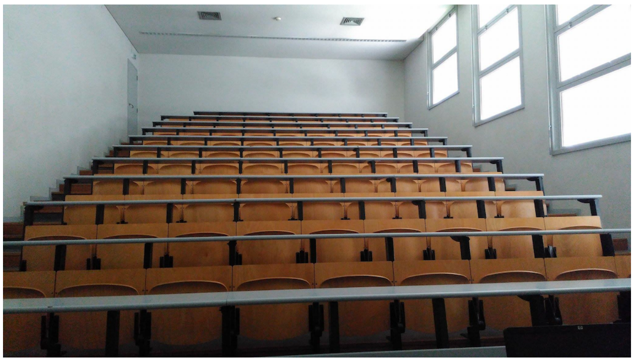

Figure 3: Rear of amphitheater B013.

Figure 4: Material used for the measurements. From left to right in the top row are two sound sources and a sound-level meter. In the bottom row are a RASTI emitter and a RASTI receiver.

For the wideband global reverberation time (averaging the results for the octave bands of 500 Hz, 1 kHz and 2 kHz) a value of 2.35 s was obtained. A graphic with the RT frequency distribution can be seen in figure 5 .The other mean obtained values were: 0.45 for RASTI, for D_{50} and C_{50} in row 2, 0.45 and -0.79 dB, respectively and 38.4 dBA for background noise. Table I presents the obtained values in comparison with the ones that would be adequate for this room[2] [11] [12]. Through a reflectometry analysis of the room impulse responses, we observed a large number of important late reflections that contribute to impair the speech intelligibility.

With those values so distanciated from the desired levels, a clear need for intervention in the space was proved.

3.2. Acoustic simulation

Exploring the possibility of evaluating the space not only through experimentation, but also using simulation software allows to take profit of the advantage that, after the required model is completed, changes may be inserted simulating space interventions virtually, in a rather quick and economic way. The studied space was sim-

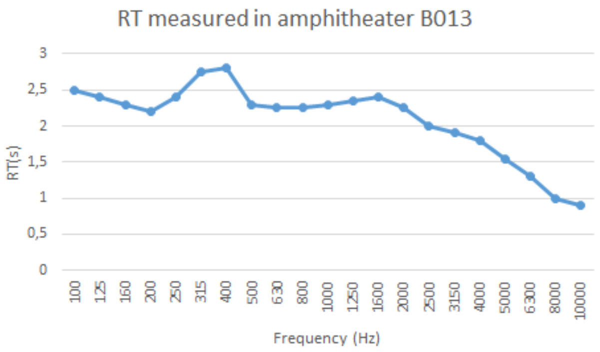

Figure 5: Measured reverberation time on amphitheater B013.

Table 1: *Presentation of the values obtained for the selected acoustic parameters in the amphitheater B013 in relation to their appropriate values.*

Parameter	Appropriate range	Obtained value
RT [500-1kHz] (s)	0,7-0,8	2,42
RASTI	$\geq$ 0,6	0,39-0,54
Definition	$>$ 0,5	$\leq$ 0,45
Clarity (dB)	$>$ 0	$\leq$ -0,79
Background noise (dBA)	$<$ 40	38,4

ulated in EASE and the descriptive acoustic parameters were obtained from the model. The model construction required some iterations and fine-tuning. Finally, simulation results were close to the experimental ones, allowing to conclude that the model was a good approximation of the reality, as can be verified by comparing figures 5 and 8 (no intervention) RT plots.

When constructing the model the first things that were needed to be taken into account were the dimensional aspects of the room, which include the dimensions of the space and its elements such as stairs, doors and windows. Consultation of the building construction blueprints still left some dimensions to be measured on site due to small alterations that were not clear in the drawings. After this part was accomplished it was necessary to carefully close the model in geometrical terms, otherwise the simulated room geometry would have leaks and the software would not allow a good simulation.

After modeling the space geometrically, several essential aspects were considered such as discovering which materials grades were used in the amphitheater in order to reproduce them in the model. It was taken into account the absorptions coefficients variations by frequency, thicknesses, mounting of false ceilings, etc. All these aspects have an impact on the acoustics of the space and for this reason they should be considered in the model.

Having reached this phase it became possible to check the accuracy of the model, not only in an objective, but also in a subjective way, using auralization. This is the process of producing the sound field created by a source in the space in a virtual way, in order to simulate a listener's binaural sensation in a defined position of the modeled space. In the developed work, auralization allowed to compare the audio recordings previously done in the space to the ones obtained with the model and verify that the sounds obtained were similar, giving the model a subjective validation as a good representation of reality.

4. SIMULATED ACOUSTIC REHABILITATION

4.1. Simulated rehabilitation of the amphitheater B013

With the calibrated model, and noting the need for intervention in the space, some solutions were considered and studied for the required improvement of its characteristics. Thus, a set of three valences were analyzed, namely, spreaded change of absortion on the enclosure surface, the use of spot absorption devices and the use of sound reinforcement as a complement.

For this amphitheater after several computational simulations, it was found that the use of the absorbent material K13 applied at the rear of the space, on the back wall and the rear part of the ceiling (2.5m length along the width of the ceiling), presented the best relation between obtained results and cost. This conclusion was obtained through the reflectometry study with which it was possible to find where the most adverse reflections come from and to guide the placement of absorbent material to attenuate them. Thus, the use of this material is proposed mainly to improve the intelligibility of the space. However, when examining the direct sound pressure level at the audience it was also noted that there was a decrease and this created a need to introduce sound reinforcement in the space to allow the direct sound to reach the listeners on the rear rows with sufficient intensity [13] [14]. Thus, a study was made on the best minimal approach for sound reinforcement taking into account the localization of the speaker and which loudspeaker type and location to use. The choice of the loudspeaker type is crucial since its characteristics models the sound radiation and how directly it reaches the listeners. For this phase the simulation is a specially important tool which allows to study the position and comparison of several loudspeakers as well as their driving parameters, time delay and power, and to select the one which produces the desired results.

In this way, the complete intervention proposal presented in this work for the studied amphitheater consists of a combination of the placement of absorbent material (K13) in the back of the amphitheater and the introduction of sound reinforcement as a complement. A representation of the model geometry of this intervention is depicted in figure 6 and the proposed electroacoustic chain to use in figure 7. The view point of the representation in figure 6 is below the floor and two walls are removed. The white board backside is visible in green, the professor's desk in brown, the loudspeaker in light blue and the new absorbent material in dark blue. If needed, color pictures are available by request to one of the authors or by downloading from the following link: `https://www.dropbox.com/s/emc74rtyv7bfhac/Model.PNG?dl=0`.

Simulating in the EASE software the changes proposed above, there was a decrease in the reverberation time in function of frequency between 0.31 s and 1.51 s, as can be seen in figure 8. It was also possible to increase the mean RASTI value to 0.6, thus reaching a subjective rating evaluated as good. In figures 9 and 10 the simulated distribution of RASTI before and after the intervention is shown. The simulated mean value of C50 after intervention also changed from -4.28 dB to 0.36 dB.

By using the proposed chain presented in figure 7, the direct sound pressure level received by the listeners is increased from 52dB before rehabilitation to near 61dB. In figure 11 the distribution of the direct sound pressure level before rehabilitation sim-

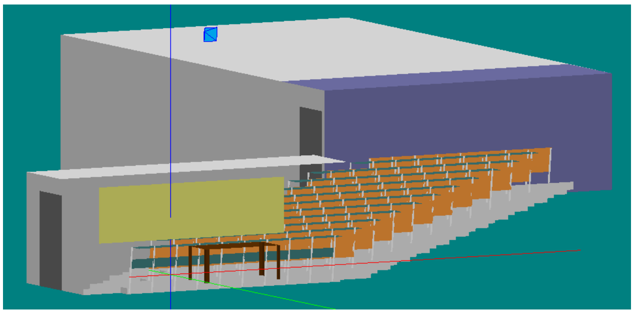

Figure 6: Model geometry of the amphitheater after intervention on EASE.

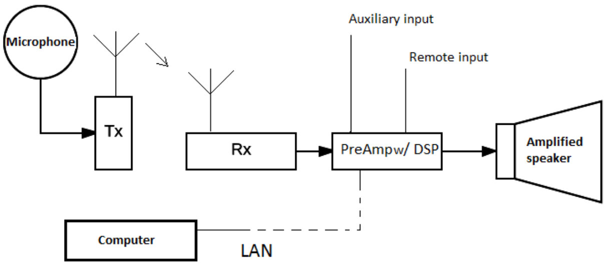

Figure 7: Proposed audio chain for sound reinforcement in the amphitheater B013.

ulated on EASE is shown and in figures 12 and 13, respectively, the direct and total sound pressure levels with acoustic reinforcement simulated on EASE, are represented. It may be concluded that this simple borderline intervention can guarantee a significant improvement of the values of the descriptive acoustic parameters of the space.

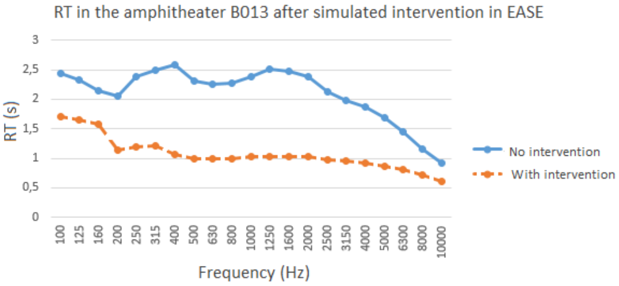

Figure 8: Simulated reverberation time before and after the intervention on EASE.

4.2. Use of auralization for subjective apreciation

As previously mentioned, auralization is a powerful tool for the subjective evaluation of a simulated model. In this work it had an important role in the validation of the model and in the simulation phase of rehabilitation since it allowed to verify the sound quality improvement introduced in the space with the application of the proposed solution. In order to do this, a speech sound segment was recorded in an anechoic chamber and the same sound recorded in the space under study, in rows 2, 6 and 10. The anechoic recording was submitted to auralization sound treatment with the EASE software where the result of this process is a binaural recording demonstrating how the sound would be perceived in the room. The result of this whole process before the rehabilitation allowed not only the quantitative but also the qualitative validation of the model, by the authors and a small group of test listeners, and to verify the improvement of the same after rehabilitation.

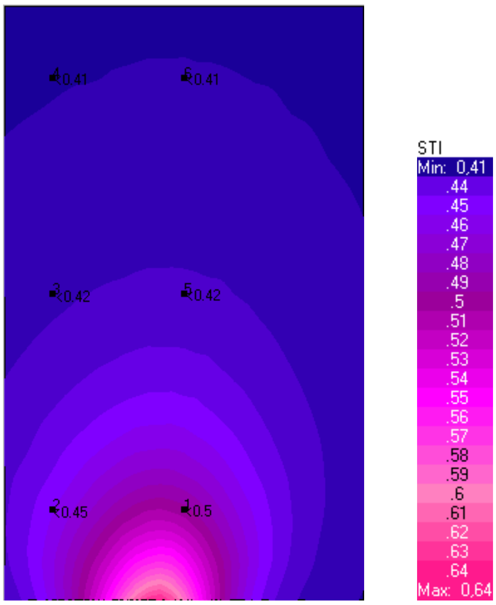

Figure 9: Distribution of simulated RASTI before intervention on EASE.

5. CONCLUSIONS

The objective of this work was fully achieved, having reached the enhancement of the acoustic design of a space adapted to speech communication with minimized implementation costs, through a proposal of intervention using a minimal amount of absorbent material and complementary introduction of a simple sound reinforcement system. Thus, a workflow is proposed for the acoustic assessment and rehabilitation design, which can be applied to several spaces, and also a way to combine acoustics and electroacoustics while reaching all main quality specifications is presented with the purpose of minimizing application prices. These are the main contributions of this work which can serve as guidelines. In this way, to implement this proposal, is a solution to provide greater acoustic comfort to the people who attend the treated space.

It is also concluded with this work that the power of the acoustic design simulation tools was demonstrated, allowing that in a simple and effective way, time and resources be saved since after the model is built it allows to simulate several changes to the space to arrive at the desired result. It is still important to emphasize the importance of auralization in the process of acoustic design since it allows to subjectively predict how the sound will be perceived

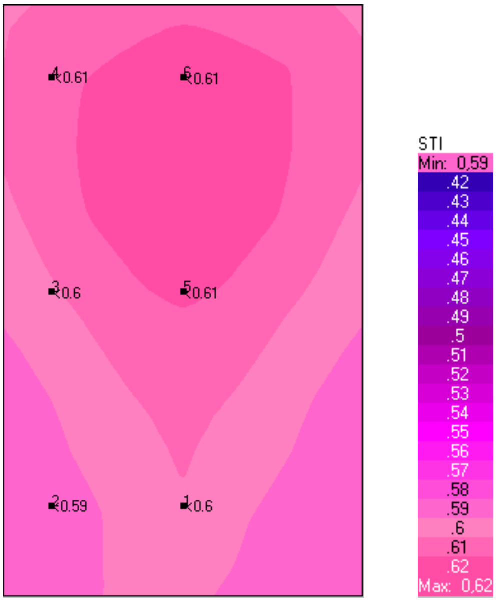

Figure 10: Distribution of simulated RASTI after intervention on EASE.

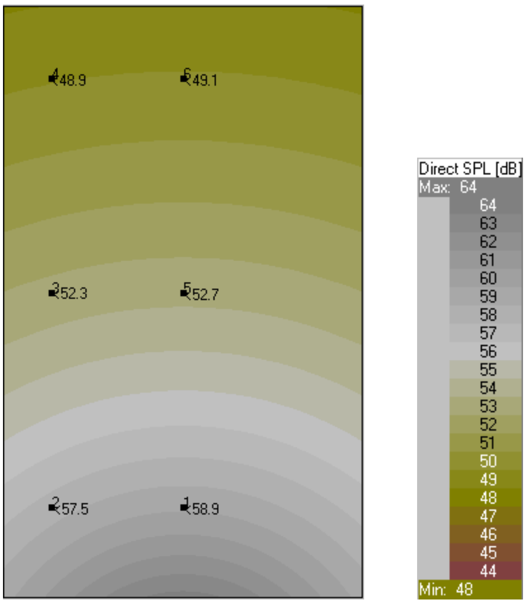

Figure 11: Distribution of direct sound pressure before rehabilitation simulated on EASE.

even before the space is built or to undergo intervention.

For future work the characterization of the average of people generated noise, the integration of other sources of background noise into the model and the other acoustic effects of the audience, mainly its per capita sound absorption, should be done to replace average empirical coefficients that are generally used and therefore, increase model accuracy. Also, in order to make the evaluation of the space more complete, it would be appropriate to introduce in this study the performance evaluation by means of subjective panel tests.

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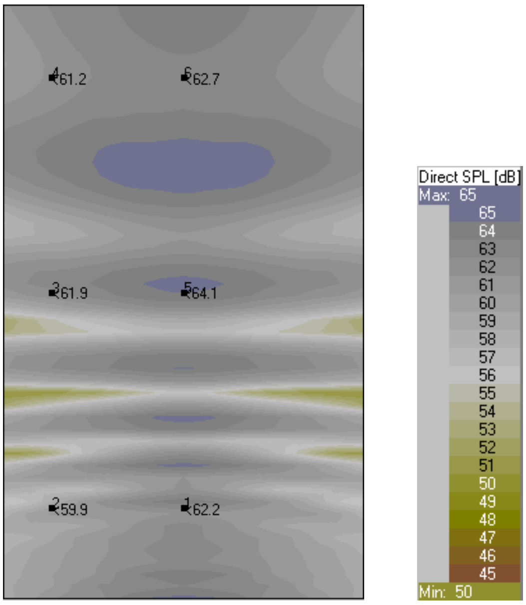

Figure 12: Distribution of direct sound pressure after rehabilitation simulated on EASE.

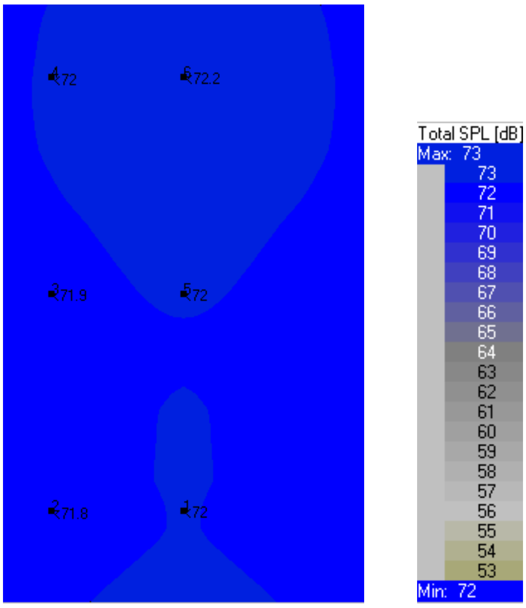

Figure 13: Distribution of total sound pressure after rehabilitation simulated on EASE.