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EVALUATION OF ACOUSTIC PARAMETERS OF INTELLIGIBILITY ON AN UNIVERSITY AUDITORIUM TO IMPROVEMENT SUGGESTIONS

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Abstract. *The analysis of acoustic parameters in auditorium is important to define if the sound is coming with enough clarity and intensity to the listeners, on closed ambient. In this paper, some of these parameters was defined in an auditorium at the Federal University of Pará to define, in an acoustic point of view, if it is able to satisfy the needs of its listeners, ensuring the hall for this function. This study presents a research about acoustic quality inside an auditorium allocated for conferences, workshops, lectures and general events, focusing on speech intelligibility. Through the impulse response, based on ISO 3382, were obtained acoustic parameters as: Reverberation Time (T30), Early Decay Time (EDT), Clarity (C80), Definition (D50), and Speech Transmission Index (STI). A three-dimensional CAD model by software was considered to study the case, and from the defined parameters, a prediction of the acoustic behavior based on source-image and the acoustic rays methods, enabling acoustic correction solutions and predict the behavior of theses parameters after improvement application on auditorium*.

Keywords: *Acoustic, Auditorium, Impulse Response, Clarity, intelligibility*

1. INTRODUCTION

Environments often not acoustically designed are used for lectures, theatre plays, classes and general presentations, making the audience understandment difficult. Due to these cases, at the end of the XIX century and beginning of the XX century, a preoccupation to attend the listeners had begun (BARRON, 2010). The first known study in this area was made by the Physicist Wallace C. Sabine (1868-1919), in which was developed the materials sound absorption, a relation between this theory and energy decay in closed environments, and an equation to find the reverberation of the room.

In this context, this paper has the goal to perform the acoustic characterization in experimental form using an auditory located at Federal University of Para, focused in the speech intelligibility.

Marros (2011) investigated the correlation between the objective and subjective, through measures and use consultations, and the results comparison allowed the confirmation of the professionals non definition existence about which items should be considered important for an efficient acoustic. Therefore, parameters as Clarity (C50), Definition (D50), Reverberation Time (T30), Initial Decay Time (EDT), and Speech Transmission Index (STI) were used to determine, under the acoustic point of view, if it is capable to satisfy the listeners necessity, and, in this way, to guarantee that the room is fit to attend whatever it was designed for.

2. THEORETICAL FOUNDATION

Room acoustics is the sound behavior study within closed enclosures, and therefore, the acoustic conditioning of these. The environment acoustics quality can be quantified according to different parameters as the type of message that is intended to transmit (MARROS, 2011). Particularly, this study is essentially focused in the transmission quality and spoken language. BARRON (2010) affirms that, in closed environments, the sound can reach the listeners in three different ways: the direct sound, the first reflections, and the reverberating sound. The first sound that the listener notices is the direct sound, because the wave dislocates itself straightly from the source to the receptor. Then, the sounds from the first wave reflections in the surfaces of the room are heard, and the reverberating sound is all that reaches the listener after the first reflections sounds. The Reverberation Time must be in line with the space use, should not be excessively long not to disturb the clear perception of sound, but also, should not short or too little, which affect the perception of some sound sources (LOSSO, 2003). Therefore, the Reverberation Time becomes a new important parameter to be defined in an acoustic quality study.

The room conditioning depends on the relation between the sound frequency and the analyzed room dimensions acoustics. Depending on this relation, different acoustic theories are applied to arrive at the sound behavior within this enclosure. Essentially, there are three different room theories: Ondulatory acoustics, statistic acoustics and geometrical acoustics. The acoustic rays theory, or geometrical acoustics theory, analyzes the acoustic ray the same way the light is analyzed in geometrical acoustics. Therefore, an entity called sound ray is created, which is a portion of acoustic energy propagated in straight line, and in an omnidirectional source, the rays leave to every direction containing the same amount of energy. Melo et al. (2007) adds that this theory comes as a simpler and more practicall alternative than the ondulatory acoustics , because it demands less energy for computational proccessing, therefore generating faster results

2.1 Reverberation Time

The reverberation time is defined as time, in seconds, so the environment sound pressure decays in 60 dB after the source interruption, Eq. (1).

$$T=0{,}161\left(\frac{V}{A+4uV}\right)\ (s)\ ;\ A=\sum a_i s_i \tag{1}$$

Sometimes, the air absorption effect is disconsidered, in which it becomes significant above 2 kHz, then simplifying the equation and getting in the form (BARRON, 2010), Eq. (2)

$$T=0{,}161\left(\frac{V}{A}\right)\ (s)\ ;\ A=\sum a_i s_I \tag{2}$$

How, in practice, it is difficult to notice a 60 dB decay, the analysis is performed using a 30dB decay, expecting an initial 5dB decay after the source shutdown to stabilize the decay, and the result is multiplied by two, this parameter is then named T30.

2.2 Early Decay Time

According to BENAREK (2003), the Early Decay Time (EDT) is time, in seconds, after the source shutdown, that the sound pressure level decay lingers 10 dB, multiplied by six. The ISO 3382-1 regulation states that the EDT, when compared to reverberation time, is subjectively more important e linked to the listeners reverberation perception, while reverberation time is related to the room physical properties.

2.3 Clarity and Definition

According to Beranek (1996), when a musician speaks about Clarity or Definition, it is talking about the distinction degree between one sound and another in a musical performance. The ISO 3382-1 (2009) regulation classifies these parameters as balances among the initial energy and late energy captured by the microphone.

The time to define the initial energy can be 50 or 80 ms, depending on the results intention to qualify the environment for speech or music, respectively. Clarity (C80), by ISO 3382-1 (2009), is defined as the logarithmic ratio between the initial energy (until 80 ms) and the final sound energy (from 80 to 3000 ms). Eq. (3)

$$c_{80}=10\log\frac{\int_0^{0{,}080}p^2\,(t)dt}{\int_{0{,}080}^{3}p^2\,(t)dt}\ dB \tag{3}$$

Where $p(t)$ is the instant sound pressure of the impulsive measure answer at the measurement point. Definition (D50), then, is the linear ratio between the initial energy (until 50 ms) and total energy. Eq. (4)

$$D_{50}=\frac{\int_0^{0{,}050}p^2(t)dt}{\int_0^{3}p^2(t)dt} \tag{4}$$

The definition is usually applied to evaluate the speaking dedicated rooms, and because of that, has the major importance in the auditorium acoustic quality evaluation.

2.4 Sound Transmission Index

The *STI* (*Speech Transmission Index*) is a widely used parameter in room acoustics quality evaluation where is necessary to the understandment of oral form transmitted information comprehension, also highlighting that this parameter takes into consideration the reverberation time, the echoes, and background noise very important factors for room intelligibility. The *STI* varies between 0 to 1, where the extremes represent bad intelligibility and good intelligibility, respectively. The table 1 presents the *STI* evaluation according to IEC 60268-16 regulation.

Tabela 1. STI values according to IEC 60268-16 regulation

STI Values	Intelligibility
0,75 – 1	Excellent
0,60 – 0,75	Good
0,45 – 0,60	Adequate
0,30 – 0,45	Weak
0 – 0,3	Awful

3. MATERIALS AND METHODS

3.1 Auditorium

Located in Federal University of Para, an auditorium was selected, which will be used for papers presentations. seminars, lectures, workshops and general use for graduation and post-graduation programs. Since the auditorium will be used, in general, for speech linked events, and the initial architectonical project does not propose to fit to these occasions, then naturally the need to ascertain if the acoustic parameters were fit appeared.

For the study, firstly it was necessary to check the auditorium characteristics, Fig. 2.

Figure 1. Inner view of the auditorium

Tabela 2. Obtained auditorium dimensions

Measures	Dimensions (m)
Lenght	12,26
Width	8,25
Height	2,94
Volume	279,25

3.2 Experimental Tests

The experiments were performed according to ISO 3382-1 regulation, the regulation determines the number of the microphone positions, averages, source positions and frequencies rates to be analyzed in the measures to obtain valid results. According to the regulation, the minimal position of the source numbers that should be used for auditorium measurements is two. However, for small spaces, with less than a dozen seats, one source position is enough and it should be positioned where the speaker would be, approximately 1,5m high from the ground. For the microphones, six positions must be used, spaced, at least, 1m of the side walls and 1,2m high from the floor.

The used frequency range was 250 to 8000 Hz. Each position was excited three times and the presented result corresponds to the average. In the end, the presented result is a space and time average of the obtained results.

In this test, *EDT*, *T30*, *C80*, *D50* e *STI* parameter values are sought, using the DIRAC *software* for further comparison with the same parameters showed in the enclosure virtual modelling with ODEON *software*. The measurement system structure was made up by two modules.

The first one, responsible for the signal processing, consisted in the impulse answer obtainment and acoustic parameters calculation, running through DIRAC software, installed on a laptop. The second one, responsible for reproduction and acquisition of sound signals, was implemented through an audio board and a set of transducers.

It is worth mentioning that, for the computational simulation, the same microphone position and test source were maintained.

3.3 Impulsive Response Measurements

The measures were performed with a 31 ºC temperature and air relative humidity of 70%. All measure points were in the auditorium seats, searching for the closest listeners possible position to representing the position of the listeners. The chosen seats were numbered according to the auditorium naming, which were: A4, A9, C4, C9, E4 e E9, being three positions for each side of the auditorium, Fig 4.

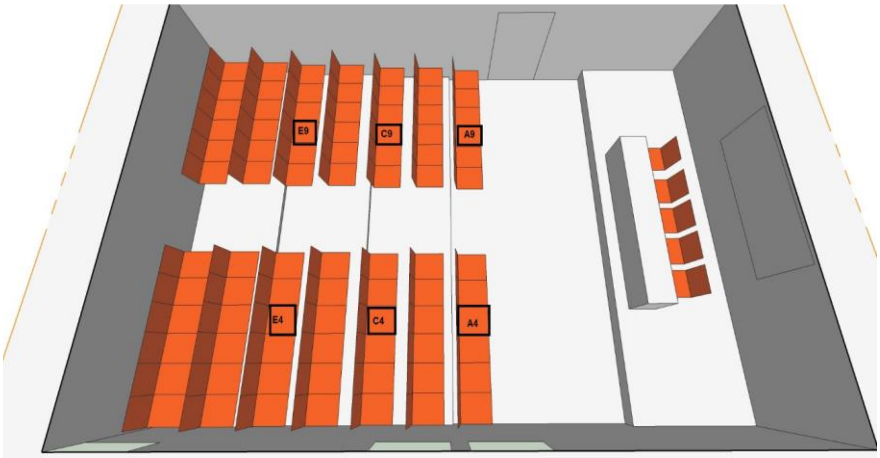

Figure 2. Inner auditorium Microphone Positions Distribution

The source was positioned according to the speaker’s position and the measurements were performed without any ocuppants in the room and in sequence, and in every three measurements the microphone position was changed.

3.4 Computational Simulation

To perform the computer simulation was created a 3D model using SketchUp Pro software, which was subsequently exported to the ODEON, a computational simulation program that uses the method of acoustic rays to determine the acoustic parameters rooms. Once at ODEON, the microphones and the source were positioned and checked if the model had no leaks through the Billiard 3D tool, being able to perform the simulations.

The surfaces of the model provided by the CAD program are devoid of acoustic attributes, so using the ODEON each surface absorption characteristics can be inserted with its bill of materials. Santana (2013) found that some areas should not be used in the way that was offered by the ODEON library, because it does not consider the loss of energy in sparsely populated areas, resulting in a limitation that should be noted and corrected at the time of definition materials.

With this information, interactions were performed to approach the results obtained experimentally in the room, and at this stage were defined materials of each element in the room, adjusting their absorption, the materials in the room were configured as shown in Table 3 below.

Table 3. Sound absorption coefficient of room surfaces.

Surfaces	Materials	Range Absorption					
		250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Tables	3063	0,21	0,1	0,08	0,06	0,06	0,06
Floor	6000	0,02	0,03	0,03	0,03	0,034	0,033
Board	3068	0,22	0,19	0,09	0,1	0,11	0,11

Chairs	11057	0,52	0,52	0,51	0,53	0,45	0,4
Glasses	10006	0,25	0,18	0,12	0,07	0,04	0,04
Roof	102	0,03	0,02	0,02	0,02	0,02	0,02
Door	4002	0,02	0,02	0,02	0,02	0,02	0,02
Wall	4002	0,04	0,04	0,03	0,03	0,02	0,02

The obtaining of the parameters for acoustic quality evaluation was performed once the room geometrical modelling, material application and acoustic, and source and receptors positioning were defined. The basic software settings were the approximate found in the measurements. .

4. RESULTS AND DISCUSSIONS

Following, the obtained data are presented and analyzed in experimental measurements and in computational simulation, discussing the obtained results, relating then, and explaining possible differences in both cases.

4.1 Experimental Tests

Following, the results are presented, in octave band, in 250 a 8.000 Hz rate, for T30, EDT, C80, D50, e STI parameters, using for acoustic room quality evaluation, and obtained from the acoustic impulsive response measurements.

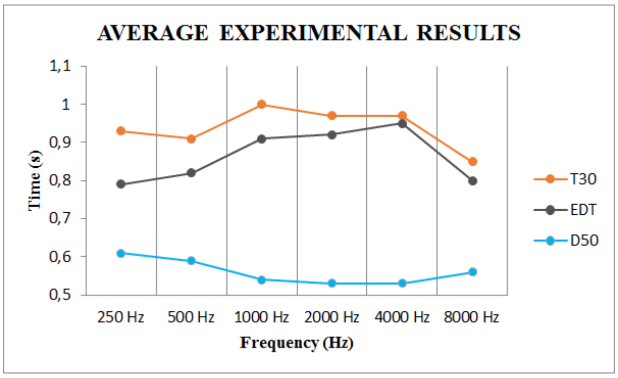

Figure 3. Acoustic Parameters average obtained in the room.

For a small size auditorium, the obtained values for T30 are elevated considering environments focused on speaking. According to NBR 12179, the ideal reverberation time would be 0,6s in 500Hz, a considerably lower value than the 0,91s obtained. According to Beranek (1996), the ideal values for the C80 varies from -4 to +5 dB, which means that the room has superior values then the indicated. Marros (2011) comments that for speaking destined rooms, D50 values above 0,65 in the central frequencies region (500 e 1.000 Hz), provide good acoustic quality. The measured values were not as close as the recommended ones, indicating a few adequate intelligibility, becoming more evident when analyzing the STI. For the auditorium, the measured STI values varies between 0,59 and 0,63, which, according to the regulation, indicates an intelligibility in the threshold of adequate and good.

4.2 Computational Numerical Results

The results were obtained approaching to the computational model with the real room as close as possible. The goal was to bring the most of the parameters between the approaches, focusing on T30.

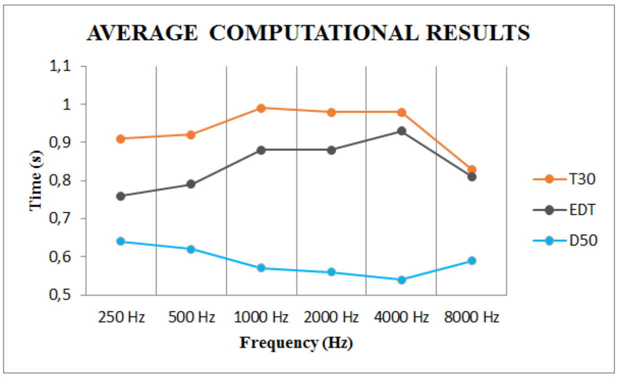

Figure 4. Acoustic Parameters average obtained computationally.

For T30 the computational simulation values are consistent with the values found experimentally, so there is good agreement between these parameters models. The values for EDT simulation were lower than the experimental ones, probably due to energy loss for the system interior not accounted for the program, by only considering the absorption loss. This difference is passed on to the following two parameters, especially for being relations between final and initial energy, creating small different in the simulated result for the measured one.

It was found a bigger difference for C80, with higher simulation values, indicating a higher energy in the system first moments in relation with the measured one in the room. The same relation was observed for D50.

The STI for simulation was slightly larger than the experimental, with 0,64 average, indicating a good intelligibility.

5. SOLUTION PROPOSITIONS FOR THE AUDITORIUM

With consistency between models guaranteed by the previous comparisons, modifications in the room can be indicated to correct the found problems, and predict the tendency of achieving modification. The used parameters in this step were different from the modelling step, the virtual models used common terms among DIRAC and ODEON softwares, those beings: T30, EDT, C80 e D50. The C80 application is indicated to rooms specific for music. In the auditorium, under studies aimed to speech, D50 parameter should be observed, being the most qualified for this function. Then, only the T30, EDT and D50 parameters will be analyzed.

The use of Sonex acoustic panels was considered, but getting in contact with the supplier, the use of Nexacustic OWA (perforated panels) Nexacustic OWA, due to the fact that Sonex panels are from a very fragile spongy material and it is not indicated to use exposed to the reach of the people. Among the models, the chosen on was de wood panel Nexacustic 16 + 5 cm of wool, because of its high absorption in 500 Hz. If a higher absorption is necessary, mineral lining plates would be applied in the roof next to the speaker, being selected the OWAcustic Premium Tonica, of good absorption.

Table 4. Acoustic absorption in the selected absorbers.

Absorption	Cost/m²	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Wood Panel	R$ 417,05	0,93	1,03	0,94	0,77	0,65	0,6
Mineral Lining Plates	R$ 73,72	0,59	0,74	0,77	0,94	0,99	0,99

5.1 Proposed Models

Proposed models are presented to improve the acoustic quality of the room. Each model was computationally simulated, determining the acoustic parameters of each one. The results are presented along with the model. Each model was proposed according to the previous model viability and quality, modifying the absorbers searching for a higher proximity to the indicated time, using as minimum material as possible.

In model A, 24 mineral linings were used in the rear part of the room, with a total are of 18,75 m², the absorbers were positioned next to the walls, with less interference in the first sound reflections between the speaker and the listeners. Due to good results in the previous model, it was proposed that a B model where it was decided the removal of the wood panels and adding 8 mineral lining plates, due to a great price difference of the materials. 11,66 m² wood panels were removed, adding 6,25 m² of lining, resulting in a total of 25 m² of mineral lining, with 16 iron plates each side.

The Figure 7, shows the proposed configurations models, followed by Table, with the obtained values for simulation in both models.

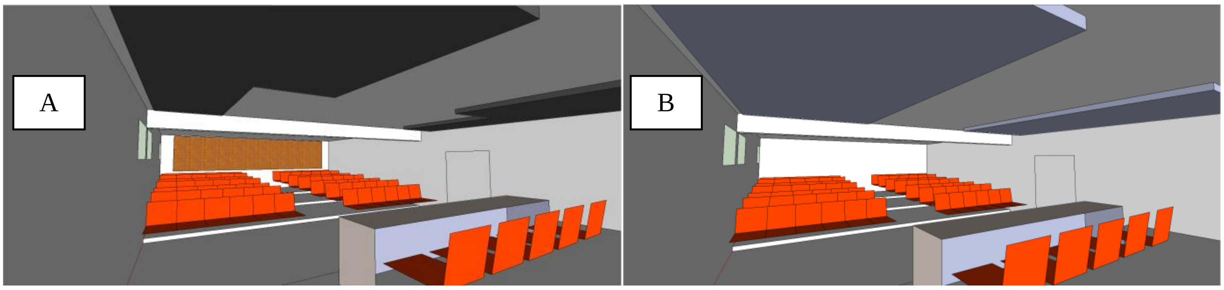

Figure 5. Models Representation applied in the Auditorium Inner side

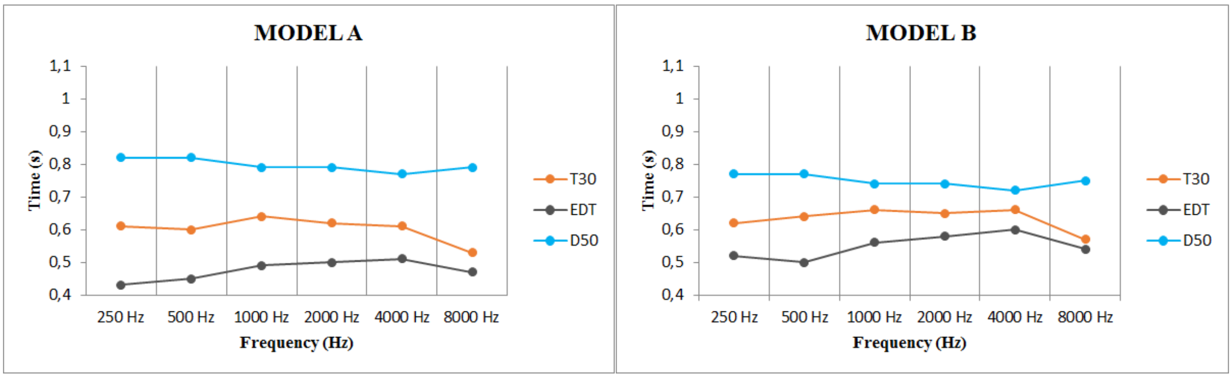

Figure 7. Models Representation applied in the Auditorium Inner side

The A model presented T30 values next to the indicated regulation, the elevated D50 and EDT values minor than the T30 ones points out a good room intelligibility, proven by the STI, indicating an excellent auditorium intelligibility value, the spent material in this model is estimated in R$ 6,245,06. The model B presented the T30 value next to 0,6s indicated by the regulation in 500Hz, and as in the previous model, the D50 and EDT indicate good intelligibility, and while for STI the value turned out to be slightly inferior then the obtained in the previous model. However, this difference is too small between the values, what does not affect intelligibility, with a cost of approximately of R$ 1843.

The two models are satisfying enough for not to be necessary the other models analysis. The model A presents better acoustic quality in the room than model B, but with costing material three times more. This cost-benefit relation between the models is mainly due to the absorbers price difference, which makes unwarranted the use of wood panels for absorption, as long as the mineral lining can be used in the roof. With the impossibility of using the Sonex absorbers, the model fit to be used in the auditorium would be the one to use only mineral lining as indicated in model B.

6. CONCLUSIONS

In this study, an auditorium located at Federal University of Para was acoustically characterized according to reverberation time parameters (T30), Early Decay Time (EDT), Clarity (C80) and Definition (D50). To obtain these parameters, the impulsive response of the room was evaluated, according to ISO 3382-1 regulation and presented in the paper methodology.

The measured reverberation value was above 0,9s average in most of frequencies, while NBR 12179 regulation indicates a value close to 0,6s for its volume, which means that the results showed a very reverberating room for speakers, considering its size.

The measured STI Value was on the threshold between adequate and good intelligibility, showing that the room is not with a low acoustic quality, but with its acoustic conditioning deficiency. The C80 values, about 4 dB, measured in the auditorium were among -2 dB to +5 dB, indicated in the literature of auditoriums. The D50 parameter, which is an important indicative in speakers designed rooms, had measures values close to 0,6, lower than the 0,65 indicated for a good acoustic quality in the room.

With these indicatives, an intervention in the room was recommended so that the room could attend properly the listener's needs. A virtual model of the room was created seeking an approximation from the real room, so they can both represent the same environment. At this stage, the acoustic phenomenon comprehension is of great importance, being necessary to vary the absorption elements of the room within plausible values for each material. The model validation was performed through values comparison obtained from the simulation with values from the real room.

Validating the virtual model, the parameters modifications encountered with the solutions applications in this model would indicate modifications in the real room. Therefore, models adding absorbers were proposed, seeking to approach the reverberation time indicated by the regulation and improvement of the other parameters, allowing the obtained values of the acoustic room parameters to improve, which indicate a considerable increase in the environment intelligibility and a good proximity of the reverberation time value indicated by the regulation. However, among these two models, one was three times less expensive in material cost than the other, showing a highly superior cost-benefit, and so it was considered the most indicated model for room application.

This way, the goals to research the desired acoustic characterization, to analyze the performance of selected new rooms and to propose solution models for the auditorium were achieved. It is safe to affirm that this combination of room parameters measurements with the computational model creation and validation it is an excellent process for acoustic conditioning, ensuring greater security in the choice of materials and their quantities.

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