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Acoustical simulation of the sound quality of standardized classrooms in higher education institutions in Natal / Brazil

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ABSTRACT

In architectural design of schools, architects usually replicate one or more types of classrooms throughout the building. However, few studies refer to the verification of acoustical quality of classrooms, which can cause damages in the teaching-learning process, in case there is low quality, commonly found in Brazilian schools. This study aimed to propose basic guidelines for room acoustics of classrooms in two universities in Rio Grande do Norte, Brazil, considering the replication of solutions in standardized rooms. The methodology was a simulation of acoustical quality of standardized classrooms with alterations on ceiling and posterior wall through the software EASE® in comparison to the results of the measurements in situ, used as calibration control of the computational model. The best solution, among the proposals, depended on the shape and proportion of each classroom, varying between different percentages of absorbent material applied in the ceiling and in the posterior wall. The Definition (D50) was better distributed in all rooms with a 100% absorbent ceiling, however, the other parameters of intelligibility presented variables according to the shape of the room and the application of absorbent material. From the simulations, some guidelines for the architectural design of these classrooms were purposed in terms of acoustical quality.

Keywords: Sound quality, Classroom acoustics, Acoustical simulation

1. INTRODUCTION

The comprehension of the speech is fundamental for the achievement of a good teaching-learning process. When the spoken message is not clearly listened by the students, the understanding and, consequently, the learning process is impaired (1). It is common to find in Brazil classrooms with poor acoustical quality (2), which implies in a bad intelligibility. According to (3), good acoustical conditions in classrooms improves the learning process, making it more fluid and less stressful.

It is important to consider that the cost of a renovation is still low in comparison to the social costs derived of classrooms with bad acoustical quality (4). Studies (5–7) reveal the importance of an acoustical design for classrooms, considering the external and internal noise as well as the architectural characteristics aiming for a good sound quality inside the room.

Besides the poor acoustical quality, it is also common in Brazil to replicate the same sort of classroom in the design of a school or university. So, the school or university is designed with the same kind of classroom with poor sound quality and taken as reference for other designs. This type of room is called here as standardized classroom, what it is also common to identify in new building extensions.

The objective of this study was to simulate the application of absorbent material in different proportions in the ceiling of classrooms in two universities in Rio Grande do Norte, Brazil, aiming to propose basic guidelines for room acoustics considering the replication of solutions in standardized rooms throughout the institutions.

To acoustically characterize a room the most important parameter is the reverberation time, which is the interval after the sound source mute that the sound remains audible (8). Considering classrooms, Brazilian standards do not have recommended values of reverberation time These standards should be reviewed, since they are an important consultation document for architects in the design process.

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2. METHODOLOGY

2.1 Characterization of the universities

Aiming to propose basic guidelines for architectural acoustics of classrooms in institutions with the replication of the same pattern of classrooms, this study was applied in two federal and public universities in the state of Rio Grande do Norte, located in Brazilian northeast. Both universities have campus in many cities of the state, but this study was applied in the campus situated in Natal, the state capital.

The first institution analyzed was the Federal Institute of Rio Grande do Norte (IFRN), founded in 1910 as a technical school which, after 1999, added higher education courses in their grade. IFRN has, nowadays, 21 campuses throughout the state and 12 undergraduate and six postgraduate courses in the campus analyzed, called Campus Natal-Central.

This campus is situated in an important region of the city in a 90.000m² lot since 1967. It has a central building which one floor for administration rooms (called Floor A) and two others with classrooms (called Floors B and C), which were used in this study. In the figure bellow, this building has a tag highlighted in yellow. The academic centers also have classrooms, but, as this rooms were adapted in building renovations, they do not follow a pattern of size or shape.

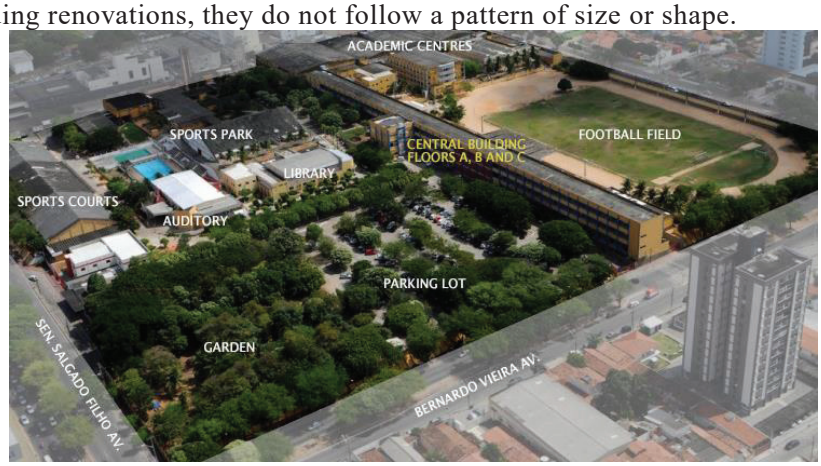


Figure 1 - The subdivision of IFRN Natal-Central campus (9).

The second institution analyzed was the Federal University of Rio Grande do Norte, founded in 1958. The Campus Central is situated at the current location since 1968 on a plot of 123 hectares in a central region of the city. There are 84 undergraduate and 86 postgraduate courses throughout the university, divided into five academic centers, according to the related study areas.

Each of these academic centers has a central academic building with classrooms, called "sectors". At the beginning of the university, five buildings were constructed with the same modular structure and, as the university expanded, other sorts of building were built, sometimes replicating the same original building or standardized classrooms of the original sectors with no significant changes. In the figure bellow, the sectors with classrooms for theorical classes are highlighted. This study was applied in the Sector IV, which houses technological courses.

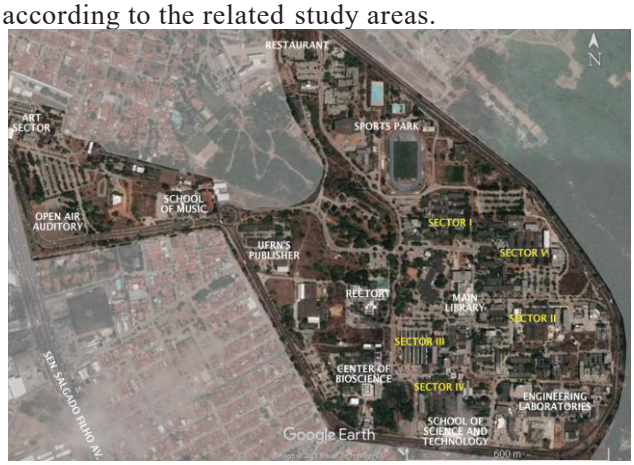


Figure 2 – The subdivision of UFRN Central campus (10).

2.2 Characterization of the standardized classrooms

In each institution some sorts of classrooms were chosen to this study, considering the dimensions, shape, proportion between width and length, volume, location in the building and representative quantity of this classroom throughout each university, which characterizes the sample as a standardized classroom in the institute.

At the IFRN, one sort of classroom has more significantly repetitions and it is called as Classroom Type 01 for this study, which groups the classrooms B01, B06, C01, C06 and C20. The rooms named as “B” are located at the second floor, called Floor B (Figure 3), and the rooms “C” are located at the third floor, called Floor C (Figure 4). For this paper the results presented are from the room C01. The Type 02 was inconsiderate for this paper because at the time of the research only one room with these characteristics (C12) was working as a classroom. The others have been used with other functions.

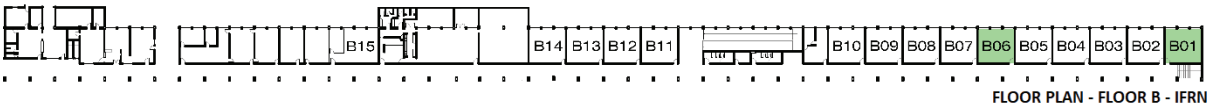


Figure 3 - Floor plan of "Floor B" with classrooms Type 01 highlighted in light green.

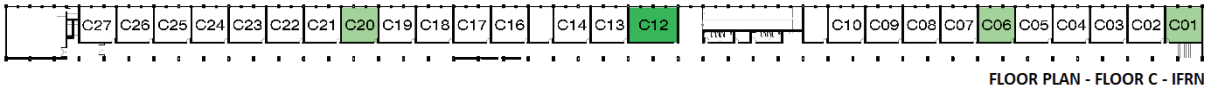


Figure 4 - Floor plan of "Floor C" with classrooms Type 01 highlighted in light and Type 02 in dark green.

At the UFRN, the academic buildings, called sectors, have a modulate structure, what allows some kinds of standardized classrooms with variation in lengths. The sector chosen for this study has classrooms with the same width and five different lengths following the structure modulation (Figure 5), what also occurs in other sectors of UFRN. For the study, three kind of classrooms were chosen: 2 modules (G03 – Type 03) and 3 modules, without (A03 and B02 – Type 04) and with absorbent ceiling (I02 – Type 05).

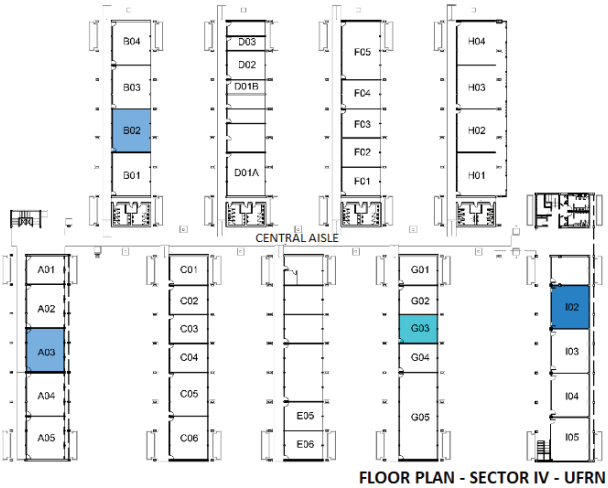


Figure 5 - Classrooms studied in UFRN.

All classrooms studied in IFRN, as shown in Figure 6, have a brick wall with ceramic coating in the lower part and painted in the upper portion, student carts with polypropylene chair and wood table, canvas blinds covering glass windows and a glass chalkboard. In UFRN, the classrooms have a brick wall painted, student carts with wood or polypropylene chair and wood table, glass windows and a glass or white board, as shown in Figure 7.

Figure 6 - Standardized classroom in IFRN.

Figure 7 - Standardized classroom in UFRN.

The **Erro! Autoreferência de indicador não válida.** presents the properties of the classrooms

analyzed regarding the types, institutions, dimensions, volume and ratio. In the “observation” cells, it is presented the most relevant motive for the study of each type of room.

Table 1 - Properties of the classrooms.

Type	Inst./Room	Dimensions	Volume	Ratio	Observation
01	IFRN/C01	6,85 x 7,35 x 3,40 m	171 m³	1:1 (1:1,07)	Classroom with the highest number of repetitions in IFRN
03	UFRN/G03	8,00 x 6,05 x 3,15 m	152 m³	1,5:1 (1,32:1)	Classroom with length higher than width
04	UFRN/A03	8,00 x 9,15 x 3,43 m	251 m³	1:1 (1:1,14)	Classroom with the highest number of repetitions in UFRN
05	UFRN/I02	8,00 x 9,15 x 2,86 m	209 m³	1:1 (1:1,14)	Classroom with absorbent ceiling

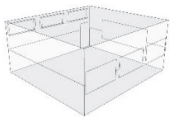
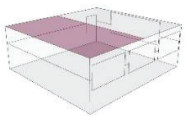
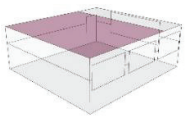
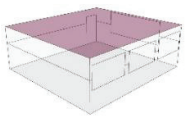
2.3 Simulation method

The first step to obtain an accurate simulation was to measure the room dimensions and to estimate the corresponding material for the determination of the coefficient of absorption according to the literature or software database. All sorts of classrooms were acoustically measured using Brüel & Kjær equipment. The measurements result of reverberation time were used as a reference value to calibrate the simulated rooms. The current situation of each classroom was modeled using Trimble Sketchup 2016 (11) and imported into EASE version 4.3 (12), acoustic simulation software, in which the materials were associated to each surface and the audience and listener seats were positioned according to the measurements. The simulations used the AURA module of EASE.

The audience area considered a distance of 0,10 m from the side and rear walls, 1,50 m from the front wall and 1,20 m from the floor. The listener seats were positioned according to the microphone position in the measurements, as well as the height of 1,20 m. The simulations considered the background noise measured in each frequency and a split time of 10 ms.

The current situation of each type of classroom was simulated and calibrated with the measurements results. After the validation of the model, a mineral ceiling was added into the model on EASE in different proportions (50, 75 or 100% of the ceiling area, as shown in the table below). For all the propositions the mineral ceiling used was the model Janus from the manufacturer OWA. This commercial ceiling was chosen based on a real proposition for the enhancement of the classrooms and on the material properties, but it could be exchanged for other material with similar acoustical characteristics. The ceiling height for all simulations was fixed in 2,60 m to compare the results according to the shape of the room, not considering height variations. The simulations encompassed the Classroom Types 01, 03, 04 and 05. The Type 02 was inconsiderate because of the low representativity of the sample. The Types 04 and 05 were grouped, being called as Type 04-05, because the addition of a plaster ceiling turns the two kinds of classrooms in one, considering that the major difference between them was the ceiling height and material. The simulations, thus, considered four situations, as described in the following table.

Table 2 - Simulation scenarios.

Nomenclature	**C.S.** (Current situation)	**AC50%** (Absorbent ceiling 50%)	**AC75%** (Absorbent ceiling 75%)	**AC100%** (Absorbent ceiling 100%)
Position of the absorbent ceiling *(in purple)*				
Absorbent ceiling	0%	50% rear	75% rear	100%
Reflector ceiling	100%	50% frontal	25% frontal	0%

2.4 Analyzed parameters

The simulations resulted in graphs, images and tables. The main objective of these simulations was to compare and analyze the improvement of the intelligibility in the classrooms studied. For that, the parameters reverberation time (T_{20}), early decay time (EDT), definition (D_{50}) and speech transmission index (STI) were analyzed. The reverberation time is the parameter that most characterize the acoustic response of a room, being the time that the sound remains in the room after the source mutes. When the late reflections carry too much energy, it is harmful for the understanding of the receivers in places of speech (8). The early decay time (EDT) is considered an important parameter for the evaluation of rooms for speech because it concerns about the early decay, which is more evidenced in the speech since the reverberant tail is often merged with the next words or syllables (13). Usually, the human beings react better to these first reflections, giving a subjective sensation of sound quality (14). The definition (D_{50}) is related to the ability of distinguish subsequent sounds, promoting a sensation of "clear sound". The greater energy transmitted by the first reflections, the greater the sound definition (13). And, finally, the speech transmission index (STI) that refers to the modulation of sound, considering the difference between the background noise and the sound pressure level of the source. The STI decreases in places with a high background noise and reverberation time (13).

In order to evaluate these results, it was important to considerer reference values. The table below presents the ideal and acceptable values of four parameters related to intelligibility.

Table 3 - Recommended values for the analyzed parameters.

Analyzed Parameters	Ideal value	Acceptable values	References
Reverberation time (T_{20})	≤ 0,6 s in 500 Hz	≤ 0,8 s in 500 Hz	(14–16)
Early Decay Time (EDT)	≤ 0,05 s	≤ 0,05 s	(17)
Definition (D_{50})	≥ 5,0	≥ 5,0	(13,14)
Speech Transmission Index (STI)	≥ 0,75	≥ 0,6	(13)

3. RESULTS AND DISCUSSION

The results obtained with the simulations were compared with the measurements results for each type of classroom analyzed in the following graphs. Each graph shows the ideal value (line), acceptable values (filling) and the data from the measurement and the three scenarios of simulation: 50, 75 or 100% of absorbent ceiling.

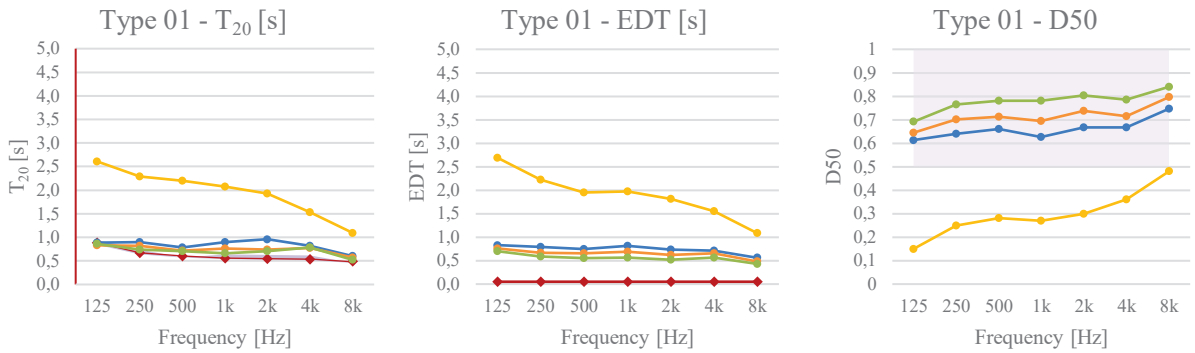
All graphs have the same color legend, presented in Figure 8. The graphs of Classrooms Type 04-05 present two "current situation", being the yellow line with circle bullets representing the room without absorbent ceiling (UFRN A03) and the yellow line with X bullets representing the room with absorbent ceiling (UFRN I02).

Figure 8 - Color legend for the graphs.

3.1 Comparison between measurements and simulations

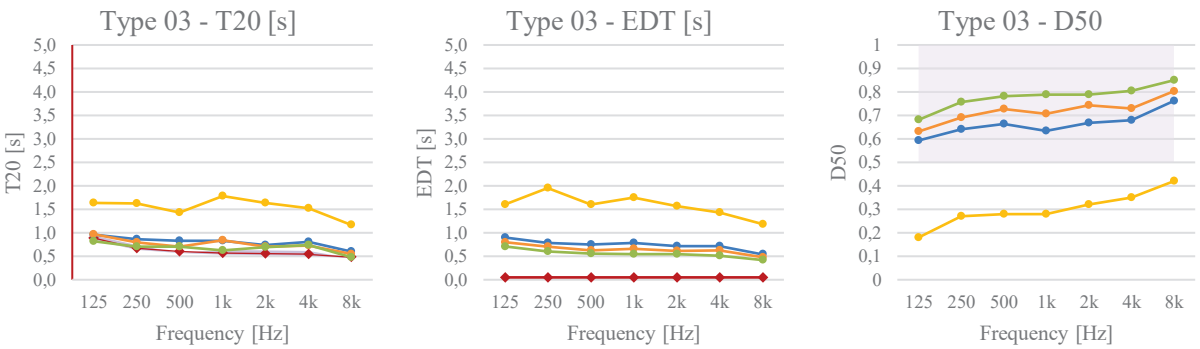
The Classroom Type 01, which is an approximately square, 1: 1 ratio, located in IFRN, presents reverberation times above 1,5 seconds in most of the frequencies analyzed and the EDT follows the same tendency, decreasing only in 500 and 1000 Hz. Regarding the Definition, none of the frequencies reach the ideal range of the parameter. Considering the simulations, all results are satisfactory, being the A.C 100% the one with the best values. The application of absorbent material in only 75% of the ceiling (A.C. 75%) also shows good results, very close to the A.C. 100% in T20 and EDT, with a little bit lower result in D50. This type of classroom presents a bad STI in the current situation and a good STI, between 0,67 and 0,74, in all the simulated scenarios.

Graphs 1 - Results of Classroom Type 01.



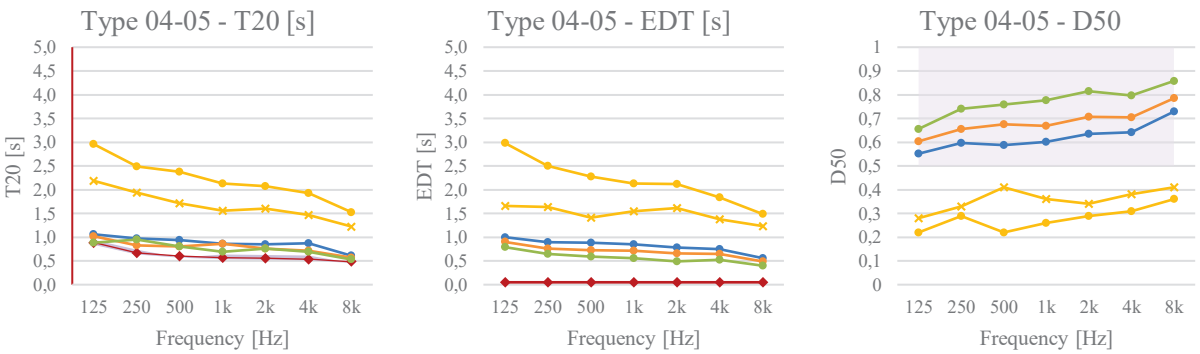
As for the Classroom Type 03, which is rectangular classroom located in UFRN and has a ratio 1,5:1, being larger than deeper, the reverberation time has the lower values among the classrooms studied. Although, the T20 is still high in comparison to the ideal values. The same happens with the EDT, which presents a different behavior in relation to T20 throughout the frequencies. Considering the simulations, all scenarios present similar values of T20 and EDT. Moreover, the T20 founded in all simulations is considerably near of the recommended values. The D50 is better with in the A.C. 100% scenario and distributed more evenly between the frequencies, although the other scenarios also reach the ideal values. Regarding the STI, the current situation is evaluated as acceptable, bordering the bad band, and the all simulated scenarios as good (values between 0,67 and 0,74).

Graphs 2 - Results of Classroom Type 03.



The Classroom Type 04-05 is located in UFRN and has a square shape with ratio 1:1. The room A03 (yellow line with circle bullets) presents the worst results between all classrooms analyzed and is the most repeated standard in the university. The room I02 (yellow line with X bullets), that is the same room but with absorbent ceiling, presents better results, although they are not satisfactory yet. The highest difference is in EDT, which determines the subjective impression of the sound. Thus, this sort of classroom promotes a better intelligibility of speech than the A03. The definition is also better, mainly in 500 Hz, but still out of the ideal values.

Graphs 3 - Results of the Classroom Type 04-05.



Considering the simulations, all scenarios present similar values in T20 and EDT, being the A.C.

100% the one with the best D50. Comparing the A.C. 75% and A.C. 100% it is possible to observe that both have a similar behavior. Considering the financial resources to buy and install an absorbent material in all ceiling area of the most repeated standard of classroom of the university, the A.C. 75% is considered as the best solution, giving a satisfactory intelligibility. The A03 presents bad STI values, while the I02 has acceptable values of STI. The simulated situations present good STI from 0,65 to 0,74.

In all cases studied, the addition of an absorbent ceiling improves the intelligibility of the classrooms in any proportion: 50, 75 or 100%. All classrooms present the best result with a 100% absorbent ceiling, but considering the proximity between the values and the achievement of a good intelligibility in all simulated scenarios, the addition of a lower area of absorbent material may indicate savings on financial resources and use of the existing ceiling in part of the classroom.

3.2 Basic Guidelines

Considering the results found, it was possible to determine some basic guidelines for the design of classrooms in these institutions or with similar conditions. The first one is that a room larger than deeper presents a better distribution of the parameters throughout the room. Thus, a classroom with a ratio until 2:1 has a better acoustical behavior than a room 1:1 (square), as long as the dimensions are compatible with classrooms (between 6 and 8 m).

The second guideline is to use a plan ceiling without the interventions of beams or other elements. Also, the ceiling in the frontal area (reflective material) of the situations A.C. 50% and A.C. 75% can be inclined for a better distribution of the early reflections. Each case should be studied to determine the better inclination of the reflective ceiling and the reinforcement area.

In addition, the lower the room volume, the better the reverberation time, regardless of the material used in the ceiling. However, if the volume change is a result of changing the ceiling material of the room, provided that at least 50% ceiling area is in absorbent material, the design or constructive transformation will bring benefits to the acoustic quality of the room. If possible, the greater the absorbent area in the ceiling, the better the result obtained.

To avoid the formation of a reverberant field at the back of the room, one can also apply absorbent materials or diffusers, causing absorption or reflections on the back wall to be scattered around the room, reaching more students. An alternative is to widen the angles between the side walls and the bottom wall, making it an oblique angle in order to promote diffusion. This solution, however, becomes more difficult to apply in classrooms already built, and can be adapted with the application of panels to avoid the right angle.

4. CONCLUSIONS

In order to promote classroom improvements and considering that speech intelligibility parameters are generally dependent on reverberation time, changes were proposed that involved the two most influential factors in RT: volume and area of absorption. A standard height ceiling was inserted for all the rooms studied in the simulations, while three situations of increase of absorbent area were simulated. These proposals indicated that the greater the area of absorption in the ceiling, the better the acoustic response of the room. The parameter that suffered the greatest variation according to the simulated proposals was the Definition, being better distributed in the case of a larger area of absorption. However, in all cases proposed, all rooms achieved good results for speech intelligibility.

Analyzing the relation of the shape of the room with the distribution of the values of the parameters in the classroom, it can be seen that the room with a ratio of 1.5:1 presents a more uniform distribution, while the room of proportion 1:1 shows the worst distribution. That is, the smaller the depth of the room, considering dimensions commonly found in classrooms, the better the sound distribution, which makes students sitting in any position have similar sound perception and understanding.

Finally, it was possible to perceive similarities in the acoustic behavior between classrooms according to the modifications made, which determined some design guidelines for classrooms with better acoustic conditioning. Some modifications in existing classrooms are easy to implement and replicate and contribute greatly to improving speech intelligibility for students. These improvements foster better interaction between teachers and students, encourage the teaching process and support the better training of students and, consequently, future professionals.

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