MEASUREMENT AND PREDICTION OF THE SOUND FIELD OF A SMALL LECTURE ROOM

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Abstract. *It is common to find intelligibility problems in many rooms for speech. This work presents a study of the acoustical field of a small lecture room of the Federal University of Pará, in the north of Brazil, based on measurements and numerical simulations. The numerical model was developed using the commercial software Raynoise (which is based on the geometrical acoustics theory) and validated by comparison with acoustical measurements in the actual room (reverberation time, sound level distribution, etc.). The proposals reported seek the adequacy of the investigated room to the current acoustical standards, regarding speech intelligibility and acoustical comfort.*

Keywords: *acoustical comfort, geometrical acoustics, speech intelligibility, numerical model.*

1. INTRODUCTION

In rooms such as concert halls, theatres, conference rooms and classrooms, the main objective of a project, concerning good hearing, should be the guaranty of a good understanding of oral communication. Thus, a fundamental requirement is that the sound waves (direct, reflected and reverberant) should be able to arrive at the audience with, at least, 15 dB above background noise (Mehta et al., 1999). Such an environment should be projected to guide the sound from the stage to the audience, without echoes nor acoustical glare.

During the last years, computational models to simulate acoustic behavior in real rooms had become an efficient method to anticipate the acoustical field in external and internal environments.

Therefore, the main goal of this paper is to develop a numerical model, in order to estimate the acoustical behavior of a real auditorium, using computational simulations based on the commercial software of geometrical acoustics Raynoise, which uses hybrid methods of ray tracing and image sources. Validation of the numerical model was achieved by comparisons with measurements in the actual room, which is mainly used as a small conference room of the Mechanical Engineering Laboratory (LABEM), located at the Federal University of Pará.

Thus, this work is intended to offer a numerical model which can be used to test virtual alternatives to optimize the acoustic field of the referred auditorium, which is commonly used for academic presentations, meetings, multimedia presentations, etc.

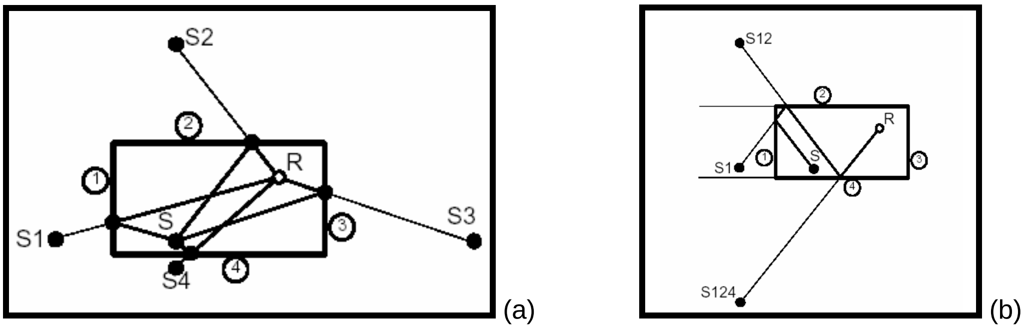
2. FUNDAMENTALS

2.1 Ray Tracing Method

Raynoise is software based on the hybrid methods of ray tracing and specular image sources, which approaches sound waves of small wavelength by rays (in the sense of light rays), calculating their reflection paths after reaching room surfaces, where part of the incident sound energy is absorbed by the surface material (Long, 2006).

Specular image source method uses virtual image sources to determine the correct sound path from source to receiver. The sound in the room is emitted by the source as rays, and each ray travels inside the room, according to the paths determined by the image sources of first and higher orders (see Fig. 1). The energy of each receiver is calculated regarding the distance traveled and reductions after each reflection (Raynoise, 1993).

Ray tracing method considers that the energy emitted by a sound source is equally distributed among a discrete number of sound rays. Each ray has incident energy equal to the total source energy, divided by the number of rays. Each ray travels with the velocity of sound and reflects on walls, floor and ceiling, according to specular reflection (Snell's law). The level of energy of each ray decreases after reflections because of the sound absorbing properties of surfaces, and also as the ray travels inside the room, due to air absorption, which is important only in large rooms, and at high frequencies. When the ray energy becomes too low, its propagation is finished (Long, 2006; Moraes et al., 2006).



(a) (b)

Figure 1. (a) Image sources of first order on rectangular rooms; (b) Image source of first, second, and third orders

To obtain an acoustic field inside the room, virtual microphones are introduced in the model, at the desired locations, as volume receivers. Then, the software calculates the sound energy reaching each virtual microphone, by accounting for the number of rays crossing the receiver volume (see Fig. 2). Losses for spherical divergence are included as a result of increasing separation between rays (Raynoise, 1993).

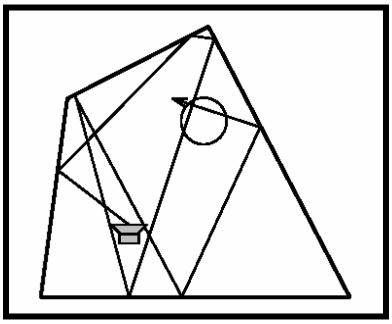


Figure 2. Acoustic ray path from source to receiver volume

The hybrid methods join the deterministic nature of image source method, with some statistical characteristics of ray tracing method (Souza, 1997), and a more detailed approach may be found in the work of Moraes (2007).

2.2 Reverberation Time

The sound field inside a room and its spectrum depend on the absorption characteristics of internal surfaces (Bistafa and Bradley, 2000). Optimal reverberation time depends on room usage. Factors influencing reverberation time are: room volume, shape, and sound absorption characteristics of internal surfaces. According to Sabine, reverberation time, T, is defined as the time it takes for the sound level inside the room decreases by 60 dB from its stationary level (Kinsler et al., 1982, Gerges, 2000).

$$T = 0{,}161\frac{V}{A} \qquad (1)$$

where V is the room volume (m^3), and A is the total absorption (sabines), given as a function of surfaces with areas S_i and respective sound absorption coefficients α_i:

$$A = \sum_i S_i\,\alpha_i \qquad (2)$$

2.3 Sound pressure level

Regarding the sound pressure level inside the room, it is necessary to reinforce the fact that all listeners should experience the same acoustic feeling. Thus, it is expected that the sound level in the audience area should not vary more than 6 dB (Mehta et al., 1999).

3. EXPERIMENTAL SET-UP

3.1 Investigated room

The studied room was initially built with local characteristics, and has incorporated several modifications since then, towards a modern architectural project. These changes, however, were accomplished without consideration of the room acoustical properties. The room has a rectangular shape and is 5,87 m wide, 12,0 m long and 3,50 m high. It also has a wood stage 5,87 m wide, 2,54 m long and 0,68 m high.

During measurements, the room remained empty, with windows and doors closed. The main surface materials are listed in Table 1, along with their sound absorption coefficients.

Table 1. Surface materials inside the room and corresponding sound absorption coefficients

Surfaces	Materials	Coefficient of Sound Absorption in Bands of Frequency (Hz)						Reference
		125	250	500	1.000	2.000	4.000	
Wall	Smooth painted wall	0,14	0,10	0,06	0,05	0,04	0,03	(Gerges, 2000)
	Varnished concrete wall	0,1	0,05	0,06	0,07	0,09	0,08	(Scarazzato, P.S)
Floor	Vitrified ceramics	0,01	0,01	0,01	0,01	0,02	0,02	(Scarazzato, P.S)
Stage	Wood floor	0,15	0,11	0,1	0,07	0,06	0,07	(Scarazzato, P.S)
Roof	Concrete painted	0,1	0,05	0,06	0,07	0,09	0,08	(Gerges, 2000)
Windows	Glass painted	0,35	0,25	0,18	0,12	0,07	0,04	(Scarazzato, P.S)
Doors	Wood door	0,14	-	0,06	-	0,10	-	(NBR 12179-1992)
Stuffing Chairs	Stuffing chairs	0,33	0,33	0,33	0,33	0,33	0,33	(Gerges, 2000)
School Chairs	Common chairs	0,02	0,02	0,03	0,04	0,06	0,08	(Gerges, 2000)

3.2 Infrastructure

Measurements were carried out according to the scheme shown in Fig. 3.

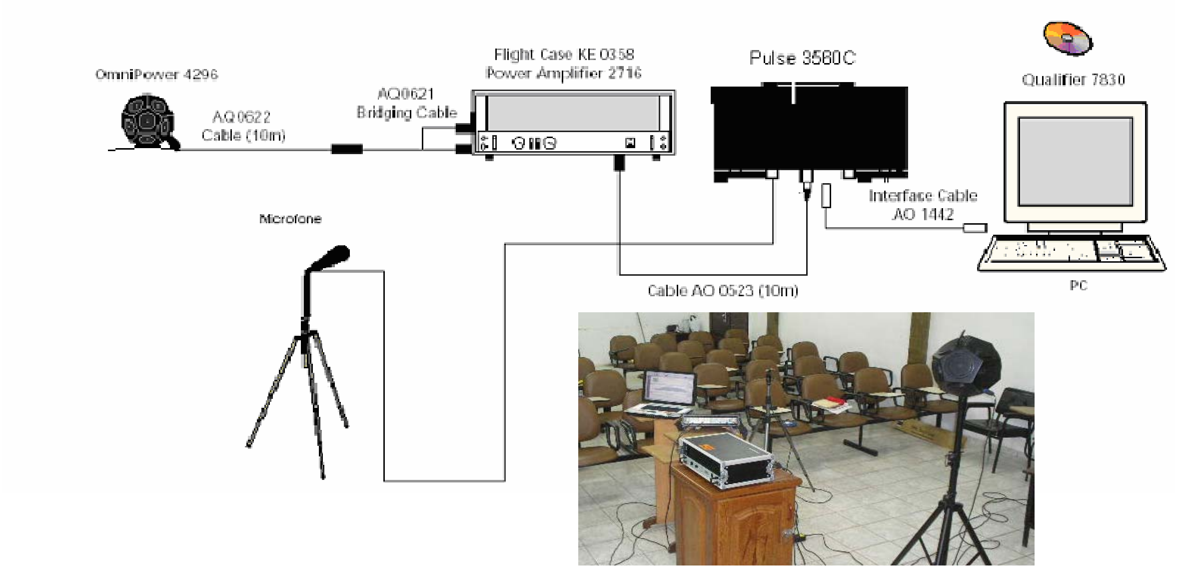


Figure 3. Experimental set-up

3.3 Results

3.3.1 Reverberation time

Measurements of reverberation time were performed in fourteen different points inside the auditorium. Microphone locations were at least 1 m distant from surfaces and more than 2 m distant from the sound source, in accordance with ISO-354 (1985), and with a distance greater than 0,5 m from each position.

Reverberation time was measured in octave bands from 125 to 4.000 Hz. Results are shown in Fig. 4.

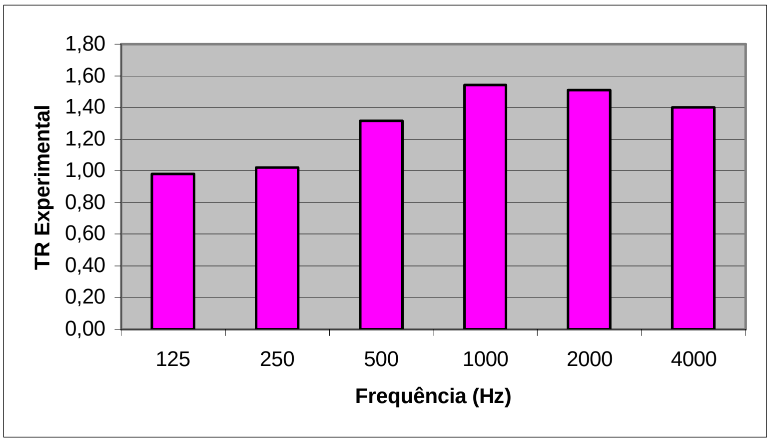


Figure 4. Measured reverberation time

3.3.2 Sound pressure level distribution

Measurements of sound pressure level were taken in the same fourteen points described above, using an average height for a seated listener.

Sound pressure levels were measured in octave bands from 125 to 4.000 Hz. Figure 5 shows the sound level distribution across the 14 microphone positions, where it is possible to see that the sound level variation along the audience area is not greater than 6 dBA.

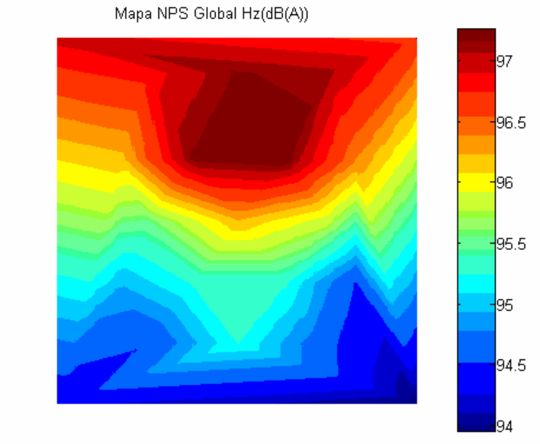


Figure 5. Measured sound pressure level distribution

4. NUMERICAL SIMULATIONS

Simulations were performed in Raynoise, version 3.1, which is based on geometrical acoustics, using hybrid methods described previously. Following the methodology used by Moraes (2006), it was decided to use the conic ray beams method. The sound source was located on a central position, in front of the stage (see Fig. 6).

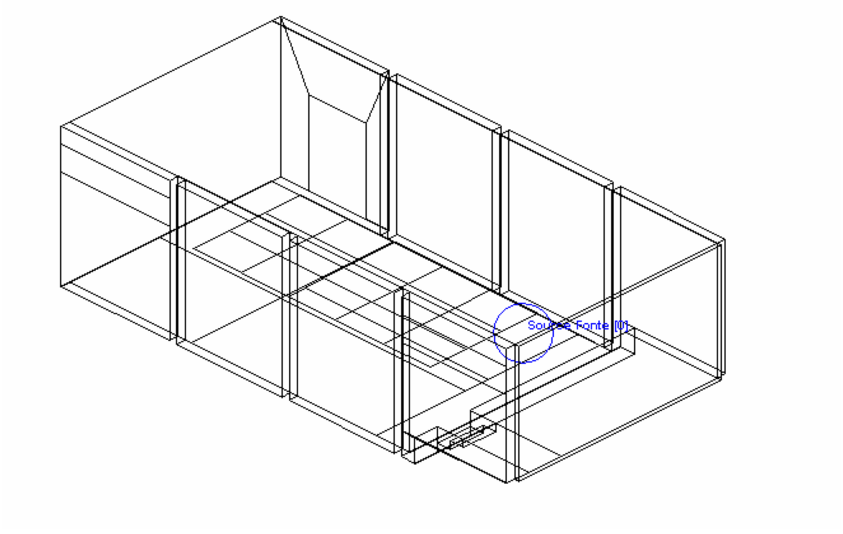


Figure 6. Computational model used for numerical simulations

4.1 Important parameters

Several simulations were performed in order to adjust the reflection order and number of rays emitted by the source, until the results become stable. Other important input parameters were: geometrical room model, room background noise, sound power level in each frequency band, position of each sound source, air absorption coefficient (according to Raynoise database), air temperature of 25 °C, relative humidity of 85%, surface materials and corresponding sound absorption coefficients (see Table 1). Convergence parameters: number of rays (330), and reflection order (192).

4.2 Numerical results

The numerical results obtained from computational analysis with Raynoise were compared with measurements, as shown in Figures 7 and 8. Good agreement is observed to some extent, despite of the simple model developed, which is just an approximation of the real room.

Reverberation time results were very close to measurements, as seen in Fig. 7.

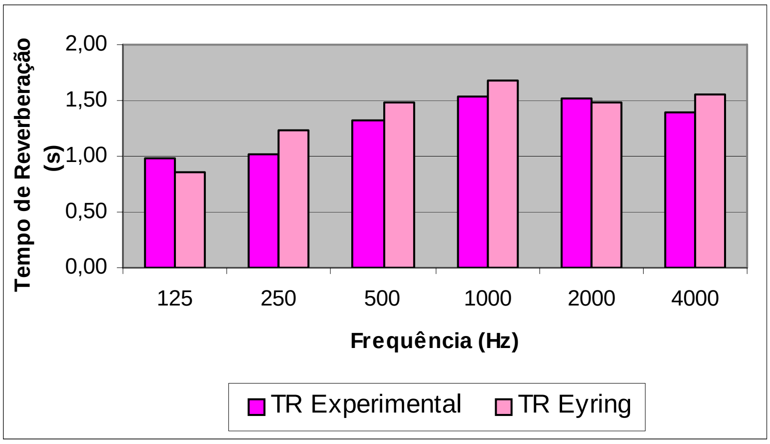


Figure 7. Comparison between measured and simulated reverberation times

The sound pressure level distribution, calculated numerically, underestimates measurements, as shown in Fig. 8.

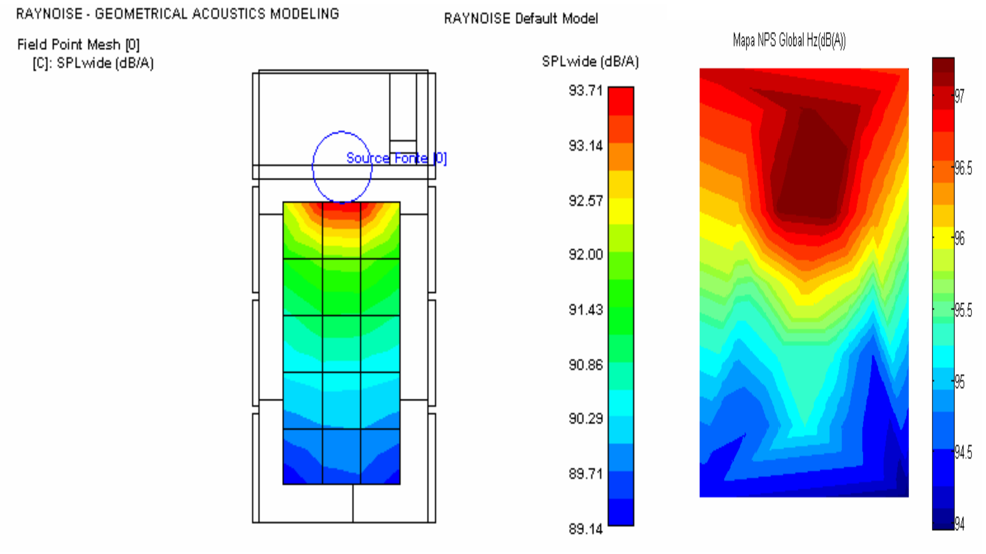


Figure 8. Comparison between measured and simulated sound pressure level distributions

5. DISCUSSION OF RESULTS

5.1 Adequacy of reverberation time

The NBR-12179 standard shows an optimal reverberation time for several rooms, as a function of their volumes (see Fig. 9). For conference rooms, it is recommended a reverberation time of about 0,5 s at all frequency bands except at 125 Hz and 250 Hz, where correction factors of 1,14 and 1,14 should be used, respectively.

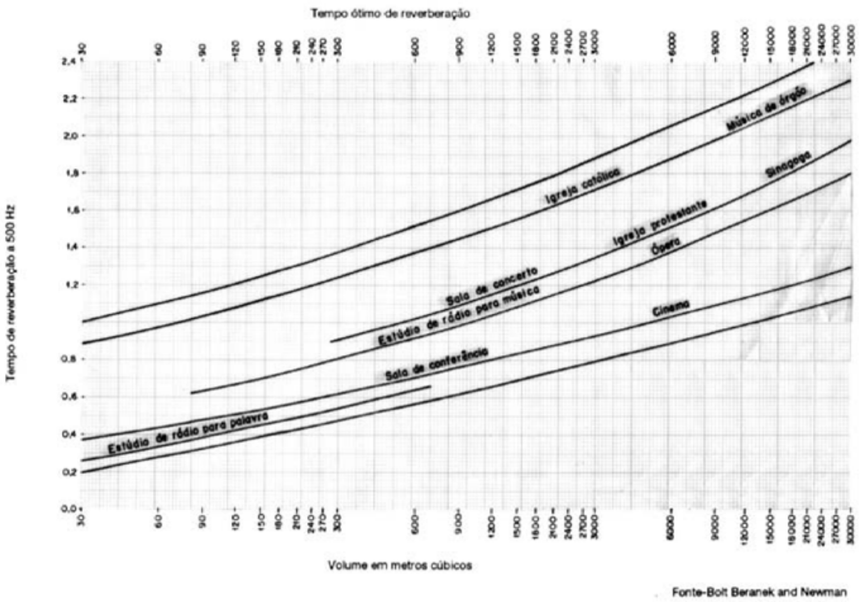


Figure 9. Optimal reverberation time as a function of room volume (m^3)
Source: NBR-12179

In order to bring the reverberation time values of the investigated room closer to the optimal values suggested in Fig. 9, it is recommended the introduction of some absorbent materials, as listed in Table 2, which makes reference to the coconut fiber material studied by Mafra (2005) and Pacheco (2007).

Table 2. Suggested acoustical treatment for optimal reverberation time, using natural fibers described by Mafra (2005) and Pacheco (2007)

Frequency (Hz)	**Coconut fiber panel (FC)**		**Sonex**	Optimal *T* (s)
	T for FC 2 (s)	*T* for FC5 (s)	*T* for Roc-30 (s)	
125	0,64	0,04	0,3	0,74
250	0,41	0,15	0,51	0,57
500	0,5	0,2	0,86	0,5
1.000	0,46	0,44	0,93	0,5
2.000	0,53	0,44	0,99	0,5
4.000	0,6	0,37	0,98	0,5
Percentage Area	100% of masonry wall	80% of ceiling	90% of ceiling	-

6 CONCLUDING REMARKS

Results for all analyzed frequency bands show a reverberation time above recommended values for rooms designed for speech, which lies around 0,5 s. However, it is necessary to observe that these preliminary results were obtained for an empty auditorium. Therefore, it is expected that these reverberation time values will strongly decrease, when the investigated room becomes fully occupied.

Nevertheless, the agreement obtained between experimental and numerical results motivates a deeper investigation about possible solutions to correct the acoustics of the studied auditorium, regarding its multi-purpose characteristics, mainly when it is considered the possibility of using regional materials, such as coconut or açaí fiber panels, which seem to be very effective, acoustically speaking, apart from being much cheaper than commercial materials commonly available.

As the sound level from the source should stay, at least, 15 dB above background noise, it is possible to identify the necessities of acoustic isolation to protect against external noises and electric amplification of sound, by means of an electroacoustic system. A homogeneous distribution of sound pressure level should be guaranteed over the entire audience area, providing the same acoustic experience to all listeners.

Finally, the model developed here can be further improved, to allow a better analysis, with new elements in the room model, where several solutions could be tested to adequate the acoustics of auditorium of LABEM, considering all manners it may be used, such as a classroom, conference room, meeting room or even as a multimedia room.

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