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Room Acoustics

Lab Reports

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1 Teatro De Silva

1.1 Introduction

During the visit to Teatro De Silva, we analyzed the acoustic behavior of the hall in different configurations and listening positions. The theater is a multi-purpose space that allows several setups, adapting to events such as concerts and operas. The stage can be lowered to accommodate the orchestra pit, making the space flexible for multiple uses.

1.2 Stage and Player Configuration

When set in opera mode, the theater uses lateral curtains called *quarte e quinte*, characterized by high sound absorption. This configuration can attenuate the direct sound perceived on stage. For this reason, musicians tend to move slightly forward to avoid excessive damping and to preserve projection.

It was clear that finding the best playing position often requires a second person, since the sound perceived by the player differs from that perceived in the audience seats. The player searches for the position where the instrument sounds most balanced, avoiding excessive high frequencies and aiming for an even spectral distribution.

1.3 Architectural and Acoustic Characteristics

The theater's acoustic treatment combines both absorption and diffusion elements:

- The ceiling is entirely covered with absorption panels some of which are aimed to catch some frequencies to not reflect back at the player. Additionally, they are tilted for reflection.
- The walls combine diffusers and large reflective surfaces. The pivoting panels on the sides adjusts the angle of reflection of sound and the absorption. For instance, for a symphony concert, it is wanted that the sound is more reflected while for theater plays, for speech recognition, sound is wanted to be more absorbed.
- The surface materials of the interior optimize the sound reflection to ensure the sound reaches every position of the room with same quality. Wood is more preferred as it is effective reflecting noise and gives a warmer tone.

This design ensures versatility, allowing different acoustic conditions depending on the type of performance hosted in the hall.

1.4 Perceived Effect of Position

From the listening test we noticed that:

- In the forward position the sound had more low and low-mid frequencies, resulting in a warmer tone.
- In the backward position the sound became sharper and brighter.

The player perceived a noticeable change in sound level between these two positions, while for listeners in the seats, the variation was much smaller.

1.5 Orchestral Layout Considerations

Instrument placement in the orchestra also plays a key role. For instance:

- When violas are placed at the center, they fill the harmonic space between violins and cellos.
- When they are placed on the sides, their melodic lines emerge more prominently in the acoustic image.

1.6 Performer Perception and Acoustic Context

Players quickly adapt to the acoustic conditions of different rooms. Entering a theater or a church, they can already anticipate the reverberation and adjust their playing accordingly.

- A recording studio is a very dry environment, where the sound is controlled and precise.
- A church, instead, is highly reverberant, requiring the performer to slightly elongate or shorten notes to maintain clarity.

1.7 Reverberation and Acoustic Challenges

Playing in highly reverberant spaces raises two main issues:

1. Room resonances that can be slightly out of tune, resulting in unpleasant coloration.
2. Strong late reflections that may interfere with the timing of the piece. This might end up musicians to lose their tempo. Late reflections can be prevented by the absorptive surfaces on the back of the audience.

Since Teatro De Silva is a multi-purpose space, it is optimized for clarity, with a reverberation time on the lower end. Reverberation can be adjusted by opening or closing the side panels, depending on the required acoustic condition.

1.8 Listening Session Observations

1st listening – Standard playing position: The sound presented a good balance between low mids and highs. Reverberation was pleasant and did not compromise clarity.

2nd listening – Middle of the theater: Low mids were more damped, and the sound appeared sharper and more distant, even if the physical distance remained nearly the same.

3rd listening – Moving across the room: It became clear that the acoustics are optimized for the seating area. The balconies tend to alter spectral balance, while the main seats provide a uniform response. The best listening spots were around rows 4–6, where distance perception and directionality resulted most natural.

1.9 Measurements

Different stimuli were used for the measurements, including balloon pops, white noise, pink noise, and chirps. The reverberation time (RT) values are reported below.

Table 1: Reverberation times of the theater for different measurement points

Measurement Point	**RT (s)**
Stage right	1.36
Seats front right	1.33
Gallery right	1.32
Corner left balcony	1.28
Front left balcony	1.30
Seats back middle	1.32
High left balcony	1.37
Gallery (balloon back)	1.31
Stage middle (balloon back)	1.36

These RT values are quite ideal for a multi-purpose theater. With the theater's adjustable features, the RT value can be reduced to around 1 second for theatrical performances, or increased to around 1.5 seconds, making it suitable for symphony orchestras.

Furthermore, the similarity of the experimental results indicates that there are no 'dead' or 'overly bright' spots in the theater, and that sound is distributed evenly to more or less every point.

1.10 Additional Notes

The seating is made of materials designed to provide the same absorption as an average person, reducing dependency on audience presence. The hall maintains good clarity, making it suitable for speech as well, although an average RT of about 1.3 seconds is more typical for musical performances.

2 Room Vento

2.1 Introduction

The objective of this experiment is to analyze the acoustic characteristics of Room Vento. We developed a computational model based on data obtained by measuring the room's current acoustic state. Since high reverberation time significantly degrades speech intelligibility, our goal is to simulate and observe potential improvements by adding acoustic panels.

2.2 Software

Software programs we can use to understand the behavior of a room include Room EQ Wizard (REW) or Audacity with the Aurora plugin.

1. **REW:** Its purpose is to measure the frequency response of a space and produce digital filters to correct standing waves. It's a free software that can be used to improve the sound quality of a room.
2. **Audacity + Aurora Plugin:** Aurora is a package specifically developed to calculate acoustic parameters according to ISO standards. It can calculate parameters such as reverberation time, clarity, and distinctness numerically and with high accuracy. More suitable for academic studies.

2.3 Room Characteristics and Theoretical Calculations

First, we will record the material of each structure in the room and its surface area, and then examine how this data affects sound propagation within the room.

Table 2: Surface area of each element of the room

Surface Description	**Area (m^2)**
Floor (measured)	60.10
Seats	35.00
Ceiling (measured - windows excluded)	129.65
Back wall (measured)	31.61
Door wall 1	5.58
Door wall 2	3.78
Internal wall 1 (door excluded)	56.37
Internal wall 2 (door excluded)	27.83
Facade (windows excluded)	10.00
Windows surface on the facade	41.31
Windows surface on the ceiling	14.10
Structures of the windows	15.71
Total surface area (S)	**431.04**

The acoustic absorption properties of the materials used vary depending on the frequency. The absorption table for each material is as follows.

Table 3: Absorption coefficients in octave bands

	Frequency (Hz)					
Material	**125**	**250**	**500**	**1000**	**2000**	**4000**
Vinyl on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Glass for windows	0.18	0.06	0.04	0.03	0.02	0.02
Seats	0.49	0.66	0.80	0.88	0.82	0.70
Wood panel 1'	0.19	0.14	0.09	0.09	0.06	0.05
Gypsum DBL (wall&window&ceiling)	0.14	0.05	0.03	0.02	0.02	0.03

The apparent sound absorption coefficient of each material can be found for each frequency using the formula: surface area · absorption coefficient.

Table 4: Apparent absorption coefficients in octave bands

	Frequency (Hz)					
Surface Element	**125**	**250**	**500**	**1000**	**2000**	**4000**
Floor (measured)	1.202	1.803	1.803	1.803	1.803	1.202
Seats	17.150	23.100	28.000	30.800	28.700	24.500
Ceiling (measured - windows exc.)	18.151	6.483	3.890	2.593	2.593	3.890
Back wall (measured)	4.425	1.580	0.948	0.632	0.632	0.948
Door wall 1	1.060	0.781	0.502	0.502	0.335	0.279
Door wall 2	0.718	0.529	0.340	0.340	0.227	0.189
Internal wall 1 (door exc.)	7.892	2.819	1.691	1.127	1.127	1.691
Internal wall 2 (door exc.)	3.896	1.391	0.835	0.557	0.557	0.835
Façade (windows exc.)	1.399	0.500	0.300	0.200	0.200	0.300
Windows surface on façade	7.436	2.479	1.653	1.239	0.826	0.826
Windows surface on ceiling	2.538	0.846	0.564	0.423	0.282	0.282
Structures of the windows	2.200	0.786	0.471	0.314	0.314	0.471

The Sabine and Eyring reverberation times for the room can be calculated using the following formulas:

$$T_{\text{Eyring}} = \frac{0.16 \cdot V}{S \cdot |\ln(1-\bar{\alpha})|} \tag{1}$$

$$T_{\text{Sabine}} = \frac{0.16 \cdot V}{A} \tag{2}$$

The term $\bar{\alpha}$ denotes the average absorption coefficient calculated for each frequency. The equivalent sound absorption area (A) corresponds to the total absorption across all surfaces, which is also calculated on a frequency basis.

First case: the seats in the room were ignored, being them a significant factor to the reverberation time. Also, as expected, measurements taken without the seats result in a much longer reverberation time, so they do not accurately reflect the room's function under normal use (i.e., when there are speakers and listeners inside). Also absorption from materials was taken from a worst case scenario.

The Eyring and Sabine RT values for the room, having a total volume of $461.44\,m^3$, are summarized in the following tables corresponding to the cases of the room without and with seats.

Table 5: Acoustic parameters vs. Frequency for the room without seats

Parameter	**Frequency (Hz)**					
	125	**250**	**500**	**1000**	**2000**	**4000**
α_{av} (Avg. Absorption)	0.12	0.05	0.03	0.03	0.02	0.03
Eq. Abs. Area (S) [m^2]	51.62	21.05	14.05	10.78	9.95	11.61
Eyring T_{60} (s)	1.34	3.42	5.17	6.76	7.34	6.27
Sabine T_{60} (s)	1.43	3.51	5.26	6.85	7.42	6.36

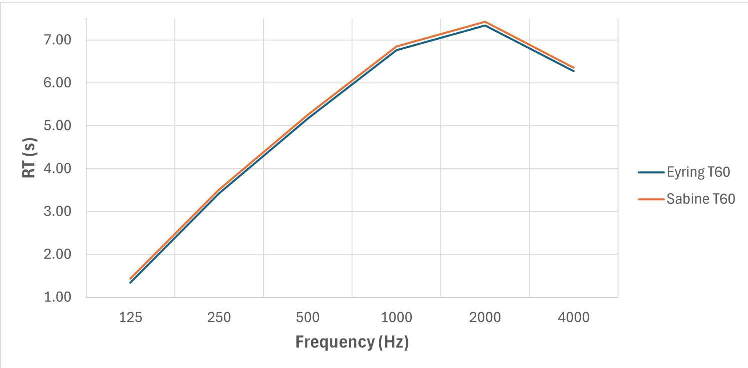

Figure 1: Reverberation time of room Vento without seats

Table 6: Acoustic parameters vs. Frequency for the room with seats

	Frequency (Hz)					
Parameter	**125**	**250**	**500**	**1000**	**2000**	**4000**
α_{av} (Avg. Absorption)	0.16	0.10	0.10	0.09	0.09	0.08
Eq. Abs. Area (S) (m^2)	68.07	43.10	41.00	40.53	37.60	35.41
Eyring T_{60} (s)	1.00	1.63	1.71	1.73	1.88	2.00
Sabine T_{60} (s)	1.08	1.71	1.80	1.82	1.96	2.08

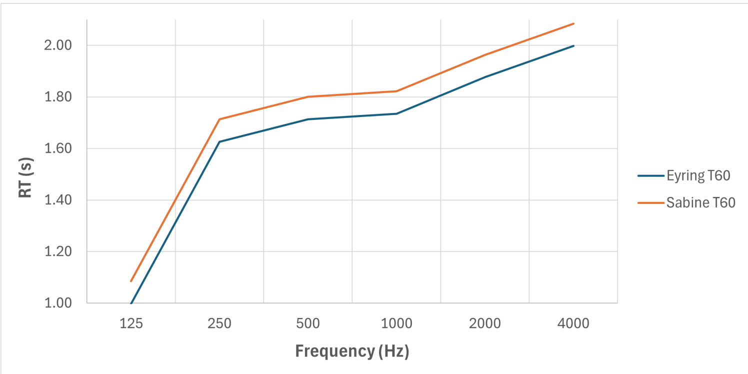

Figure 2: Reverberation time of room Vento with seats

As expected from the absorption effects of the seat material, after placing the seat in the room, RT values in all bands lowered considerably. In Figure 1, the room is more "empty" and reflective, and between 500-2000 Hz, T_{60} values are higher. Seats have an effect of dampening the energy faster, resulting in close to one-third of the T_{60} values.

2.4 Experiment

To characterize the room, we placed a dodecahedron at the speaker position, while several microphones were placed in different locations in the room to measure.

Table 7: Microphone placements

Microphone	**x (m)** (distance with the back wall)	**y (m)** (distance with the right wall)	**z (m)** (distance from the ground)
Dodecahedron	0.950	3.570	1.460
Microphone 1	4.100	3.370	1.317
Microphone 2	7.405	3.452	1.320
Microphone 3	10.12	3.390	1.313

The measurement process is based on both the sine sweep and the balloon pop methods. Using our software, we generated a signal ranging from 22 Hz to 22 kHz. The recorded signal was then convolved with an Inverse Filter to derive the room's Impulse Response. This technique is highly effective due to its superior robustness against background noise.

The program calculates **T20** and **T30** values and provides both (i) reverberation times with an A-weighted filter applied and, (ii) the average reverberation times for all frequencies, including bass and treble, without any filter applied.

Table 8: Reverberation time measurements for different configurations

		T_{20} **(s)**		T_{30} **(s)**	
Test	**Configuration Description**	**(A)**	**Avg**	**(A)**	**Avg**
1	Microphone positioned in front of the first row; Source located behind the teacher's desk.	1.35	1.23	1.36	1.31
2	Microphone positioned in the center of the room; Source behind the teacher's desk.	1.32	–	1.42	–
3	Microphone positioned behind the last row of chairs; Source behind the teacher's desk.	1.35	1.29	–	–
4	Microphone positioned behind the last row of chairs; Source behind the teacher's desk (Repeat).	1.33	1.27	1.39	1.37
5	Microphone behind the last row. Chairs on the right side (rows 3-7) were moved to the perimeter of the room.	1.31	1.24	1.32	1.27
6	Same as Test 5, with additional sound-absorbing material installed on the back wall.	1.21	1.12	1.22	1.15

Two points to consider during the experiment:

1. **Larsen effect:** If input monitoring is not disabled on the sound card, the sound entering the microphone will come back out of the speaker, creating feedback. This makes measurement impossible.
2. **Balanced vs. Unbalanced:** The cable we used in the experiment (BNC) is a cable susceptible to noise. Balanced cables (XLR) carry the same signal with one of the two cores in inverted phase. When the signal reaches the end, these two lines are separated. As a result, the sound is doubled, while the noise coming from the same medium in the two cores cancels each other out.

2.5 Conclusion

Comparing the values in Figure 1 and Table 8, it is generally observed that the theoretical and experimental results are consistent with each other. The proximity of these results indicates that the material definitions within the room were modeled accurately.

Theoretically, we observe that the reverberation time for low frequencies (125 Hz) is very low, at approximately 1.08 seconds. However, in the experimental data, while the average value for all frequencies is around 1.27 seconds, the A-weighted value (which filters out low frequencies) is 1.39 seconds. The fact that the A-weighted value is higher than the average indicates that the bass frequencies are pulling the overall average down. This suggests that the walls are likely absorbing bass energy, thereby preventing ”boominess” and enhancing the speech intelligibility of the room.

The addition of sound-absorbing materials to the back wall reduced the reverberation time from approximately 1.30 to 1.15 seconds. Reflections from the back wall typically return to the listener as late reflections, which can degrade speech intelligibility. Therefore, this intervention was a critical step in optimizing the room for use as a conference hall or classroom.

Finally, examining Test 1 and Test 4, we see that the values are very similar. This indicates a uniform sound distribution within the room, implying that a listener in the front row experiences a similar acoustic performance to one in the back row.