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Concert hall: acoustic design comparing statistical results and ray tracing.

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ABSTRACT

With the intention of designing architecture for music and inspired by music, the J.C. Martins Concert Hall was created with 1008 seats and an approximate volume of 640000 ft^3*. Among all the architectural aspects considered, such as strategic location analysed from the mass plan, study of volumetrics, acoustics is the highlight due to its importance and complexity of the project. The Concert Hall is the object of the present study, the purpose of the article is to compare the simulated results in the EASE software with the statistical results of the reverberation time calculated by the Sabine and Eyring equations for the Concert Hall. Acoustic parameters such as reverberation time and clarity were simulated to verify the acoustic quality of the room in question. With that, it was possible to analyse and discuss the limitations of the analytical method and the simulations. Even so, the results were satisfactory to reach the adequate indexes of the acoustic parameters.*

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1. INTRODUCTION

The object of study of the present article is the design of a concert hall that is part of a Musical Complex, where there is also a music school and a shared square that integrates the two projects. The J.C. Martins Musical Complex bears the name of the pianist and conductor from São Paulo, João Carlos Martins, as a tribute. It is a fictitious project developed for academic purposes, aiming to propose the implantation of an urban equipment that would make the execution of musical concerts possible and that would create a place for gathering and entertainment for the population in the inserted environment, stimulating the formation of audience for musical concerts and contributing to the propagation and preservation of classical music.

The proposal was motivated by the idea of designing Architecture for Music and inspired by Music, uniting two forms of artistic expressions, seeking possible relations and convergences between the two. It was also intended to build a new landmark for the southern zone of the city of São Paulo, benefiting neighbourhoods furthest from the city centre, promoting integration and spreading art and culture to the population. Figures 1 and 2 show the external perspective of the project developed and a perspective section, respectively.

Figure 1: External perspective of the J. C. Martins Concert Hall, object of the present study.

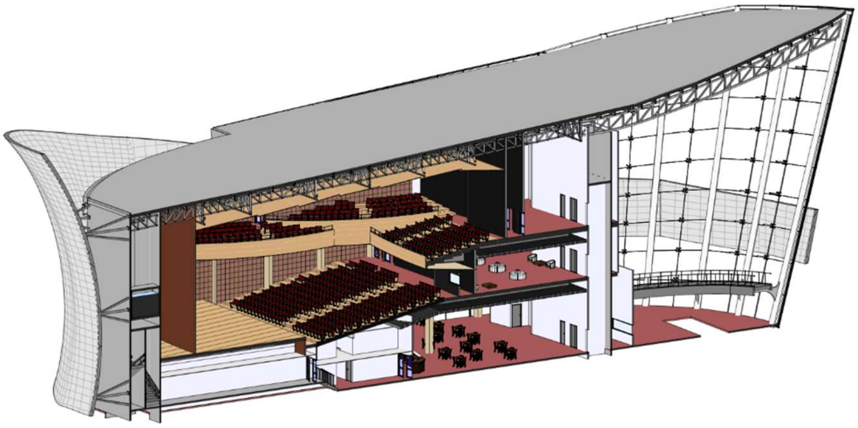

Figure 2: Perspective section with details of the inside of the Concert Hall

Despite the relevance and the importance of other aspects of the project, such as sound insulation, this article focuses on the acoustic conditioning project of the Concert Hall. Ensuring an adequate acoustic quality, considering that it is a musical performance room, for the musicians and for listeners,

the latter distributed in 1008 seats, is a big challenge, for which simulation techniques must be employed.
To highlight the importance of this type of acoustic simulation, the main objective of the study is to compare the reverberation time results calculated statistically and using the EASE 4.4 (Enhanced Acoustic Simulator for Engineers) software, which is based on the ray tracing method. In addition to the comparison between the reverberation times, it is intended to simulate, analyse, and discuss the values of Clarity, which is another important acoustic parameter for a concert hall.

2. METHODOLOGY

Although the number of seats is not in accordance with the preferable number, according to Long [1] between 1750 to 2200, there is a considerable ceiling height in the area of the central audience, with almost 45ft. Being the purpose of the room especially for classical music, the objective reverberation time of the project is between 1.6 to 1.75 seconds at medium frequencies [1] considering the volume of 64185 ft³. In addition to the main audience, the concert hall had counters, which makes it essential that the acoustic quality is guaranteed throughout the whole audience area. Therefore, a study was carried out for the setup of acoustic reflectors on the ceiling, to verify the best positioning so that the projections of the sound waves reached all seats, as shown in Figure 3.

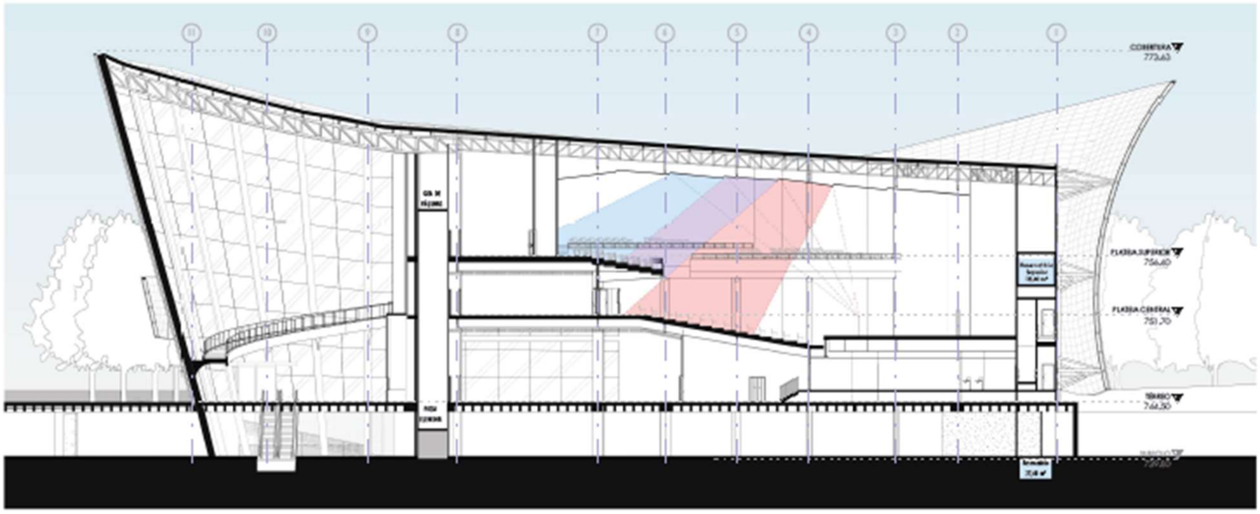

Figure 3: Architectural section of the project with study of acoustic reflectors projection.

In addition to the reverberation time, the clarity, C_{80}, will be evaluated according to the preferred values presented by Beranek [2,6] and Long [1], summarized in Table 1.

Table1: Objective reference values considered for the J.C. Martins Concert Hall.

Parameter	Objective Value
T_{60}	1.6 a 1.75 s
C_{80}(occupied room)	-4 a 0 dB
C_{80}(empty room)	1 a 5 dB

In the present study, the reverberation time was calculated through a statistical method, using the Sabine and Eyring reverberation time, and also the geometric method, using the EASE 4.4 software. Both methods are commonly used to solve problems for medium and high frequencies, which is a disadvantage of the statistical method that it does not consider the geometry of the room, although it has the advantage of having a more practical and computationally light implementation, as pointed out by Brandão [3]. Both methods used in the present study will be better explained in the following sections.

For both methods, the analyses are made from the Schroeder Frequency, from which the analyses are valid for these methods. Schroeder's frequency, F_S, is given by Equation 1:

$$F_S = 2000\sqrt{\frac{T_{60}}{V}} \ , \qquad (1)$$

where T_{60} is the reverberation time and Vo the volume of the room.

It is worth mentioning that the materials considered in all analyses were the same, making it possible to compare the methods used.

2.1 Statistical method

The statistical method considers geometric characteristics of the room analysed, such as the volume of the environment, although it does not consider the geometric shape of this environment, which causes the estimate to have some limitations. With the evolution of the studies on this matter, there are several equations for calculating the reverberation time, which bear the name of their respective scholar. Sabine [4], in his initially empirical study, presents the concept of reverberation time, which is Equation 2, known as Sabine's reverberation time, $T_{60,Sabine}$:

$$T_{60,Sabine} = \frac{0.161V}{S\bar{\alpha} + 4mV} \ , \qquad (2)$$

where m is the air absorption coefficient 1/m, S is the sum of the absorbent areas in the room and $\bar{\alpha}$ the average absorption coefficient, given by Equation 3:

$$\bar{\alpha} = \frac{1}{S}\sum_i S_i\,\alpha_i \ , \qquad (3)$$

where S_i is the area of each absorbent material and α_i their respective absorption coefficient.

In 1930, Eyring [5] presents a new equation for estimating the reverberation time, in order to solve a problem verified by him in Sabine's equation when there is a room with a lot of absorption. Eyring's absorption time, which considers the sound absorption effects of air, is given by Equation 4:

$$T_{60,Eyring} = \frac{0.161V}{-Sln(1-\bar{\alpha}) + 4mV} \ . \qquad (4)$$

In the present study, the statistical reverberation time was estimated by both Sabine and Eyring's reverberation time.

2.2 Geometric method

According to Brandão [3], the use of the geometric method to estimate the objective parameters requires the use of a software for the construction and adjustment of the 3D model, which can take a considerable time of the project. However, unlike the statistical method, the geometric method, as evidenced in its own name, considers the geometry of the room, which is an extremely important consideration in situations such as the concert hall, which has balconies, and audience area well-defined and devices for acoustic absorption and diffusion strategically placed. Briefly, the geometric method considers sound energy as a portion of wavefront energy, which varies with time depending on the distance covered and absorption materials found along the way, also considering the direction of propagation [3]. Brandão [3] specifies the series of steps that must be followed to model the sound field of a room: model the room three-dimensionally, define the position and characteristics of the sound sources and receivers. Still, it is also necessary to define the values of the absorption and scattering coefficient of the materials in the environment. In the present study, the software EASE 4.4 was used to estimate the reverberation time and other pertinent parameters using the geometric method.

3. RESULTS

To be valid the comparison between the results obtained between the methods used, the same materials and their respective absorption areas were considered in the calculations referring to the statistical method, both for the calculation of the Sabine and Eyring reverberation times, and also in the computational analysis simulation performed in EASE 4.4. According to Long [1], the seated audience provides about 85% of the total sound absorption in large concert halls. Thus, in order to ensure acoustic consistency and to provide certain acoustic quality for concerts in which the audience is not complete, seats with a sound absorption coefficient were used close to the absorption coefficients of people dressed in light clothing, since the room is in a tropical climate region. In other areas of the floor, Parquet flooring was used.

On the walls of the stage, acoustic diffusers were used on its side walls and reflective material on the back wall. On the other side walls and on the upper slab, concrete wall with paint. The suspended reflectors are made of plasterboard. The doors are made of solid wood. The bottom wall below the counter has absorbent material and the bottom wall of the top is composed of absorption and diffusion.

3.1. Reverberation time

It is possible to observe in Figure 4 the comparison between the results obtained for the reverberation time through the reverberation time of Sabine, Eyring and using simulation in the EASE 4.4 AURA software for the T_{30}.

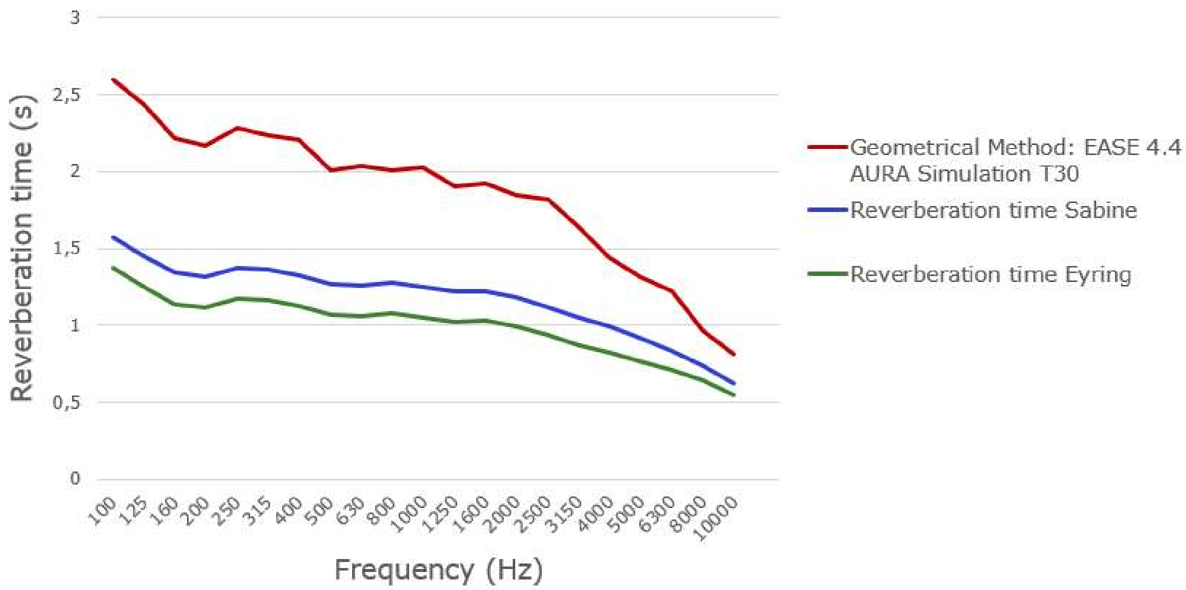

Figure 4: Comparison of the obtained reverberation times.

Figure 5, obtained in the simulation in the EASE 4.4 AURA software, shows that the reverberation time (T_{30}) is homogeneously distributed throughout the central and upper audience.

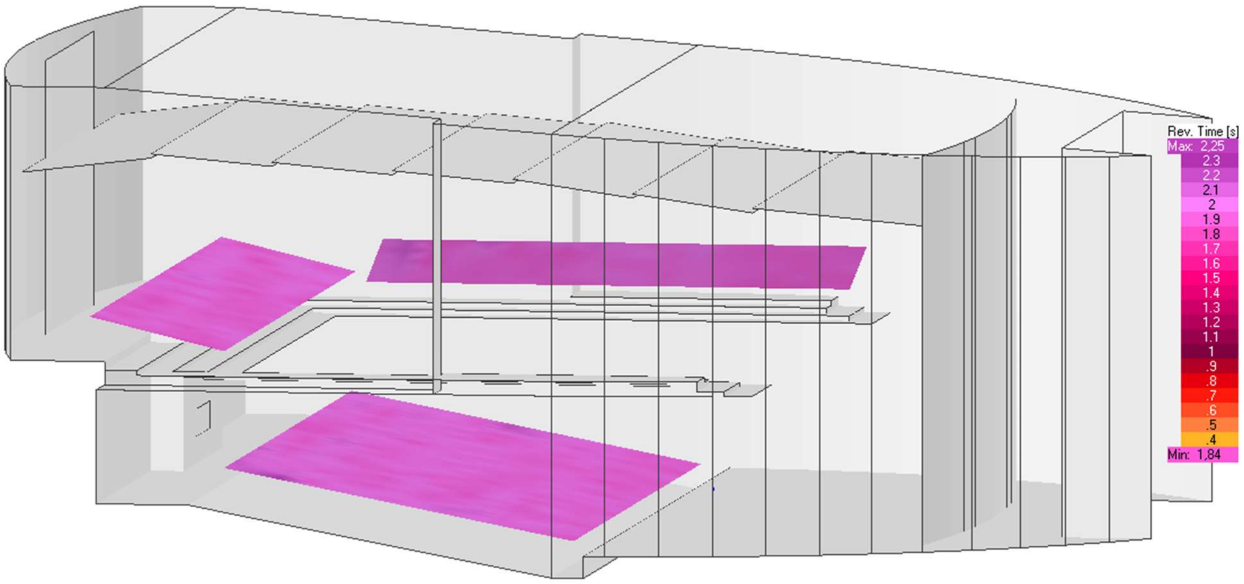

Figure 5 – Distribution of the T_{30}(1000 Hz) simulated in EASE 4.4 AURA in the 3D model.

3.2 Clarity

The C_{80} clarity is a parameter intended for the evaluation of rooms destined for musical purposes, when a room has a good degree of clarity, the music played in it sounds well defined, clean, and accurate. For the frequency of 1000 Hz, the average of the simulated positions for the audience areas is of 2.48 dB.

Figure 6 presents the distribution of the C_{80} (1000 Hz) in the audience areas, in which it is possible to observe that the results vary between -2 to 3 dB. The results show a greater variation over the audience than in the reverberation time, yet, it can be considered an acceptable variation, since the values vary between the reference values of the parameter for empty and occupied room. Although the simulation was performed considering an empty room, the result obtained makes sense since the choice of seats seeks to compensate for room's occupation, as explained in the previous sections.

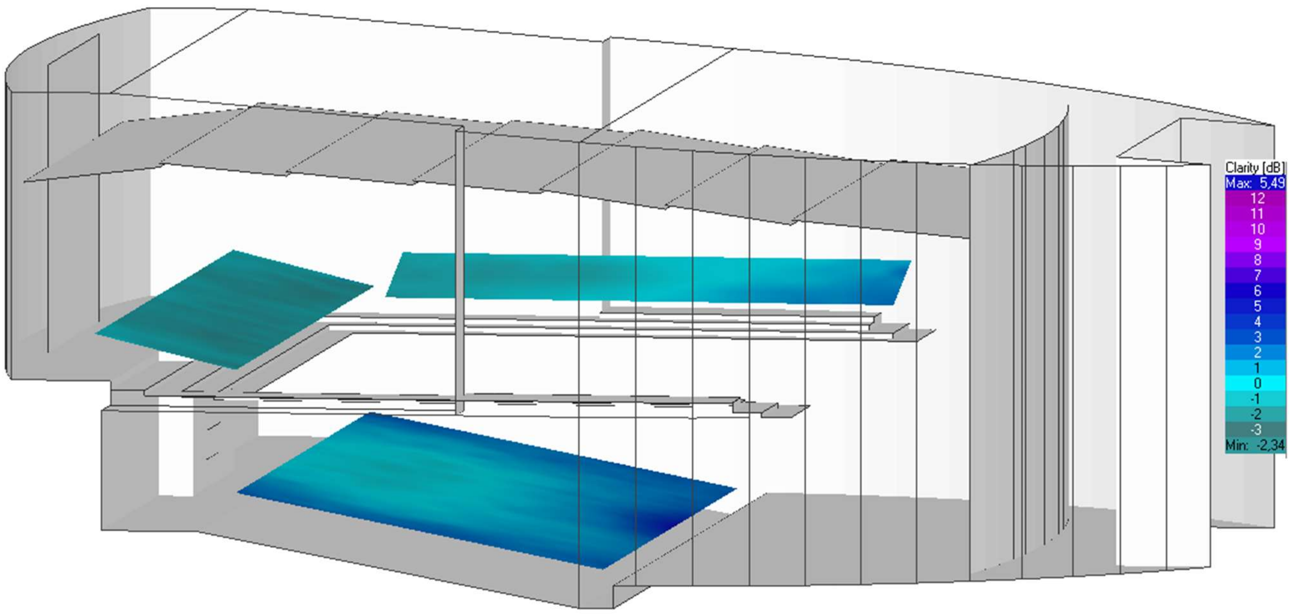

Figure 6 – Distribution of the C_{80}(1000 Hz) simulated in EASE 4.4 AURA in the 3D model.

4. CONCLUSIONS

Despite having a considerable absorption area with diffusion, the J.C. Martins Concert Hall cannot be considered a “dead” room. Nevertheless, when comparing the two results obtained by the statistical method, by the Sabine and Eyring equation, it is possible to verify that different values were obtained. With the results obtained, it is possible to identify the limitation of the estimates using the statistical method. Not only the geometry of the room, but also other relevant information such as the scattering coefficient of the materials, are important factors that must be considered in this type of project, given its complexity.
In addition, we used armchairs with an absorption coefficient similar to the absorption coefficients of people dressed in light clothing to avoid a drastic change in the acoustic response of the room occupied and unoccupied. Therefore, musicians can rehearse in an empty room without noticing differences to when the room is occupied. Likewise, the audience is not affected by a divergent acoustic quality between concerts with a full house or not.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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