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Design of a Concert Hall for Symphonic Music

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This work presents the design of a concert hall for two thousand spectators for symphonic music. For this purpose, a target reverberation time is established in order to compare it with the results obtained and also to observe the role played by the acoustic absorption of the seats in this type of halls.

Keywords: reverberation time, concert hall, absorption.

1. Introduction

This report focuses on the influence of the absorption phenomenon in an auditorium. In particular, we work on the design of a *concert hall for symphonic music*. Its dimensions are based on a number of 2000 spectators, and from the volume, its functionality, the type of seats and the chosen materials, the theoretical reverberation time is calculated. The purpose of this is to compare the results defined as objectives. In this case, the reverberation time of the Boston Symphony Hall (B.S.H.) is used as a representative of this value. In addition, the entire design is to be carried out with one type of seating, one type of absorptive material and one type of gypsum board as cladding.

[1]The reverberation time of a room is related both to the volume of the room and to the sound absorption of the surfaces inside the room. This phenomenon was studied by Sabine, who discovered this relationship and implemented it in the equation that bears his name. That is to say, for a volume V and a total sound absorption A_t we have that:

$$Reverberation\ time\ (TR) = \frac{0.161\,(V)}{A_t} \quad [1]$$

Where $A_t = \sum_{i=1}^{n} \alpha_i S_i$ the sum of the product of the surfaces and the corresponding absorption coefficient α(i).
absorption coefficient α_i. In turn, this value is calculated for the different bands of interest. of interest, being chosen for this report those corresponding from 125 to 4000 Hz.

In addition, there is the $4m$ factor to be taken into account due to air absorption, which affects especially at high frequencies.
especially at high frequencies, so the Sabine equation is as follows:

$$\text{Reverberation time } (TR) = \frac{0.161V}{A_t + 4mV} \qquad [2]$$

[1]On the other hand, the total sound absorption of the room is characterized as follows
mainly by the audience area (seats + spectators). This is due to its high absorption coefficient, so it is generally necessary to apply a low absorption on the remaining surfaces (walls, ceiling) so that the reverberation time does not decrease below the required value. In turn, the seats are classified into three groups in relation to the degree of sound absorption: light upholstery (minimum absorption), medium upholstery (medium absorption) and heavy upholstery (maximum absorption). The criterion for the choice of upholstery is mainly determined by the reverberation time and the volume. However, the audience area presents a problem due to the difficulty of measuring the total absorption coefficient of a large number of seats. This is due to the fact that the measurement is performed in a reverberation chamber, in which arrangements of up to approximately 24 seats can be measured. The problem arises at the edges of these arrays, where a higher level of absorption is obtained than the equivalent area of the whole set of seats. One way to mitigate this effect is to enlarge the audience area by 0.5 m per side, except at the boundaries with walls or at the edges of balconies.
balconies.

From Sabine's formula it is possible to apply the first calculations in the design of a hall taking into account the style of show that is going to take place in that hall. In other words, different parameters are defined according to the type of hall to be designed. For example, for a concert hall for symphonic music, the following parameters are established
a volume per seat ratio between 8 and 12 $m^3$and a reverberation time between 1.7 and 2.2 seconds for an occupied hall.
2.2 seconds for an occupied hall. The established target reverberation time is used for the design stage.

[2]Another element to take into account for the design of a concert hall is its shape. Figure 1.1 shows the main ones, being the one with parallel walls or shoebox the one used for this report. Its main characteristic is the level and amount of early lateral reflections which provide spatiality. With a limit of 40 meters long, mainly due to visual reasons, for enclosures of large volumes, heights from 15 m are applied to obtain an adequate reverberation time.

In addition, the following aspects are taken into account for the enclosure design:

- Excessively wide audience areas should be avoided. Seats should be placed in the most favorable sectors from an auditory and visual point of view.
- Slopes are applied to improve the visual aspect, with a maximum of up to 10°, so as not to considerably reduce the volume of the audience.
  so as not to considerably reduce the volume of the room.
- The sound source should be surrounded by reflective surfaces in order to provide additional sound energy to the audience.

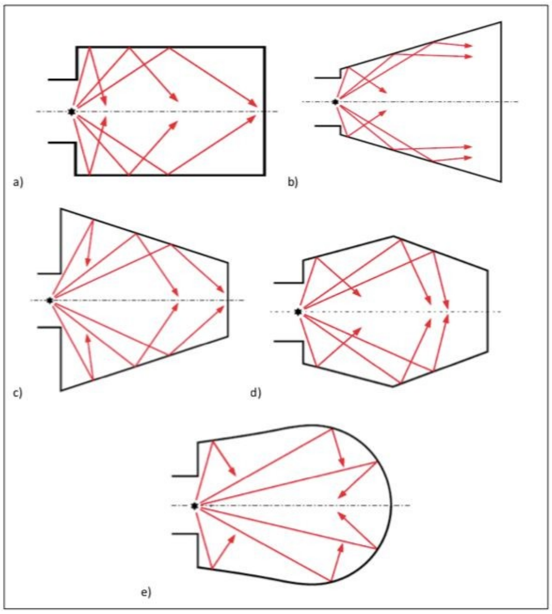

Figure 1.1: Basic concert hall shapes "shoebox" (a), "fan-shaped" (b), "reverse-play" (c), "elongated hexagon" (d) and "horseshoe" (e).

Finally, we take into account the provisions of the law 962 [3]on physical accessibility for all. Some of these points are not presented in this report due to the scope of the report.

- Entrances must have a clear width of not less than 1.5 meters.
- According to article 4.7.6.3 the number of seats may not exceed 8 seats unless it is between two aisles, in which case the maximum number of seats may be doubled.
- 2% of the courtroom is reserved for wheelchair users located on the first floor.
- The building must have means of egress consisting of doors, stairs, ramps and horizontal exits.
- Each unit of use must have direct access to an exit.
- Every corridor must lead to an exit.

2. Procedure

2.1 Determination of the characteristics of the concert hall.

[4]As already mentioned, the type of hall chosen is rectangular or shoebox since allows a regular acoustic distribution, a large number o f early lateral reflections due to the proximity of the audience to the walls, good spatial impression and the possibility of raising the loudness by such reflections. With respect to the length-to-width ratio of the hall, it is sought to be greater than 1.5, in order to have a considerable amount of early lateral reflections. The limit for the length is 40 meters, which is given so that the spectators in the last seats do not lose visibility of the stage. From this, and taking into account both the number of spectators and a maximum ratio of 10:10.
spectators as well as a maximum ratio of 10 m(3)per spectator, the dimensions defined in meters for the room are 40x25x20 (length x width x height). This gives a maximum volume of 20,000 m(3) .

a maximum volume of 20,000 m^3. These values are maximum because when adding the different design stages such as audience or stage, the volume decreases.

The next step is to establish an audience surface area given by the number of spectators and the surface area covered by a seat. The limit values are taken to be between 0.55 m^2($1m\ x\ 0.55m$) and 0.65 m^2($1m\ x\ 0.65m$) of seating area, so the total audience area must be between 1100 $m^2$and 1300 m^2. In addition, to determine the audience area, the already developed criterion of extending the sides by 0.5 m is used due to the edge problems presented by the large number of seats.

Once the approximate value of the audience surface is known, the spaces that the audience will occupy in the hall are designed. In appropriate cases, the optimum slope value is calculated by tracing isoptics. For these cases, the aim is to maintain a visibility of at least 80% of the stage, for which a 10° slope is added for both visual and acoustic reasons. This slope will have an impact on the reduction of the volume of the hall.

To increase the audience area, an upper floor is added 10 meters above the ground floor, the same with a slope of 10º. In addition, for groups of seats with more than 8 across, access aisles are added for both sides of the set, taking into account that the central part of the room with respect to the stage is occupied by the audience and not by aisles, since this axis is the geometric and acoustic focal point. To complete the audience area, balconies are added on the sides, both on the upper floor and in the middle of both floors.

Once the total audience surface area was obtained, the type of seat was chosen. Since it was not possible to find information on the absorption coefficient of the various seats available on the market, we turned to the information provided by the literature ([1]) ([5]) .
bibliography ([1]) ([5]). In other words, a choice is made between light, medium or heavy upholstery. The choice is based
The choice is directly based on the reverberation time sought for the room, since the total set of seats is what contributes the most acoustic absorption to the whole system. In this case, the target reverberation time is used to find the approximate absorption coefficient of the seats.

Once the type of seat has been chosen, the type of gypsum board and the absorbent material for each surface is selected. Materials are selected whose absorption coefficient complies with the total absorption ranges necessary to achieve the desired reverberation time. For the walls and ceiling surrounding the stage, reflective surfaces are placed oriented towards the audience in order to direct the sound energy towards it, and thus obtain a higher sound level and acoustic quality. Therefore, they are not considered in the absorption calculation due to their reflective nature. As well as the slopes applied in the audience area, their directionality has repercussions in a decrease of the effective volume of the room.

With the effective volume defined along with the audience area, type of seating and materials for each surface, reverberation time calculations are performed for each band between 125 Hz and 4000 Hz. The results are shown in the following section.

At the same time, four main doors of 2 m wide and 2.5 m high are placed. One
on each floor, in the center of the back wall, and then one on each side wall on the first floor, where the non-sloped audience area is located, where 20 of the spaces are reserved for people with reduced mobility. Four 1.5 m wide emergency doors
1.5 m wide and 2 m high, two on each floor on the back wall, both on the ground floor and on the first floor.
on the far left and on the far right. Finally, two doors in the front wall, 1.5 m wide and 2 m high

wall, 1.5 m wide and 2 m high, with entrance to the stage, one on the far left and one on the far right.
left end and the other at the right end.

3. Results

Figure 3.1 shows a lateral image of the room design with references. Figures 6.1.1, 6.1.2 and 6.1.3 in Annex 6.1 also show different views with their respective references.

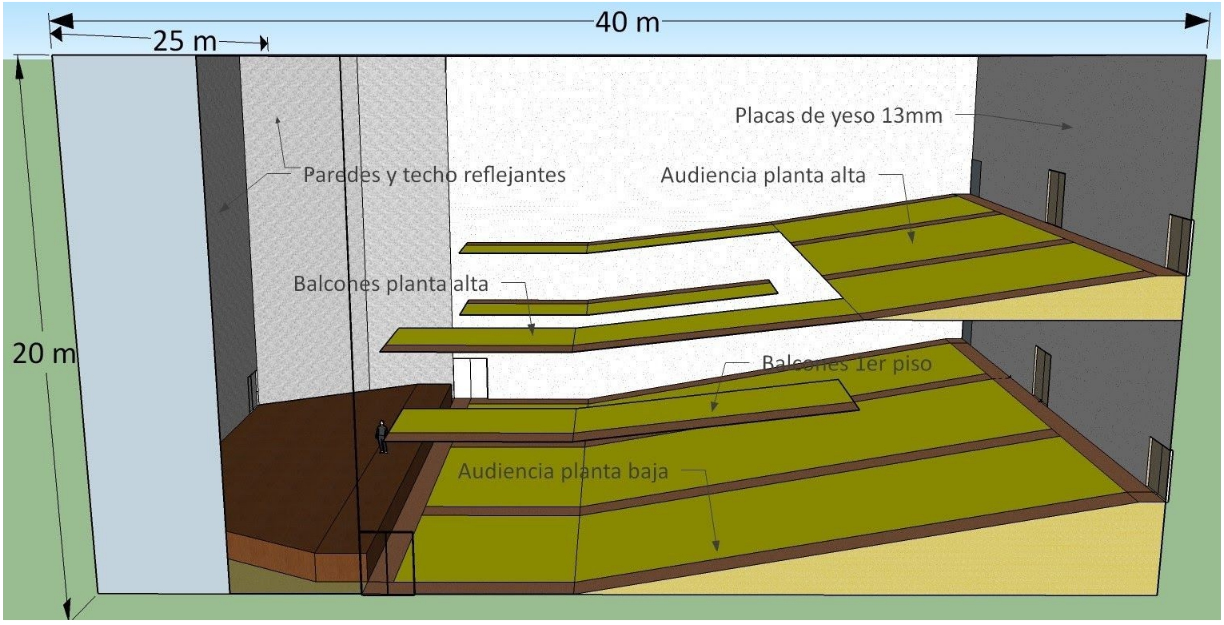

Figure 3.1: Side view of the designed concert hall.

It presents a 1.2 m high stage. The first floor audience area consists of
of 181 m^2without slope and 522.11 $m^2$with a slope of 10º. Upstairs an area of 264 m(2) with a slope
of 264 $m^2$with a slope also of 10º, and two balconies on the sides of 56.55 m^2
each. The second floor balconies occupy 61.74 m^2each.

From the design we have the following data of the room:

- Total volume: 16765 m^3
- Total audience area:1203.69 m^2

Taking into account the average reverberation time of the B.S.H. (figure 6.1.1) [6]and the values presented above, an estimated value of the absorption coefficient for the audience area can be obtained by applying Sabine's formula and disregarding the other surfaces. With this we have that:

$$abutacas = \frac{0{,}161 * 16765 m^3}{1203{,}^{69m2} (*)\ 2{,}41\ s} = 0{,}93 \qquad [3]$$

It is observed that the required average absorption value is high, although the resulting one will be lower due to the influence of the remaining surfaces. The type of seat with the closest value is the one corresponding to heavy upholstery. Table 3.1 shows the values of this coefficient for each octave band.

From the absorption coefficient of the armchairs, the materials for the remaining surfaces are chosen, as already established. Table 3.1 shows the data corresponding to all the surfaces and materials chosen, with the final calculation of the reverberation time per octave band.

Regarding the materials, a 27mm wood was chosen for the stage. For the side walls a 13mm gypsum board is used, since low absorption is sought both to achieve a good amount of early lateral reflections and to have a low influence on the reverberation time. For the ceiling, a gypsum board with some absorption at low frequencies is applied in order to balance the TR for that frequency range.

Table 3.1.

Reverberation time per octave band for unoccupied room							
Material	S [m^2]	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Unoccupied seat Heavy upholstery [1]	1203,69	0.7	0.76	0.81	0.84	0.84	0.81
Plasterboard 13mm [5]	1463,4	0.15	0.1	0.06	0.04	0.05	0.05
Ceiling plasterboard [5]	750	0.2	0.15	0.1	0.08	0.04	0.02
27mm wood scenario [5]	251	0.1	0.07	0.06	0.06	0.06	0.06
Air absorption [1]	-	0	0.001	0.003	0.004	0.009	0.027
Sα [*sabines*]		1237.19	1207.98	1203.15	1211.75	1280.21	1530.87
Equivalent volume [m^3] 16765		16765					
Reverberation time [s]		2.17	2.22	2.23	2.21	2.10	1.75

As a first observation from the results obtained, the influence of air absorption in the 4000 Hz band is noticeable. This is explained from the behavior of the sound waves in the air for high frequencies, being greater the attenuation the higher the volume. In turn, for the 250 Hz, 500 Hz and 1000 Hz frequency bands, a TR just above the recommended maximum value of 2.2 seconds is obtained. However, this value is specified for an occupied room, so that in this case its value is expected to decrease, since the spectators provide absorption, especially due to their clothing.

As for the comparison with respect to the target TR, the average for the designed room is 2.11 seconds while that of the B.S.H. is 2.41 seconds (the average value is taken from several measurements made after 1988, as shown in the figure below).
6.2.1 in the appendix). This difference could be attributed to a large extent to the fact that the B.S.H. has a light upholstery in the seats, which has a considerably lower degree of absorption than the heavy upholstery chosen for the present design.

6.2.2 in the appendix shows the comparison by bands where the slopes at 1000 Hz and above are similar.

Finally, to observe the influence of the acoustic absorption of the seats, their absorption coefficient is varied by +10% and -10% and the impact on the average TR is observed. The same percentages are applied to the average TR to observe the difference between the two. It is obtained that for +10% by varying the coefficient 1.96 seconds is obtained and 1.9 seconds if applied to the average TR directly. For -10% we obtain 2.29 and 2.32 seconds respectively. From the similarity for both variations, it is evident the great influence that the absorption of the audience area has on the total TR of the room.

4. Conclusions

After designing a concert hall for symphonic music with a capacity of 2000 spectators, it is concluded that the reverberation time of the hall depends to a large extent on the absorbing material used for the seats. While the absorption in the walls and ceiling can be modified by the selected material, to achieve a more precise but not substantial control of the reverberation time.

However, despite its importance in the design and final result, this coefficient is not given by the manufacturers, which implies a difficulty in obtaining an accurate estimate in the characterization of a concert hall.

5. References

[1] "Auditorium Acoustics and Architectural Design" (Michael Barron)

[2] "Master Handbook of Acoustics" (F. Alton Everest)

[3] Law 962 from CABA: Accessibility accessibility for all: https://www.buenosaires.gob.ar/sites/gcaba/files/ley_962_-_codigo_de_edificacion_de_la_ci udad_de_buenos_aires.pdf

[4] "ABC of Architectural Acoustics" (Arau,Higini).

[5] "Auralization: Fundamentals of Acoustics, Modelling, Simulation, Algorithms and Acoustic Virtual Reality" (Michael Vorlander)

[6] "Concert Halls and Opera Houses" (Leo Beranek)

6. Annex

6.1 Concert hall design views.

The following are the front, back and side views of the concert hall with their respective measurements:

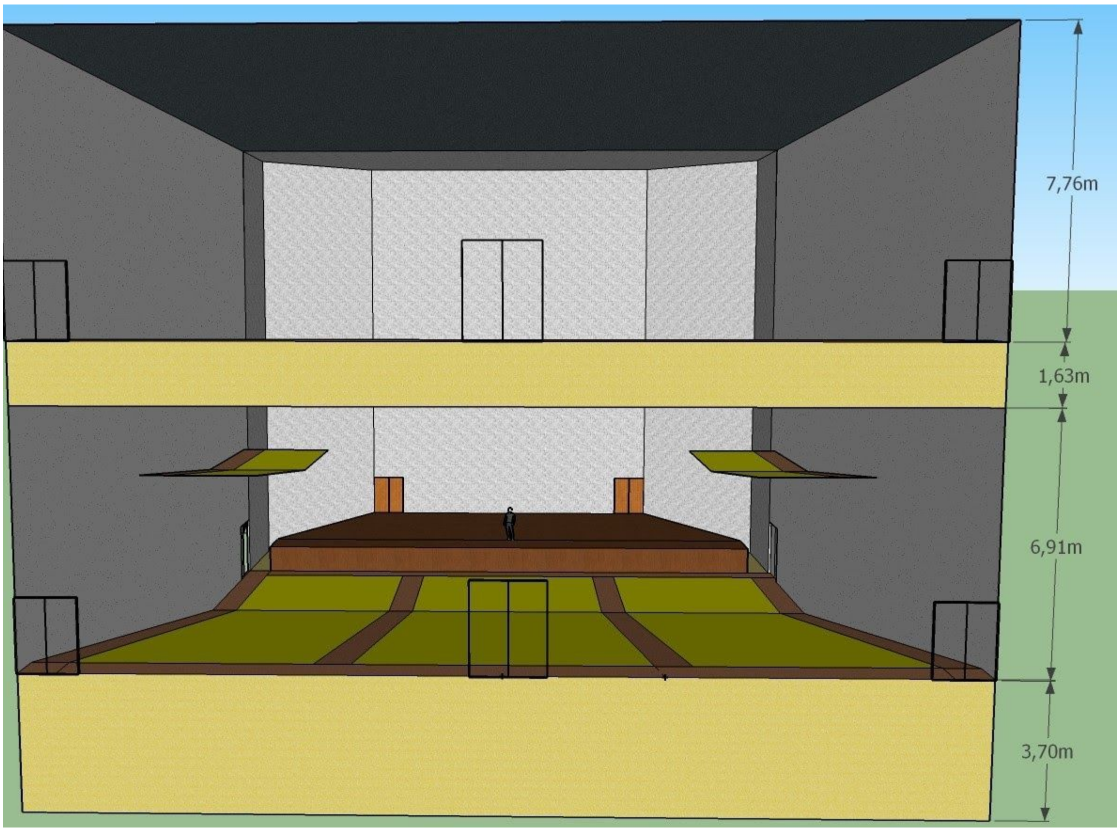

Figure 6.1.1: Rear view of the designed concert hall.

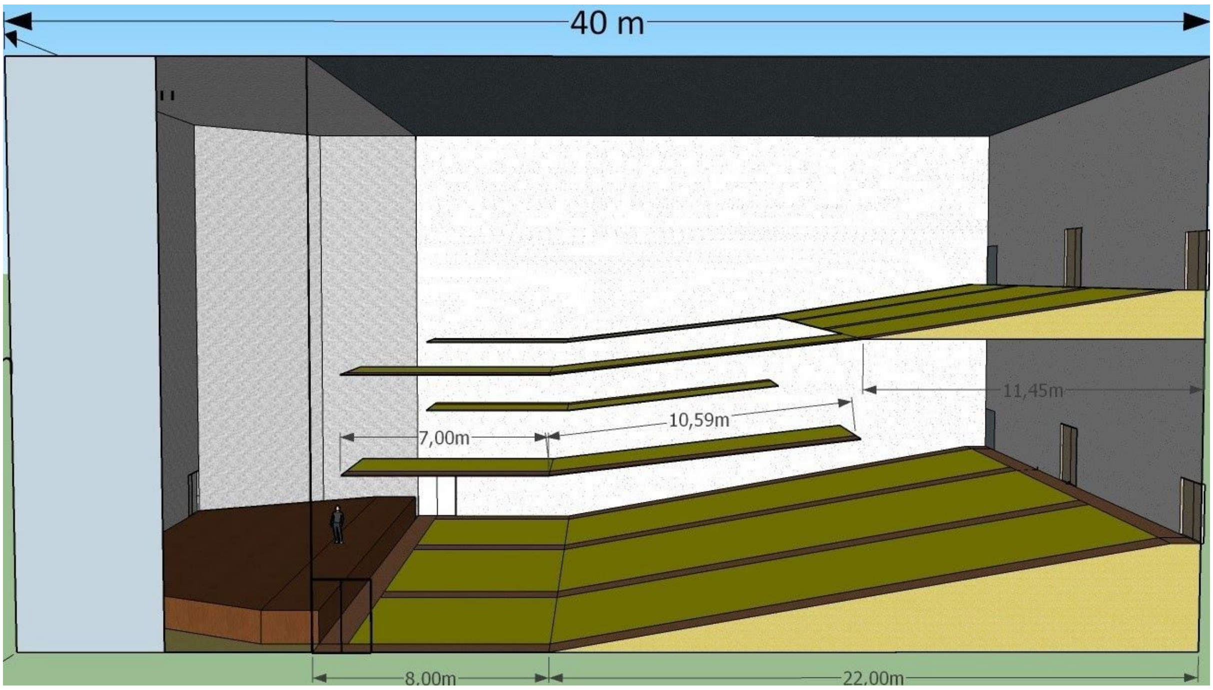

Figure 6.1.2: Side view with measurements.

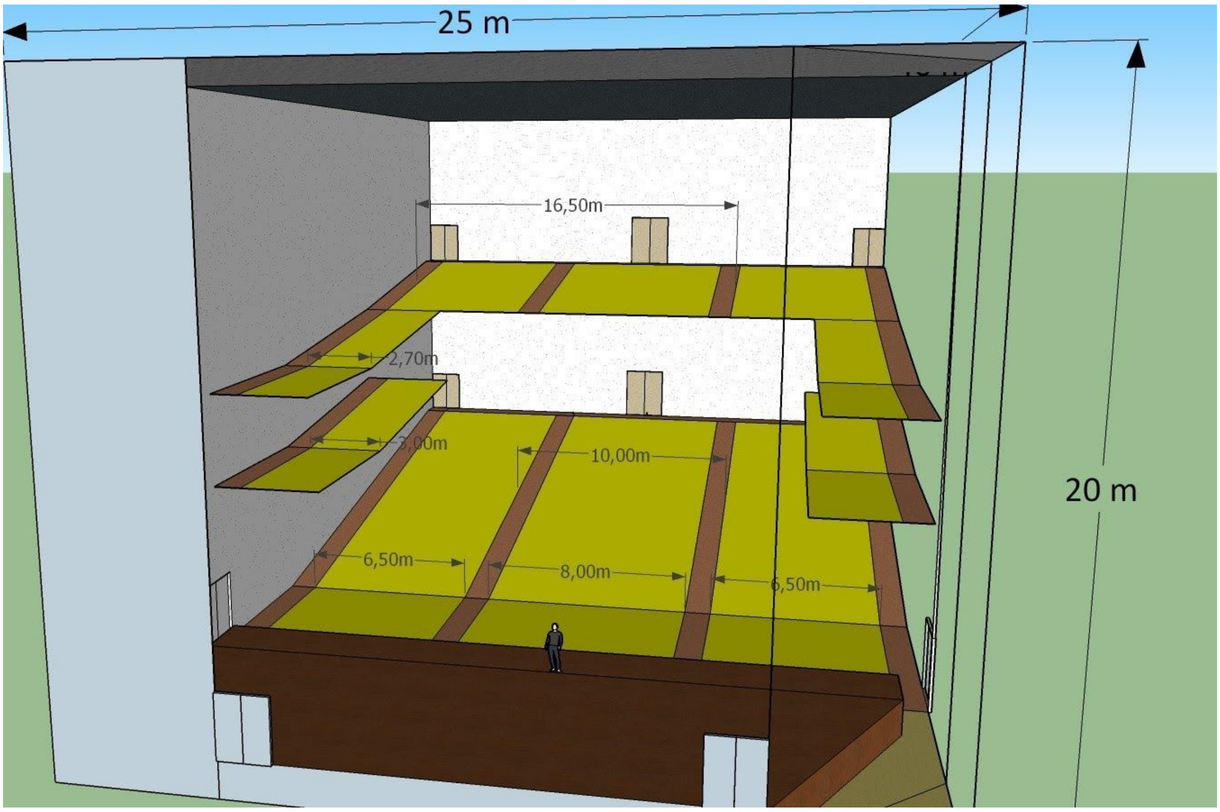

Figure 6.1.3: Anterior view with measurements.

6.2 Reverberation time of Boston Symphony Hall and comparison with the designed hall.

Attribute	Measured by	Year of Data	Center Frequencies of Filter Bands (Hertz) 125	250	500	1,000	2,000	4,000
3. BOSTON, SYMPHONY HALL (Opened 1900, 2,625 seats)								
RT, unoccupied	M.A.A.	1958	2.50	2.80	2.70	2.85	2.85	2.10
	Schultz	1963	2.70	2.70	2.60	2.50	2.30	1.95
	Mastracco	1981	2.60	2.40	2.70	3.00	2.80	
	Average before 1982		2.60	2.63	2.67	2.78	2.65	2.03
	Takenaka	1991	2.11	2.19	2.33	2.69	2.80	2.47
	Bradley	1992	2.17	2.38	2.56	2.70	2.67	2.38
	Gade	1992	2.12	2.30	2.39	2.56	2.59	2.26
	Selected average after 1988		2.13	2.29	2.40	2.63	2.66	2.38

Figure 6.2.1: Reverberation time without B.S.H. occupancy.

*Image obtained from the book Concert Halls and Opera Houses by Beranek ([6]).

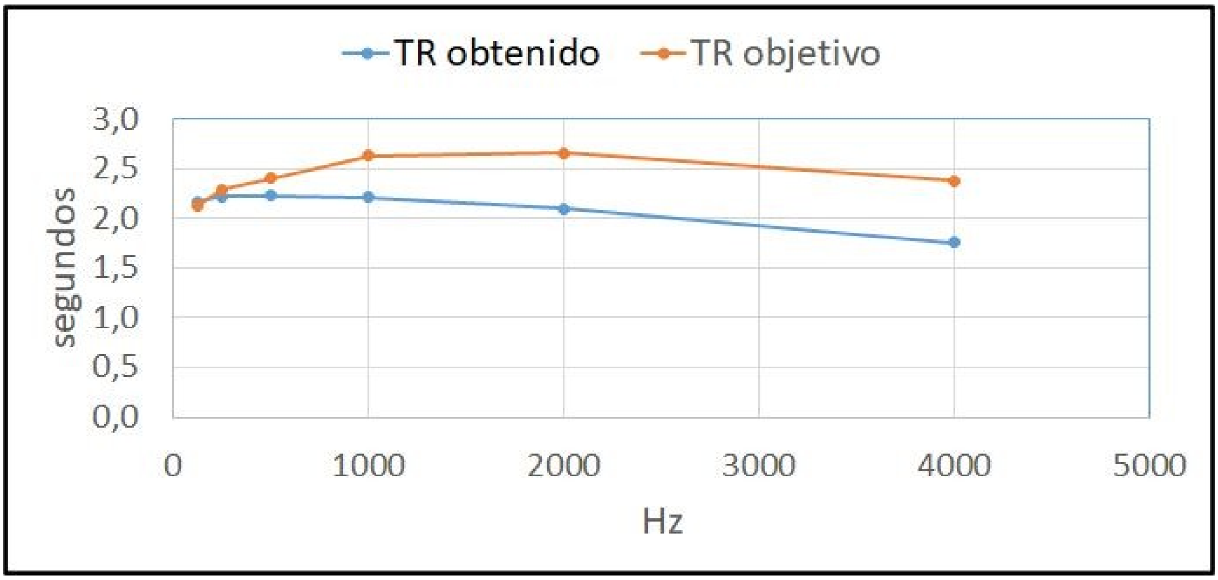

Figure 6.2.2: Average reverberation time of the B.S.H. vs. designed hall.