Acoustic design of an auditorium : San Martín concert hall

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Abstract

A concert hall of was designed at the site of the existing auditorium, Teatro Auditorium in Buenos Aires. Possible surrounding noise sources are people movement and heavy traffic. The building consists of lobby, ticket office, cafeteria/bar, dressing rooms and practice rooms for performers, restroom, staff office, machine rooms as well as main hall space. In the hall, 960 seats were arranged in two levels according to Buenos Aires city's building code. The materials realized the reverberation time of 1.97 s at middle frequencies. The triangular reflector panel were designed above the frontal audience to improve the initial time delay gap between 15 ms and 35 ms. The concert hall design trough a acoustic simulation software provides to the audience a SPL variation less than 4 dB, an EDT of 1.63 s at 1 kHz and an IAGG of 0.25 s at 1 kHz.

Keywords: Buenos aires building code

1 INTRODUCTION

From the theaters of ancient ages located in the hillside of a preindustrial society like the Epidaurus in Greece to the sophisticated postmodern theaters like the Berlin Philarmonic in Germany, the architectural acoustics requires an almost unlimited theory and a lot of experience in the field. In this case the auditorium used is the "Teatro Auditorium" located at Mar Del Plata city, with capacity for 1000 spectators.

The aim of the current study is design a new concert hall for quartet strings (Romantic period) is shown, using the theory provided by authors like Sabine, Beranek, Barron and so many others mixed with a acoustic prediction tool to get the acoustic parameters.

2 THEORICAL FRAMEWORK

To understand the most of the acoustics parameters using in this study is necessary a theorical framework, for this the follow concepts are shown.

- **Reverberation Time (RT)**: Time, expressed in seconds, that would required for the sound pressure level to decrease by 60 dB, at a rate of decay given by the linear last-squares regression of the measured decay curve from a level 5 dB below the initial level to 35 dB below.[1]

Table 1: Recommended occupied RT (seconds) [2].

Auditorium purpose	RT [s]
Organ music	>2.4
Romantic classical music	1.8-2.2
Early classical music	1.6-1.8
Opera	1.3-1.8
Chamber music	1.4-1.7
Drama theater	0.7-1

- **Early decay time (EDT)**: It is a measure of the sound decay rate, expressed in the same way as a reverberation time, based on the first 10 db portion of the decay. (Reverberation time, RT, is based on 30 db of decay.) In a highly diffuse space where the decay is completely linear, the two quantities, RT and EDT, would be identi-cal. The early decay time has been shown to be better related to the subjective judgement of reverberation, also called 'reverberance', than the traditional reverberation time (Atal, Schroed-er and Sessler, 1965).[3]

- **Diffusion**: The sounds diffusion occurs when energy of the reverberant field arrives equally in all directions of space to the ears of the spectators. This helps to establish a surround sound and, therefore, increase the sense of spatial impression. The greater the sense of spatial impression, the better the subjective evaluation of the viewers.[3]

- **Strength (G)**: Loudness G corresponds to the gain level produced by the room naturally.It depends on listener's distance to the stage, energy associated with the first reflections, surface occupied by the audience and level of reverberant field. The loudness G is defined as difference between total sound pressure level produced by an onminidirectional source and the sound pressure level produced by the same source located in a free field and measured at a distance of 10 m.[3]

- **Inter-aural cross correlation (IACC)**: IACC is a factor that allows to quantify the ASW (Apparent source width) associated with the amplitude of sound coming from the stage. That when the apparent amplitude of the source (lower value of IACC) is greater, the greater the spatial impression of sound and the better the subjective evaluation of listeners will result.[3]

- **Initial time delay gap (ITDG)**: ITDG is the time difference (delay) between direct sound and the first reflection. It is also associated with acoustic intimacy.

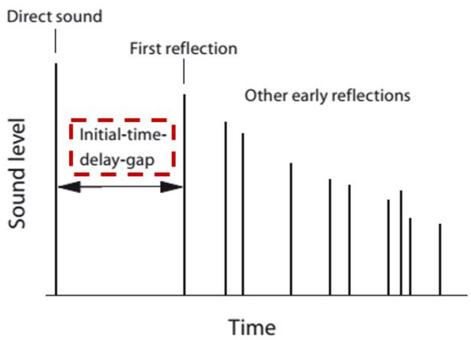

Figure 1: Initial time delay gap (ITDG)

3 SITE INFORMATION

The "Teatro Auditorium" is located in the complex "Edificio Casino Hotel provincial" (Boulevard Marítimo 2280), Mar del Plata, Buenos Aires, Argentina with a building area of 2247 m^2. One of the most important noise sources is the Avenue Boulevard Marìtimo because it is very busy and even more in holidays. Furthermore, another noise source is the constant people movement because this auditorium is near to the beach and some iconic monuments.

With a building coverage ratio of %100 the distribution of rooms was design in order to provide more comfort both for musicians and spectators as shown in figure 2. The building at ground floor has on one hand a main lobby with the coffee/bar, tickets office, shop, cloakroom and bathrooms. At the other, two dressing rooms, bathrooms for performers and the clean room. Furthermore at the first floor are the restroom, practice rooms, offices, machines room, storage and meeting rooms.

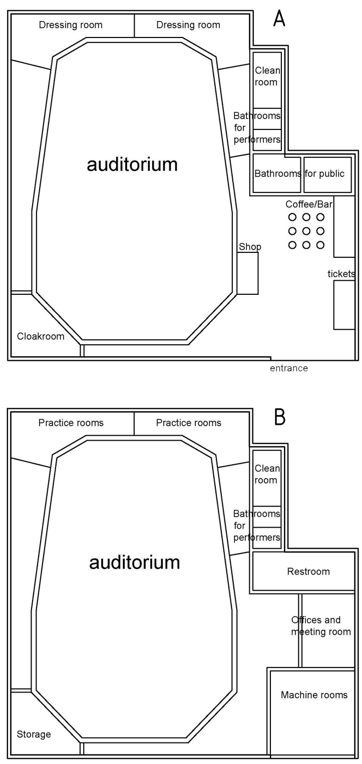

Figure 2: Building design at ground (**A**) and 1st floor (**B**).

Altough is important contemplate the noise inside the building and especially in the auditorium. Due to this, the auditorium has two walls of 70 cm each with an air cavity fill with rock wool.

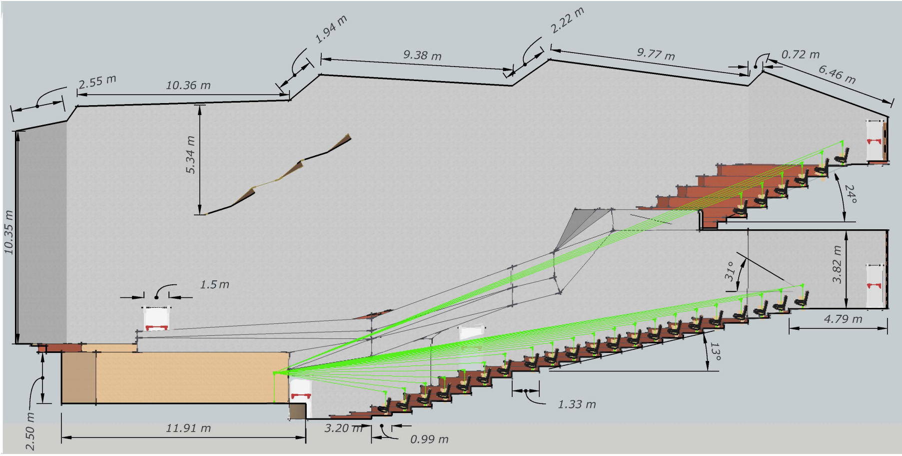

Figure 5: Longitudinal cross section and clearance.

4 PLAN AND SEAT ARRANGEMENT

The San Martin concert hall has capacity for 960 spectators and 12800 m^3 as a result a relation volume per spectator of 13.3 m^3 and has ten exit doors 1.5 m each.

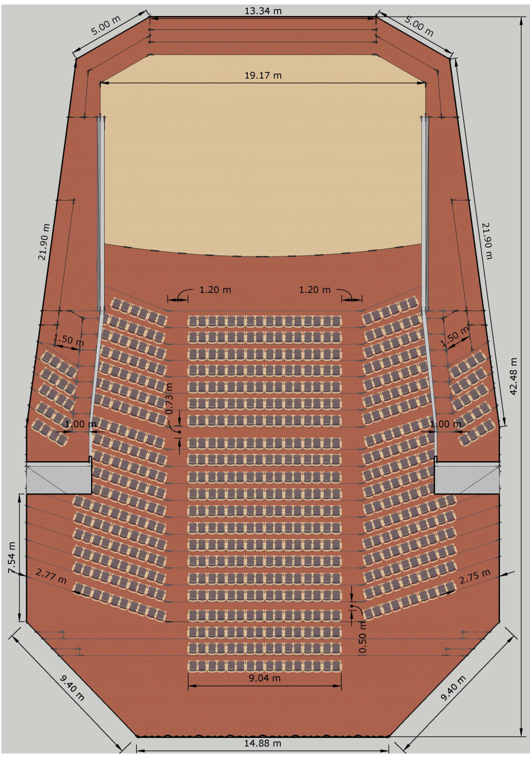

Figure 3: Main floor and lateral balcony plan.

The main floor has capacity for 680 spectators and it has two special sites for people with disabilities. In addition ,the maximum longitudinal length is 42.48 m, the stage has 219 m^2 and has separate elevated choir balcony as shown in figure 3.

Lastly, the balcony has space for 240 spectators, two exit doors 1.5 m each and two main corridors 1.2 m as seen in figure 4.

All the design complies with the Buenos Aires city's building code, ten doors with 1.5m each (150 m in total) when the minimum established is 872 m for 960 spectators, all the corridors has 1.2 m as minimum, the distance between seats is 0.5 m and seats dimensions are 0.5 m between arms, a backrest of 0.5m height and a depth of 0.45 m. All seats are grid arrangement.

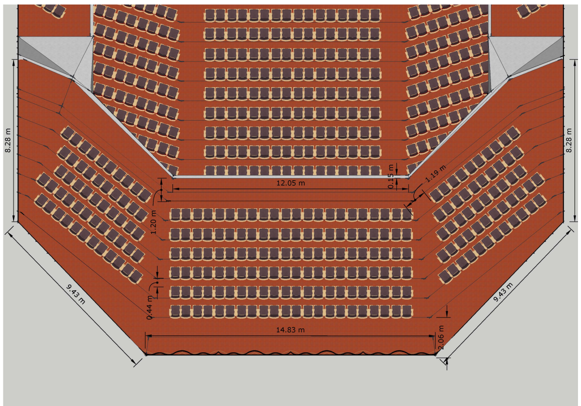

Figure 4: Balcony plan.

5 CROSS SECTION AND SIGHTLINE

When designing a theater is important the spectator sightline to stage, for this following table 2 shows sightline check.

Table 3: Absorption coffiecient per material (α). **A**: Perf panel 79% on 8" cavity; **B**: Perf panel 1.4% on 4" cavity; **C**: Sonex foam 2"; **D**: Masonry painted; **E**: Wood parquet on concrete; **F**: Hardwood floor on beams; **G**: Wooden parquet floor; **H**: Public in medium upholestery seats; **I**: Medium upholestery seats.

	Frequency																	
Material	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**
A	0.98	0.98	0.94	0.91	0.87	0.75	0.64	0.52	0.41	0.31	0.2	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.13
B	0.25	0.25	0.48	0.72	0.95	0.85	0.76	0.66	0.53	0.41	0.28	0.25	0.21	0.18	0.16	0.13	0.11	0.11	0.1
C	0.08	0.08	0.14	0.19	0.25	0.37	0.49	0.61	0.71	0.82	0.92	0.93	0.94	0.95	0.94	0.93	0.92	0.92	0.92
D	0.1	0.1	0.08	0.07	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.08
E	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
F	0.15	0.15	0.14	0.12	0.11	0.11	0.1	0.1	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.07
G	0.02	0.02	0.06	0.11	0.15	0.13	0.12	0.1	0.09	0.09	0.08	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.05
H	0.6	0.65	0.67	0.68	0.72	0.74	0.77	0.8	0.8	0.8	0.83	0.83	0.83	0.84	0.84	0.84	0.85	0.8	0.8
I	0.5	0.54	0.56	0.59	0.62	0.64	0.66	0.68	0.68	0.69	0.7	0.67	0.64	0.62	0.61	0.6	0.6	0.6	0.6

Table 2: Sightline check for 3 first and last rows

Main floor	Sightline [cm]
2nd	20.6
3rd	21
20th	11.8
21th	11.2
Balcony	**Sightline [cm]**
2nd	11.6
3rd	12
5th	14.3
6th	14.7

Furthermore, in figure 5 longitudinal section with the clearance are shown.

6 ABSORPTION AND REVERBERATION TIME

Most determining aspect when classifying a theater is certainly the reverberation time and this is highly influenced by absorption of different materials used in auditorium. Due to this, in first place table 3 shows absorption for each material.

In second place, figure 6 shows reverberation time occupied and unoccupied. In addition RT_{mid} = 1.975 s, BR(Bass ratio) = 1.038 s and TR(Treble ratio) = 0.8938 s. Should be noted that all this results are from a software simulation.

"Though at high sound levels the ear is roughly equally sensitive to different frequencies,at low sound levels it is much less sensitive to bass frequencies (otherwise we would hear our own heart beats). A longer bass reverberation time can compensate for this. Up to a 40 per cent rise at 125 Hz compared with mid-frequencies is considered appropriate for orchestral music[...]"[2]. This added to table 1 prove that reverberation time in the auditorium is correct for the established purpose.

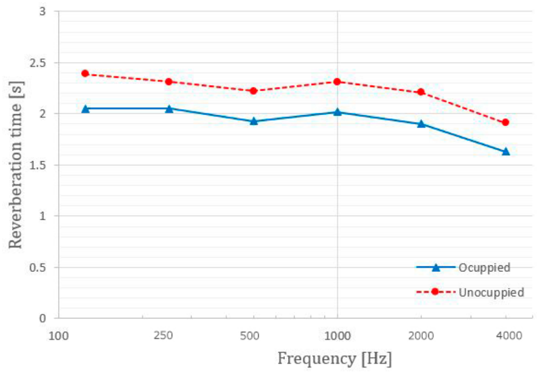

Figure 6: Reverberation time for full occupied and unoccupied.

7 REFLECTION DESIGN

To acquire the values for all acoustic parameters it was used the same receiver points(seats) into a room model from the entire auditorium as illustrated in figure 7. Unfortunately the software cannot import reflector design and the stairs in balcony.

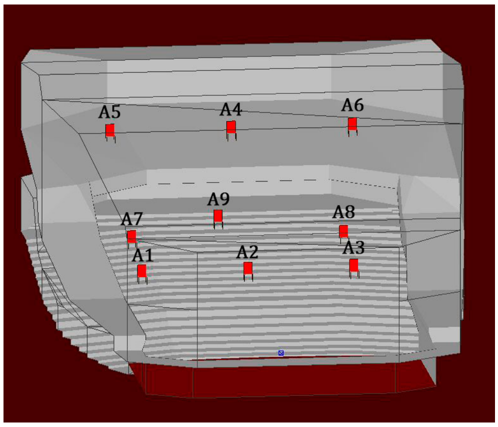

Figure 7: Room model and listeners position

As explained in the introduction, ITDG is the time between direct sound and the 1st reflection. Using a computer software trought ray tracing method with reflection order 5 and 30000 rays for one speaker, ITDG values for nine seats (six from the main floor and three from the balcony) are obtained as shows table 4 and a reflectogram for example in figure 8.

Table 4: ITDG values for nine seats.

Seat	A1	A2	A3	A4	A5	A6	A7	A8	A9
ITDG	36.6	38.2	37.1	19.7	13.6	14.3	17	16.5	26.9

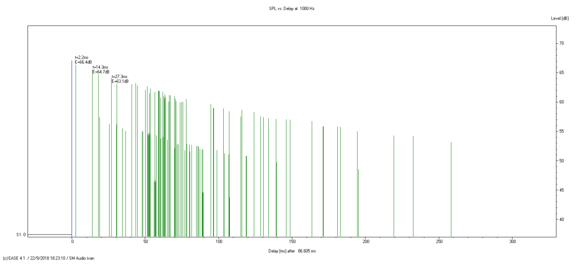

Figure 8: Reflectogram from seat A6.

Therefore, it can be seen that the first reflection in the most of seats arrives early. Neverthless, should not be ignored that reflector is not in the simulation, due to this is it expected that the results with reflector will be better in the first rows (A1,A2,A3).

In relation to this last point, to provide better first reflections the auditorium has a hanging triangular reflector as shows figure 9. For smoothest level response, reflector has 50% of covered area with a total area 95.85 m^2, subdivided in 4 convex triangle with an interior angle 110^o and 10.65 m^2 per triangle.[4]

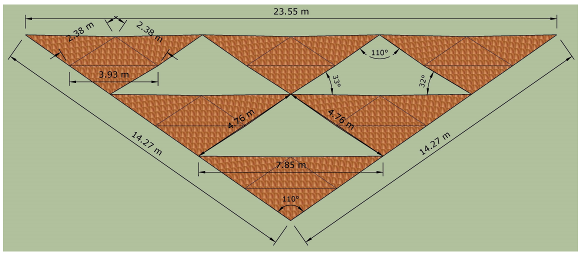

Figure 9: Reflector design.

8 ACOUSTIC PARAMETERS

For this section is used two different methods trought a simulation software and an audio editor software (IACC and EDT). On one hand, in the same way that last section a ray tracing method is used to obtain the G and SPL variation values for the nine seats in audience area. On the other, with the simulation software a binaural response in .wav (one for each seat) is exported to audio editor to calculate IACC and EDT.

8.1 G(Strength) and SPL variation

"As a criterion for total sound level there was no broad agreement. Lehmann and Wilkens (1980) suggested a minimum value of +3 dB, but this is considered too severe as it eliminates 60 per cent of positions in British halls. A criterion for a minimum mid-frequency sound level of 0 db seems reasonable from experience"(Barron,2010,p.69). Also, Beranek recommend a loudness central value (500 Hz and 1 kHz) between 4 dB and 5.5 dB.

Table 5: G(Strength) and SPL values for nine seats at 1 kHz.

SEAT	**SPL**	**Level ref**	**G**
A1	80.68	76.73	3.95
A2	80.38	76.73	3.65
A3	80.67	76.73	3.94
A4	78.81	76.73	2.08
A5	79.23	76.73	2.5
A6	79.24	76.73	2.51
A7	79.47	76.73	2.74
A8	79.75	76.73	3.02

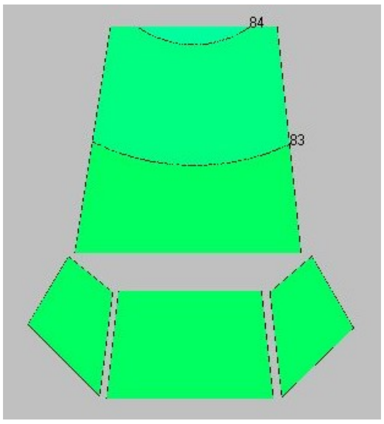

Figure 10: Total SPL variation [dB]

As can be seen, table 5 shows strength values at 1 kHz and this are between 2 dB and 4 dB, therefore they are closer to Barron revised theory but also there are not bad for Beranek theory. In second place, figure 10 shows sound pressure level variation for audience area, and the difference between first and last rows is less than 3 dB, in other words, is hardly perceptible for the human ear.

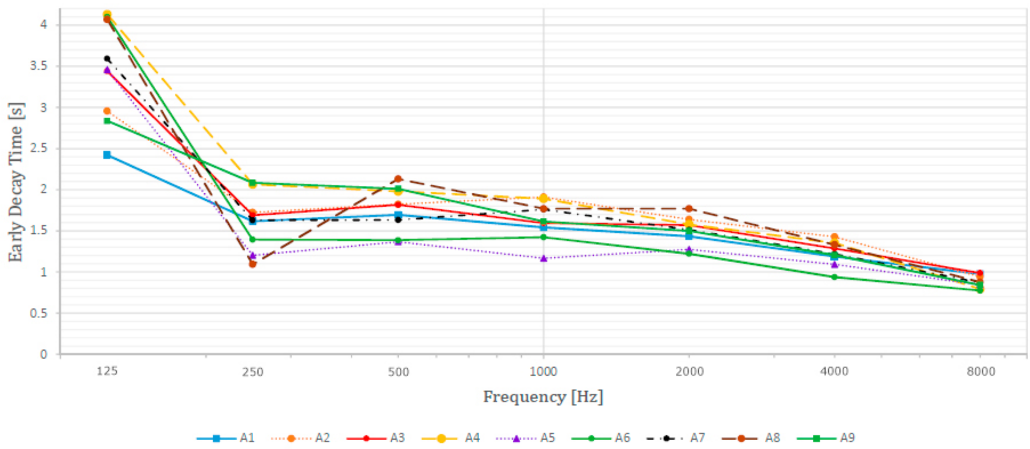

Figure 11: EDT values for 9 seats.

8.2 EDT

With the method described in last section, obtained values are shown in figure 11.

The EDT is defined so that for a linear decay it takes the same value as the reverberation time. Because of this, the same criterion can be applied to both measures of between 1.8 and 2.2 seconds. Whereas the reverberation time (RT) tends to be constant throughout a hall, the EDT varies with position. Particularly low EDT values are normally found under deep balcony overhangs[2]. Based on Barron theory EDT values (except for frequency of 125 Hz which explain later) are correct because the average is between 1.5 s and 2 s, and that last part of the reference can explain why seats A5-A6 under the ceiling in balcony have a lower value. Therefore, EDT and RT at mid frequencies are very similar, this reveals a good diffuse sound field.

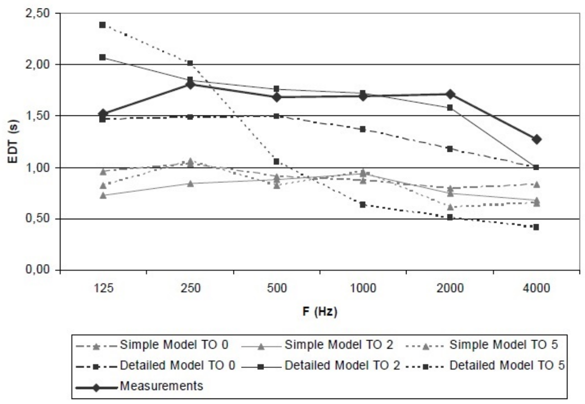

Figure 12: EDT values of Aspendos theater.[5]

While a higher EDT value on low frequencies can be product of a vibration problem[6]. Or, in this case, a resonance in certain materials (concrete for example), but nevertheless this fact would alter the results of RT and SPL variation. Another explication about this phenomenon underlay in the order of reflections(and the method) in simulation software, figure 12 shows the EDT values for different prediction sample models.

The transition order (or "cut off order" in software) at which calculation method changes from image-source to ray tracing can be adjusted according to the complexity and shape of the room. If T.O. is set to 0 the calculation method used for all reflections will be the secondary source / ray tracing method. For simulated EDT the simple model seems to underestimate this parameter to a great degree regardless of transition order. For detailed model the best results are obtained when using a transition order of 2. For a higher transition order then 5 error becomes much larger [5]. Considering that in simulation it was used a 5 cut off order and compare both curves it can be seen a strong similarity.

8.3 IACC

The interaural cross correlation is one of the most relevant parameter in the subjetive evaluation of an auditorium. Ando demonstrated trough experiments from the point of view of the sound spacial impression, that the most important first reflections are those that reach ears of the spectators with an angle between 35° and 75° (with respect to the vertical plane that goes through them) it is therefore lateral first reflections. This type of reflections can be generated by handrails corresponding to balconies, by side walls of auditoriums with a rectangular shape, or by special reflectors placed on side walls [3]. Figure 13 illustrate IACC obtained values.

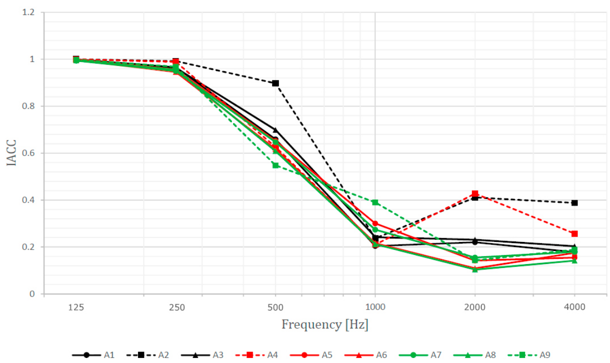

Figure 13: IACC values for nine seats.

Taking into account that walls of the side balconies are used like reflectors and that a great value for a concert hall is 0.4/0.3 or less (in mid-freq) [7], prove that the auditorium has a good ASW.

Also, two interesting aspects to analyze put foward in this figure. In first place, dotted lines that correspond to central seats presents highers IACC values and this is tied with the second aspect, the relation between wavelength and phase difference. The higher is the frequency (shorter wavelenght) the diffraction and scattering by the head and pinna affect IACC and the lower is frequency (higher wavelenght) a 90° sound incidence maximize the phase difference between ears. In addition to this it can be seen that in L. Beranek, Concert Halls and Opera Houses - Music, Acoustics, and Architecture, Appendix B. that all various concert halls studied presents same tendency. Therefore, this explain why lower frequencies have the most higher IACC values.

9 REMARKS

Next item list propose a set of implementations for better results in the project.

- Import the reflector design to simulation software, this action can greatly improve the ITDG values, especially in central rows.
- In the same way as last item, make more realistic design in software simulation, in other words, add audience steps, choir balcony and seats.
- Use different transient order (cutoff order) in the creation of binaural response, investigate and compare to determinate the best conditions in this case.
- Add reflectors on the side walls that this enhancement eliminate flutter echoes possible creation and decrease ITDG and IACC values, getting a better subjective evaluation of the concert hall.
- Implement knowledge learned in module II to make building acoustics study and provide more acoustics parameters like noise criteria (NC) that was established on 45.
- Realize psychoacoustic test with the convolution between binaural response file from different auditoriums and an anechoic recording (instrumental or orchestra) to visualize the relation between subjective evaluations and acoustic parameters obtained by simulations.

As a final conclusion, this report made in Acoustics and pyschoacoustics II subject helps a lot to understand basic acoustics inside an auditorium and increases the desire to investigate and continue learning to students who are interesting in this field.

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