THE ACOUSTIC DESIGN OF THE KURSAAL CENTER

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ABSTRACT:
The Kursaal Centre of Donostia was inaugurated in 1999.
The main hall of 1839 seats is used for symphonic music, opera and conventions and cinema.
The Kursaal Centre of the Architect Rafael Moneo has obtained the main existing awards at the moment in the Architecture world.
In this paper we will treat about the auditorium as a concert hall. We will expose about designing aspects of the hall and we will realise an analysis about the acoustical magnitudes obtained.
Its acoustic is so admirable that even two years later has filled with praises pages of the main newspaper.

1. INTRODUCTION

The main hall of the Kursaal has been designed to be used both for symphonic music and opera house. Also, it will be able to be used for conferences, reinforced music, congress activities and cinema.
This hall will have 1839 seats. The appearance of a shell enclosure transforms the Opera House to a Concert Hall.
The hall is rectangular with longitude 41.5 m from mouth stage and width of nearly 26 m between sidewalls. The shell enclosure has a floor area for musicians of 251 m^2. The shell maximum height is 10.5 m, (which is prolonged inside stage by an inclined plane until 11.95 m), and the minimum is 7.7 m.
The main stall is placed in front of the stage. The main stall is softly raked. Behind this, there are two elevated terraces, steeply raked and called amphitheatre one and amphitheatre two. At both sides of these terraces are nine boxes.
The sidewalls are formed by inclined surfaces to provide good specular reflections to the audience area and, at the same time, taking care to avoid echoes and long-path reflections.
The ceiling is formed in each transversal section by two inclined surfaces that rise from the sidewalls to the centre. In the longitudinal section there are four planes increasing their height, in relation to stage platform, from the stage to rear wall of the hall.
The hall is completely made of plywood, the main absorption is due to the seats, musicians and audience.
In symphonic use, the reverberation time at mid-frequencies, fully occupied with shell and with musicians on stage, will be 1.86 sec.

In opera use the shell enclosure will disappear. In this situation, the reverberation time at mid-frequencies, fully occupied, will be 1.55 sec.
In the conference-use it will appear several velvet curtains covering the sidewalls and the stage. In this use, the reverberation time at mid-frequencies, fully occupied, will be 1.3 sec, good for reinforced music, conferences and cinema.
The background noise inside the hall it will be really low. With air conditioning system on, it will satisfy the NC-15.

2. ARCHITECTURAL AND STRUCTURAL DETAILS

Usage: Symphonic music, opera, reinforced music, conferences and cinema. *Ceiling:* 20 mm to 35 mm plywood with airspace behind. *Side, front and rear walls:* 20mm or 30 mm plywood + gypsum board fixed to wall with a hard and elastic fill up material. *Floor:* Oak parquet fixed over rigid floor. *Carpet:* none. *Stage enclosure:* Yes. *Stage floor:* 40 mm pine over deep airspace (and 15 mm of oak wood placed above pine only for symphonic music). *Stage height:* 0.60 m. *Added absorptive material:* (Only in reinforced music and conferences) Velvet curtains covering the side walls and also the back stage wall. *Seating:* Special designed, rigid seat back, front of seat back upholstered; top of the seat-bottom upholstered; underseat, wood linear perforated Helmholtz resonator.
Architect: Rafael Moneo. *Structural Engineer:*Jesús Jiménez NB35.*Acoustical Consultant:* Higini Arau..

Acoustical and technical details*

Concert hall

V = 17530 m^3	S_A = 1282 m^2	S_o = 251 m^2
S_T = 1533 m^2	N = 1839	
H = 13.86 m	W = 26 m	L = 41.5 m
D = 41.5 m	SD = 15.4 m	SW = 18.25 m
SH = 9.5 m	V/S_T = 12.85 m	V/S_A = 13.67 m
V/N = 9.53 m^3	S_A/N = 0.697 m^2	H/W = 0.53
L/W = 1.596		
T_{MID} = 1.87 s (occ.)	EDT_{MID} = 2.17 s (unocc.)	EDT_{MID}/T_{MID} = 1.08
$C_{80\ MID}$ = 2.0 dB (occ.)	BR(occ.) = 1.15	LEF (unocc) > 0.20
ITDG = 21 ms	G_{MID} (unocc) =6.4 dB	ST1 = -13 dB

Opera house

V = 14956 m^3	S_A = 1282 m^2	S_o (pit)= 120m^2
S_T = 1402 m^2	N = 1839	V/S_T = 10.67 m
V/S_A = 11.67 m	V/N = 8.132 m^3	S_A/N = 0.697 m^2
T_{MID} = 1.58 s (occ.)	EDT_{MID} = 1.80 s (unocc.)	EDT_{MID}/T_{MID} = 1.14
$C_{80\ MID}$ = 4 dB (occ.)	BR(occ.) = 1.25	LEF (unocc) > 0.20
RASTI = 0.6 (occ.)		

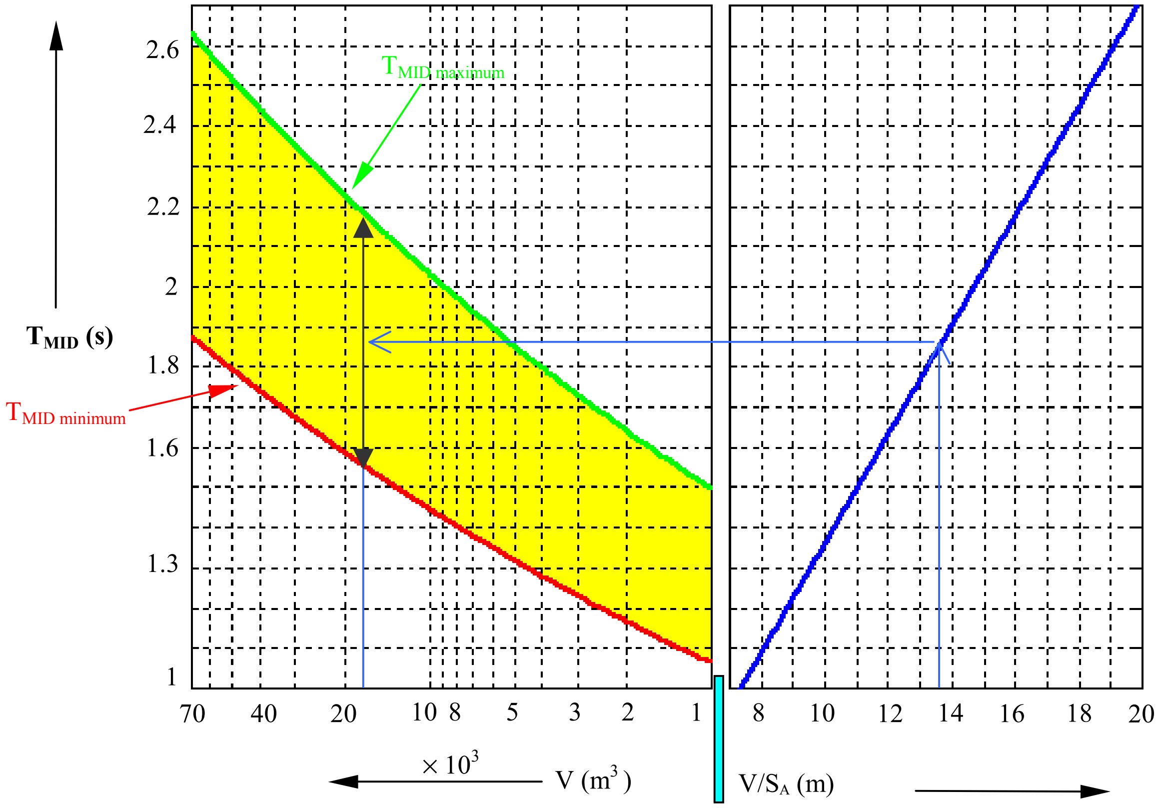
Conferences, Reinforced music and cinema

T_{MID} = 1.3 s (occ.)	*RASTI* > 0.6 (occ.)

* *The terminology is explained by Leo Beranek in Appendix 1 of [1] How They Sound Concert and Opera Halls written.*

The Reverberation Time predicted using the H.Arau Theory, [2], is: T_{mid} = 1.86 s. This is shown in the figure 1.

KURSAAL CONCERT HALL



V: Air volume hall (included acoustical shell)
S_A: Acoustical audience area. It includes de area of floor space over which the audience chairs are located, the aisles and the areas of strips 1.5-m wide around the seating area.

Figure 1: Correlation between the optimum reverberation times for music (T_{MID}) and the relation volume versus audience area, of according to the theory of H.Arau, [2], [3].

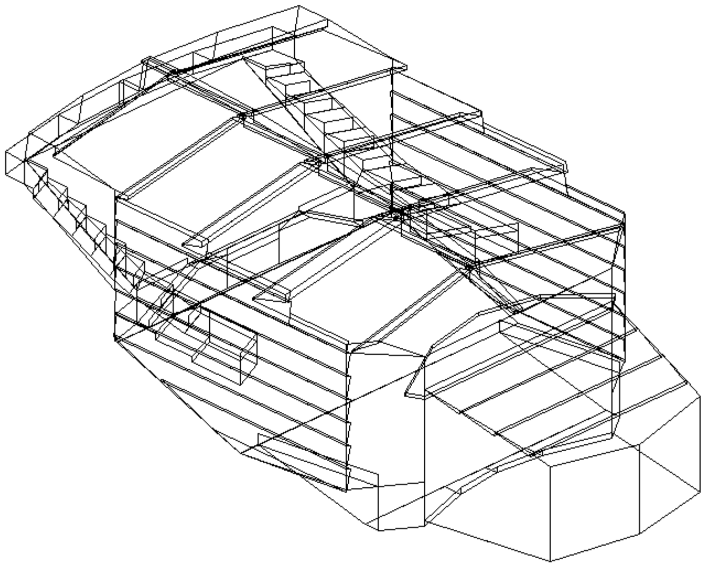


Figure 2: Kursaal Concert Hall in a 3D view.

3. EXPERIMENTAL ANALYSIS AND COMPARISON WITH OTHER SYMPHONIC HALLS

Following we expose the values measured, with MLS of according ISO 3382, in the Kursaal for unoccupied and occupied seats, and moreover we realise a comparison with the best halls considered, [1], [4].

- **RT REVERBERATION TIME**

RT Kursaal	**125**	**250**	**500**	**1000**	**2000**	**4000**	T_{low}	T_{mid}	T_{high}
RT unoccupied	2,85	2,66	2,42	2,40	2,45	2,36	2.76	2.41	2.41
RT occupied (*)	2.28	2.11	1.93	1.80	1.76	1.78	2.19	1.87	1.77
RT occupied (**)	2.45	2.19	2.13	1.99	1.94	1.94	2.37	2.06	1.94
RT Boston									
RT unoccupied	2.13	2.29	2.40	2.63	2.66	2.38	2.21	2.51	2.52
RT occupied	1.95	1.85	1.85	1.85	1.65	1.30	1.90	1.85	1.47
RT Viena									
RT unoccupied	2.97	3.03	3.06	3.05	2.67	2.10	3	2.86	2.38
RT occupied	2.25	2.18	2.04	1.96	1.80	1.62	2.21	2.00	1.71
RT Concertgebouw									
RT unoccupied	2.68	2.51	2.55	2.62	2.39	1.96	2.59	2.58	2.19
RT occupied	2.20	2.15	2.05	1.95	1.80	1.55	2.17	2.00	1.67

(*) With 150 musicians included choral on stage
(**) Without musicians on stage

Table 3: Reverberation Time for unoccupied and occupied seats

The occupied RT values have been obtained from the expression given by [3], using the experimental test values obtained in a reverberant room of "Laboratori General d'Asssaigs i Investigacions".
The incremental absorption values α among occupied and unoccupied seats were:

	125	**250**	**500**	**1000**	**2000**	**4000**
Incremental absorption $\Delta\alpha$	0.130	0.136	0.129	0.187	0.244	0.201

Table 4: Table of the incremental absorption values $\Delta\alpha$ among occupied and unoccupied seats.

NOTE: These values will be used with the expressions [4], proposed by Bradley, to obtain the energetic magnitudes for occupied condition.

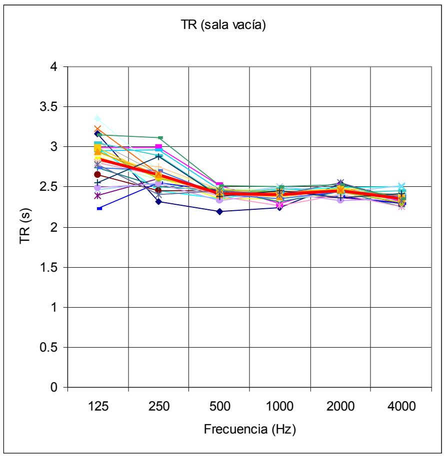


Figure 4: Reverberation Time Kursaal hall unoccupied

- **WARMTH AND BRIGHTNESS INDEX**

Averaged values (occupied)	**Warmth (T_{low} / T_{mid})**	**Brightness (T_{high} / T_{mid})**
Kursaal	1.15	0.95
Boston	1.03	0.79
Musikverein saal	1.11	0.85
Concertgebow	1.08	0.83

Table 5: Warmth and brightness for occupied state

- **EDT EARLY DECAY TIME**

EDT (s)	**125**	**250**	**500**	**1000**	**2000**	**4000**	**EDT_{mid}**
Kursaal Unoccupied	2,47	2,35	2,20	2,14	2,13	1.86	2.17
Kursaal Occupied	2,12	2.02	1.94	1.78	1.68	1.53	1.86
Boston Unoccupied	1.63	1.94	1.96	1.78	1.78	1.50	1.87
Musikverein Saal Unoc.	2.96	3.04	3.05	3.01	2.71	2.09	3.03
Concertgebow Unoc.	2.61	2.50	2.59	2.66	2.42	2.00	2.63

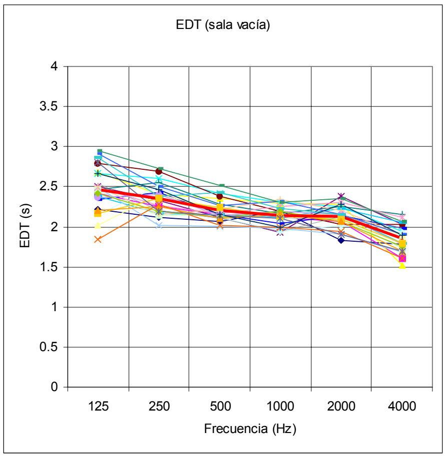


Table 6: EDT values for unoccupied and occupied state

Figure 5: measured EDT Kursaal (unocc.)

- **CLARITY INDEX C_{80}**

C_{80} dB	**125**	**250**	**500**	**1000**	**2000**	**4000**	**$C_{80\ mid}$**
Kursaal Unoccupied	-1.8	-0.5	1.10	1.08	0.26	1.27	1.09
Kursaal Occupied	-0.92	0.38	1.85	2.14	1.61	2.38	2
Boston Unoccupied	-2.42	-2.63	-2.76	-2.52	-2.97	-2.31	-2.63
Musikverein Saal Unoc.	-5.28	-5.47	-4.72	-3.95	-3.32	-1.57	-4.33
Concertgebow Unoc.	-5.40	-4.67	-4.19	-3.07	-2.65	-1.47	-3.63

Table 7: Experimental Kursaal C_{80} unoccupied

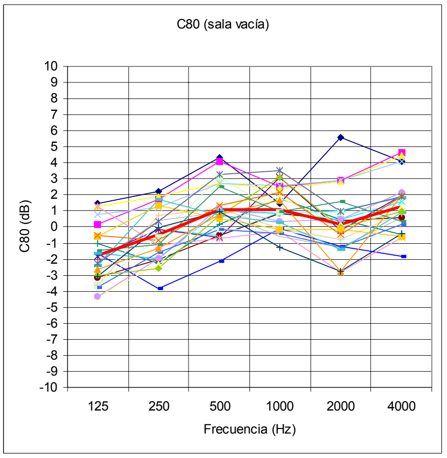


Figure 6: measured Kursaal C_{80} (unocc.)

- **G TOTAL SOUND LEVEL OR STRENGHT FACTOR**

Strength G	125	250	500	1000	2000	4000	G_{mid}
Kursaal Unoc.	8.8	7.2	6.3	6.5	5.5	6.6	6.4
Kursaal Occ.	7.72	6.13	5.38	5.20	3.84	5.24	5.3
Boston Unoc.	1.43	2.61	3.70	4.27	3.70	2.34	3.98
Musikverein Saal Unoc.	6.10	6.04	5.97	6.57	6.04	4.51	6.27
Concertgebow Unoc.	5.46	4.99	5.37	5.71	5.23	4.20	5.54

Table 8: Experimental G

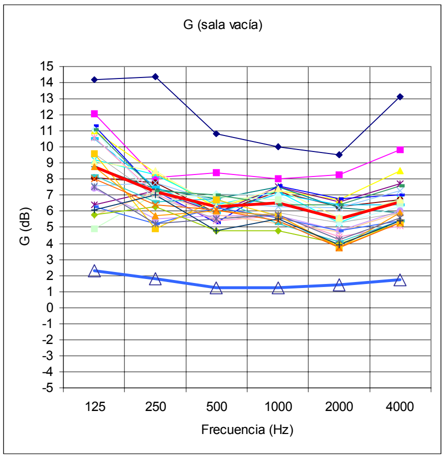


Figure 7: measured G Kursaal (unocc.)

4. CONCLUSIONS

The main hall of the Kursaal Centre, in symphonic configuration, is a very fine hall, as is easy to derive it from of data supplied in our analysis. Is this hall the world's finest symphonic hall? Answer it is useless task because his people they think that it is so and they are happy because it is felt in so his heart; and it was the main goal of our design. However the importance of this hall is that its acoustics is variable being also an excellent opera, a good congress hall and moreover a great cinema hall, where is celebrated the Cinema International Cinema feast of San Sebastian.

5. REFERENCES

[1] L.Beranek (1996) How They Sound Concert and Opera Halls. Ed. Acoustical Society of America.
[2] Higini Arau (1997) Variation of the Reverberation Time of places of public assembly with audience size. Building Acoustics, Volume 4 nº 2.
[3] Higini Arau (1999) ABC de la Acustica Arquitectonica. Ed. CEAC.
[4] J.S.Bradley (1991) A comparison of three classical concert. J.A.S.A. Vol 89 nº3- March.