Proceedings of the Institute of Acoustics

SUCCESSFUL ACOUSTIC DESIGN BY AN ARCHITECT: VICTOR HORTA AND THE PALAIS DES BEAUX-ARTS CONCERT HALL, BRUSSELS

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1. INTRODUCTION

The main Belgian concert hall, the so-called Salle Henry le Boeuf of the Brussels Palais des Beaux-Arts has been inaugurated on October 19, 1929. At the time, it was considered to be one of the very best concert halls in the world.

The concept and the actual detailed design were led entirely by the architect himself, Victor Horta, a key figure of the Art Nouveau school.

Like all other concert halls, opera houses or theatres, the hall has been transformed and new technology has been introduced. Its acoustics has changed. Today, the hall is considered to be too dry. It has lost its extraordinary bass qualities.

It is very difficult to measure this change but it is interesting to investigate what these changes were and what their effects may have been. Each of these modifications could be considered, individually, almost harmless, but they finally led to a significant deterioration of the outstanding acoustics of the hall.

The purpose of the present paper is merely to provide information on the concert hall itself and on its design and to comment some of the measurement results. The effects of the modifications should be accurately evaluated.

2. EARLY ENQUIRIES

Enquiries conducted in 1945 by F. Winckel and around 1960 by L. Beranek, in particular by questioning major orchestra conductors, has confirmed the reputation of this concert hall: the Salle Henry le Boeuf was rated then at the level of the Grosser Muzikvereinsaal in Vienna, the Concertgebouw[1] in Amsterdam and Symphony Hall in Boston.

The Palais des Beaux-Arts concert hall was famous for its rich bass response[2], its intimacy and its warmth and for enhancing the sound of the violin. This particular characteristic is of importance since, in those days, the Belgian school of violin was considered, with Moscow, to be the best.

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[1] It is surprising to find out in the archives of the Horta Museum in Brussels, that Horta, who visited thoroughly the Concertgebouw before embarking in the design of his concert hall, noted that the acoustics of the Concertgebouw had been heavily criticised when it opened. This fact has not been reported, as far as we know.

[2] Of all the halls for which "Average bass ratio " data is available, the Salle Henry Le Boeuf was at the time practically the most efficient.

3. A BRIEF DESCRIPTION OF THE SALLE HENRY LE BOEUF

The plan of figure 1 and the cross-section of figure 2 provide the main dimensions and characteristics of the concert hall. It contains 2150 seats.

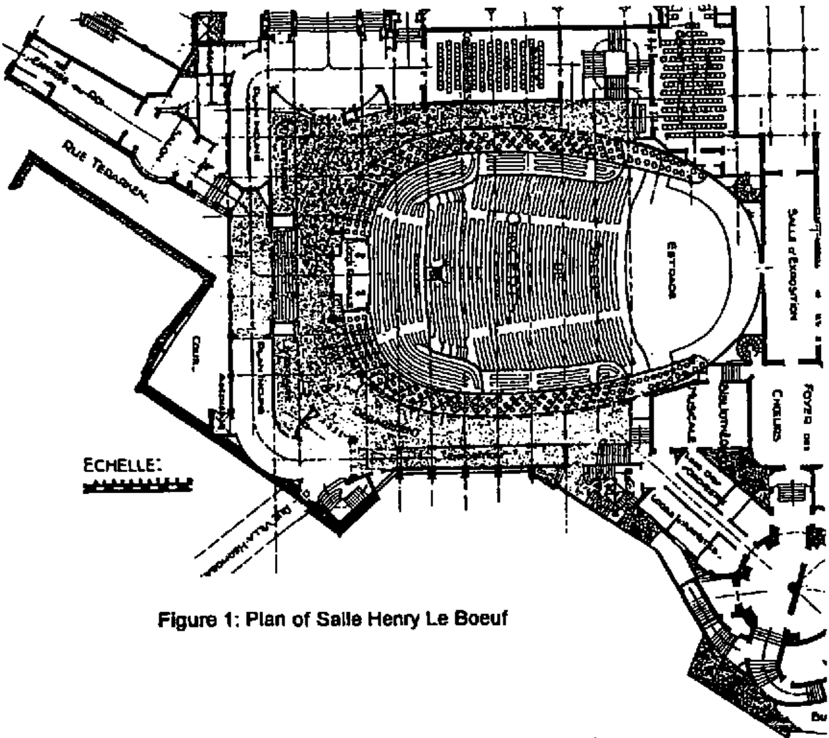

Figure 1: Plan of Salle Henry Le Boeuf

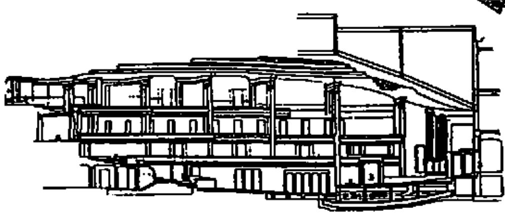

Figure 2: Cross-section of Salle Henry Le Boeuf
1. Stage.- 2. Resonant volume.- 3. Musician's entrance.- 4. Organ.- 5. Stalls.- 6. Circle.- 7. Balcony.- 8. Boxes.- 9. Gallery

Its shape in plan is approximately that of an ellipse which merges, at the stage end, into a trapeze.

According to L. Beranek, its volume is approximately 12500 m3 which means 5.8 m3 per person[3]. Some other estimates provide slightly larger values of the order of 6.5 m3 per person. Anyway, for a concert hall, this volume can be considered quite small since the goal for most recent buildings has been 9 to 10 m3 per person.

The main parameters are as follows:

- Number of seats N_A : 2150.
- Public area $S_A = 1300\ m^2$.
- Stage $S_o = 186\ m^2$.
- Total area $S_T = 1486\ m^2$.
- V / S_A = 8.4 or 9.4 according to various estimates.
- V / N_A = 5.8 or 6.5 according to various estimates.
- S_A / N_A = 0,60.

The materials are the following (present state as of May 1997):

- Ceiling: 75 % plaster on metal grid, 20 % in heavy glass on heavy metal structures, damped by a wire mesh (according to Horta), 5 % of light systems.
- Walls: Plaster on brick residue, painted.
- Columns: plaster on concrete
- Main floor: pine on 75 mm sleepers on concrete
- Upper floors: pine glued directly on concrete
- Stage floor: wooden floor on concrete floor. Under the concrete floor remains the resonant cavity designed by Horta. Originally the floor was pine with an oak veneer as top layer.
- Height of the stage: 92 cm above main floor, first row.
- Carpeting: thick carpet on foam in the stalls, balcony and boxes. The original carpet was presumably thin and on undercarpeting.
- Seats[4] of the stalls, dress-circle, balcony and boxes: seat with absorption on all sides and with thick seat and back (not the original).
- Seats of galleries[5]: seats with thick wood layer under the seat and thin wood layer on the back. Upholstered seat, thin upholstery on back.

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[3] As often happens, surprisingly, the volume is not known accurately. Another evaluation leads to a volume of 14000 m3 or 6,5 m3 per person. It would be quite interesting to obtain reliable measures.

[4] One notices on the original drawings that the seating layout and the aisles have been modified. It is likely that the floor has also been rebuilt.

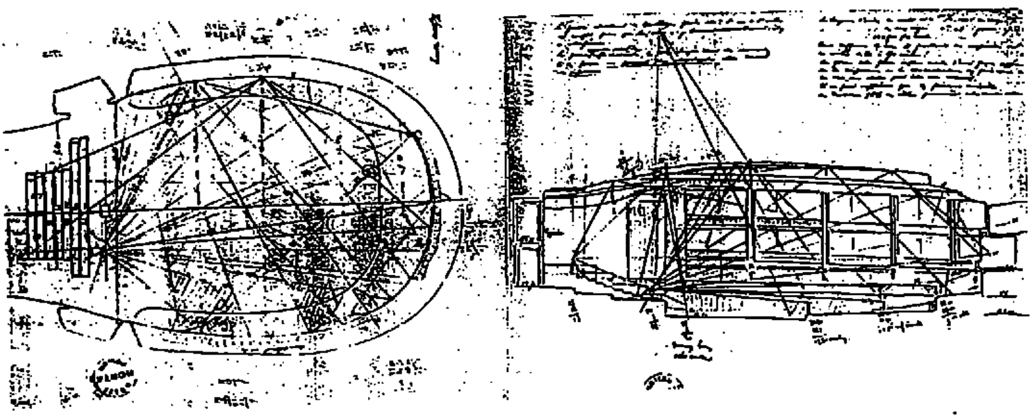
4. HORTA'S APPROACH TO ACOUSTICS

The architect Victor Horta, had been lobbying for the construction of a genuine concert hall in Brussels. In fact, he had been interested in Music for a long time and had, apparently, attended the Gand (Gent) Conservatory of Music before becoming an architect.

When the possibility of designing a large concert hall appeared, he proceeded to educate himself thoroughly in acoustics, consulted known American acousticians, among which Watson, visited many halls in Europe and America.

Little by little, gathering information and knowledge on physical and musical acoustics, Horta summarised the key acoustical rules of concert hall design. None of the rules that he has adopted contradicts today's known approaches, in spite of the progress that has undoubtedly been made in the last seventy years.

Horta defined himself the shape of the hall, its volume, the diffusing ceiling and all the other details. The quasi-elliptical shape is very efficient and provides a feeling of intimacy in spite of its size, the lines of sight are excellent. It is not known whether Horta was fully aware of the pitfalls of the ellipse; for a larger seating capacity and volume, Horta's design would have been problematic as simulations indicate.



Figures 3 and 4: Horta's graphical studies of the acoustics of the concert hall (archives of the Horta Museum).

[5] Today, the galleries are called « second balcony ».

It might be of interest to note that, during the design phase, the architect and his client sometimes sharply disagreed. Henry le Boeuf, who gets considerable credit for having been able to bring the project about in spite of official opposition to the project, attempted to convince Horta to consult a French engineer, Gustave Lyon. Horta resisted rather violently because he had understood that Lyon had a rather dogmatic and brutal approach to acoustics which did not really consider the actual behaviour of a sound field and ignore musical acoustics. Horta later proved that he was right: while Horta was designing and building the highly successful Palais de Beaux-Arts, Gustave Lyon was busy with the Salle Pleyel which turned out to be less than satisfactory. Until today, attempts are being made again and again to improve its acoustics.

On the contrary, the « Grande Salle des Concerts » of Horta has been acclaimed as one of the best concert halls by music-goers and musicians alike. The most knowledgeable conductors and soloists have stressed the exceptional acoustical qualities of this concert hall.

5. AN INVENTORY OF KNOWN MODIFICATIONS

As it is curiously very often the case for most concert halls or opera houses, many modifications have been introduced which seemed harmless. In fact, music lovers and musicians who could remember the excellent acoustics of this hall, noticed a significant deterioration of acoustics.

In the seventies, in particular, for safety reasons, the stage was rebuilt mostly in concrete. This error is quite common and there are several known examples of halls where a concrete stage , floor or orchestra pit has replaced, without due consideration to acoustics, the original wooden structures and floors. Safety considerations receive the highest priority and acoustics is forgotten. The users of the rooms, and foremost among them musicians, notice the dramatic change.

In the case of the Palais de Beaux-Arts, it is surprising that such an incident occurred since a inquiry in Horta's archives reveals quickly that the architect had taken very great care in the design of the stage and its « resonant cavity » as he called it. It is likely that Horta knew more on this subject than contemporary architects.

It is not easy to determine exactly what changes have actually been made to the hall. However an inventory of the main modifications that may have affected the acoustic response of the hall may be attempted.

- Carpet: it is very likely that today's carpet is much more absorptive than the original. It is not clearly established that Horta actually approved the installation of a carpet; it would contradict his skilled approach to acoustical problems [6]. According to the archives, it seems that Horta had been considering a rubber surface, a rather original choice.
- Seats: the seats have been replaced several times. Some copies of the original seat may have been found but nothing is certain. The existing seats can obviously be improved upon.

[6] The order for the original carpet dates from 1930, several moths after the inauguration.

- Stage: the original orchestra wooden stage, made of pine with a layer of oak, has been destroyed in the early seventies and replaced by a concrete stage with a wooden floor on thin sleepers. This modification was decided to reduce fire hazard after a large department store had burnt, with considerable human losses. The resonant cavity, so carefully designed and constructed by Horta, has almost completely disappeared. This is probably the most significant change, from the point of view of acoustics[7].
- Orchestra pit: a makeshift orchestra pit has been introduced, probably around 1975, in an attempt to make the room multipurpose. This device has of course modified the relationship between stage and stalls. It still exists today but is used only occasionally.
- Paint and coatings: the room has been painted and even redecorated several times. The surfaces have been altered but it is hard to know whether the acoustical response of the hall has been significantly altered.
- Organ: the original organ, which did not seem to be a success when it was inaugurated in early November 1930, has been destroyed and replaced by a stage set representing...an organ.[8]
- Lights and other electrical equipment: they have been modified several times. Holes have been made in the ceiling for electrical and television cables. The acoustic response of the ceiling has certainly been modified.

7. SOME MEASUREMENT RESULTS

Of course, in the course of this investigation, measurements have been performed in the hall using classical MLS techniques. For the record, some of the measurement results are reported here and compared with other known measurements.

Most of the tests were performed in the empty hall but it has been possible with the co-operation of the National Orchestra, of the Palais des Beaux-Arts and of the public, to obtain some data with a full audience.

The results of the acoustic tests can be briefly summarised as follows:

- The hall is quite dry in its present state. It is partly due to the relatively small volume but it is also the consequence of various low, medium and high frequency absorption mechanisms that did not exist in the original design.

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[7] It is surprising that the consultant who was questioned at the time approved this modification. It is possible that Horta's resonant cavity had be forgotten by then and that the volume under the stage was considered to be a storage area.

[8] According to a letter by Horta dated February 27, 1930, the floor supporting the organ had been carefully designed: « Le buffet d'orgue (est placé) sur une gaine de chauffage avec isolement réglé ».

- The room impulse response, as illustrated in figure 5, is close to the typical response expected from a good concert hall, of elliptical shape.

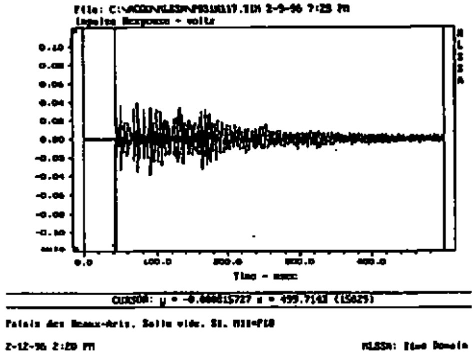

Figure 5: Example of impulse response of the la Salle Henry Le Boeuf

- However the shape of this response varies significantly for various positions of the source on stage or of the receiver in the hall. One cannot claim that the hall's acoustics is uniform. It was found that, in the case of this hall, the presence of furniture on stage and also of musicians contributed to a more even response throughout the hall.
- Even in cases when focalisation effects due to the elliptical shape appear (figure 6), they are never annoying because delays remain short and because there is enough diffusion.

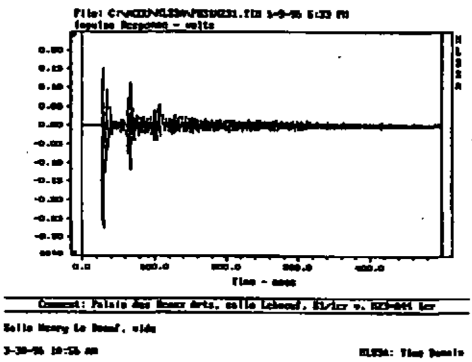

Figure 6: Impulse response with strong reflections.

- Frequency analysis of this response indicates that the distribution of energy vs. frequency is quite correct. However when the stage is empty, one identifies strong reflections for certain pairs source-receiver [9].
- The reverberation time curve, in the present state of the hall, is not what would be expected from such a concert hall. Reverberation time is too short for most seats at low frequencies and it decreases too quickly as frequency increases. Figure 7 summarises recent and older measurements results, for the empty room.

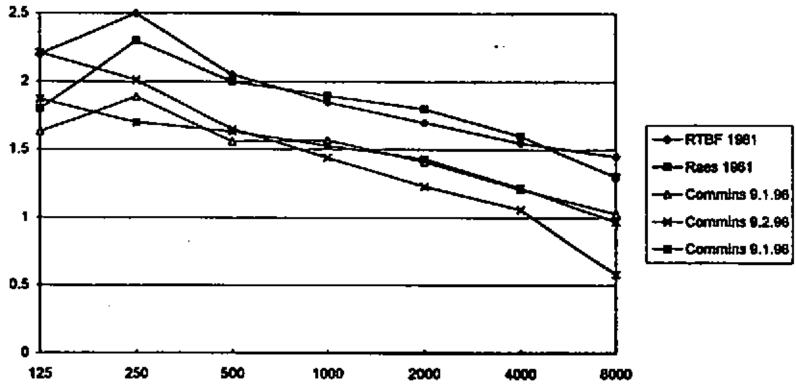

Figure 7: Reverberation time of Salle Henry Le Boeuf, empty.

- It is obvious that the hall is too dry. Objectively, its seems to have been drier in 1996 than it was in 1961, before the most traumatic modifications.

8. CONCLUSIONS

The origin of this investigation was an interest in Horta's approach to acoustics. It actually led to a comparison between early and present acoustical conditions in the concert hall. Hopefully, the next instalment will deal with the recuperation of the hall's acoustics.

The author wishes to thank the Palais des Beaux-Arts and the Horta Museum for giving him the opportunity to analyse this problem

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[9] Since the furniture on stage and the musicians play such an important role, one may assume that this hall is less suitable to recitals or small ensembles that to symphony orchestras.

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SUBJECTIVE PARAMETERS OF MUSICAL ROOMS

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1. INTRODUCTION

The acoustic quality of a listen room depends on different characteristics (volume, surface, form, absorption coefficient, directionality and source location, etc.) that with the properties of the human hearing, establishes the two ways to approach the problem:

- Physical study
- Psychological study .
- Estudio sicológico

By means of the ***physical study*** the process of sound transmission by the room is analyzed, that depends on characteristics of the enclosure, on inherent factors to the sound propagation and on factors of the source.
In the ***pshycological study*** the characteristics of the human hearing chanel, of complex behavior because it depends on variables of difficult quantification is fundamental.

For the first analysis is necessary the knowledge of the characteristics of the emitter source. In "*Concert Halls*" the dependence of the music source on multiple factors as the orchestra location, number of performers, as well as the disposition and types of instruments with their corresponding spectrums, make difficult their treatment, so the calculation is carried out for sources with standard geometry and directivity.

In the pshycological study, subjective criterions of quality are established by means of several parameters that quantify the sensibility of the human hearing to the perceived sign.

On the other hand, in order to stydy thorughly in certain aspects of the problem of the quality of a room destined to the music, it should also be known other own factors of the musical composition, couldn't affirm that a room is "good" or "bad" for the music, but good or bad for certain type of music and instrumental group, in determining points of the room or in all of them.

This complexity of the musical composition and of the auditive mechanism (especially the influential factors on it), have created several lines of investigation. By analyzing them the parameters for the determination of the acoustic quality of concerts halls will be gotten.

2. SELECTION OF ASSESSMENT PARAMETERS

If the study of criterions for the evaluation of rooms is made chronologicaly we would begin by **Sabine**, for whom the only valid parameter was the *reverberation time*. There for, one wonders how many parameters are necessary and enough. In order to respond us to this question we studied comparatively the evolution of several groups of investigators, of several schools (Dresden Berlin, Gottingen, Japan), mentioned in the references. whose conclusions about the searched subjective qualities we collect in three criteria.

- **Energy Criterion** for the study of the quality named ***TRANSPARENCY***
- **Time Criterion**. quantify the quality named ***REVERBERATION***
- **Spatial Criteria** for the calculation of parameters which give the ***SPACE SENSATION***

The study of the several schools, their analysis and differences, conduct us to the election of the qualifiers parameters of Concert Halls. We have to indicate that there is another series of parameters in each block that we considered them as previous demands to the room or as complementary criterion to those selected.

Energy Criterion

The relationships energy-time are assessment of the transparency, that means the separately perception of tones in time and of instruments played simultaneously.

The first energy parameter is named DEFINITION (D) (Deutlinchkeit). This parameter relates the early energy reaching the hearer in the first 50 ms. to the total energy received.

$$D=\frac{E_{0-50}}{E_{0-\infty}}=\frac{\int_0^{50} p^2(t)\,dt}{\int_0^{\infty} p^2(t)\,dt}$$

A lack of Definition in a room is indicative that it is deficient in intimacy, it has possible echoes and long times of reverberation. This parameter doesn't depend on the type of music and situation in the room and its good values is between 0,4 and 0,6.

Following the criterion of energy relationships function of the arriving time, this was increased from the first 50 ms. used in the Definition, to an interval of effective energy of 80 ms. after the arrival of the direct sound in the next parameter, the **CLARITY**:

$$C=10\log\frac{E_{0-80(ms)}}{E_{80-\infty(ms)}}=10\log\frac{\int_0^{80} p^2(t)\,dt}{\int_{80}^{\infty} p^2(t)\,dt}\quad (dB)$$

This parameter represents the correct perception of the details of a composition. It depends on the style of music and situation in the room and their optimum values are between 3 and 8 for front seats and between 0 and 5 for the back seats.

Time Criterion

The time calculation of the room answer will conduce to determine the reverberation that was for many years the fundamental characteristic for the assessment and design of rooms. In music this characteristic can have a positive effect (fused effect) or a negative one if it decreases the necessary transparency.

Their calculation will be carried out by means of the equations by **Sabine, Eyring, Millington, Pujolle.**, as well as for several techniques that minimize the error in the absorptions.

Shows next the optimal values of RT, parameter that depends with the frequency and style of music, basing us in the studies in concert halls that **Beranek** and **W.Kuhl** carried out independently. A first limitation in the range of values of this parameter will be carried out for half frequencies (500-1000Hz) attending to the style of music. The optimun values in seconds are the following:

- *Baroque music* (1600-1750), RT: 1.4-1.6
- *Classical music* (1750-1820, RT: 1.6-1.8
- *Romantic music* (1820-1920), RT: 1.9-2.2
- *Non Wagnerian opera* (1700-), RT: 1.4-1.7
- *Wagnerian opera* (1865-1931), RT: 1.8-2
- *Gregorian song* , RT: 3
- *Modern músic* (1920-):RT: 1.4-1.9

Respect to the optimum reverberation time for the modern music, is supposed that, due to the great variety of music and composers in this century, it is difficult their assessment., the reverberation times will be the suitable.

For the valuation of these parameters to the totality of the frequencies, the following approaches will be applied:

LOW FREQUENCIES

$\frac{RT_{125}}{RT}$ values from 1 to 1.3

$\frac{RT_{250}}{RT}$ values from 1 to 1.2

HIGH FREQUENCIES

For each musical style, according to the Reverberation Time obtained for half frequences, the adequate coefficients in the table will be applied.

	$\frac{RT_{2000}}{RT}$	$\frac{RT_{4000}}{RT}$	$\frac{RT_{8000}}{RT}$
(1)Rooms with low RT	0.93	0.83	0.75
(2) Rooms with high RT	0.91	0.80	0.67
(3) Rooms with adequate RT	0.95	0.83	0.73

Classical music - Wagnerian opera

RT ≤ 1.6: The coefficients (1) will be applied
1.6 < RT < 1.8: The coefficients (3) will be applied
RT ≥ 1.8: The coefficients (2) will be applied

Baroque music - Non Wagnerian opera

RT ≤ 1.6: The coefficients (1) they will be applied
1.4 < RT < 1.6: The coefficients (3) they will be applied
RT ≥ 1.6: The coefficients (2) they will be applied

Romantic music

RT ≤ 2.1: The coefficients (1) they will be applied
2.1 < RT < 2.3: The coefficients (3) they will be applied
RT ≥ 2.3: The coefficients (2) they will be applied

The second parameter in this group is the EARLY DECAY TIME (EDT) defined as "The Reverberation Time for a decrease of 10 dB" .It is the most subjective parameter and it depends on the frequency and on the style of music. Its ranges and its optimum values are obtained by decreasing a 10 % the Reverberation Time values.

Spatial Criteria

The impression of space corresponds with the auditive sensation that one, in an enclosure, is beside the sound source, and for a great number of investigators this quality could be the fundamental attribute.

The most signiticative and influential factors for this quality can be abridged in:

- Origin of the early reflections. Masking
- Secuence of the early reflections
- Arriving Angle

The spatial impression is determined for the lateral early reflections, being these affected for their masking, that is very depending on the form of the room. The greatest masking is that produced by the reflections on the roof that they don't suffer attenuation in the audience. Therefore, the lateral reflections will be audible if they arrives before those coming from the roof, and not audible if their arrival is later. So the importance of the width-high proportions of the room.

The representative parameters for the study of the directional distribution of the energy are: **LATERAL ENERGY FACTOR** (L), **CORRELATION DEGREE** (Korrelationsgrad, K), and **INTERAURAL CROSS CORRELATION** (IACC).

The **LATERAL ENERGY FACTOR** (L) represents the relationship between the energy that arrives sidelong to the listener during the first 80 ms since the arrival of the direct sound, and the total energy in the same time. Their equation of definition is the following:

$$L=\frac{\int_{5}^{80} p^2(t)\cos^2(\theta)dt}{\int_{0}^{80} p^2(t)dt}=\frac{\sum_{5}^{80} E_i\cos\theta}{\sum_{0}^{80} E_i}$$

where E_i is the the energy of each ray and θ the angle between the falling in direction and the axis of the hearings.

The component of the energy on the axis of the hearings ($\sum_{5}^{80} E_i\cos\theta$) is calculated in the interval from 5 to 80 ms due to the lateral reflections before the first 5 ms is less probable.

The experimental study of this parameter reflects that it is linearly related with the impression of space , and its minimum advisable values are between 0,2 and 0,3.

Measuring the impulsive answer of the room with a dummy-head, and correlating the sign in the two hearings, two parameters have been defined: the **CORRELATION DEGREE** (K) and the **INTERAURAL CROSS CORRELATION** (IACC). Both are calculated by averaging to half-high frequencies with omnidirectional source.

The first represents the relationship between the not lateral early energy and the total early energy.

$$K_t=\frac{\int_0^t p_1(t)\,p_2(t)\,dt}{\sqrt{\int_0^t p_1^2(t)dt\int_0^t p_2^2(t)dt}}=\frac{E_{0-100(\text{no lateral})}}{E_{0-100(\text{total})}}$$

$p_1(t)$ and $p_2(t)$ are the signs arriving to each hearing, t is the interval of time of the sign used in the correlation. The better correlation with subjective preference is gotten using only the initial part of the impulsive answer, $t=100ms$.

The front energy is that which arrives to the receiver inside an angle of ±6° with its frontal axis.

The prefarable acoustic fields are those that have great part of their early energy falling in sidelong, getting good values for K from 0,3 to 0,4.

The last parameter of this block, **INTERAURAL CROSS CORRELATION** (IACC), is defined as the cross correlation between the impulse answer measured in both hearings, and it is indicative of the grade of similitude existent between the signals arriving them. If these are equal, this parameter will be the unit, and null if they are independent aleatory signals. Today two indexes of crossed correlation exist that differ in the interval of time that consider for the signal: the $IACC_E$ and the $IACC_L$.

The $IACC_E$ corresponds at first 80 ms since the arrival of the direct sound and it is related with the space impression. Its equation of definition is the following:

$$IACC_E = \max\left[\frac{\int_{0{,}005}^{0{,}08} p_i(t)\ p_d(t+\tau)\ dt}{\sqrt{\int_{0{,}005}^{0{,}08} p_i^2(t)\,dt \int_{0{,}005}^{0{,}08} p_d^2(t)\,dt}}\right], \tau \le 1ms$$

Being $p_i(t)$ y $p_d(t)$ the impulse answers measured respectively at the end of the left and right external auditive ducts and τ the delay time between them.

In the same way, the $IACC_L$ is defined starting from the 80 ms as:

$$IACC_L = \max\left[\frac{\int_{0{,}08}^{\infty} p_i(t)\ p_d(t+\tau)\ dt}{\sqrt{\int_{0{,}08}^{\infty} p_i^2(t)\,dt \int_{0{,}08}^{\infty} p_d^2(t)\,dt}}\right], \tau \le 1ms$$

and it is indicative of the grade of diffusion of the room.

The best values for the IACC are gotten in a field with abundant lateral reflections, being between 0,2 and 0,6. The best one is below 0,4.

3. VALUATION SCALES

Next we propose the selected acoustic parameters and their punctuation according to individual scales and considering their variability with the type of music.

In order to give to the qualification a general character and because of the variability of the musical sound source, so much the calculation as the measurements will be carried out with omnidirectional spherical punctual sound source.

In order to get a global valuation, we have begun establishing an individual scale for each one of the seven selected parameters, with a maximal punctuation of 10 points in their best values. Later, we carried out a pondered sum with the punctuations gotten in each one of them, getting a global punctuation that indicates us if the room is adequate or not for determined musical style. That is to say:

$$V = \sum_{i=1}^{7} \alpha_i C_i$$

The ponderation coefficients, α_i, used for each parameter, in base to the bibliographical revision carried out, are the following:

- Energy Criterion, 30 points: **D** (10 points), **C** (20 points)
- Time Criterion, 30 points: **RT** (10 points), **EDT** (20 points)
- Spatial Criteria, 40 points: **L** (10 points), **K** (10 points), **IACC** (20 points)

Gotten their global valuation, V, the analyzed room will be qualified as:

Excellent:]90,100]

Good: [70,90[

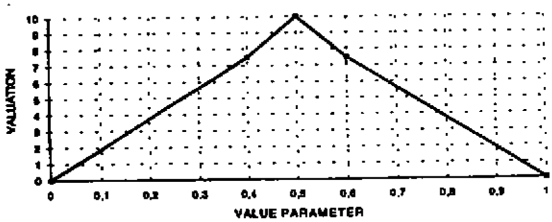
Critical: [50,70[

Deficient: [0,50[

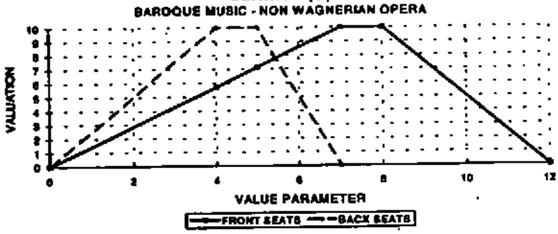
Next we indicate graphically, the valuation scales for the different parameters: C_D, C_C, C_{RT}, C_{EDT}, C_L, C_K, C_{IACC}.

VALUATION SCALES. ENERGY CRITERION

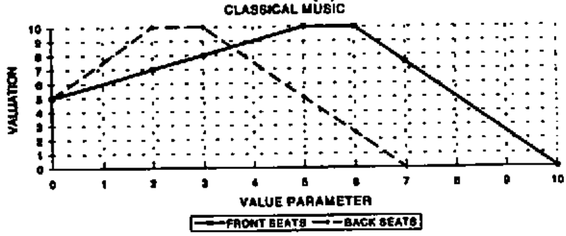
DEFINITION (D)



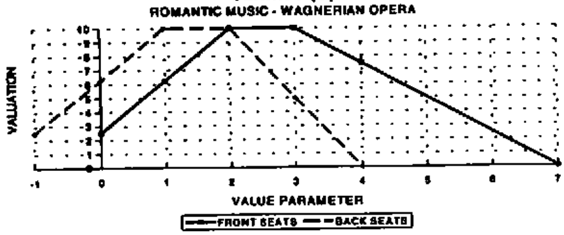
CLARITY (C)
BAROQUE MUSIC - NON WAGNERIAN OPERA



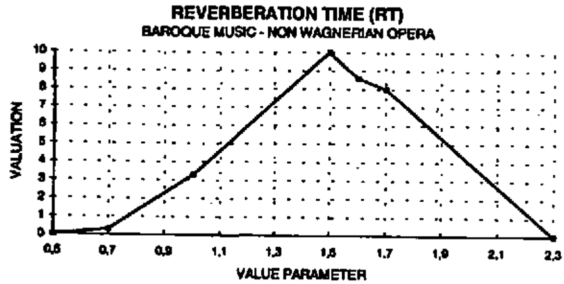
CLARITY (C)
CLASSICAL MUSIC

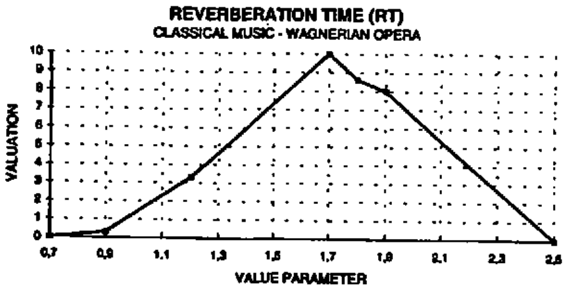


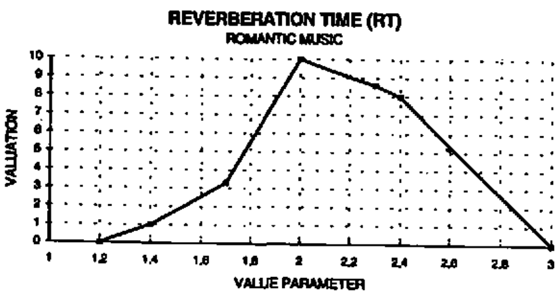
CLARITY (C)
ROMANTIC MUSIC - WAGNERIAN OPERA



VALUATION SCALES. TIME CRITERION

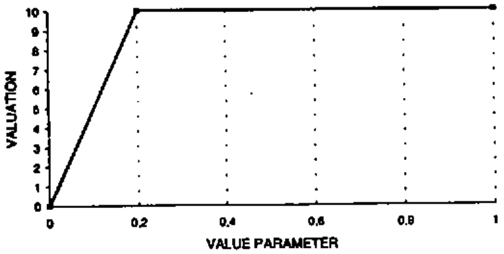




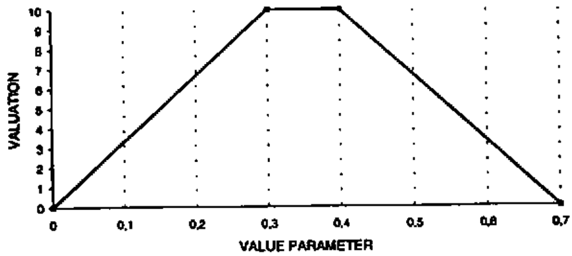


VALUATION SCALES. SPATIAL CRITERIA

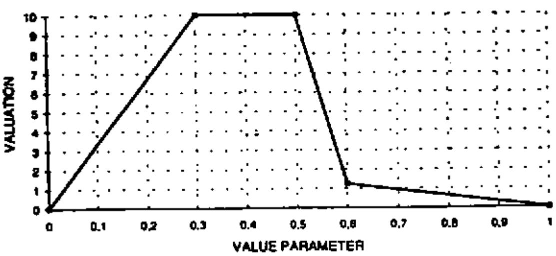
LATERAL ENERGY FACTOR (L)



CORRELATION DEGREE (K)



INTERAURAL CROSS CORRELATION (IACC)



4. EXPERIMENTAL RESULTS

The selected parameters are gotten by means of a calculation program implemented in a computer based on the ray tracing method, with omnidirectional spherical punctual sound source.

The calculation of the energy and spatial parameters is carried out in each zone in that the surface of audience of the room have been divided, fixing the origin of times with the arrival of the first ray and accumulating the energy in the intervals of time and the range of angles fixed by each parameter. In the same way, the temporal parameters are gotten from the sound curve of the room, obtained by the geometric tracing of the "sound rays" and their distribution temporal-spatial.

Among the several studied rooms, we include the outputs of the AULA MAGNA in the UNIVERSITY OF VALENCIA, room of prismatic irregular form, maximal dimensions 15.08 x 10.89 x 4.65 m, and with capacity for 172 people.

We must indicate that with this model is not possible to determine the IACC parameter since we worked with energy. So the ponderation coefficients for the spatial parameters K and L have been varied in this case from those proposed, passing to a value of 2, due to the great importance of this quality. At present, we are carrying out this calculation by means of an improven model that operates with the sound pressure and the particle speed, that we hope verify its results very soon.

VALUES OF THE PARAMETERS

ZONE	D	C	L	K	EDT	RT
1	0.53	4.97	0.13	0.20	1.05	1.23
2	0.52	4.08	0.10	0.22	0.95	1.12
3	0.57	4.89	0.10	0.23	1.04	1.20
4	0.52	4.46	0.09	0.21	0.98	1.15
5	0.50	4.66	0.11	0.20	0.80	1.01
6	0.47	3.95	0.14	0.22	0.87	1.05
7	0.49	4.51	0.10	0.24	0.91	1.02
8	0.48	5.04	0.10	0.21	0.83	1.00
9	0.55	3.16	0.11	0.20	0.81	0.95
10	0.55	3.23	0.15	0.22	1.01	1.10
11	0.57	4.06	0.11	0.24	1.07	1.16
12	0.56	2.89	0.10	0.21	0.81	0.91
13	0.59	3.31	0.11	0.20	0.79	0.90
14	0.53	3.14	0.14	0.22	0.85	0.92
15	0.53	3.25	0.09	0.25	0.76	0.95
16	0.58	3.34	0.09	0.21	0.76	0.89

MUSICAL PARAMETERS

PUNCTUATION OF THE PARAMETERS AND GLOBAL VALUATION
CLASSICAL MUSIC

ZONE	D	C		L	K	EDT	RT	GLOBAL VAL.	
		Front	Back					Front.	Back
1	9.25	9.97		6.50	6.67	2.97	3.70	65.16	
2	9.50	9.08		5.00	7.33	1.86	2.50	58.54	
3	8.25	9.89		5.00	7.67	2.86	3.30	62.37	
4	9.50	9.46		4.50	7.00	2.19	2.80	58.60	
5	10.00	9.66		5.50	6.67	0.28	1.40	55.62	
6	9.25	8.95		7.00	7.33	0.97	1.80	59.55	
7	9.75	9.51		5.00	8.00	1.41	1.50	59.09	
8	9.50	10.00		5.00	7.00	0.52	1.30	55.84	
9	8.75		9.60	5.50	6.67	0.30	0.80		53.68
10	8.75		9.43	7.50	7.33	2.52	2.30		64.61
11	8.25		7.35	5.50	8.00	3.19	2.90		59.23
12	8.50		10.00	5.00	7.00	0.30	0.40		53.50
13	7.75		9.23	5.50	6.67	0.27	0.30		51.37
14	9.25		9.65	7.00	7.33	0.74	0.50		59.21
15	9.25		9.38	4.50	8.33	0.22	0.80		54.90
16	8.00		9.15	4.50	7.00	0.22	0.28		50.02

Qualification: critical; superior sound quality in the front seats

PUNCTUATION OF THE PARAMETERS AND GLOBAL VALUATION
BAROQUE MUSIC

ZONE	D	C		L	K	EDT	RT	GLOBAL VAL.	
		Front.	Back					Front.	Back
1	9.25	7.10		6.50	6.67	5.53	6.38	67.23	
2	9.50	5.83		5.00	7.33	4.04	4.91	58.82	
3	8.25	6.99		5.00	7.67	5.38	5.98	64.30	
4	9.50	6.37		4.50	7.00	4.49	5.31	59.54	
5	10.00	6.66		5.50	6.67	2.19	3.43	55.46	
6	9.25	5.64		7.00	7.33	2.97	3.97	59.11	
7	9.75	6.44		5.00	8.00	3.45	3.57	59.10	
8	9.50	7.20		5.00	7.00	2.52	3.30	56.24	
9	8.75		7.90	5.50	6.67	2.30	2.80		56.28
10	8.75		8.07	7.50	7.33	4.94	4.64		69.08
11	8.25		10.00	5.50	8.00	5.83	5.44		72.36
12	8.50		7.23	5.00	7.00	2.30	2.40		53.95
13	7.75		8.27	5.50	6.67	2.08	2.30		55.09
14	9.25		7.85	7.00	7.33	2.74	2.50		61.61
15	9.25		8.13	4.50	8.33	1.74	2.80		57.46
16	8.00		8.35	4.50	7.00	1.74	2.20		53.39

Qualification: critical-good

PUNCTUATION OF THE PARAMETERS AND GLOBAL VALUATION
ROMANTIC MUSIC

ZONE	D	C		L	K	EDT	RT	GLOBAL VAL.	
		Front.	Back					Front.	Back
1	9.25	5.08		6.50	6.67	0.00	0.15	45.88	
2	9.50	7.30		5.00	7.33	0.00	0.00	48.77	
3	8.25	5.28		5.00	7.67	0.00	0.00	44.13	
4	9.50	6.35		4.50	7.00	0.00	0.00	45.20	
5	10.00	5.85		5.50	6.67	0.00	0.00	46.03	
6	9.25	7.63		7.00	7.33	0.00	0.00	53.17	
7	9.75	6.22		5.00	8.00	0.00	0.00	48.20	
8	9.50	4.90		5.00	7.00	0.00	0.00	43.30	
9	8.75		4.20	5.50	6.67	0.00	0.00		41.48
10	8.75		3.85	7.50	7.33	0.00	0.00		46.12
11	8.25		0.00	5.50	8.00	0.00	0.00		35.25
12	8.50		5.55	5.00	7.00	0.00	0.00		43.60
13	7.75		3.45	5.50	6.67	0.00	0.00		38.98
14	9.25		4.30	7.00	7.33	0.00	0.00		46.52
15	9.25		3.75	4.50	8.33	0.00	0.00		42.42
16	8.00		3.30	4.50	7.00	0.00	0.00		37.60

Qualification: deficient

5. CONCLUSIONS

Starting from the published works about concert halls, a global scale of valuation has been gotten, keeping in mind the preferences of the listener for the several musical styles and its possibility of calculation by means of a mathematical model fundamentally based in the geometrical acoustics. The validity of this calculation for enclosures has been checked by means of the statistical program BMDP II, by comparing the theoretical and experimental outputs obtained in several rooms studied in our city. so much of the spectrum of sound levels, as of the values of the proposed parameters. This calculation has been also carried out for the hall GROSSER MUSIKVEREINSSAAL in Vienna, well-known for their excellent acoustic quality and of whose outputs are referenced in the bibliography.

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