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ON THE SPECIFIC PARAMETERS OF THE ARCHITECTURAL ACOUSTICS

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Abstract A brief overview on the specific parameters of the architectural acoustics is presented in this paper. The measurements were carried out to Lyrical Theater and Philharmonic Oltenia from Craiova, Theatre Luceafarul for Athenaeum Tatarasi from Iasi. We tried to give us a clear picture of how these halls sound and how the listeners perceive that sound. Our measurements show that an optimum reverberation time is a compromise between clarity which requires a short reverberation time, sound intensity with a high reverberant level, and liveness requiring a long reverberation time. In addition, the reverberation time is dependent on the use for which it is designed, i.e. speaking, opera, orchestral music, etc.). A short EDT provides clarity and a long RT provides liveness to music. A good audition for theaters and concert halls is obtained only by a strong collaboration between design and acoustics from the beginning and not separately, i.e. after the building was built.

Key words: Architectural acoustics, sound absorption, sound isolation.

1. INTRODUCTION

Speech auditoriums are essential spaces in our life, and the interest in the acoustics of theatres and concert halls has significantly increased in the last years. We know that the ancient architectural acoustics has developed the concepts of reverberation, interference, echo disturbance, and clarity of voice [1]. It was found from measurements beside the reflection from the orchestra floor and the stage tower, the scattered waves and reverberant sound from the audience area. A theater with good acoustics allows sound to propagate for long distances, enabling people to hear music or a play even for sitting far away from the stage. The poor acoustics do not allow the sound to propagate well from one side to another of the space.

Architectural acoustics is the scientific and technological field that deals with the sound quality of buildings [2-9]. The applications of architectural acoustics are addressed to auditoriums and recording studios, but is also found in other types of buildings such as offices or sports halls. Sound audition in the halls is different from free field due to the presence of reflections on the walls. In the free field, only the direct sound comes to the listener. When space is closed, the sound gives rise to a multitude of reflections that decrease in time and space. In a library, for example, it is important to minimize the propagation of sound so that the people can study in comfort. The goal is exactly the opposite in bulky rooms where the people are viewing a performance. The key to sound acoustics is to find a balance between selected material and layout in order to allow sound to be absorbed or reflected in an optimum way for the task of the building that is being designed.

In order to characterize the response of a hall or room in a synthetic way, the acoustics have defined specifically criteria/parameters, such as: reverberation duration, early decay time (EDT), clarity, uniformity, balance, intelligibility and others. For the same hall, the audible perception of audiences will be different depending of the finishes changing. If the walls are too absorbent, the room will be *deaf*, and if too reflective, the room is then *reverberant*. Common requirements for a good acoustic include adequate loudness, uniformity, clarity, reverberance, freedom from echoes, and minimal background noise.

2. REVERBERATION TIME

An important parameter for sound quality of a public halls is the reverberation duration, expressed in seconds. The reverberant sound in a hall dies away with time as the sound energy is absorbed by interactions with the walls. In a reflective room, the sound dies away hardly and the room is said to be *live*. In an absorbent room, the sound dies away quickly and the room is said to be *dead*.

The time for reverberation to completely die away depends on the strength of the sound and on the acuity of the hearing of the observer. To provide a reproducible parameter, a standard reverberation time has been defined as the time for the sound to die away to a level 60 decibels below its original level.

RT60 is the time required for reflections of a direct sound to decay 60 dB. The reverberation time is frequently stated as a single value, if measured as a wide band signal (20 Hz to 20 kHz). However, it can be described in terms of frequency bands (one octave, 1/3 octave, 1/6 octave, etc.). The reverberation time can be modeled as

$$\text{reverberation time} = RT_{60} = \text{time to drop 60dB below original level}. \quad (1)$$

The reverberation measurements T30 were carried out for the Lyrical Theater Craiova (Fig.1). The T30 is a measure of the persistence of sound in the space.

Fig.1. Lyrical theater Elena Teodorini from Craiova.

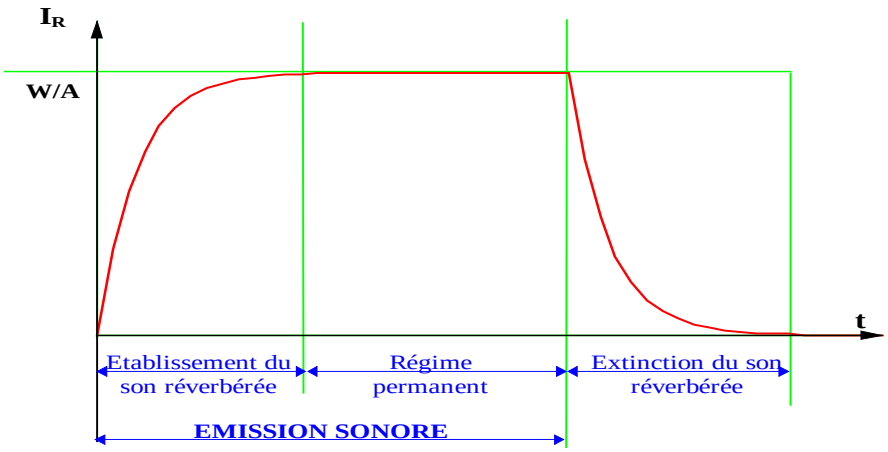

Fig. 2. The reverberation duration.

Fig.2 shows the values of the T30 reverberation time as the average of all scene-room measurement points (36 distinct source-receiver positions) as well as the maximum and minimum frequency values.

For T30 there is a large variation of the results with a continuous decrease of the values between 1.80 and 0.83 sec. The reverberation time decreases continuously from 1.80 sec to 63 Hz and 1.63 sec at 125 Hz, from 1.09 sec to 1000 Hz to 0.83 sec at 4000 Hz

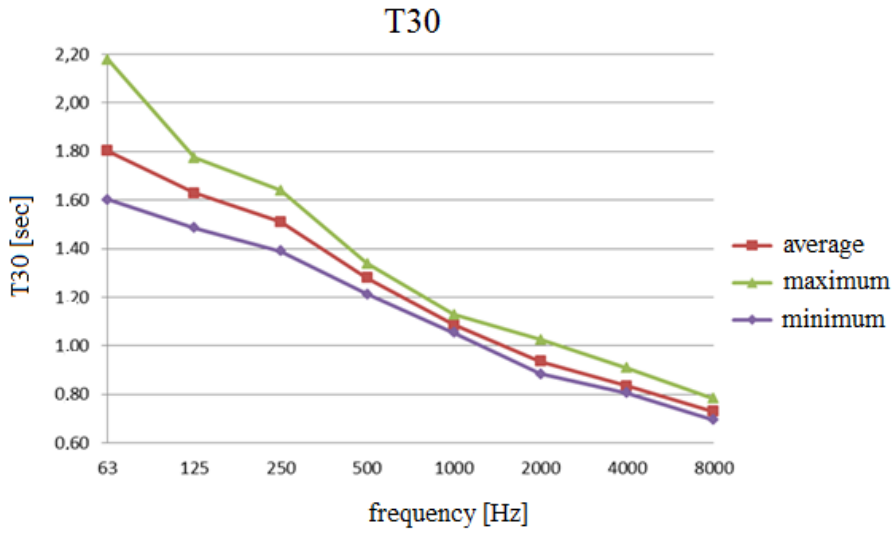

Fig. 3. T30 values averaged between the 36 scene-room metering positions for Lyrical Theater Craiova.

3. EARLY DECAY TIME (EDT)

Despite many efforts of researchers, there is little information available for acoustical design of theatres and the best criteria/parameters to predict a good acoustics.

Extensive measurements show that T30 is a late reverberation time because it is evaluated from the last part of the reverberation curve. The early decay time (EDT) represents the early reverberation time and is considered to better reflect how the reverberance is perceived into the hall.

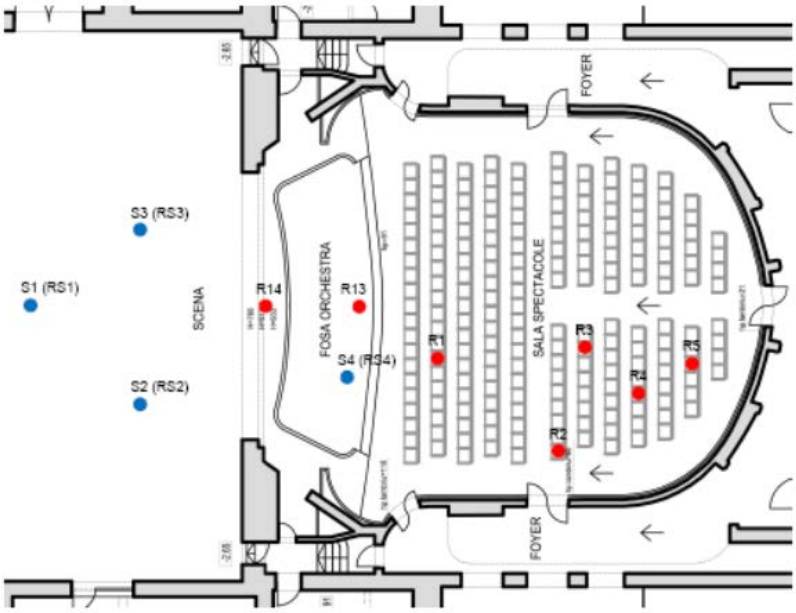

Fig. 4. Hall of Lyrical Theater of Craiova.

The EDT value is determined by the slope of the impulse response curve in the octave bands on the decrease portion between 0 and – 10 dB, calculated for a 60dB decrease. EDT is important from a subjective point of view because it is related to the reverberation perceived by listeners, while T30 is dependent on the physical properties of the auditorium.

The EDT measurements were made to the Hall of the Lyrical Theater Craiova (fig.4) and are presented in Fig.5. The values of the reverberation time and the early decrease duration indicate a suitable room dedicated for example to a theater, but at some frequencies they are lower than known admissible values, due to the phono absorbent treatment.

The reverberation time measured in both the hall and the fossa, has values between 2 sec at 125 Hz and 0.7 sec at 4000 Hz, while the average admissible value for a room in which people speaks and plays of volume of approx. 3500 mc is 1.3 sec, and the maximum and minimum admissible values are ranged between 1.82 sec and 1.06 sec.

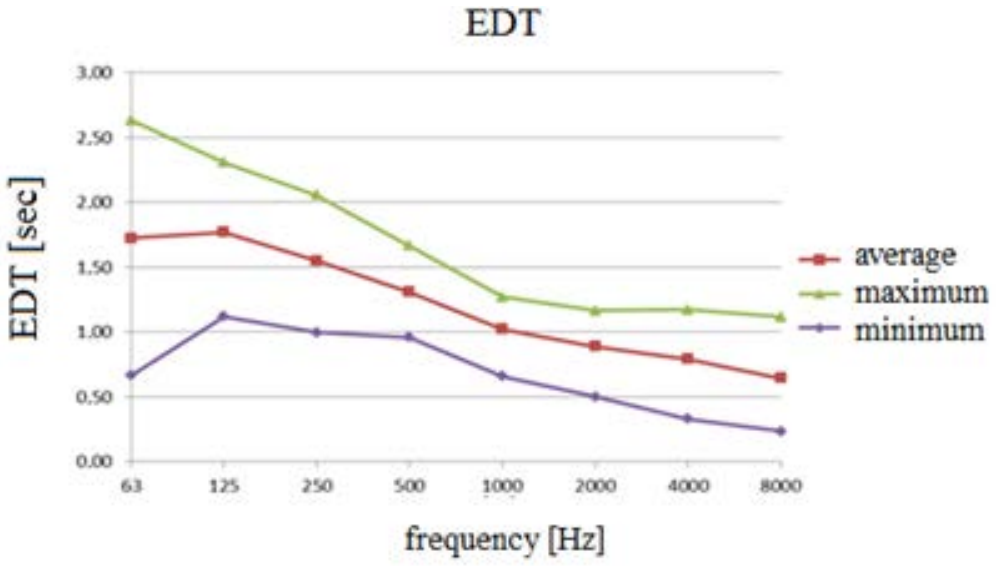

Fig. 5. Variation of EDT with respect to frequency for Lyrical Theater of Craiova.

The EDT measures the initial rate of sound decay in a room, and therefore3 it is most important to our perception of the reverberance. The EDT represents in facts a few isolated early reflections.

4. CLARITY C_{50}

The clarity is defined as the difference (in dB) of the sound energy received by the listener in the first milliseconds.

The C_{50} clarity index is determined on the basis of the earliest sound energy values in the first 50 milliseconds of the reception. The C_{50} clarity index at a certain point in the room is expressed by

$$C_{50} = 10 \lg \frac{E_{50}}{E_{\infty} - E_{50}}, \tag{2}$$

where E_{50} is the early sound energy received at the reception point in the first 50 milliseconds, E_{∞} is the total sound energy received at the reception point. A good acoustics recommends $C_{50} \geq 3$.

The measurements were carried out for the Theatre Luceafarul from lasi (Figs. 6 and 7).

The variation of C50 with respect to frequency for the Theatre Luceafarul from lasi is shown in Fig.8.

A greater value of C50 (green lines) gives music a sensation of definition, while decreased values (mauve lines) adds fullness or dirty tones when excessive.

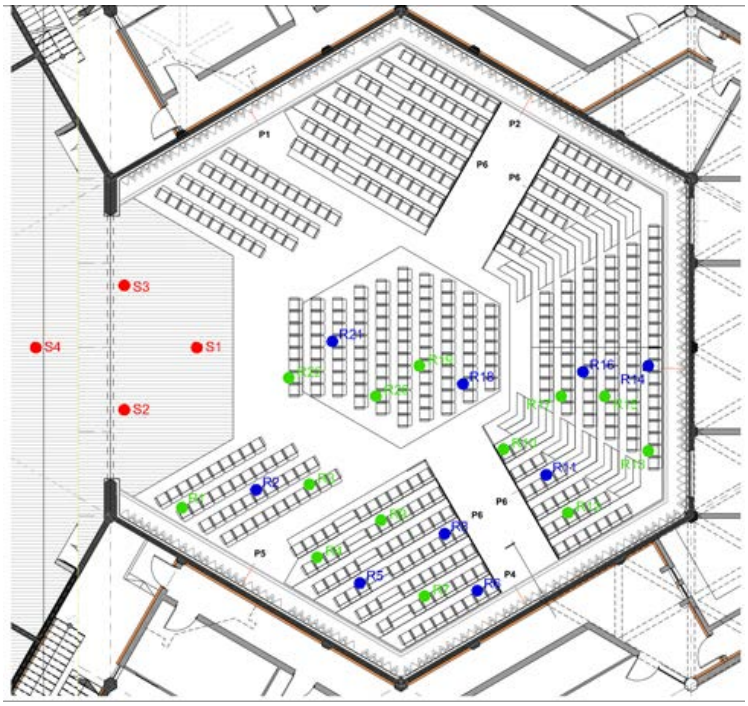

Fig. 6. Hall of the Theatre Luceafarul from lasi.

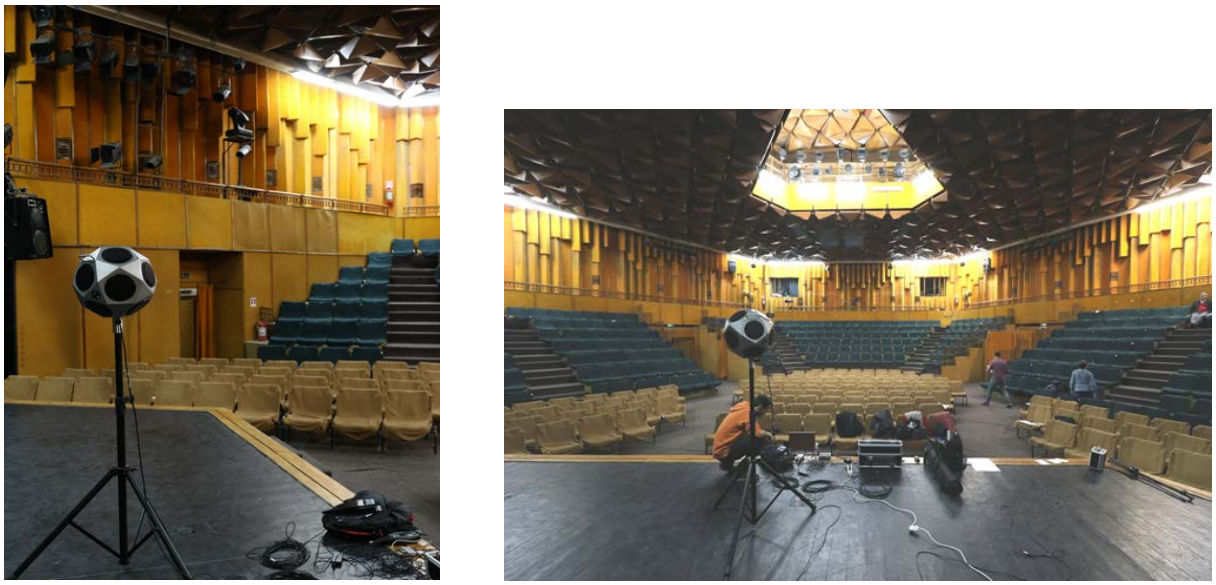

Fig. 7. Theatre Luceafarul from Iasi.

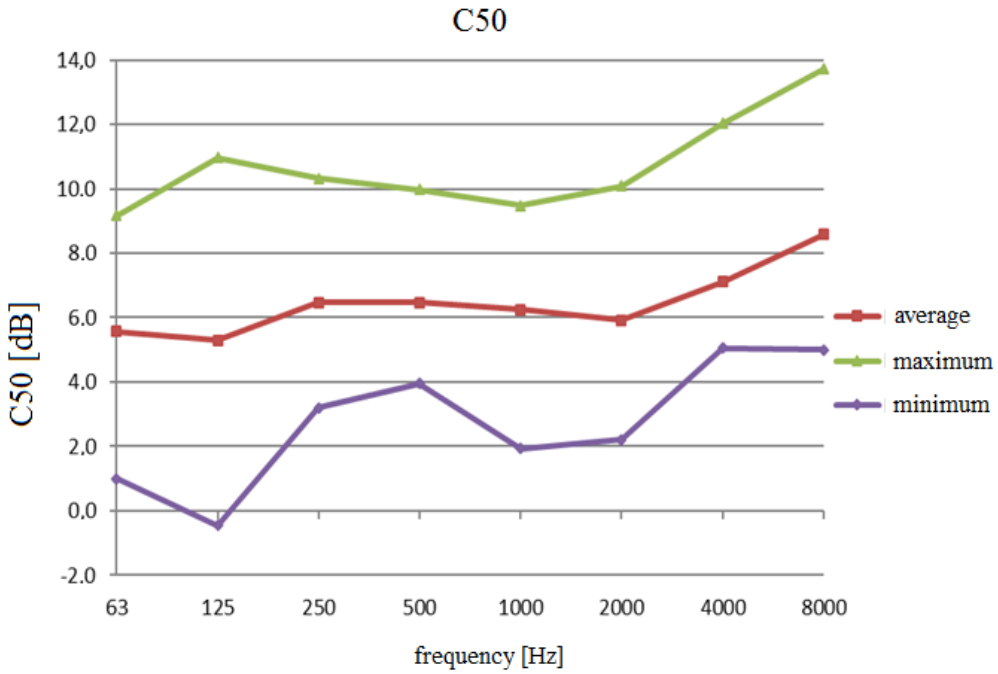

Fig. 8. Variation of with C_{50} with respect to frequency for Theatre Luceafarul from Iasi.

5. UNIFORMITY

The uniformity principle consists in recording the sound pressure level along one direction in order to highlight its variations in this direction.

In this paper, the measurement was carried out on two axes: *OX* on the row seats of the hall (two points of measurements per row) and *OY* along the hall (on two longitudinal directions). For the broadcast, a loudspeaker was used for giving rise to pink noise.

The uniformity coefficients in each direction (*OX* and *OY*) and finally the total uniformity ε_T were evaluated as

$$\varepsilon_X^i = 2\frac{L_{p\max_X} - L_{p\min X}}{l_X},\quad \varepsilon_X = \frac{\sum \varepsilon_x}{n}\quad ,\quad \varepsilon_T = \sqrt{\varepsilon_X^2 + \varepsilon_Y^2}\quad , \tag{3}$$

The allowable standard values for multifunctional halls are:

$$\begin{aligned} &\varepsilon_X \le 0.4,\ \varepsilon_Y \le 0.4,\ \varepsilon_T \le 0.6,\quad \text{for theater spoken,}\\ &\varepsilon_X \le 0.5,\ \varepsilon_Y \le 0.5,\ \varepsilon_T \le 0.8,\quad \text{for simphonic concert,}\\ &\varepsilon_X \le 0.5,\ \varepsilon_Y \le 0.5,\ \varepsilon_T \le 0.6, \text{for movie theaters.} \end{aligned} \tag{4}$$

The values measured by us for the *Athenaeum Tatarasi*, *Iasi* (Fig.9) are

$$\varepsilon_X \le 0.13,\ \varepsilon_Y \le 1.26,\ \varepsilon_T \le 1.27. \tag{5}$$

It is found that the sound uniformity (sound level/per meter) in the OX direction (in the width direction of the hall) are in the admissible range, but in the direction OY (in the length direction of the room) exceeds the admissible value, so that the resulting uniformity parameter exceeds the admissible value.

Fig. 9. Athenaeum *Tatarasi*, Iasi.

6. BALANCE

Balance B, in dB, highlights the balance between the sounds produced instrument groups or vocal parties. Balance B, in dB, is expressed through the relationship

$$B = 10 \lg \frac{E_X 200}{E_Y 200} + B_{XY} , \tag{6}$$

where $E_X 200$ is the energy recorded at the receiving point in the first 200 ms from the direct wave arrival emitted by a group X of instruments or voices, $E_Y 200$ is the energy recorded at the receiving point in the first 200 ms from the arrival of the direct wave emitted by the group Y of instruments or voices, and B_{XY} is the relative balance between the X and Y groups, respectively.

For concert and opera concerts, the allowable limits for balance are between – 4dB and + 4 dB. The measurements were performed for the Hall of Philharmonic Oltenia, Craiova (Fig.10).

In order to determine the sound balance between the groups of instruments, each separate group was performing the same musical fragment and then the differences between the levels emitted by different groups were analyzed. The measurement points include a point in the center of the hall (lines 8-9, measuring point 6) and the conductor location (D1).

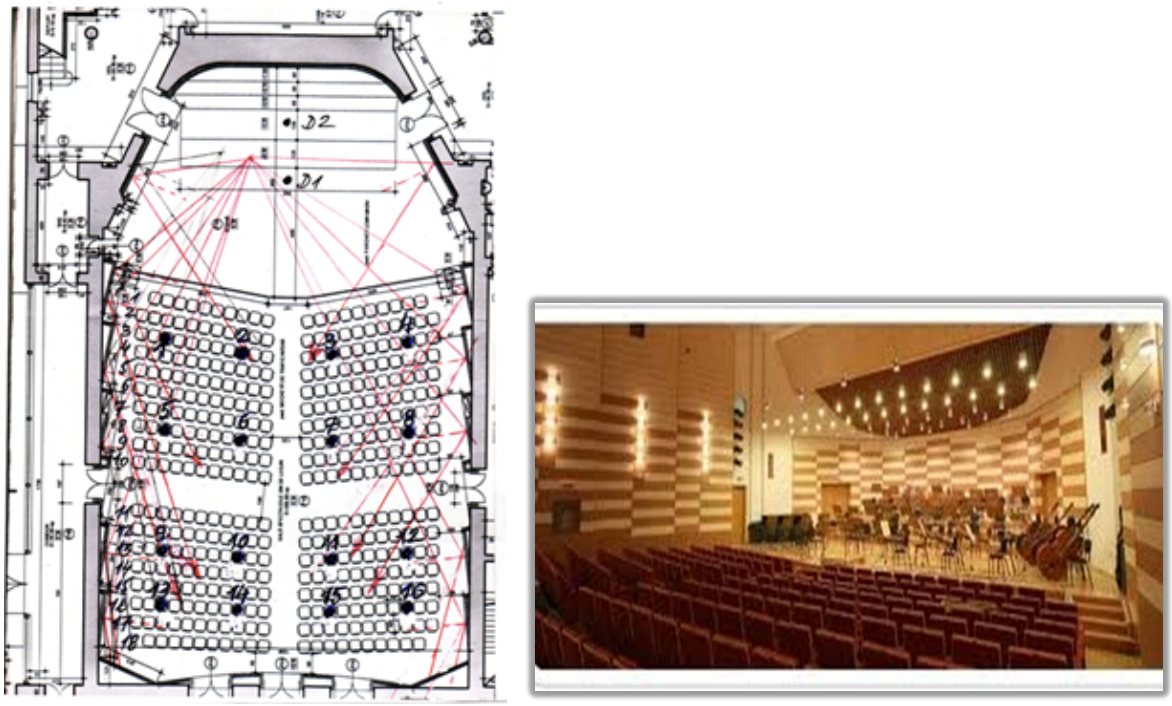

Fig. 10. Hall of Philharmonic Oltenia, Craiova.

location	group number	group	sound level	differences in sound levels [dB]					
				1- 2	1- 3	1- 4	2- 3	2- 4	3- 4
8-9 (6)	1	string instruments	78,5	6.2	3.5	5.3	9.7	11.5	1.8
	2	wood blowing instruments	72,3						
	3	brass blowing instruments	82.0						
	4	percussion instruments	83.8						

Table 1. Results of measurements for Hall of Philharmonic Oltenia, Craiova.

The orchestra had the following composition: 33 string instruments, 7 wooden blowing instruments, 9 brass blowing instruments and 4 percussion instruments. The measurement of the balance between the instrument groups was made with the participation of the members of the Oltenia Philharmonic Orchestra of Craiova, who, under the leadership of conductor Radu Popa, interpreted the final fragment from Bolero by Maurice Ravel. The results are shown in Table 1.

The analysis of results shows that the sound level produced by the wood blowing instruments is exceeded by more than 7.0 dB (A) by the one produced by brass blowing instruments and percussion instruments, respectively. In this situation, the masking effect of lower sounds appears. This phenomenon could have multiple explanations: on the one hand, the amplitude of wooden instruments and the number of harmonics, on the other hand, the number of wood instruments in relation to strings and brass instruments.

In order to correct these aspects, some panels placed over the grill, with a reflective surface above the wood blowing instruments and absorbance above the brass blowing instruments is a pertinent solution.

7. INTELIGIBILITY

The intelligibility is an acoustic parameter of a public auditorium which defines the degree of understanding of the sounds spoken on the stage. The principle of the subjective evaluation consists in assessing the correctness of reception by the existing auditorium in the hall, the list of logos (artificial monosyllabic words with no significance) from STAS 9783 / 1-94 standard [11].

The value of the degree of intelligibility (PA) corresponding to a place i in the hall is calculated as

$$\mathrm{PA}_i = 100\left[1-(1-vc^2)^{0.9}\right], \tag{7}$$

where c, v are number of consonants and vowels correctly received, based on the total number of consonants and voices emitted.

The average PA is determined from PA_i of different areas in the room and then the average PA for the whole room is evaluated.

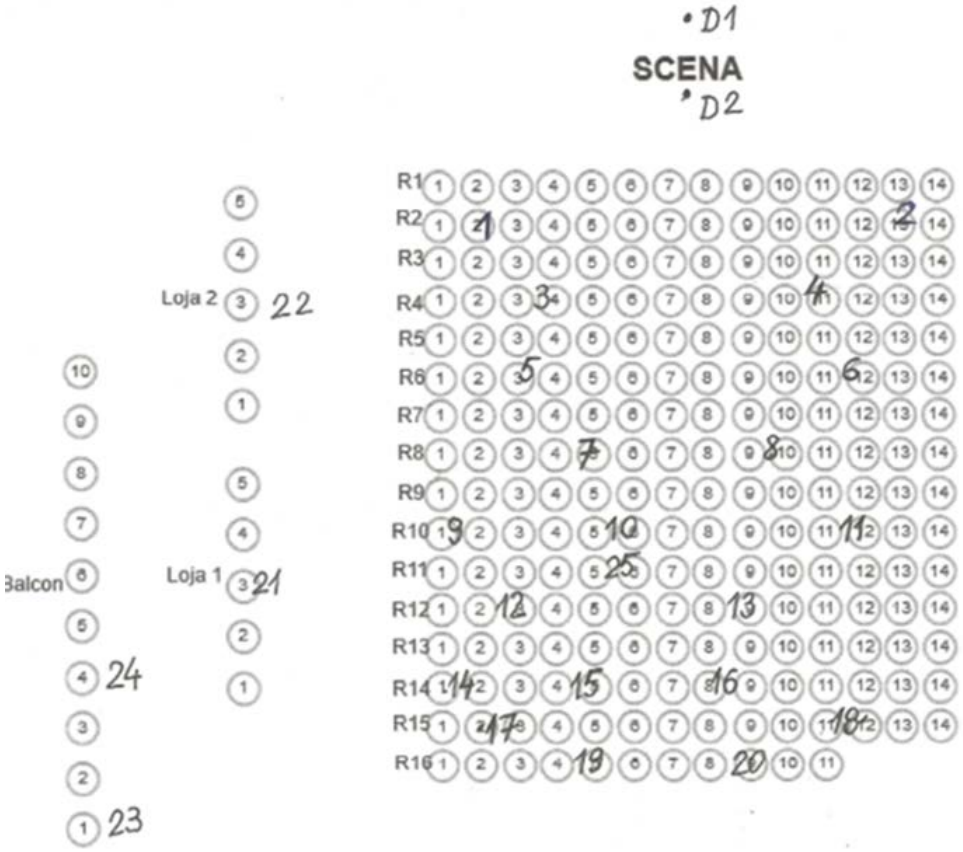

Fig.11. Athenaeum *Tatarasi*, Iasi.

Our measurements were carried out for *Athenaeum Tatarasi, Iasi* (Fig.11).

The measurements consisted from 25 normal otologic subjects with good binaural audience, able to listen and text. The subjects were placed in 25 points, covering the hall surface. The number of points in the room was chosen in function of the number of seats in each area. Reading the logos list is done by two soprano and baritone, i.e. professional actors with good diction (*Cezara Fantu* and *Daniel Onoae*).

The results are shown in Table 2. We see that average of PA is greater that 85%.

A very special situation was represented by the values at the point 25 (just behind the listener in item 10) which are with 20-25% lower than those in item 10 because of the seat seating on the same line without breaking between them.

LISTĂ LOGATOMI 1 - METODA SUBIECTIVĂ

Nr. crt.	Propoziția de anunțare a unei grupe de trei logatomi	Grupa de logatomi ce se anunță odată		
1	Dictez prima grupă	LEF	RAD	DOZ
2	Vă rog să scrieți	CEAM	TUD	GOAC
3	Notați următorii logatomi	NIN	REȚ	LAV
4	Scrieți grupa a patra	CIR	TAT	NET
5	Grupa aceasta cuprinde	TOS	RIEM	CEIB
6	Continuăm cu	ȚÎC	LIS	STAC
7	Următoarele sunete sunt	FIAS	MEP	NUS
8	Scrieți din nou	GIR	TAIN	DÎS
9	Vă rog să notați	CAD	VET	PRUC
10	Numărul 10 este	MIM	SEL	LOAS
11	Scrieți următoarele silabe	SAN	CUN	LEP
12	Citez alți logatomi	TRĂN	NOT	SIR
13	Notați acum	RAT	VÎN	RUM
14	Următoarea grupă este	NER	DON	LES
15	Grupa 15 cuprinde	TRUL	PAD	TÎP
16	Notați logatomii	NED	RAB	ZEC
17	Dictez din nou	RIP	HET	LOP
18	Scrieți ceea ce rostesc	CIAR	PÎS	NET
19	Următorii logatomi sunt	TAR	CUZ	TIN
20	Continuăm cu	RER	BUR	NAV
21	Urmează grupa	RIET	NÎN	ȘOT
22	Scrieți următoarele sunete	BED	DAIP	NIS
23	Notați ceea ce auziți	SAD	MEL	CAV
24	Recepționați silabele	GIM	STUT	SON
25	Numărul 25 este	CEAN	DAȘ	NEP
26	Dictez alți logatomi	PRÎR	CEL	NUM
27	Transmit acum	LAR	DEF	SIN
28	Grupa aceasta cuprinde	TRAL	REC	MOAL
29	Vă rog să notați	LON	TRUV	ȚAM
30	Grupa 30 cuprinde	MID	SEIC	NUT
31	Urmează alți logatomi	DEF	TAS	DÎC
32	Dictez încă trei silabe	LOAR	SEC	TAG
33	Ultima grupă este	DIC	TER	PED/ZIM

Fig. 12. List of logatoms (in Romanian).

zone	results		average
	D1	D2	
ground floor	88.5	90.55	89.52
lodges	85	94.75	89.87
balcony	92.5	92.75	92.62
average	88.66	92.68	**90.67**

Table 2. Results of measurements for Athenaeum *Tatarasi*, Iasi.

8. CONCLUSIONS

In this paper, a brief overview on the specific parameters of the architectural acoustics is presented, with reference to our measurements carried out to Lyrical Theater and Philharmonic Oltenia from Craiova, Theatre Luceafarul for Athenaeum Tatarasi from Iasi. The specifically criteria/parameters considered in this paper are: reverberation duration, early decay time (EDT), clarity, uniformity, balance and intelligibility. The work compares our measurements to optimum values of indicators T_{30}, EDT, C_{50} and ε_T. The measurements led us to the conclusion that the architectural design and acoustics need to be performed together.

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