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Measures of acoustical spatiality in an Italian Opera house

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Abstract: -
The sound spatial characteristics of concert halls are extremely relevant for 3D auralisation of spaces for music, as well as for designing acoustical enhancements in the halls. Moreover, the theatre "Comunale" in Bologna is also an ancient Italian opera house (realized in late 18th Century by Galli Bibiena) with peculiar spatial characteristics. In the Theatre "Comunale" balconies are realized with different shape and materials respect to classical Italian opera house. This special feature of balconies provokes some effects in the listening conditions that are related with the position of sound sources in the stage and in the orchestra pit. These special characteristics have been experimentally investigated by means of an omni-directional, pre-equalized sound source located in different positions in the orchestra pit and stage, and a dummy head, accomplished with a soundfield microphone, located in many different listening positions in the balconies and the stalls. The special features of ACF and IACC, as well as other acoustical parameters, measured experimentally, have been reproduced in a second step in the listening room "Arlecchino" at the laboratory of DIENCA – CIARM, by means of the Stereo Dipole and Ambisonics technique. In this paper the results from these experiments are presented and analyzed

Key words: - Teatro Comunale of Bologna, Acoustical measurements, Impulse Response, Acoustical Parameters, Spatiality
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INTRODUCTION

The acoustic properties of historical opera houses are considered one of the most important cultural heritages of Italian history. Since the paper of M. Gerzon, [1], recently revised [2], the acoustic properties of special opera house are considered at the same importance of ancient musical instruments. In this paper the acoustic properties of one of the most important Italian opera houses, the teatro Comunale in Bologna, are therefore measured and evaluated, by means of a dummy head and a B-format microphone in order to preserve their acoustics for posterity. These acoustic data will be utilized also for 3D auralization purposes.

THE THEATRE IN THE HISTORY

The Teatro Comunale in Bologna opened in 1763. The architect Antonio Galli Bibiena, one of the most active architects for spaces for music in 18th Century, designed the theatre.
However since the early drawings, Galli Bibiena thought about a different shape of the teatro Comunale of Bologna: a bell shape, different from the horse-shoe shape. The Comunale di Bologna (which followed the Teatro Scientifico in Mantua and the Teatro of Four Horsemen in Pavia) was therefore the first example of a special "phonic" shape in the idea of Galli Bibiena. Nevertheless, other physicians and acousticians at that time did not agree with this idea. Moreover, the Comunale of Bologna has other different characteristics. One of the most significant innovations was the bricks structure of the main hall, instead of a wooden one. In this manner, it would have been easier to avoid the burning of the theatre.

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Fig. 1 The cavity below the stalls

But this theatre has also two relevant innovations in the balconies and in the stalls. The balconies were conceived giving the opportunity to the holders to personalize the walls, coloring the walls, modifying the interiors, etc. The pavement of the stalls was provided with a special device: a special mechanism was able to elevate the pavement until the stage. In this case a huge cavity would be created, and musicians and singers would have been at the same level.
In the opinion of Bibiena, the movement of the floor could have also enhanced the intelligibility of singers. This device was active until 1820.

MEASUREMENTS IN THE TEATRE

Many acoustic measurements were performed during last 15 years in the Teatro Comunale of Bologna. However, all these measurements consisted of only binaural measurements by means of different dummy heads. Since the laboratory of DIENCA – CIARM has also created a listening room (called "Arlecchino") able to reproduce virtual sound fields following Stereo Dipole and Ambisonics methodologies [3,4], a new throughout campaign of measurements was undertaken in order to properly describe spatial sound characteristics of the hall, and especially the stage and orchestra pit, and their relations with the perception of sound in the stalls and balconies [5,6,7]

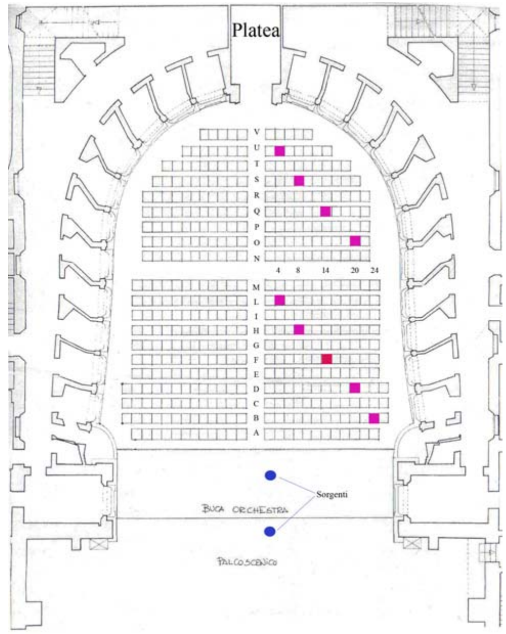

Fig. 2 Measuring positions in the stalls

During the measurements, the following instrumentations have been employed.
·- An omni-directional, frequency-equalized sound source (namely LookLine) was utilized, and positioned in the stage and in the orchestra pit [8,9].
·- A dummy head was positioned at the receiver's positions (Neumann KU-100). It allowed the measurements of binaural impulse responses, and consequently binaural parameters.
·- A Soundfield microphone (MK V) probe accomplished the dummy head in the theatre. The 4 channels output were utilized during the calculation of monoaural and 3-dimensional parameters.
A log sine sweep (chirp), 30 seconds long, was utilized in the measurements.
The signals coming from the microphones were directly stored in the PC by means of a 20 bit 96 kHz 8 channels soundboard.
The measurements were conducted in 25 different positions, ranging from stalls to balconies, as depicted in figure 2, where also the numerical model, which will be used for simulation, is shown. The sound source was positioned in the stage and then the measurements were repeated moving the sound source into the orchestra pit. A reference position at 1 meter was added, in order to compute spatial maps of strength.

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Some further measurements were conducted with a directive sound source, in order to appreciate differences in impulse responses (both binaural and B-format) during the 3D auralization process.

The Soundfield microphone allowed both the measurements of mono-aural parameters, like reverberation time and clarity, both spatial parameters, like LE and LF, and B-format (3D) Impulse Responses. The dummy head allowed the measurements of binaural parameters, like IACC. Moreover, the B-format impulse responses obtained with the Soundfield, and binaural impulse responses obtained with the dummy head, allowed creating the virtual acoustics of the theatre [10]

RESULTS

In the following paragraphs the results are briefly reported. From the measurements many different acoustical parameters were calculated. In tab. 1 the mean values obtained in the theatre are represented. The results are reported differentiating the position of sound source in the stage and in the orchestra pit, respectively. As mentioned previously, a sound source with directivity pattern was also used during the measurements. In order to better analyze the influence of both the position of sound source and both its directivity patterns, in the following pictures the results for one specific position in stalls are presented.

Frequency	31.5	63	125	250	500	1k	2k	4k	8k	16k
STAGE										
C50 [dB]	-1.1	-5.2	-5.3	-2.6	-2.4	-2.8	-3.1	-2.4	1.1	6.0
C80 [dB]	0.8	-1.7	-1.5	0.6	0.6	0.2	0.2	1.2	4.6	10.8
D50 [%]	44.4	26.2	25.0	36.5	37.6	35.3	34.1	37.4	55.8	78.2
Ts [ms]	161.3	179.9	154.2	117.8	111.3	114.7	113.1	94.9	58.5	28.0
EDT [s]	2.6	2.1	1.8	1.6	1.6	1.6	1.6	1.3	0.9	0.6
T20 [s]	2.4	2.3	2.0	1.8	1.7	1.6	1.6	1.3	1.0	0.5
LF	0.68	0.94	0.81	0.81	0.78	0.78	0.68	0.58	0.48	0.38
PIT										
C50 [dB]	3.9	-0.2	-8.7	-4.3	-4.2	-3.4	-3.0	-1.7	2.1	5.5
C80 [dB]	5.5	3.5	-0.8	2.1	1.3	0.8	1.0	2.2	5.9	11.5
D50 [%]	70.0	49.1	17.7	31.2	32.0	34.5	35.3	41.1	59.9	72.3
Ts [ms]	93.0	112.4	148.5	110.8	108.2	110.9	104.1	86.7	54.0	34.1
EDT [s]	1.2	1.0	1.7	1.4	1.4	1.6	1.5	1.2	0.7	0.4
T20 [s]	2.0	2.1	2.0	1.7	1.6	1.6	1.5	1.3	0.9	0.5
LF	0.6	0.8	0.7	1.0	1.1	1.0	0.8	0.6	0.5	0.5

Tab. 1 Values of acoustic parameters measured

As an overall impression, the Teatro Comunale presents the typical sound characteristics of Italian-styled opera houses. The reverberation time at mid frequencies resulted about 1.4 s.

However, a remarkable difference between the acoustics of orchestra pit and stage has been found.

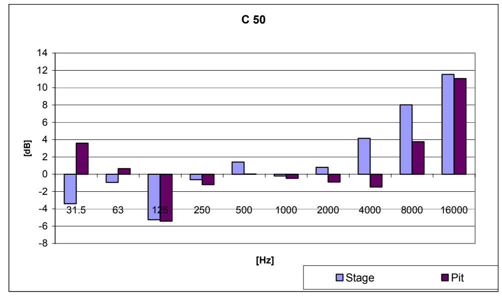

Fig. 3 Clarity C50 measured with sound source in the stage (blue) and in the pit (red)

These differences are particularly remarkable in the stalls, rather than in the balconies.

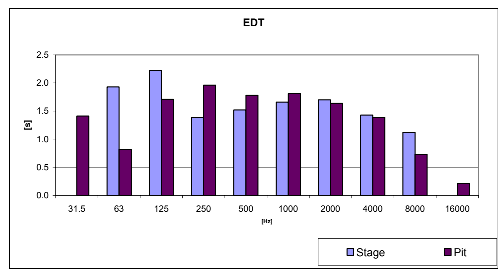

Fig. 4 EDT measured with sound source in the stage (blue) and in the pit (red)

Considering the graphics representing the values of acoustical parameters measured in one position not far from the orchestra pit, it could be appreciated the variation of the acoustical parameters especially in the initial part of the sound field (less than 100 ms).

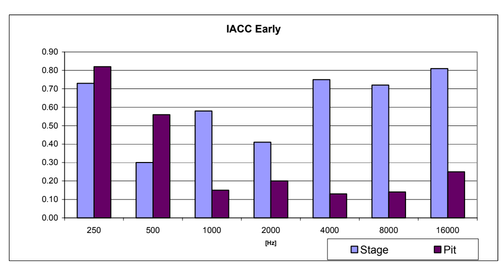

Fig. 5 IACC measured with sound source in the stage (blue) and in the pit (red)

Both the energetic parameters (i.e. clarity) showed a relevant difference between the stage (which its direct sound that is clearly perceived by the receiver) and the orchestra pit, where the position of the sound source and the effect of the fence provoked a diffuse sound field without direct sound from source to receivers.

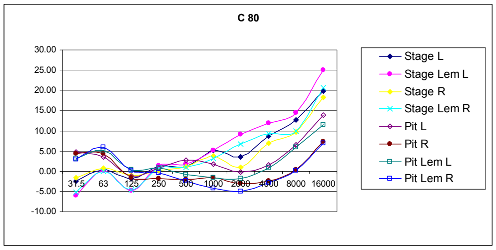

Fig. 6 Clarity C80 measured in stalls with different sound sources and positions

Even reverberation time resulted considerably different, moving sound source from stage to pit. The Early Decay Time, which is calculated in the early decay time, resulted more influenced than the RT30, which take into account a longer decay time. EDT at mid frequencies varied of also 0.5 s in some cases, whereas RT30 varied of 0.2 s.

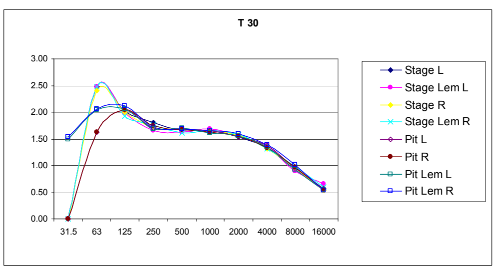

Fig. 7 RT30 measured in stalls with different sound sources and positions

One more analysis involved different positions of sound source and directivity patterns. In the figs 6-8 some acoustic parameters measured in the hall are represented. The variations of these parameters were really remarkable. Even clarity changed considerably with sound source.

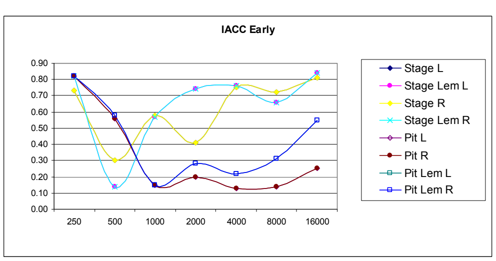

Fig. 8 RT30 measured in stalls with different sound sources and positions

Only Reverberation Time remained fairly stable with sound sources. But analyzing the values of IACC, it resulted quite depending from the sound source, with variations ranging from 0.15 to .075 at the frequency of 2 kHz. This was not a surprising result, since IACC is calculated from the initial 80 ms of impulse responses, i.e. the component of IRs that strongly depended on different sound sources and positions.

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