ON THE TESTING OF RENOVATIONS INSIDE HISTORICAL OPERA HOUSES

P. Fausti, L. Parati, N. Prodi, R. Pompoli and M. Severi*
Dipartimento di Ingegneria, Università degli Studi di Ferrara, 44100 Ferrara, Italy
*Architect, Reggio Emilia, Italy

Introduction

In the history of Italian music opera has played a key role, which is witnessed by the outstanding national repertoire and by the unique concentration of opera houses expressly build for its appraisal during four centuries (from late XVI to XX). Of course the vehicle for the transmission and comprehension of the special mix of singing voice and music which is typical of opera is the acoustics of the theatre, whose importance has been stressed since the very early days of opera. Notwithstanding this, only in recent years has there been a revival of interest on the acoustics of opera houses and on the scientific means for their study and safeguard [1] [2] [3]. Many theatres in the country have in fact been subjected to renovations in the past and many more are to be refurbished in the near future. Unfortunately the lack of attention to acoustical issues has lead in some cases to the spoilage of theatre's acoustics. That is why it is important to establish a procedure for controlling, evaluating and possibly enhancing the acoustics of historical theatres in case of refurbishment. This task, which might have seemed ambitious in the past, is now possible thanks to the modern tools of analysis brought about by information technology.
In the present work the refurbishment of the Teatro Municipale "Romolo Valli" in Reggio Emilia is considered as an effective example of a positive approach to the problem. This theatre, which is one of the national "traditional theatres", hosts regular high profile opera seasons, concerts and ballet and is seldom used for plays [4]. Different sets of acoustical measurements were done in the hall before and after the renovations, and the impact of the works on the acoustics of the theatre for its opera usage was tested.

The theatre and its refurbishment

The Teatro Municipale "R.Valli" was build between 1852 and 1857 on the project of Cesare Costa and is an example of the neoclassical architecture typical of the town. The facade is sustained in the lower part by twelve columns and in the upper part is divided into fourteen ionic pilots (Fig.1). The hall has a horseshoe shaped plan with four orders of boxes surmounted by a gallery (Fig.2). The total number of seats is 1136. The stage width is 31.35m, its depth is 19.75m. The volume of the stage-tower is nearly 13.700 m^3 while the main hall has a volume of 4.700m^3.


Fig.1 : façade of the Teatro Romolo Valli.


Fig.2 : view of the hall and of the stage curtain.

In the last years the theatre has undergone major refurbishments, which were necessary mainly for safety reasons. The works were organised in two phases and carried out during the summer breaks, with a schedule that avoided the interruption of the normal activity. The former phase took place in the summer of 1998, when the padding and the velvet of stalls seats were replaced with fireproof materials. During this operations the original frame of the seats was kept (Fig.3).
The latter phase of refurbishment was carried out between June and November 1999 and regarded most of the surfaces of the hall and the furnishing of the boxes (Fig.4-5-6). In particular the synthetic varnishes on the walls were removed and the stucco of marmorino was brought back to its former evidence. The decorated and painted surfaces were polished and all of the gilt frames and the painted ceiling were restored. In addition the red tapestry in the boxes and in the upper gallery was changed with a fireproof one and the padding and the velvet cover of the furnishing in the boxes were also substituted with fireproof materials.

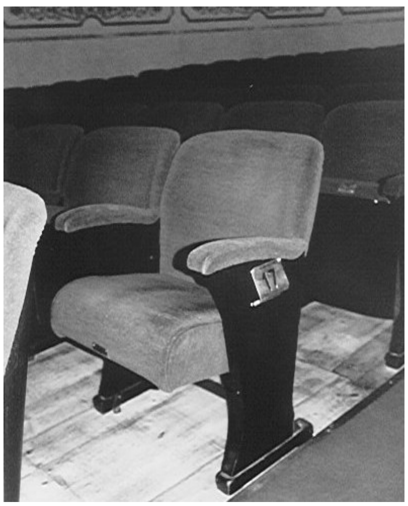

Fig.3 : a typical chair in the stalls.

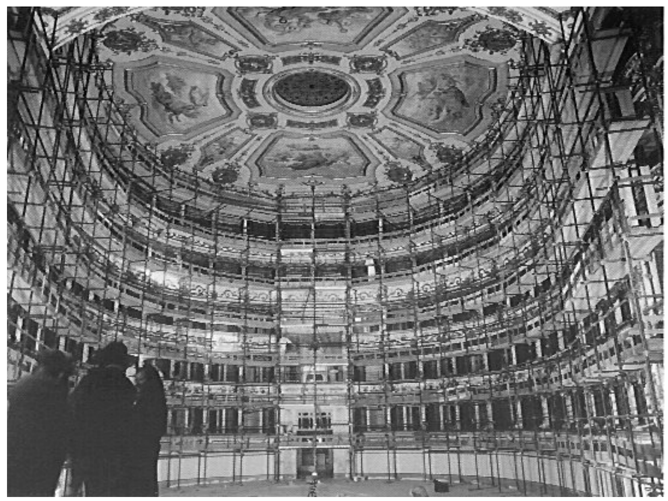

Fig.4 : the scaffolding inside the theatre.

Fig.5 : detail of the wall restoration.

Fig.6 : the typical furniture of a box.

Brief acoustical issues in opera houses

In order to characterise the acoustics of a room it is customary to refer to the norm [5] which describes some of the employed acoustical parameters and the technical means for their measurement. In this respect the impulse response, which is the collection of the direct sound from the source and of all the reflections provided by the room, can be considered as the basic acoustical data. From the impulse response all the acoustical parameters can be calculated by post-processing. Usually, sets of impulse responses are measured for combinations of a grid of receivers and of some sound source positions in the tested room.

Among the proposed set of parameters, a brief description can be made of the two fundamental attributes known as reverberation and clarity. The former is linked to the impression of permanence of the sound in the room and is quantified by the indicator known as “reverberation time”. This parameter is primarily affected by the volume of the enclosure and by the characteristics of sound absorption of the materials at its boundaries. Technically speaking this indicator is measured as the time taken by the sound energy to decrease by 60dB after the sudden interruption of a stationary sound source. The reverberation time has optimum values in relation to the destination of the enclosure under test (Table 1). For an opera house the range of optimal values can be set between 1.8sec and 1.2sec, with the further specification that the higher values are expected in the lower frequency range and the lower values are typical for the high frequencies.
The clarity of sound, as a perceptual attribute, is linked to the capability of correctly detecting both musical notes played in rapid succession and different musical lines played together (also referred to as transparency of sound). Technically speaking the sound energy which arrives closer to the direct sound is rated favourably for clarity whereas the energy arriving with longer delay is detrimental. This is somewhat reflected in the definition of the parameter, which can be calculated from the impulse response as the ratio of sound energies expressed in Equation 1, where the integration limit marks the conventional transition from useful to detrimental sound. This limit is set at 50ms for speech (C_{50}) and at 80ms for music (C_{80}). The optimum values are in the range between 0dB and 3 dB for C_{50} and between –4dB to +2 dB for C_{80}.

TYPE OF AUDITORIUM	**RT_{20} [s]**
Conference room	< 1.0
Opera house	1.2 – 1.8
Chamber music	1.4 – 2.0
Concert hall	1.7 – 2.3
Church	2.0 – 4.0

Table 1 : optimal values for the reverberation time.

$$C_{XX} = 10 \log \frac{\int_0^{XXms} p^2(t)dt}{\int_{XXms}^{\infty} p^2(t)dt} \quad [dB]$$

Equation 1 : expression of the clarity.

The acoustical measurements in the theatre

A suitable measurement chain for acoustical surveys in rooms is divided into two parts. The former includes the sound source which delivers a special test signal in the room and the latter consists of the microphones and recording devices. The whole chain is driven by computer with measurement software. The testing procedure consists in exciting all of the acoustical vibration modes of the room and recording the respective sound field for later analysis. In this respect it is necessary to operate the sound source at a sufficient sound power so that a good signal to noise ratio is also achieved. The sound source itself is made by twelve faces arranged on a dodechaedron so that the radiation of sound is isotropic (complying with the requirements of [5]). A similar measurement chain was employed during repeated measurements in the “R.Valli” theatre (Table 2). In this case the sound source was put on the stage at a distance of 1 m from the line of symmetry of the hall, 1 m from the border of the stage and 1.3 m above the floor (Fig.7). As micing apparatus a binaural system Sennheiser MKE2002 was used (Fig.8-9) and a sound level meter level RION NA29 was employed simultaneously. The receivers were placed 1.15m above the floor and were successively passed at different positions in the stalls and in the boxes while keeping the source fixed on the stage (Table 3 and Fig.10). At each position the test signal was recorded both for post-processing and calculating the impulse response and for direct measurement of the sound level.

TASK	INSTRUMENTATION
Generation of test signal	Laptop with Aurora Software B&K Amplifier Norsonik dodechaedric source
Micing of the sound field	Binaural system Senneheiser MKE200
Recording of the signal	DAT Hitachi Cooledit software
Post-processing	Laptop with Aurora Software
Sound level measurement	Sound level meter RIONA29

Table 2 : components of the measurement chain.

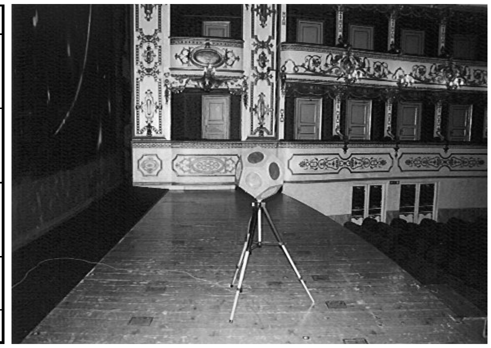

Fig.7 : the location of the sound source.

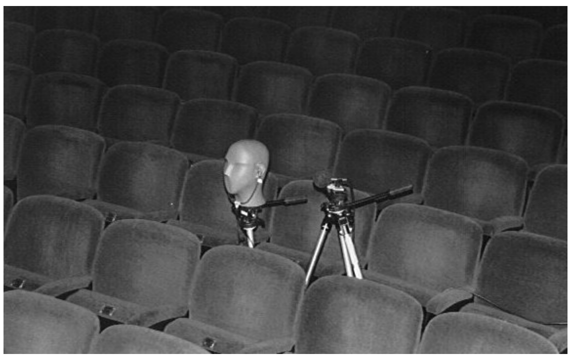

Fig. 8 : the two receivers in the stalls.

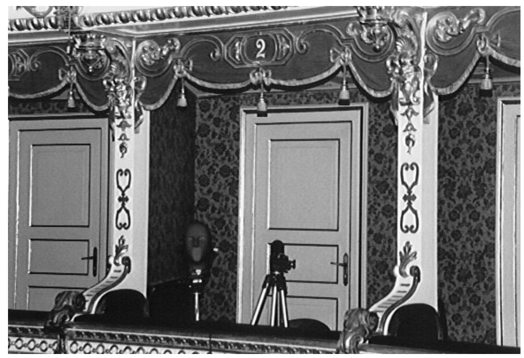

Fig.9 : the two receivers in a box.

SOUND SOURCE

- ONE POSITION (ON THE LINE OF SYMMETRY AT 1m FROM THE STAGE BORDER)

RECEIVERS (TOT. 23)

- ELEVEN IN THE STALLS
- FOUR IN I° ORDER BOXES
- FOUR IN III° ORDER BOXES
- FOUR IN THE UPPER GALLERY

Table 3 : Distribution of the receivers in the theatre.

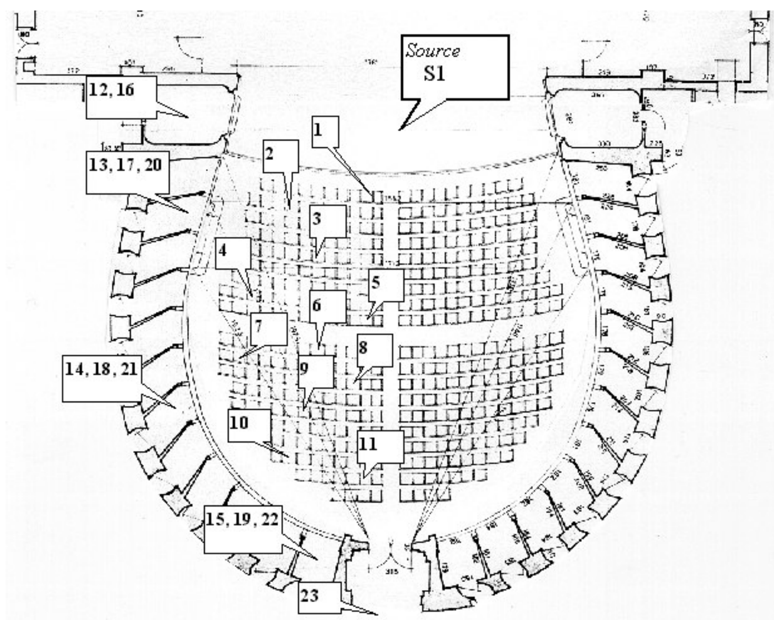

Fig.10 : plan of the theatre with locations of receivers.

Results and discussion

Two measurement sessions took place in the theatre in April and in December 1997 respectively. The former was finalised at the design of the orchestra shell while the latter

aimed at the qualification of the main hall before the refurbishment. In march 2001 a third session was pursued in order to evaluate the impact of the completed renovations inside the theatre. In the following the results from the late 1997 and 2001 measures will be compared. The theatre had the same set-up with lowered fire-curtain and curtain, and the same grid of positions for the receivers and location of the sound source were fixed. Moreover exactly the same measurement chain was employed, as described above. Thus the changes in the acoustical parameters can be traced back directly to the refurbishment since no significant effect of the measuring procedure can be expected.
Firstly, the reverberation time (indicated as RT20) has increased in the whole band of analysis. The increase is more relevant (up to 40%) in the range of higher frequencies (4kHz and 8kHz octave bands), where it reaches the value of 1s, which is closer to the suggested optimal values. Also another parameter directly linked to reverberation, known as Early Decay Time (EDT), has undergone an increase both in the high frequencies (as much as 0.9s) and in the lower ones (1.8s). Also in this case the latest values can be considered closer to the optimum ones (Fig. 11-12). From a qualitative point of view, it can be stated that the remarkable change in reverberation between the two sessions is due to the decreased absorption coefficients of the new materials compared to the old ones. In other words, from basic theory we know that the lower the absorption coefficients, the higher the reverberation time. To have a better quantitative estimate of the effect, one would need the measures of the acoustical properties of both old and new materials and a correct computation of their surface extension, but these data are unfortunately lacking at present.
Considering the analysis of clarity, it can be seen that C_{80} is closer to the optimum value at high frequencies (4kHz and 8kHz octave bands) decreasing from 10dB to 5dB (see Fig.13) in agreement with the increase in the reverberation time.
In addition, the variation of the sound level between the 1997 and the 2001 measurements was considered. The evaluation of this quantity required that the sound source operated at the same power level during the two sessions. Unfortunately this condition was not met, since no calibration of level was done in 1997. To overcome this problem a calibration was accomplished "a posteriori" between the two sets of sound level data. In particular the five points in the stalls closer to the source were considered and a calibration parameter was derived as the average of the level differences between the 2001 and 1997 data in the respective points. The obtained parameter was applied to all of the 2001 data so that the differences could thus be more accurately attributed to the renovations. As a result the different areas of the theatre show a similar trend with the exception of the upper gallery (Fig.14). In this part the level in 2001 is increased especially in the 8kHz band in a way consistent with former results for reverberation time and clarity.

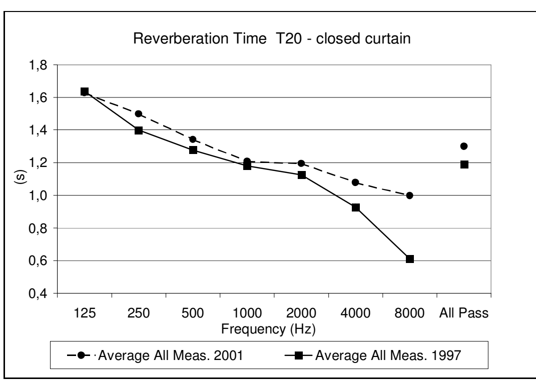

Fig.11

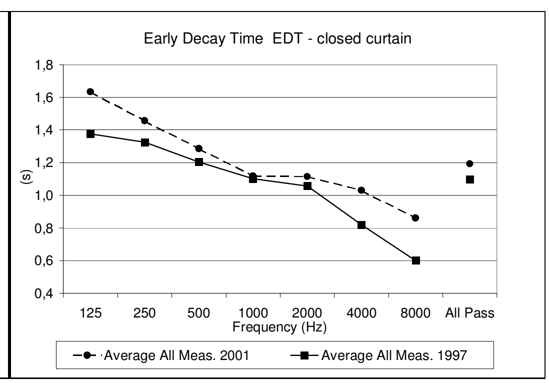

Fig.12

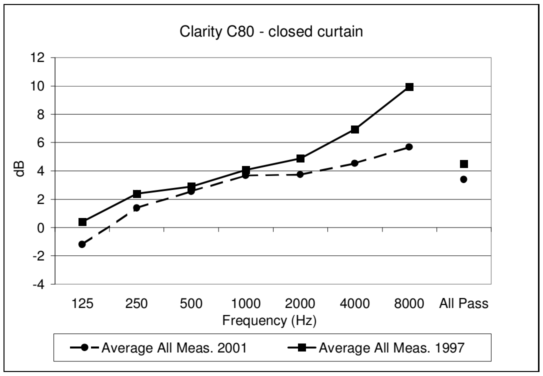

Fig.13

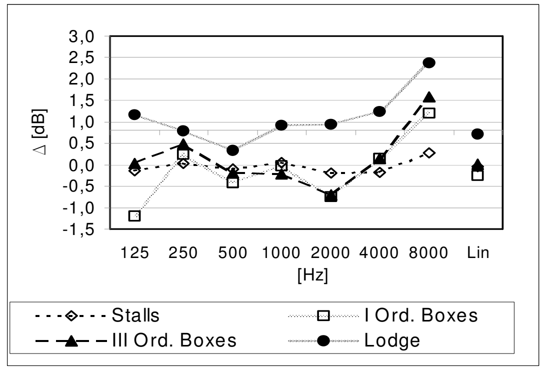

Fig.14

Concluding remarks

The acoustic measurements in the Teatro Comunale "R.Valli" in Reggio Emilia validated the procedure of refurbishment which was implemented in the theatre in recent years. As an outcome of the comparative measurement sessions the acoustics of the theatre was not just preserved, but improved in many respects. A conclusion that can be drawn is thus that it is possible to match the requirements of safety and technological improvement with the acoustics of an historical opera house. Further developments of the testing and monitoring of the acoustical impact of renovations will include:

a) measurements of the sound absorption properties of materials;
b) room-acoustics surveys in the theatre during the different stages of refurbishments.

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