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ON THE TESTING OF RENOVATIONS INSIDE HISTORICAL OPERA HOUSES

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Due to the large number of historical opera houses in Italy, many theatres have been renovated in the past, but still more will undergo major restoration in the near future. Unfortunately in this context, the quality and protection of acoustics is rarely considered as an issue of its own. As a consequence, the renovations are hardly ever accompanied by proper scientific and technical support. In this paper, the acoustical impact of works inside the Teatro Municipale "R.Valli" in Reggio Emilia, including the restoration of the main hall and the construction of a new acoustic shell, will be dealt with. Surveys were held in the theatre before renovation and were repeated with identical procedure and instruments after its completion. By means of a comparative analysis of the architectural project and of acoustical data, the impact of major changes in the theatre can be predicted. It is shown that this approach can help in drafting an operational scheme for safeguarding the acoustics of historical opera houses.

1. INTRODUCTION

The acoustics of historical theatres can be regarded as a cultural heritage, which has been handed down to the present generation from the past and which calls for preservation and protection in order to be passed onto future users. The term 'preservation and protection of acoustics' is intended to mean the understanding and evaluation of the acoustics in the actual opera house, knowledge of the modifications in the furnishings or other refurbishments which have occurred since the construction of the building and of their qualitative effect on the acoustics, and the appraisal of the acoustic quality of opera houses for possible enhancement in case of future refurbishment. Despite a consensus among the public and professionals on the necessity of such a policy during refurbishment work, this task has seldom been achieved in the past. That is why the development of the technical means for the diagnosis and evaluation of the impact of renovation work on the acoustics of theatres has received growing interest in recent years [1], even though a specific and technically sensitive concern for acoustics is rarely found in the tenders for refurbishment. Other issues which involve acoustics, such as, for instance, the adoption of an orchestra shell or installation of heating, ventilation and air conditioning (HVAC) systems, are usually dealt with insufficient concern for their real acoustical impact, in spite of the fact that the use of an orchestra shell to adapt the acoustics of the hall to the needs of symphonic music is nowadays common practice in many Italian opera houses.

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Figure 1. View of the main hall of the Teatro Municipale "Romolo Valli" in Reggio Emilia, Italy.

TABLE 1

Basic geometrical data of the theatre

	S (m^2)	H (m)	V (m^3)	N	V/N	S/N
Stalls	340	13·9	4700	414	11·3	0·82
Boxes and Lodge	625	2·5	1500	722	2	0·86
Total	965	—	6200	1136	5·45	0·85

S is the surface area, V is the volume, H is the height and N is the number of seats in the respective area.

In this paper a case history will be examined, involving major refurbishment and the construction of a new acoustic shell in an outstanding Italian opera house, the Municipal Theatre "Romolo Valli" in Reggio Emilia.

This theatre was designed by the architect Cesare Costa and opened on April 21st 1857. Nowadays it regularly hosts seasons of concerts, opera, plays and ballets and is recognized as an important cultural centre for the region of Emilia-Romagna. The building occupies an area of 3890 m^2. The main hall, shown in Figure 1, has a horseshoe plan and is subdivided into stalls, four levels of boxes (totalling 106) and an upper gallery. This space is particularly interesting since its central part is rather deep and is equipped with a small raked tier. The total number of seats in the theatre is 1136. Some geometrical data of the main hall are reported in Table 1.

Recently, the theatre has undergone major refurbishment, which was necessary mainly for safety reasons. The works were organized in two phases and carried out during the summer breaks, with a schedule that avoided interrupting normal activity. In addition, shortly before the refurbishment, in 1997, the management of the theatre decided to build a new orchestra shell. This was actually an acoustical renovation with potentially great effectiveness, the evaluation of which has been included in the current research.

A series of acoustical surveys was held in the theatre. In early 1997, initial measurements were carried out with different set-ups: with the curtain lowered in order to qualify the auditorium main hall independent of the stage set-up, with the curtain raised and the stage empty and with two configurations of the old acoustic shell. The aim of these measurements was to collect data prior to the construction of the new acoustic shell. At that stage, the restoration work had not yet been programmed. Then in late 1997, further measurements were made with the new orchestra shell in place in order to evaluate the improvements introduced by it. Finally, in 2001, after the completion of all renovation work, another set of acoustical surveys was carried out.

2. IMPACT OF RESTORATIONS

An initial phase of restorations took place in the summer of 1998, when the padding and the velvet lining of the seats stalls and of the furniture of the boxes were replaced with fireproof materials. During this operation, the original frame of the seats was retained (Figure 2). A further phase of refurbishment was carried out between June and November 1999 and affected most of the surfaces of the hall and the furnishing of the boxes (Figures 3–5). In particular the synthetic varnishes on the walls were removed and the stucco of marmorino was brought back to its former condition. 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 replaced by fireproof tapestry and the padding and the velvet cover of the furnishing in the boxes were also replaced by fireproof materials.

2.1. THE ACOUSTICAL MEASUREMENTS

In the first 1997 surveys and in those of 2001, the theatre was prepared according to the same set-up and also the same operational scheme was maintained. In addition the same measurement programme was adopted for both. However, as in 1997, the restoration work had not been planned, and the sound power level of the source was not calibrated. This caused some difficulties in the later comparison of the data with the 2001 measurements, but a procedure was implemented to compensate for the difference. Thanks to this procedure, the comparison was still possible and allowed for the investigation of the impact of renovation on the acoustics of the theatre.

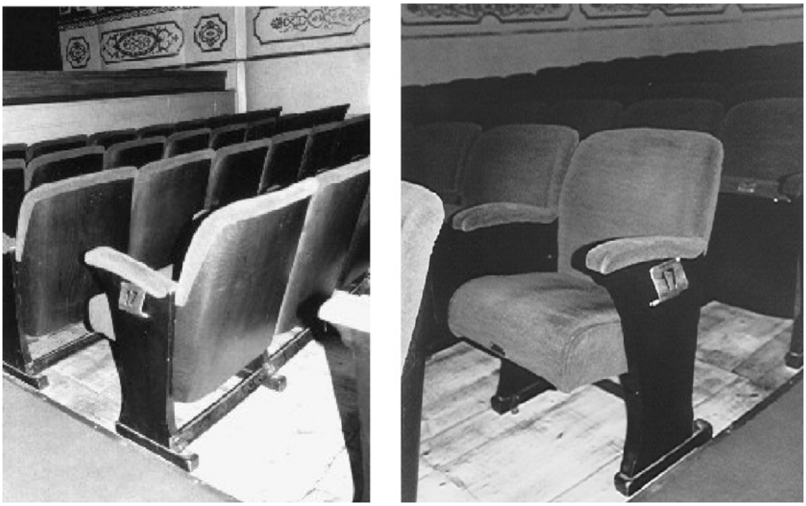


Figure 2. Original frame of the chairs in the stalls. Left, back view; right, front view.

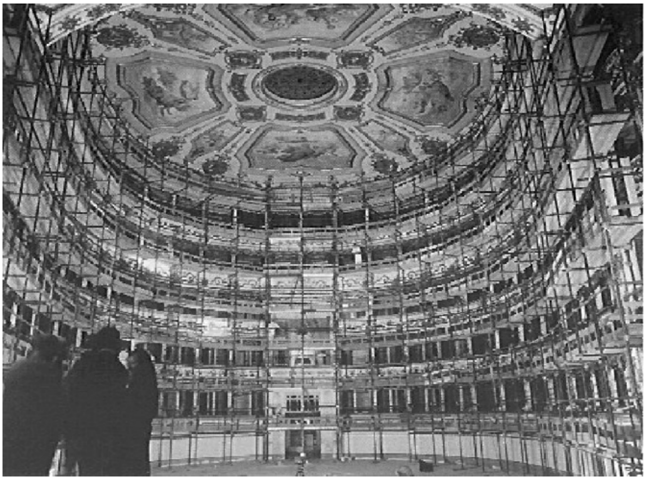


Figure 3. Scaffolding inside the theatre during the refurbishment.

Figure 4. Detail of the wall restoration in the cavea.

During the two surveys the theatre was set-up for chamber music or recital, that is the fire curtain and painted curtain were lowered and the orchestra pit was raised up. The sound source, a Norsonik dodechaedron, was placed in a symmetric position in the centre of the stage, at 3·5 m from its border. A group of 11 receivers were distributed in the left side of the stalls, four in the first level boxes, four in the third level boxes and four in the upper gallery. The plan of receivers is shown in Figure 6. The test sequence was an order 16 MLS signal and a Sennheiser MKE2002 binaural probe was used. While the source was looped, in each position a sample of about 30 s of test signal was recorded on a DAT and a sound level meter measured the sound pressure level (L_{eq}). Later, in the laboratory, the recordings were processed to obtain related impulse responses and, by means of Aurora software, most of the acoustical parameters indicated in the norm [2].

Figure 5. Seats in a box.

2.2. RESULTS

To show and discuss the results of the measurements made before 1997 and after the renovation 2001, two of the most important parameters described in the standard ISO 3382 [2] were used: reverberation time RT20 and clarity C_{80}. The two parameters are partly correlated and the effects of the variations of the physical properties, due to the renovation of materials and surfaces, could be shown, in this case, by using only one of the two parameters. This would not have been the case if the shape of the theatre had been modified by adding new reflecting surfaces. Should this be the case, then a different pattern of the early reflections could be created and a more independent change in clarity could be found. In any case, in the present work both reverberation time and clarity are analyzed to give an objective description of the acoustical properties of the theatre. The plots of the two parameters are shown, respectively, in Figure 7 (reverberation time) and Figure 8 (clarity). Each figure includes the data measured in 1997 (upper graph) and those measured after refurbishment in 2001 (lower graph).

In the present state (year 2001), the acoustics of the theatre can be described as follows. The reverberation of the main hall is rich in the lower range whereas it fits the requirements for opera in the higher range. While the first level of boxes shows a slightly lower RT20 than the stalls, the upper gallery has a markedly higher reverberation in almost the whole pass-band. This is the effect of the additional, partly uncoupled, volume of this area. The C_{80} has optimal values in most of the pass-bands.

A closer comparison with the parameters before renovations (year 1997) can now be pursued. In this respect note that the stalls and the boxes underwent different types of renovation. Despite this, the influence on the acoustical parameters is spread over all of the positions in the theatre. In fact, a match between some particular changes in a given area and a specific variation of parameters in the same area could not be firmly established. For this reason, the comparison is made using the average values of the parameters for all the positions. Figure 9 reports the comparison of averaged values of RT20 and early decay time (EDT) between the 1997 and the 2001 sessions. Both parameters show that the reverberation has undergone a moderate increase in all the bands, which becomes evident above the 2 kHz octave band. In the case of EDT there is a greater increase in the lower frequency range also. Considering the analysis of clarity, it can be seen that C_{80} is closer to the optimum value at high frequencies (4 and 8 kHz octave

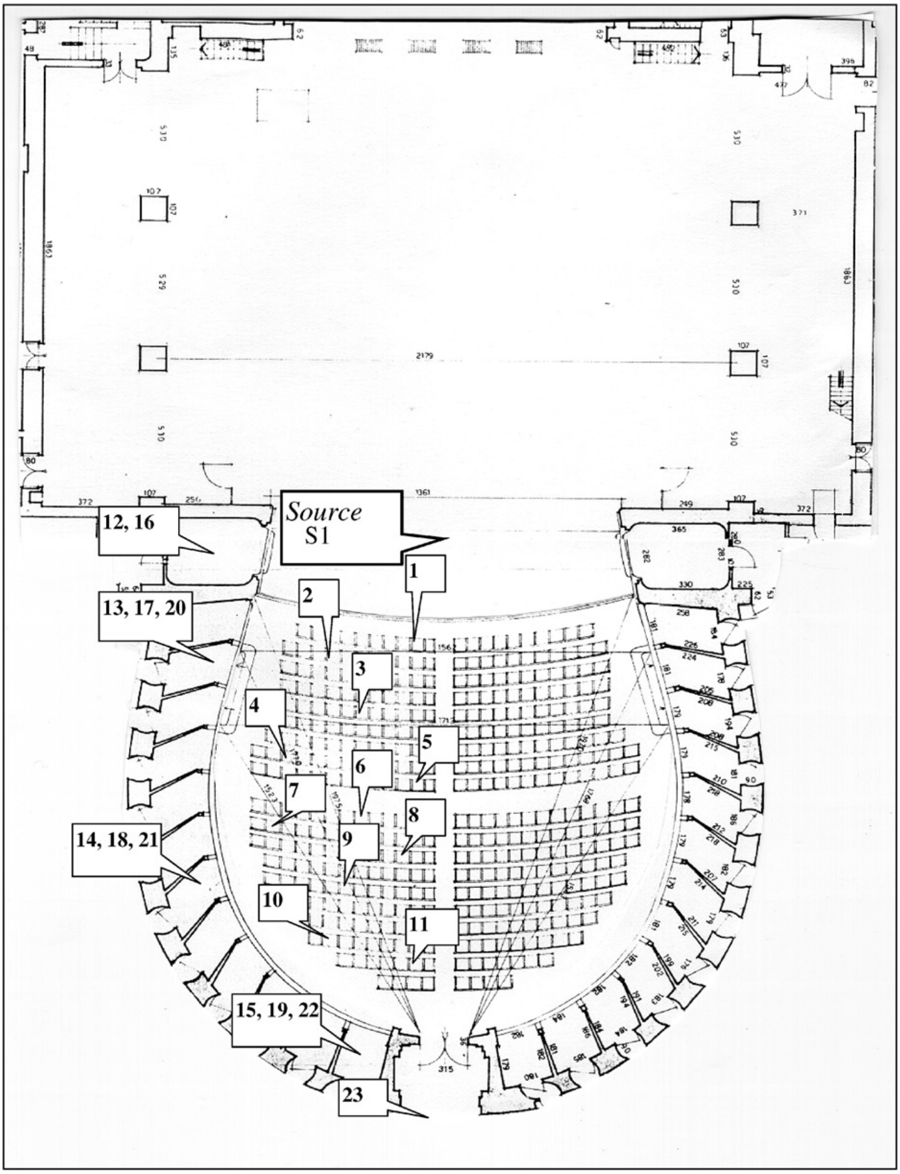


Figure 6. Plan of receivers distributed in the theatre with location of the sound source.

bands) decreasing from 10 to 5 dB (see Figure 10) 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 and the relevant results are reported in Figure 11. The evaluation of this quantity required the sound source to be operated at the same power level during both sessions. As previously explained, this condition was not met. To overcome this problem normalization between the two sets of sound level data was accomplished after the event. In particular, the five points in the stalls closer to the source were considered and a normalization parameter was defined as the average of the level differences between the 2001 and 1997 data at the respective points. The parameter

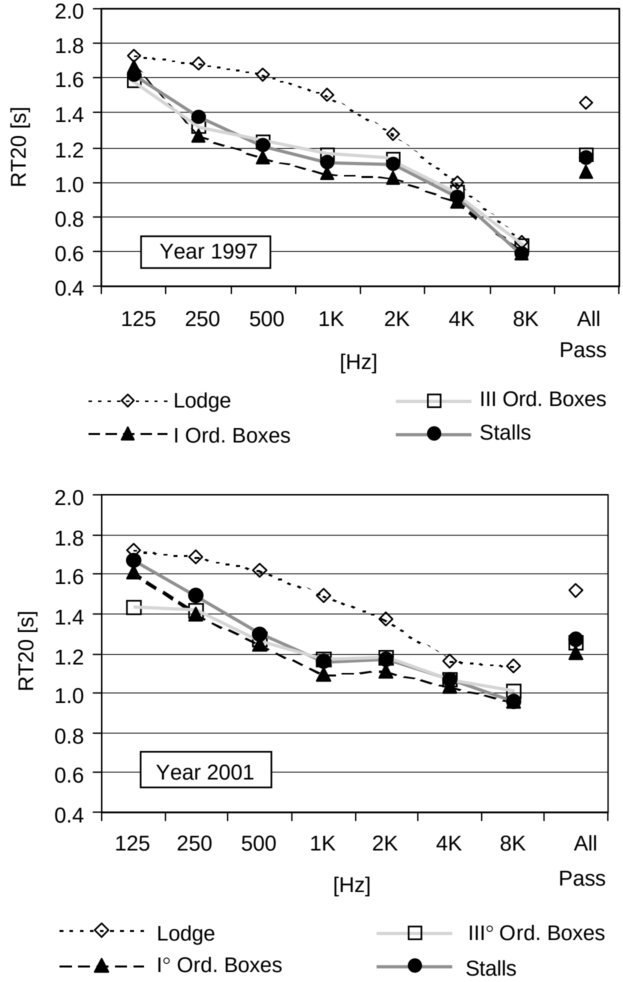
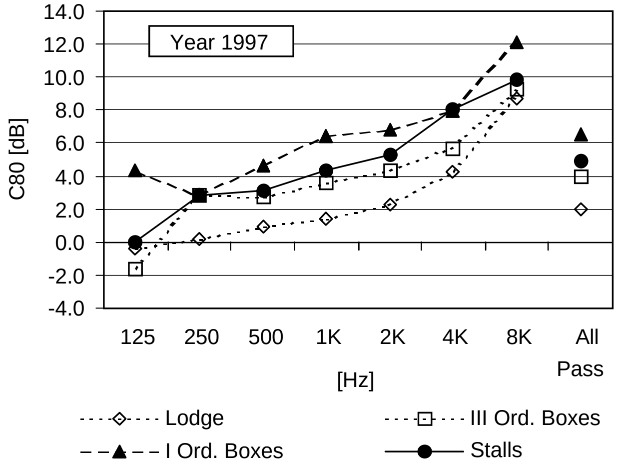


Figure 7. Reverberation time RT20 in the theatre. In the upper graph: values in the different areas as measured in 1997; in the lower graph: values in the same areas of the theatre as measured in 2001.

obtained 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. In this part, the level in 2001 has increased especially in the 8 kHz band in a way consistent with the former results for reverberation time and clarity.

2.3. DISCUSSION

The present acoustical conditions of the theatre are to be preferred and the improvement is extended to every area of the main hall. In particular, the sound is more frequency-balanced thanks to the increased reverberation in the higher frequency range and the correlated effect of a lower clarity determines, for the listeners, a better mixing of the different instruments. The upper gallery seems to have had an even better outcome, but



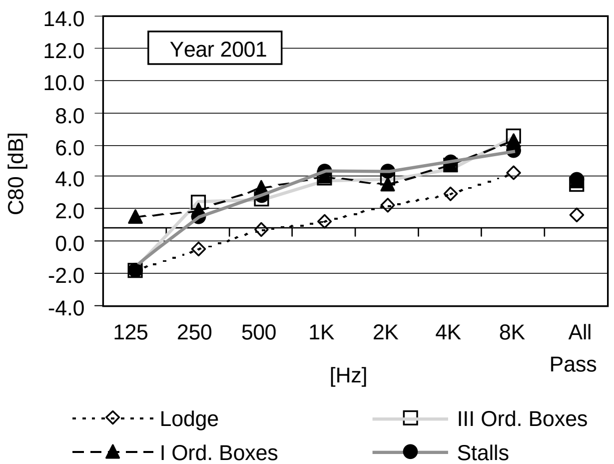


Figure 8. Clarity C_{80} in the theatre. In the upper graph: values in the different areas as measured in 1997; in the lower graph: values in the same areas of the theatre as measured in 2001.

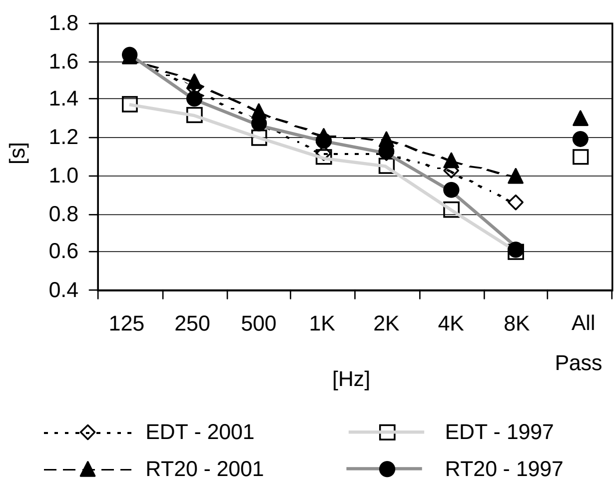


Figure 9. Comparison of EDT and RT20 measured in 1997 and 2001. Averaged values of all receivers.

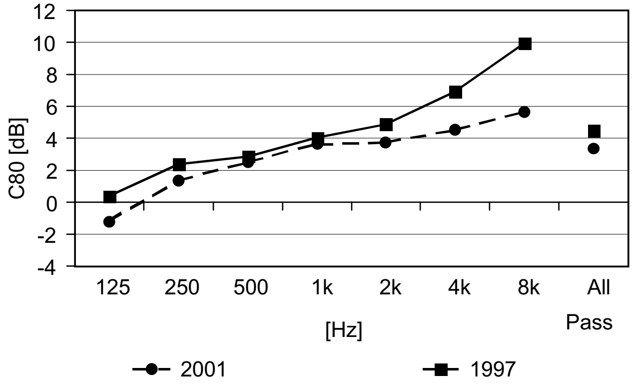


Figure 10. Comparison of C_{80} measured in 1997 and 2001. Averaged values of all receivers.

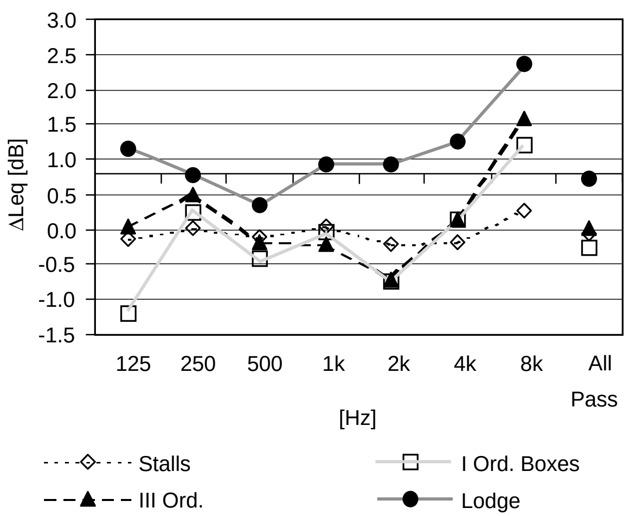


Figure 11. Difference between sound pressure level (*Leq*) measured in 2001 and in 1997. Data are normalized in the second session.

the acoustical conditions (especially in its central part) are still markedly different from the rest of the hall.

A former working hypothesis to explain those results was that the upholstering of seats in the stalls and the furniture and wallpaper in the boxes caused the greatest change in the reverberation time. It seemed more difficult to identify the effect of polishing the plasters and decorations.

To test this hypothesis, some samples of both old and new velvet lining of the seats in the stalls and of the furniture in the boxes were collected. These were analyzed and their absorption coefficient for normal incidence was measured in Kundt's tube and compared. The measurements did not include the related padding, which had in the meantime been discarded. The results for the linings of the seats in the stalls and for those of the furniture in the boxes (two old types were replaced by one new type only) are presented in Figures 12 and 13 respectively. In the former case (stalls seats) it is found that the old

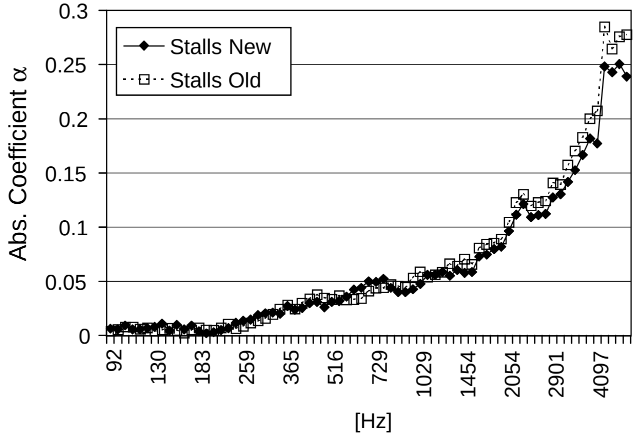


Figure 12. Sound absorption coefficient for normal incidence of the lining of the seats in the stalls before and after refurbishment.

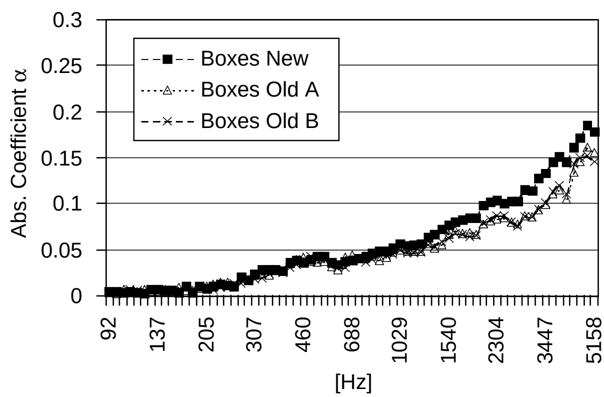


Figure 13. Sound absorption coefficient for normal incidence of the lining of the furniture in the boxes before and after refurbishment. Two types of material were present in the old configuration.

lining is in fact slightly more absorptive, and the difference is slightly amplified by transforming the data into diffuse field absorption. On the other hand, the data related to the boxes show an inverse trend with the new ones being more absorptive than both old types. Even from a very simple numerical estimate it was found that the change in reverberation time could not be explained by the diffuse field absorption coefficients. This is also true if the effect of the boxes is neglected together with that of painted surfaces and decorations. It is thought that the reason for such an inconsistency can be due mainly to the difference in the padding, which could not be considered.

3. RENOVATION OF THE ORCHESTRA SHELL

In the Teatro Valli, the old orchestra shell was made with flat plywood mounted on a metal frame. Each panel was 2 m wide and 8 m high, and had a layer of 4 mm thick plywood. The panels were mounted side by side in order to create an orchestra shell 14 m wide and 10 m deep. No ceiling components were mounted.

The old orchestra shell had several problems, some of which regarded the acoustics, while others regarded safety and flexibility when mounting and storing the single panels. Acoustically, the problems regarded the lack of reflection at low frequencies due to the limited thickness of the plywood, the presence of some noisy resonance of the panels due to the gap between the points of connection of the plywood and the metal frame, and the lack of diffusion due to the flatness of the panels. The old orchestra shell had only two entrance doors, which presented safety problems for the musicians if the need for rapid escape should arise. Furthermore, as each panel with the metal frame was 2 m wide and 8 m high, the weight and the dimensions created problems when moving and storing the panels. For these reasons, the management of the theatre decided to build a new orchestra shell.

The new shell has a depth of 9·8 m and the same width (14 m) as the old one. The panels are 7 m high and 1·4 m wide. Each panel is equipped with a double wooden grid between 6 and 7 cm deep, exposed to the sound field with the aim of increasing the diffusion. The back of the panels consists of a plywood layer with a thickness of 5–6 mm. At the moment only the lateral walls of the orchestra shell are built, but the design also includes the construction of ceiling panels used as reflectors.

The design and the construction of the new orchestra shell were made entirely by a team from the theatre itself with the advice and suggestions of the musicians and conductors who, however, expressed positive views on the acoustic quality of the former shell.

3.1. RESULTS

Some effects of using orchestra shells in multipurpose halls, as described by Bradley in reference [3], are a general increase of the overall sound levels by 2–3 dB, a slight increase in the reverberation time and EDT (0·1–0·4 s), and a decrease in C_{80} by up to 3 dB. In reference [4], one of the authors found similar results using an orchestra shell in an Italian opera house, with an increase of the reverberation time of up to 0·5 s, a decrease of the clarity of up to 5 dB and an average decrease of the inter-aural cross-correlation coefficient (IACC) of 0·2.

In Figures 14 and 15 the comparisons of RT20 and of C_{80} obtained with four different configurations of the theatre are reported. The following configurations were compared:

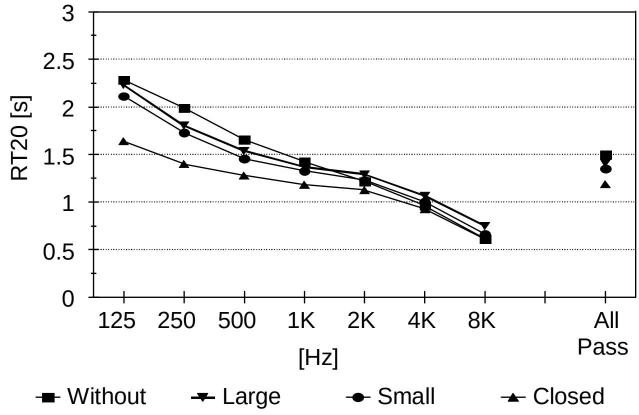


Figure 14. Reverberation time RT20 as measured in 1997 for different configurations of the old orchestra shell (the details of the configurations are explained in the text). The data are averaged among all receivers.

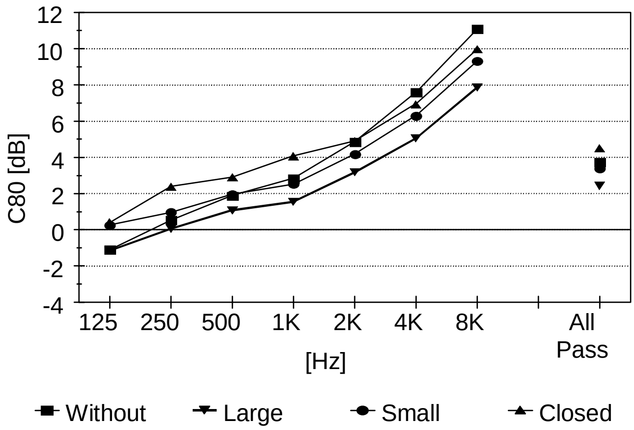


Figure 15. Clarity C_{80} as measured in 1997 for different configurations of the old orchestra shell (the details of the configurations are explained in the text). The data are averaged among all receivers.

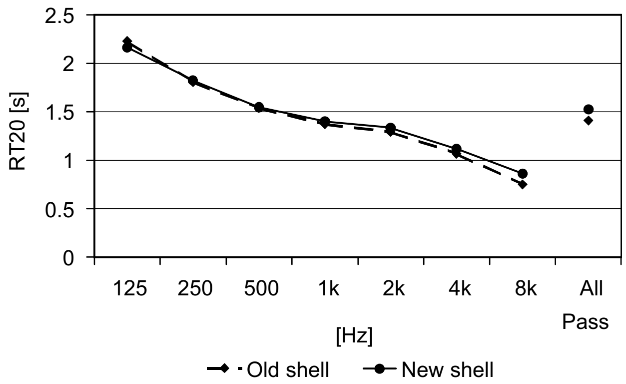


Figure 16. Comparison of RT20 measured with the old and the new orchestra shell. Data are averaged among all receivers.

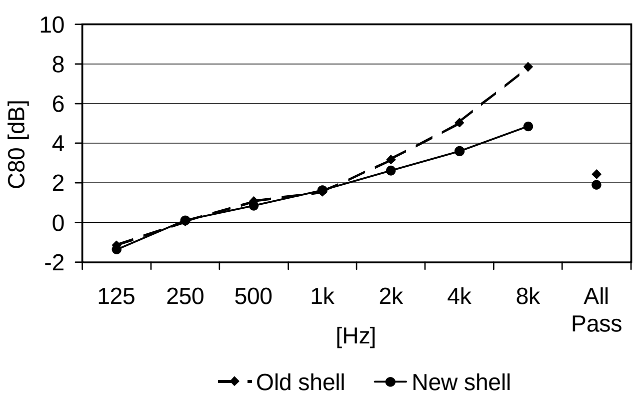


Figure 17. Comparison of C_{80} measured with the old and the new orchestra shell. Data are averaged among all receivers.

("*Without*") without the orchestra shell, ("*Large*") with the large 10 m deep old orchestra shell, ("*Small*") with the small 6 m deep old orchestra shell, ("*Closed*") with the curtain closed. The figure also shows that the old orchestra shell gave similar results to those obtained in reference [4] although in this case the differences were not as evident as for other Italian opera houses.

The comparison between RT20 and C_{80}, measured with the old and the new orchestra shell, is reported in Figures 16 and 17. For RT20 there are only slight differences for frequencies above 1000 Hz.The same result was obtained also for the early decay time EDT although it is not reported. The parameter C_{80} shows more marked differences in the same range of frequencies.

3.2. DISCUSSION

The values of C_{80} obtained with the new orchestra shell can be considered better than with the old one although there are still some values above the optimal ones considered for music. Actually the improvements obtained with the new shell were limited mainly by two factors. Firstly, the increase in the sound diffusion obtained with the wooden grids turned out to be relatively effective only over a limited frequency range. Furthermore, both shells still lack a proper ceiling surface whose efficiency in blending the sound of the orchestra and in directing it towards the audience is well recognized.

4. CONCLUDING REMARKS

Not only were the renovations not harmful; in fact, the measured data show significant improvements in some aspects of the acoustics of the theatre. It is thought that the previous conditions were due to deterioration and alteration of interior materials and decorations over time. This work validates the renovation procedure and confirms that matching safety requirements and acoustic quality is now possible. In any case, it is necessary to introduce more detailed acoustical measurements on the materials to be changed before and after renovations and their data are to be combined together with fire-class specifications.

On the other hand, the theatre acoustics does not seem to have improved significantly by the construction of the new orchestra shell whose effectiveness is limited by the absence of the ceiling.

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