INTERNATIONAL SYMPOSIUM on MUSICAL and ROOM ACOUSTICS
ISMRA 2016
September 11-13, 2016
La Plata, Buenos Aires, Argentina

Evaluation of Concert Halls / Opera Houses: Paper ISMRA2016-37

Acoustics in the restoration of Italian historical opera houses: Lessons learned

Nicola Prodi[(a)], Roberto Pompoli[(b)]
Dipartimento di Ingegneria, Università di Ferrara, Italy,
(a) nicola.prodi@unife.it
(b) roberto.pompoli@unife.it

Abstract

Dealing with the restoration of an historical opera house (OH) involves many specialties in the fields of architecture, engineering and fine arts. Acoustics is one of the most important since its mission is crucial for several reasons, aside those obviously connected with the vocation of the space. First, restoring the OH even with the best possible architectural practice by means of a “blind” copying of the original materials, which was done in the past at some places, can be risky without a control of single items and an accurate check of production processes. Second, an occasion to valorize the sound in the whole theatre and to enhance listening attributes in the hall in particular cannot be missed. Third, the close control of the acoustics in the stagehouse, where latest technologies are often installed, is mandatory. Based mostly on direct experience, this work discusses some of the problems that arise in the management of acoustics during restorations. In particular the approach proposed is a blend of respect for the heritage value of acoustics and of technical improvements, consisting in the inclusion of devices and solutions to optimize the listening for public and performers.

Keywords: historical opera houses, restoration, acoustical heritage

INTERNATIONAL SYMPOSIUM on MUSICAL and ROOM ACOUSTICS
ISMRA 2016
September 11-13, 2016
La Plata, Buenos Aires, Argentina

Acoustics in the restoration of Italian historical opera houses: lessons learned

1 Introduction

Italian historical opera houses provided the traditional place for performance of opera and are still today at the core of the National system for musical production. Due to the large number of larger and smaller OHs in the Country it is essential that this heritage is well preserved and possibly valorised during renovations and restorations. Besides the easily recognized architectural constraints from Superintendents that impede substantial changes in the structures and in the types of materials, there are indeed several issues that may impact on the acoustics even if the aesthetical output is very slightly changed. In fact acoustics of such spaces of performance is depending on a number of features, some of them being interlinked. In particular the sound field perceived in the historical opera house is shaped by the geometry of the cavea, by the boxed lateral walls and by the usual presence of the orchestra pit that mostly influence the propagation of sound: it is possible to describe a general trend although variations do exist from hall to hall [1]. So, in view of renovations, it is necessary to plan multiple controls on acoustics starting even before the works start, and following the progress of renovations until the final check. The first step is the definition the acoustical character of the OH, and this can be done by a set of preliminary acoustical measurements that have been strongly recommended from several years on [2]. This is not a bare exercise but is the unavoidable technical root to define that set of elements that need to be kept and delivered in the refurbished hall in order to preserve the acoustical heritage. This acoustician's task is subtle because to the modern ears some traditional design criteria (box design, concave plan shape, short reverberation time) which are also the results of a complex socio-cultural development and not just of a technical acoustics one [3], might seem difficult to support. Anyhow, improvements can be also introduced to some extent, given that modern technologies and criteria are adapted without distortion of the original design. In other words acoustics is to be dealt with in the context of restoration theory to set the goal of the works both visually and aurally. Acoustical measures are not restricted to the response of the enclosure but a wide range of checks on materials needs planning, as for instance the very useful acquisition of the acoustical data of the elements to be replaced. In particular seats, velvets, upholstery etc.. should be characterized acoustically rather than estimated, and this too has to be done before the works start since their contribution will greatly affect the acoustical results. Moreover these same figures will be the input of acoustical CAD models whose reliability increases the more the input data are accurately known. Nowadays in fact simulations are always used to predict how the renovated hall will sound and are used as a step-by-step aural check of the works. For the present application the correspondence of real and simulated sound fields needs careful consideration due to the OH geometry that produce several genuine wave effects, which are only approximated in most of the commercially available codes. That is why collaboration with musicians and theatre goers can be a great benefit for such projects and can help in tuning the acoustics subjectively beyond the figures output from the necessary objective measurements and simulations. This paper will

focus on the acoustical issues in the restoration works and will provide some examples taken from the authors' experience. In particular the paper develops some of the points raised in the work [4] that it was not possible to fully discuss therein.

2 What is restored

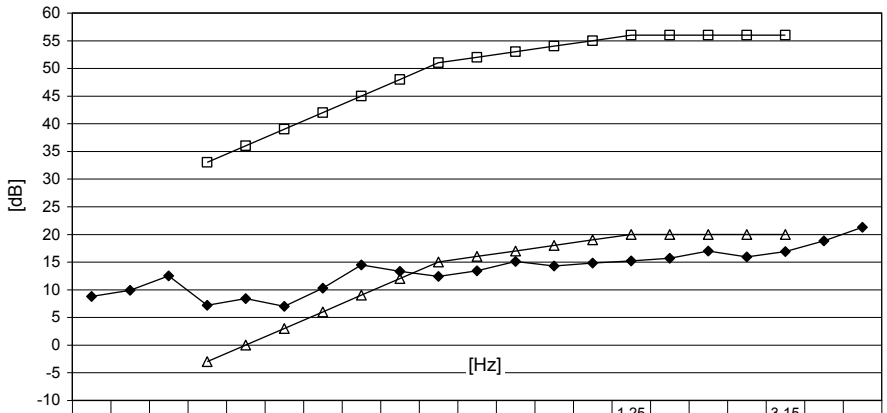
It is difficult to provide a simple definition of the timing, type and of the extension of the restorations/refurbishments that take place in a typical Italian historical opera house during its life. In fact, aside the world-famous theatres that undergone major well-documented renovations or reconstructions in the last decades (Teatro alla Scala, Teatro La Fenice, Teatro S.Carlo, Teatro Petruzzelli), the majority of historical opera houses in the National territory (which sum up to close to 800 in number) undergo relevant renovations typically not earlier than 40 years when used regularly. A list of items to be cared for always includes the refurbishment of seats, to replace an exhausted upholstery and most often to introduce a fire proof one. The furniture inside boxes (seats, sofas, arm rests) share the same treatment. Also the whole box preparation is an important issue including interior lateral surfaces, ceiling and floor (Fig. 1). Moreover, depending on the integrity of the structure carrying the load of the boxes, it is sometimes necessary to substitute wooden beams, laths and panels, and seldom the whole wooden structure is rebuild with a high potential impact on the vibration response and thus on the acoustics of the hall. On the other hand, in the case of brick constructions, renovations to the structure are more cosmetic and focused on the polishing of the surface paintings and of the decorative plasters.

Figure 1: Teatro Zandonai, Rovereto: the interior of a box prior to renovations (left) and after refurbishment (right). Note that a panel was removed from the box fence to revamp the original lathed structure. Moreover removing the carpeted floors is often intended as a philological approach to the heritage, since carpets were introduced in earlier renovations, when sometimes theatres were used also as cinemas especially in smaller towns [5].

The stalls and stage floors are often rebuild or revised with sometimes a change of their height and of their mutual inclination. These important changes are connected on the one hand with the insertion of a proper orchestra pit for those theatres that are still not equipped with it, and on the other hand with the choice of distributing air by a plenum underneath the stalls floor. In fact

the setup of an HVAC is another quite usual topic in the renovations and, together with the orchestra pit, they are considered technical improvements that widen the range of fruition and thus make the return of the investment more probable. Unfortunately, inserting an HVAC in the historical building poses a number of layout concerns which regard for instance the location of air-handling units, of compressors and the design of pipes' tracks and of the type and placement of terminals. Stringent requirements can be achieved but an extra effort is mandatory.

Other "bulk" interventions are often scheduled to improve the stagehouse functionality and may consist in its enlargement with the possibility to hang complete scenes during the shows or more simply in providing grids of hatches in the stage floor to allow for maximum scene flexibility. The relationship of the stagehouse volume with that of the main hall is one of the most important issues when enlargements of the former are implemented.



	50	63	80	100	125	160	200	250	315	400	500	630	800	1k	1.25 k	1.6k	2k	2.5k	3.15 k	4k	5k
Misure	8.8	9.9	12.5	7.2	8.4	7	10.3	14.5	13.3	12.4	13.4	15.1	14.3	14.8	15.2	15.7	17	15.9	16.9	18.8	21.3
Rif.				33	36	39	42	45	48	51	52	53	54	55	56	56	56	56	56		
Rif. tr.				-3	0	3	6	9	12	15	16	17	18	19	20	20	20	20	20		

Figure 2: Sound insulation D of a box door in the II tier of Teatro Zandonai prior to restoration. The respective weighted indicator was $D_w(C_{50\ 5000Hz}; Ctr_{\ 50\ 5000Hz}) = 16\ (0;-2)$ dB.

Aside the interventions directly related with the main hall and stagehouse, it is obvious that many other ancillary spaces are touched in the works but they are not considered here. It is anyway to be stressed that sound insulation between building zones (corridors, foyers, boxes etc..) is usually to be improved since quieter interior conditions are greatly appreciated in the core of the performance space. Separation with the entrance foyer is one of the main issues since historical closures provide usually a loose sound insulation and boxes doors are a weak point in this respect (Fig. 2). In practice it happens that the situation can be improved to some extent with a relatively simple strategy of sealing. This is the typical solution for boxes' doors and is largely obliged, since the doors are hardly replaced unless damaged.

3 Acoustical criteria

Availability of acoustical measures taken before renovations helps in setting the acoustical targets of the renovations, but a more theoretical point of view is also necessary. In fact, as a design target, it has to be clarified if the reverberation gap compared to modern opera houses of the same volume [1] is to be compensated for or not. This is probably the main preliminary question to resolve and it has been practically tackled with an increase of reverberation time in some recent cases [6]. There are anyhow also motivations not to follow this option, as it may be considered either as a transient trend as seldom happens in architecture or simply as a not entirely philological approach. The point is that visual control is easier and widely accessible whereas the acoustical reputation needs years of time to settle, primarily within the performers and then in the public attending regularly the performance venue. In this sense it has to be recalled that listening in the historical OH is still the most common musical experience for the Italian public since these are in a large part of the territory the most accessible and spacious places for music (not just for opera, indeed). So, changing the acoustics in the renovations means changing the way the public listens, and shaping a new taste is the final output of the process. For this reason a conscious decision has to be taken since acoustics is in itself an heritage. Analogous to the fact that we would not accept the flutes of a Hellenistic column to be filled because of today's visual taste for smooth surfaces, one may not like to fill the reverberation time gap simply to adhere to modern aural taste. It has to be remarked that this is not an argument to refuse or question enhancements. In many cases there are indeed possible improvements such as achieving a more uniform listening in the stalls by removing a possible focussing [7], delivering a more balanced sound between pit and stage by detailing the orchestra pit design with also a consideration of musicians' aural safety, increasing the fullness of tone for the orchestra by working on the pit floor "keel" [8] and tuning the sound absorption in the boxes as discussed later. All of these and several other changes that can be planned in a specific venue after the careful analysis of *ante operam* acoustical conditions are in line with the original design concepts which is preferably optimized rather than conceptually revised.

4 Examples of acoustical control

4.1 Seats

Replacement of seats with newer models is not the only choice because seldom seats themselves shall be preserved, despite having probably an unfavourable ergonomics compared to recent standards. Should this be the case, revamping is the common solution with the seat structure kept and paddings and worn out velvets replaced with fresh ones. In this process there is a certain deal of uncertainty which is not limited to the correspondence of the acoustical performance of the respective items. In fact the final result also depends on specific solutions adopted for the assembly (i.e. gluing, fixing etc..) that may alter the output even when the same materials are employed. So, uncertainty needs to be minimized with a careful match of pre and post data of components and of upholstery techniques in order to avoid uncontrollable impact on the acoustics of the hall. It is reasonable to set a ± 10% tolerance of acoustical performance

across frequencies to be confident that the refurbished seats will comply with previous ones. A pre-series of refreshed seats is necessary in this respect to check the goals. The old ones' data are to be acquired [9] prior to decommissioning and the revamped ones are to be processed in the same laboratory and under the very same mounting conditions to minimize variance due to sound absorption measures. When entirely new seats are provided, the match of acoustical data can be more difficult when the product is industrialized. In the more important projects there is anyway the possibility of customizing to some extent the basic seat, for instance keeping the structure and developing the best mix for the variable details. This process requires the concourse of the producer and a closer aesthetical look and acoustical performance of the new seats with the previous one can be achieved. This is to say once more that historical opera houses are not "normal" buildings, but require more than others some tailoring of the most relevant components, and seats are the clearest example. Of course this option has to be considered in the context of budget but it is a good place where to allocate resources for acoustical control. Finally it is interesting to mention that several products entered the seats producers' catalogues after being developed expressly for renown projects and became *de facto* a reference in the field also for smaller and less appealing projects.

4.2 Boxes

There is a trend in the recent OH refurbishments to reproduce in the box the home-like atmosphere that originally characterized those spaces. This practically means that the preparation of box interior surfaces often includes claddings on the walls as a design option. Anyway it is impossible to generalize in this case, because some houses had effectively such soft wall covering, which was maybe removed during previous interventions. In some other cases the same solution was added later, while it was not present in the original design. To solve the dilemma the renovation project may fix an year of reference in the past, sufficiently close to the opening (but not necessarily coinciding with it) where most of the design details are known, congruent and philological. The target will thus be taking back the opera house as much as possible to that specific year, with or without cladding. This is a wise solution that also helps the acoustician to better predict the outcome and puts the discussion on the boxes on more solid grounds. In fact boxes are peculiar since the listening attributes are known to be appropriate for the front positions only [10]. For this reason allowing for excessive sound absorption inside the box may result in a critical sound perception in the box recess. Controlling the cladding of boxes, when it is inserted in the targeted conditions, is thus a good exercise, which will give a reward also for the main hall, and not just locally [11]. Simulations do support this need and can be implemented in the context of numerical control of renovations. Moreover acoustical measurements demonstrate that historical OHs build across centuries are very rarely too reverberating and thus limiting the box cladding to the minimum possible when there are specific philological requirements is not a risk in the other way round. Also sound absorption measures on small samples of cladding can be employed to demonstrate how the performance is variable with preparation once the data are fed to the numerical model [4]. In this respect in situ measures, which are far more complicated primarily due to the small enclosed volume of the box, are less reliable to take decisions.

4.3 Stagehouse

The usage of technology has greatly increased over the years in the opera production and, together with the need of reducing costs, automation of scenery logistics and advanced lighting techniques have made the stagehouse similar to a sophisticated factory department. So, one the one side a large number of somehow noisy devices such as motors, inverters, power lamps etc.. is placed in the stagehouse volume and, on the other, often the scenery consists in PVC screens where context is projected partly replacing bulky constructions of the past. Thus the sound absorption of scenery within this technological approach is rather faint and the risk of excess of reverberation in the main hall due to the coupling with the big stagehouse volume is realistic. Seen in an historical perspective one shall recall that the concept of an acoustically treated flytower came up in the modern theatres, whereas in the historical OH the control of reverberation was mostly left to curtains and wings without any fixed sound absorbing treatment of the walls on the perimeter. The renovation is the occasion of solving this critical aspect and of providing an extensive passive wide band sound absorption in this volume (Fig. 3). Moreover the tower itself is in some cases enlarged to widen the range of mountable scenery and possibly hosting those from bigger theatres: the estimated reverberation in the stagehouse might increase and the risk of improper coupling too. The target of the design of the sound treatment can be to provide a passive stagehouse such that either with closed or opened fire-curtain, the reverberation time in the main hall is equal. This is a strategy to make the acoustics of the main hall as independent as possible from the coupling. It will not mean that the acoustical conditions will not vary at all, but deviations will occur over a much narrower range of values.

Figure 3: Materials for a simple and effective treatment of the stagehouse. The design needs to be developed numerically in the context of the coupling of stagehouse and main hall.

4.4 Pit

It can be technically complicated to insert a pit in an OH which had not it before, or to extend pits that are too small to the present needs of orchestras [12]. Furthermore the debate on the pit insertion from scratch can be very harsh and involve politics too [13]. In simpler cases, when a pit of sufficient dimensions and accessibility exists, the constraints of architectural conservation restrict the range of possible interventions. Typically the automation of the pit floor movement is added to allow several levels of height to be reached and warrant the possibility of adding the pit floor at the forestage when concerts are scheduled. This will take part of the ensemble for concert into the main hall volume with a great benefit for intimacy and sound level. Anyhow, the need of moving the pit floor has deprived in few cases the structure of its resonating volume underneath, the so-called “kneel”. This apparatus can actually be integrated in the renewed movable parts but a specific study needs to be assessed. Optimization of the pit with respect to excess sound for musicians is a relatively recent concern which finds solutions with an accurate mixture of sound absorbing treatments especially close to the most exposed locations. Given that the orchestral arrangement is variable, design trends are focused to provide movable, double-faceted panels to configure local sound absorption and reflection. As regards the balance between singers and pit as perceived in the hall, and the communication between these zones, there are few strategies available with minimal architecture intervention (e.g. inclination of pit rail or see [14] for pit and [15] for proscenium boxes) but solutions are very much depending on the specific case under consideration. So, the pit is one of the more complicated issues to deal with in the historical opera houses because of the mixture of requirements it carries, that are seldom contrasting.

5 Concluding remarks

Restoration of the historical opera house and, at the same time, its adaptation to the modern technologies with the task of valorising the heritage and its potentials requires a relevant effort also for acoustics. The nature of the building, its architectural stratifications and the cultural implications it carries, forces to adopt solutions which possibly review all of the points above. The strategy of tailoring of solutions is typically necessary for most of the historical sound absorbing elements whereas the effect of polishing of hard surfaces can be more easily controlled. As pointed out in [4], the vibro-acoustics issues in the historical OH deserve an increased attention since very few data are available and no specific technical norm covers these procedures. On the contrary the methodologies to qualify the aeral propagation of sound in performance venues and the measurement of the acoustical performance of materials are well described in the technical literature. It is finally desirable that all of the works in this area are technically documented and disseminated to increase the knowledge in the field in order to learn as much as possible from previous experiences.

References

[1] N. Prodi, R. Pompoli, F. Martellotta, S. Sato, Acoustics of Italian historical opera houses, *J. Acoust. Soc. Am.* 138(2), (2015) 769–781.

[2] N. Prodi and R. Pompoli, Guidelines for acoustical measurements inside historical opera houses: procedures and validation, *J. Sound Vib.* 232, (2000) 281–301.

[3] R. Pompoli, N. Prodi, Acoustics of Italian historical opera houses: a Cultural Heritage, *Proceedings of ICSV22*, Florence (2015).

[4] N. Prodi, R. Pompoli, Acoustics in the restoration of Italian historical opera houses: a review. *to appear on Journal of Cultural Heritage* (2016).

[5] R. Pompoli, N. Prodi, I. Ortega, C-H. Jeong, Teatro Zandonai in Rovereto, Italy: a case study for restoration, *Proceedings of ICSV22*, Florence (2015).

[6] J. Reinhold, Teatro di San Carlo, Naples – Conservation of the excellent acoustics in the oldest active opera house in Europe during restoration and extension, *Proceedings of 20th ICA Congress*, Sydney (2010).

[7] L. Tronchin, The design of acoustical enhancements and diffusion in the opera house of Treviso, Italy. *Proceedings of 6th International Conference on Auditorium Acoustics*, Copenhagen, Institute of Acoustics (UK), vol. 28(2) (2006).

[8] A. Cocchi, M. Garai, L. Tronchin, Influence of the resonating cavities underneath the orchestra pit: the case history of the Alighieri theatre in Ravenna (in Italian), in *Teatri Storici – dal restauro allo spettacolo*, Nardini Editore, Fiesole (FI), 1997.

[9] ISO 354:2003 Acoustics -- Measurement of sound absorption in a reverberation room, International Organization for Standardization, Geneva 2003.

[10] C. Ianniello, A note on historical theaters for opera, (in Italian), *Rivista Italiana di Acustica* 26, 2002, 45-62

[11] A. Farina, A. Capra, E. Armelloni, C. Varani, A. Amendola, Caratterizzazione Acustica Del Teatro Alla Scala Di Milano, *Proc. Of AIA Conference "Teatri d'opera dell'Unità d'Italia" Teatro La Fenice, Venezia, 23 Novembre 2011*

[12] http://www.comune.siena.it/La-Citta/Cultura/Teatri/TEATRO-DEI-RINNOVATI

[13] http://ricerca.gelocal.it/trentinocorrierealpi/archivio/trentinocorrierealpi/2007/06/07/AR1PO_AR101.html?refresh_ce

[14] L. Parati, N. Prodi, and R. Pompoli, Computer model investigations on the balance between stage and pit sources in opera houses, *App. Acoust.* 68, 2007,1156-1176.

[15] D. Š. Pavlović, M. Mijić, D. Mašović, The influence of proscenium boxes on acoustic response in historical opera halls, *J. Acoust. Soc. Am.* 138(3), 2015, 1533-1536.