THE ACOUSTICS OF THREE ITALIAN HISTORICAL THEATRES: THE EARLY DAYS OF MODERN PERFORMANCE SPACES

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ABSTRACT

In the last decades the theatres dating to XVI and XVII centuries, which are of paramount importance for the development of modern performance spaces, were almost completely neglected by acoustical studies. In this work the acoustics of three world-famous Italian theatres will be presented, namely the Teatro all'Antica in Sabbioneta, the Teatro Olimpico in Vicenza and the Teatro Farnese in Parma. This comparative study spot new light in the process that led to the definition of the acoustic qualities of opera houses and concert halls.

INTRODUCTION

The three theatres object of this study, that is the Teatro Olimpico in Vicenza (referred to as VC), the Teatro all'Antica in Sabbioneta (in the province of Mantova, here indicated with MN) and the Teatro Farnese in Parma (named PR), are generally considered of outstanding importance in the historical development of performance spaces. They all date back to the early days of modern halls and precisely to the transition from XVI to XVII century. In particular the oldest of them, the Olimpico, which opened on 3rd of March 1585 with "Oedipus rex", is a masterpiece of architecture from Andrea Palladio (1508 – 1580) completed with the perspective scenery of the streets of Tebe by Vincenzo Scamozzi (1552 – 1616). The theatre is organized in a rigorous classical style with a fixed scenery, a large stage, an open orchestra and, on an hemielliptical curve, fourteen tiers of steps leading up to a colonnade, which in turn is surmounted by a balustrade with statuary. This very impressive playhouse is covered with fixed ceiling with a painting of blue sky and clouds, to signify the direct link with open-air classical performance spaces. After the grandeur of its opening the theatre hosted the activities of the Accademia Olimpica and is prefectly conserved. Nowadays the theatre is used mainly for music festivals in the summer hosting recitals and reduced ensemble orchestras. The architect Scamozzi built entirely the second theatre, the Teatro all'Antica, which is placed in Sabbioneta, the ideal city of the duke Vespasiano Gonzaga. The theatre opened on the carnival of 1590 and has a small rectangular plan also based on the classical model of stage (equipped with single-vista scenery) with an open orchestra and an auditorium in tiers of steps which are closed by a back wall surmounted by a loggia with colonnade. The life of the theatre had alternate fortunes and, after being used in the past also as a warehouse, was later restored and is currently used for music venues and conferences. The third theatre was constructed by Giovanni Battista Aleotti (1546 – 1636) in the Great Hall of Arms at the first floor in palace of the Duke Ranuccio I Farnese, who wanted a representative theatre for large spectacles and festivals. The theatre was completed in 1618 but the first venue was in 1628 with the opera “Mercury and Mars” by Monteverdi. The theatre has a rectangular plan of very long dimensions and presents a U-shaped steeply-raked tier of grids which delimit wide and flat orchestra area by high lateral surfaces. In the theatre some of the crucial innovations in the design of opera houses can be found, which stem from the demanding needs of baroque spectacles. One of them was the design of a proscenium arch connecting the cavea with the stage and another was the introduction of a fly-tower together with the use of wings moving in grooves on the stagefloor instead of the fixed scenery as used in VC and MN. The Teatro Farnese was almost completely destroyed by bombing in 1944 and later rebuilt following original drawings. The original ceiling was already missing in 1944 and was not restored.

THE BASIC GEOMETRICAL DATA OF THE THEATRES

The gross architectural data of the three theatres are resumed in Table 1. As can easily be seen the volumes and surfaces of the theatres greatly differ with MN having the lower values and PR being exceedingly big, even compared with modern opera houses or concert halls. In this case the value is split into cavea and stagehouse, which contributes with one-third of the global figure. In the other cases a unique figure has been calculated since no such clear separation is possible. Moreover, though the models inspiring the designs had evident similarities, the ratio of height and width to length are markedly different in the case of VC whereas the other values are more close with rectangular plan concert halls.

	V [m³]	**H** [m]	**W** [m]	**L** [m]	$S_{orchestra}$ [m²]	S_{loggia} [m²]	S_{tier} [m²]		S_{cavea} [m²]	S_{stage} [m²]	**H/W**	**L/W**	**ITDG** [ms]
							plan	*devel.*					
MN	2500	11,7	11,35	28	71	49	69	89	140	62	1,03	2,47	17
PR	30000 (45000)	23	29,3	58	580	160	365	565	945	290	0,62	1,98	12
VC	7300	15	30,5	20	86	80	240	300	326	130	0,49	0,66	44

Table 1 – Basic geometrical data of the theatres. The volume of PR is that of the cavea with the addition of the stagehouse (in parenthesis). The values of the tiers are divided into plan and developed surfaces. The surface S_{cavea} includes the areas where the audience actually seats.

It is also interesting to note that the Initial Time Delay Gap calculated from the reported geometry is in line with the best suggested values for concert halls for MN and PR (due to high lateral surfaces) but is too long for VC. Another interesting preliminary study based on the available information concerns the conditions of occupancy of the theatres and its relation with gross geometrical data. In Table 2 a comparison of the conditions of occupancy is presented. The data indicated with XVII and XXI refer to the relative century. The estimates in the table are derived from available documents or by a direct inquiry to present holders of the places.

	XVII		**XXI**		**V/N**		**S/N**	
	Orch.	***Aud.***	***Orch.***	***Aud.***	***XVII***	***XXI***	***XVII***	***XXI***
MN	150	100	90	60	10	16,6	0,56	0,93
PR	950 – 1450	1450	300	0	12,5 - 10,3 (15 - 18)	100 (150)	0,3 - 0,4	3,15
VC	175	750	0	470	6	15,5	0,35	0,7

Table 2 – Estimates of the conditions of occupancy in XVII and XXI centuries and ratio of volume and surface in plan with number of audience. In the case of PR the values for orchestra refer to seated and standing people respectively. The values in parenthesis refer to actual global volume (cavea plus stagehouse).

Compared to present standards the theatres at the time they were built were overcrowded since no rule were fixed for security or preservation of the building itself. The most striking result is that the ratios of number of listeners and volume are in line with the values suggested for concert halls, especially regarding volumes (with 10m³ for MN !) while the ratio S/N is rather small for PR and VC. It also evident that the present use of the theatres has to deal with an unfavorable match of number of listeners with the volume and the surface of the halls.

THE ACOUSTICAL MEASUREMENTS

The Positions Of Sound Sources And Receivers

Though an extensive range of studies on the architecture and design concepts of the theatres is available, to the knowledge of the authors the acoustical characteristics of such spaces has not been scientifically documented until now. This is one of the major motivations to pursue a dedicated measurement campaigns inside the three theatres, which were done in the Summer and Autumn 1999. Previous to these measurements a document was elaborated concerning the guidelines for making acoustical surveys inside historical theatres [1]. In this document the positioning of sound sources and the grid of receivers is suggested for the typology of theatres included in this study and a sketch of possible measurement chains is also provided. Referring to the above document the number of sources receivers according to the measured theatres can be found in the Table 3.

	Receivers				**Sources**		
	Orch.	***Aud.***	***Log.***	***Stage***	***A1***	***A3***	***A4***
MN	11	5	2	-	-	X	-
PR	11	10	-	2	X	X	X
VC	12	3	-	1	X	X	-

Table 3 – Number of receivers according to the area of the theatre during acoustical measurements and positioning of the sound sources. A1 lays in the orchestra in the close proximity of the stage; A3 and A4 are respectively in the front and rear parts of the stage.

The indicated receivers were placed on only one side of the caveas due to the architectural symmetry of the spaces and the sound sources laid on a line parallel to the symmetry line, at 1m from it. Though the coverage of the receivers was good in orchestra and tiers of steps it was not possible to access the loggia both in PR and in VC. On the contrary in MN no measurement was done on the stage whereas this was possible in PR (both front and rear) and VC (only front). The results of the surveys in terms of acoustical parameters will be relative only to the source position A3, which is placed at 2m from the stage border (1m for MN), since A3 is common to the three theatres. During the measurements the orchestras and stages of the theatres were completely empty and no listeners were present.

The Measurement Chain

The measurement chain was the same in the three theatres. The parts of the chain are recalled in the Table 4, where each task has the indication of the respective instrumentation.

Task	**Instrumentation**
Generation of test signal	– PC with MOTU2048 soundcard – Amplifier – Lookline dodecaedric equalized sound source
Micing of sound field	– Binaural probe Neumann KU100 – B-format probe Soundfield ST250
Recording of the signal	– Line preamplifier Tascam MA/AD8 – Digital recrder Tascam DA38
Post elaboration	– PC with MOTU2048 soundcard – Cooledit with Aurora package

Table 4 – Chart of the measurement chain employed for the acosutical measurements inside the three theatres.

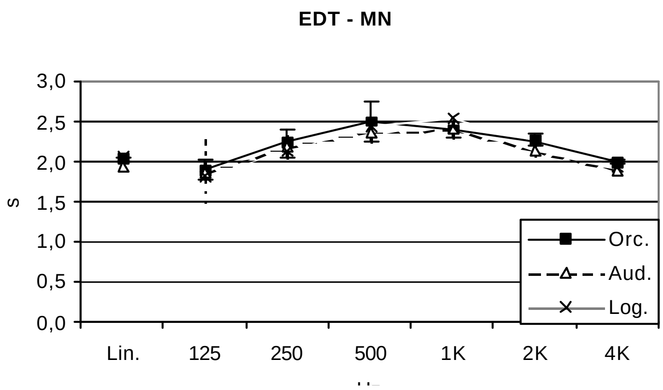
The measurement chain permitted the parallel spatial sampling of binaural and B-format data of the sound field created by the dodecaedric sound source within the empty halls and the successive off-line post-elaboration. The test signal consisted in a 17th order Maximum Length Sequence. The test sample was repeated at least sixteen times at each position to improve the S/N ratio. The raw data were then digitally stored on magnetic tapes via 20bit digital recorder and later processed for calculation of acoustical parameters. The sound sources were placed at 1.25m from the floor whereas the receivers were at 1.1m. The two sound probes were put side by side at nearly 0.7m to minimize mutual influence. The calculation of acoustical parameters was based on the omnidirectional signal enclosed in the B-format coding (called W) whereas the binaural signals and the other B-format tracks served to implement analysis not reported in this work.The calibration of the measurement chain was done by means of a reference measurement at the end of each session. In this case the sound probes and the source were put on the stage at a fixed mutual distance (3m) and height above the floor (2m). This measure was used to establish the level of the direct sound with respect to the other source-receiver couples.

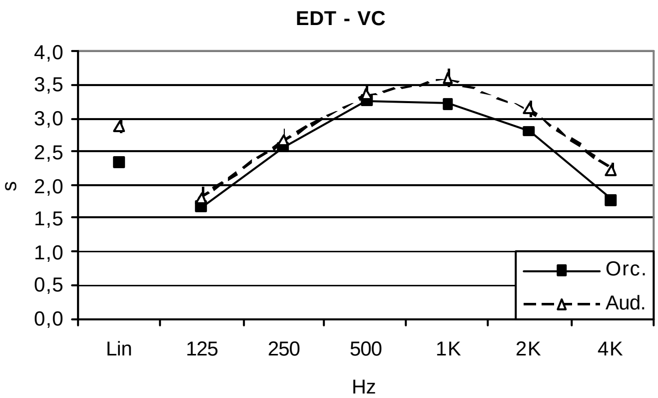
THE RESULTS OF THE ACOUSTICAL MEASUREMENTS

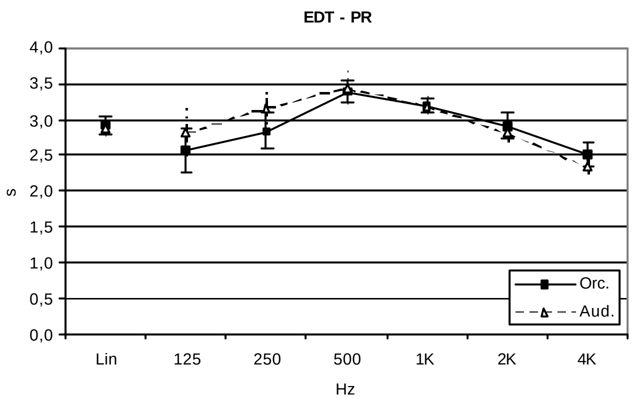
The results of the measurements will be now presented mostly in the form of graphics with the frequency distribution of acoustical parameters, whose definition can be found in [2] and whose suggested values are reported in [3]. The graphics are divided according to each theatre and, within each plot, to the area. The error bars of 66% confidence are included where there are sufficient data for statistical analisys. The all pass ‘Lin” values are also plotted as reference.

Early Reverberation Time

The dependence of the reverberation time with frequency in the empty halls has a similar pattern with maxima found either at 500 or 1000Hz. The pattern seems to characterize well the typology of theatres, mainly because of the massive presence of wood panels absorbing sound in the lower frequency range. The curves in MN show reduced mutual differences and have in general the lowest values compared to PR and VC. The latter two have some major gap in the early reverberation between orchestra and tiers which is probably due to different design of this area. In fact in both cases the Orc. is delimited by rather high lateral walls (wooden in PR and plaster in VC). In absolute terms the recommended concert hall values are not met, but it is to be recalled that for this theatres the presence of audience shall cause dramatic change of reverberation. The values of reverberation time RT20, not reported here, show a good agreement with the curves for Aud. in the respective halls.

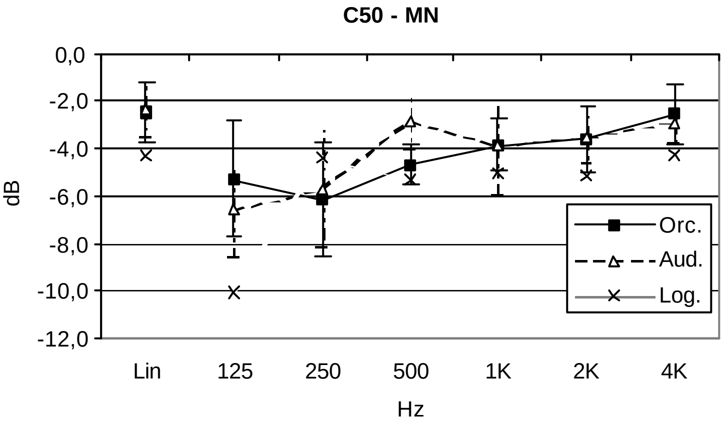


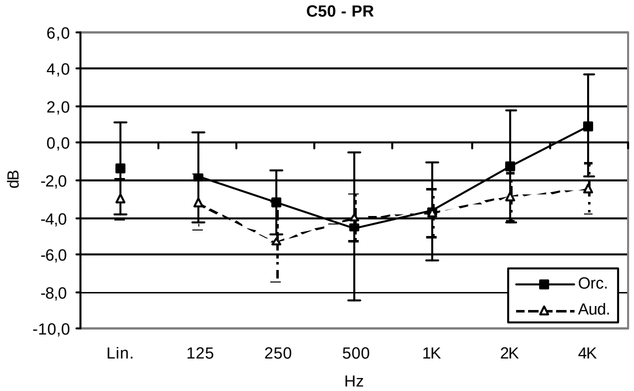


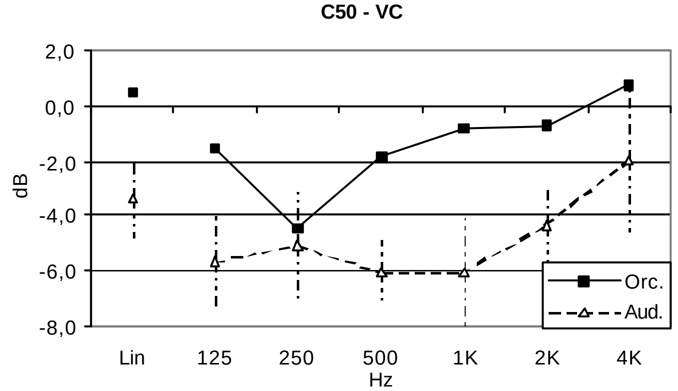


Clarity

The next figures show the plots of C50 in the three theatres. The values of the parameter are low and in the conditions of measurement the clarity is not satisfactory. The parameter has also fairly large fluctations in each area probably due to peaked contributions of single reflections. Nevertheless it is interesting to note that there are both similar patterns and values between PR and VC, especially in the Aud. The Orc. curve of VC lays well above the others, because of the close strong reflections from the hemielliptical side wall. The MN graphic has rather uniform trend of Orc. and Aud, with the Log. points showing a more irregular behaviour. The C80 plots, not reported here, show a course very similar to C50, with a translation along the y-axis by nearly +2dB for VC and PR and by nearly +1dB in the case of MN.

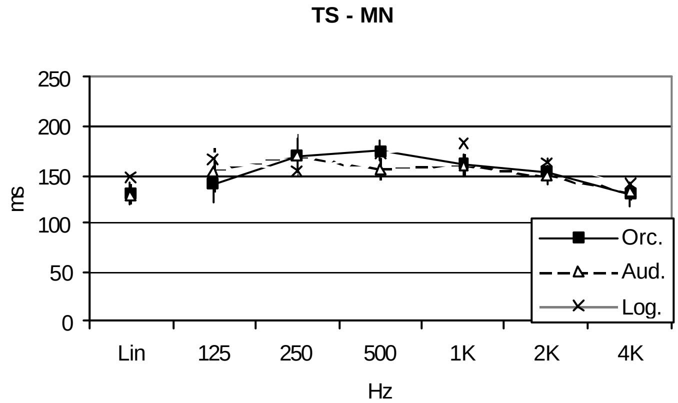


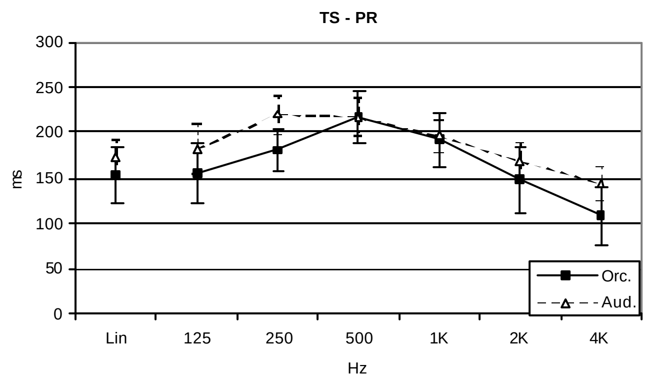


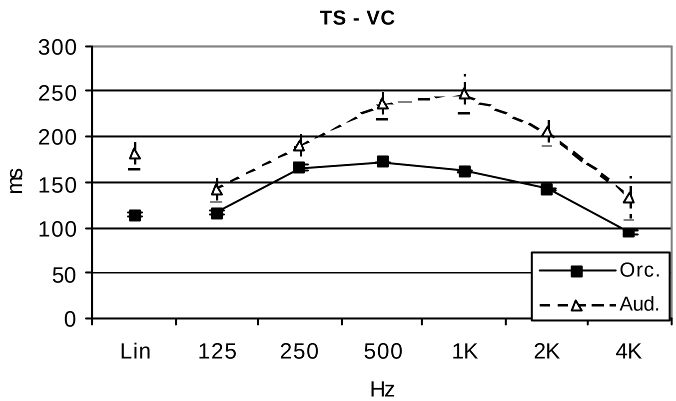


Centre Time

In the MN plot this parameter shows rather well balanced values across frequency, which conform well with conditions for musical performance. The plots for Orc and Aud in PR and VC are more curved and separated. They tend also to be more dispersed and have globally higher values, especially in the medium frequency range. In particular VC lays close to the upper bounds of the useful range of TS. Moreover an evident split is noted in VC which is still due to the presence of close surfaces for points in the Orc.

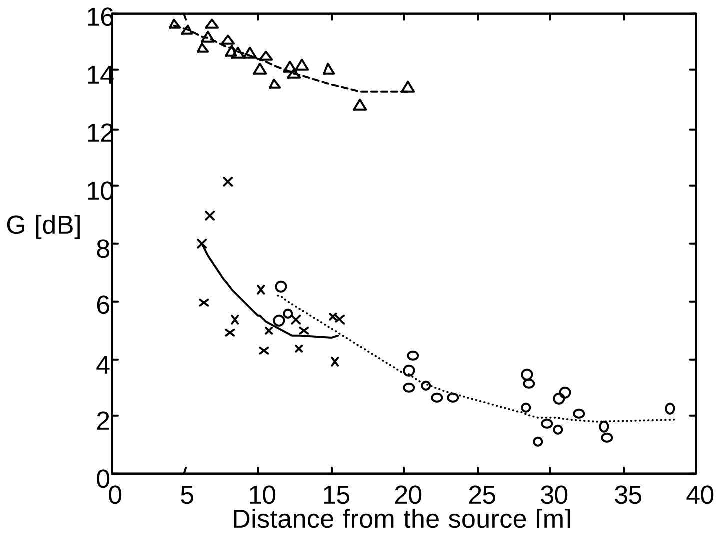






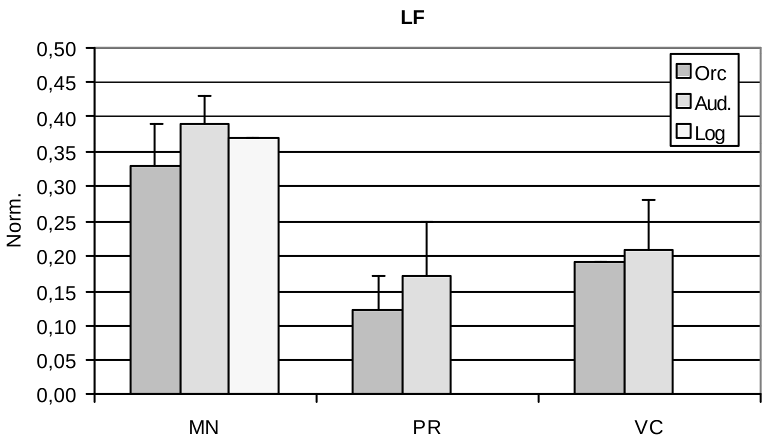
Strength

The figure on the side shows the all pass values of G in the MN (Ä), VC(x) and PR(o) theatres. The respective points are interpolated by a regression line calculated in order to describe a possible dependence of G with distance. The points used in the calculation are those measured for the single source position indicated above, ordered with distance. Though G is satisfactory for each hall it is shown that MN has very favorable values so that also recitals and small groups would be able to play without significant effort. The curves for VC and PR lay well below MN and have a region of overlap which corresponds to the farthest point of VC and the closest of PR. Effectively the dimensions of PR caused the receivers to be mostly grouped into three major distance ranges at 10 – 13 m, 19 – 24 m and 28 – 35m.



Lateral Fraction

Finally the graphic on the side shows the averaged values of the all pass Lateral Fraction with the 66% dispersion indication. The values are markedly high for MN due to the limited width of the cavea and the design of the tiers, surrounded by a curved wall. The values of PR and VC are also rather good and in particular it is shown that the Aud. bars always surpass Orc.. The design of tiers seems to improve lateral energy together with the upper colonnades present in each of the halls.



DISCUSSION

The most evident difference between either concert halls or opera houses and the theatres here considered is the almost complete absence, in the latter, of massive sound absorbing areas like upholstered seats or audience. So it seems that a further effort is necessary to investigate the variation of acoustical conditions with the presence of audience, which, as briefly estimated in Table 2, might set excellent values for musical or also play venues. Nevertheless the data here reported gave interesting clues to better know the typology of performance spaces. In particular the shape of the reverberation across frequency seems to well define the kind of interior surfaces notwithstanding the very different volumes of the theatres. The reverberation times exceed the suggested values for concert halls or opera houses even for MN which has the comparatively lower values. Moreover the study of clarity and centre of gravity of energy both show that the lower values of distinctness are found in the medium range of frequency for PR and VC, which might result in a lower ability of perceiving vocal or singing pieces. The study of lateral fraction confirmed the robust design of MN but showed that a satisfactory spatial impression that can be experienced in PR and VC too. As regards the strength it is important to relate the measured values to the kind of venues possibly held in the theatres. In this respect the shape and area of the stage in MN and VC are suitable for recitals and chamber music (or play as well) whereas the very wide stage in PR could easily host a symphonic orchestra. The respective values of G are somehow tailored on this considerations so that, while MN has remarkable levels, also VC and PR fit well with the relative destination.

CONCLUDING REMARKS

The measurement and analysis of the acoustical parameters inside three world-famous Italian renaissance theatres has been accomplished for the first time. The acoustical environment of these spaces has some evident similarities which are anyway subject to major geometrical differences mainly due to volume and ratio of respective dimensions. Further researches will include simulations of occupancy and relation with classical theory of reverberation.

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