

Spatial distribution of monaural normal descriptors in eight historical Italian theaters

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ABSTRACT

This paper studies the spatial resolution needed to measure and to characterize an horseshoe shaped Italian theatre. Eight historical theatres have been studied measuring the impulse response at each seat position. The case study theatres have been chosen with different volumes, seating capacities and structural materials. Monaural normal factors T_{sub} and Δt_1 have been extracted from the IRs and analyzed. The statistical frequency distribution of the parameter is presented, according to similar literature in different shaped theatres.

1. INTRODUCTION

The acoustical quality of an historical theatre may be assessed using the criteria extracted from impulse responses (IRs) measured at listener seats. ISO 3382 [1] recommends a minimal set of positions, but also suggests that increasing the receiver number the accuracy of the measurements increases. The Charter of Ferrara [2] suggests different minimum sets of measurement points in different historical type of theatres.

The present study evaluates the accuracy of measurements studying the statistics of the monaural criteria T_{sub} and Δt_1 extracted from IRs measured at each seat in the audience.

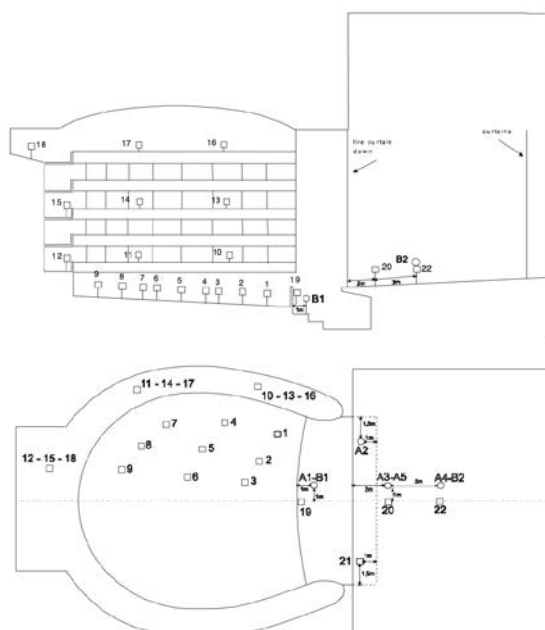


Figure 1: Measurement positions suggested by Ferrara Charter in an historic Italian Theatre [2]

2. MEASUREMENT PROCEDURES

Measurements of IR have been made in eight historical theatres with different size but similar shape (see Fig. 2):

- a) Bonci Theatre of Cesena, inaugurated in 1846, after almost 20 years of works. The auditorium is in fact divided into four tiers of boxes with the addition of a fifth tier which is the gallery.
- b) Rossini Theatre of Lugo, the oldest municipal theatre in Emilia Romagna among those still existing: it was erected in 1757. The theater is bell-shaped and presents 4 tiers of boxes and a gallery at the 5th floor.
- c) Masini Theatre of Faenza, inaugurated in 1788. The Masini presents the usual horseshoe shape, with 4 tiers of boxes and a gallery at the 5th floor.
- d) Petrella Theatre of Longiano. Inaugurated in July 1870. It is the result of stylistic academic encoding, represented by the typical horseshoe-shaped auditorium. The audience is surrounded by 2 tiers of boxes and a gallery at the 3rd floor.
- e) Dragoni Theatre of Meldola, inaugurated in 1837. The building presents a horseshoe-shaped audience, surrounded by 3 tiers of boxes and a gallery.
- f) Comunale Theatre of Russi, built in 1881, when the old Comunale was declared unsafe. The horseshoe-shaped audience is surrounded by 2 tiers of boxes and a gallery.
- g) Comunale Theatre of Cesenatico, inaugurated in 1865, presents 2 tiers of boxes and a gallery at the 3rd floor.
- h) Comunale Theatre of Cervia, the new theater was completed in 1860. The building is composed by 2 tiers of boxes and a gallery at the 3rd floor.

Table 1. Data of the measured theaters

| Theater | Bonci | Lugo | Faenza | Longiano | Meldola | Russi | Cesenatico | Cervia |
|--------------------------|-------|------|--------|----------|---------|-------|------------|--------|
| Year of inauguration | 1846 | 1757 | 1788 | 1870 | 1838 | 1881 | 1865 | 1860 |
| Volume (m ³) | 2798 | 1455 | 2628 | 679 | 1205 | 924 | 733 | 858 |
| Seats (total) | 800 | 448 | 500 | 241 | 318 | 305 | 271 | 224 |
| Scenic arch length (m) | 12 | 9.2 | 10 | 7.8 | 6.8 | 8 | 7.3 | 8.1 |
| Scenic arch height (m) | 7.8 | 7.6 | 12.6 | 8.8 | 8.1 | 7.2 | 8.5 | 7.1 |
| Audience slope | 4.6% | 1.9% | 0.8% | 5.8% | 3.3% | 1.7% | 5.5% | 5.75% |

IRs have been measured at each seat. The values of T_{sub} have been extracted from the envelope of the decay curves, as presented in [10]. The values of Δt_1 have been extracted using the algorithm proposed in [3]. Only the IRs measured in the audience are evaluated and compared here.



(a) Bonci Theatre, Cesena



(b) Rossini Theatre, Lugo



(c) Masini Theatre, Faenza



(d) Petrella Theatre, Longiano



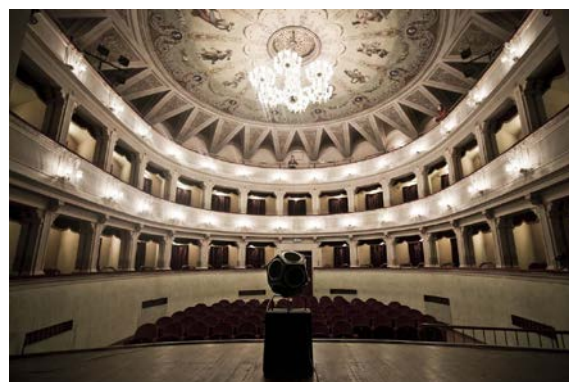
(e) Dragoni Theatre, Meldola



(f) Comunale Theatre, Russi

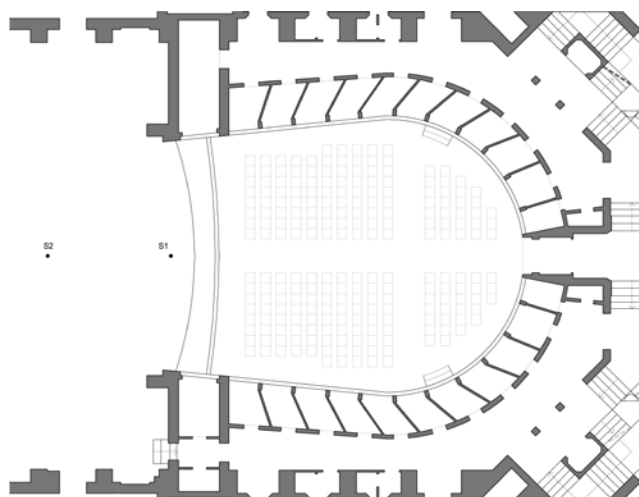


(g) Comunale Theatre, Cesenatico

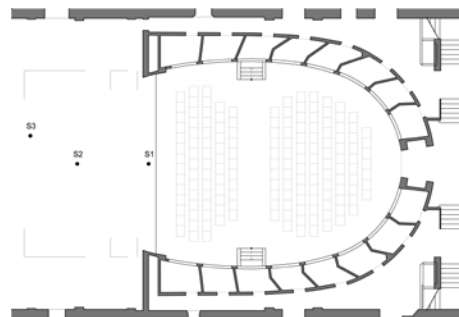


(h) Comunale Theatre, Cervia

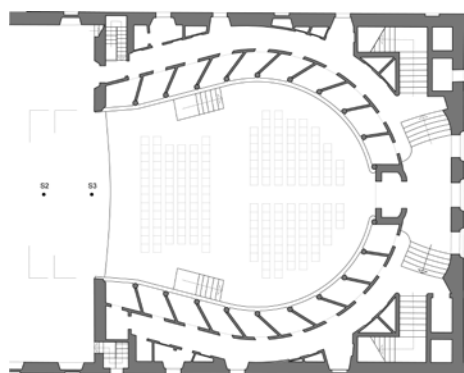
Figure 2: Photos of the test theatres measured in this study



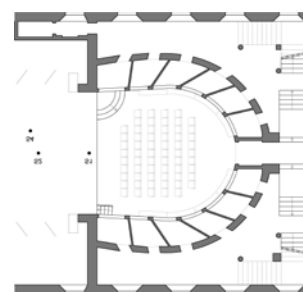
(a) Bonci Theatre, Cesena



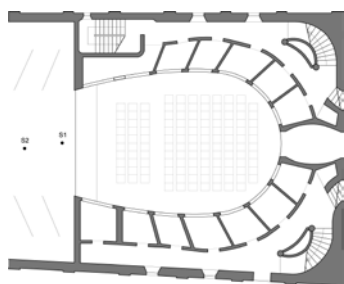
(b) Rossini Theatre, Lugo



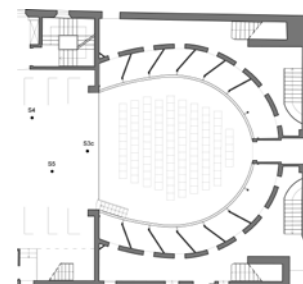
(c) Masini Theatre, Faenza



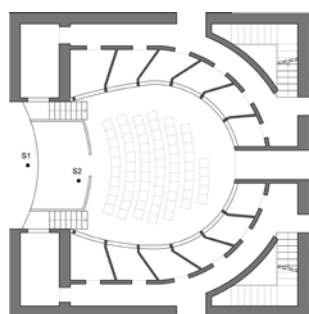
(d) Petrella Theatre, Longiano



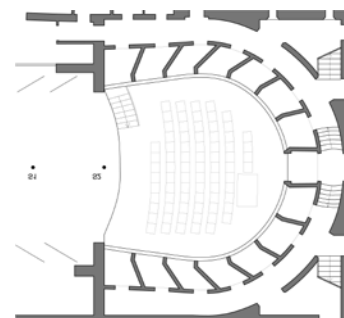
(e) Dragoni Theatre, Meldola



(f) Comunale Theatre, Russi



(g) Comunale Theatre, Cesenatico



(h) Comunale Theatre, Cervia

Figure 3: Plans of the measured audiences, with source positions

3. ANALYSIS OF NORMALITY TEST

Normality tests were carried out for each criterion extending what has been done in [5, 6] using statistical moments and the empirical cumulative distribution function $F(z_i)$:

$$F(z_i) = \frac{1}{\sqrt{2}} \int_{-\infty}^{z_i} e^{-\frac{t^2}{2}} dt \tag{1}$$

where z_i are the i -th measured data of the studied configuration, ordered and normalized.

Anderson-Darling statistics (ADT)

$$A^2 = \lambda \left[-\sum_{n=1}^N (2n-1) \frac{\ln(F(z_i)) + \ln(1-F(z_{N+1-i}))}{N} - N \right] \tag{2}$$

$$\lambda = 1 + \frac{0.75}{N} + \frac{2.25}{N^2} \tag{3}$$

Kolmogorov-Smirnov statistics (KS)

$$D = \max(D^+, D^-) \tag{4}$$

$$D^+ = \max_{1 \leq i \leq n} \left[\left(\frac{i}{n} \right) - F(z_i) \right] \qquad D^- = \max_{1 \leq i \leq n} \left[F(z_i) - \left(\frac{i-1}{n} \right) \right] \tag{5}$$

Pearson χ^2 (CHI)

$$\chi^2 = \sum_{i=1}^n \frac{(z_i - \mu)^2}{\mu} \tag{6}$$

Jarque-Bera (JB)

$$JB = \frac{n}{6} \left[S^2 + \frac{1}{4}(K-3)^2 \right] \tag{7}$$

where S is the skewness and K is the kurtosis. If the calculated statistic exceeds the critical value (a type I error of $\alpha = 0.05$ is assumed), the so called null hypothesis of normality may be rejected. The results of the normality tests are summarized in table 1. The ‘0’ value means that the test has been passed; the ‘1’ value means that the test has not been passed.

Table 2. Results of normality tests in the boxes (0: test passed, 1: test not passed)

| Theatre | CESENA | | | | | | | | LUGO | | | |
|------------------|--------|----|-----|----|-----|----|-----|----|------|----|-----|----|
| Source | S1 | | | | S2 | | | | S2 | | | |
| Test | ADT | KS | CHI | JB | ADT | KS | CHI | JB | ADT | KS | CHI | JB |
| T_{sub} 125 Hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 250 Hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 500 Hz | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 KHz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 KHz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Δt_1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| Theatre | FAENZA | | | | | | | | LONGIANO | | | | | | | |
|------------------|--------|----|-----|----|-----|----|-----|----|----------|----|-----|----|-----|----|-----|----|
| Source | S2 | | | | S3 | | | | S1 | | | | S4 | | | |
| Test | ADT | KS | CHI | JB | ADT | KS | CHI | JB | ADT | KS | CHI | JB | ADT | KS | CHI | JB |
| T_{sub} 125 Hz | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 250 Hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 500 Hz | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 KHz | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 KHz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Δt_1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |

| Theatre | MELDOLA | | | | RUSSI | | | | | | | |
|------------------|---------|----|-----|----|-------|----|-----|----|-----|----|-----|----|
| Source | S1 | | | | S3 | | | | S3C | | | |
| Test | ADT | KS | CHI | JB | ADT | KS | CHI | JB | ADT | KS | CHI | JB |
| T_{sub} 125 Hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 250 Hz | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 500 Hz | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1 KHz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 2 KHz | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Δt_1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| Theatre | CESENATICO | | | | | | | | CERVIA | | | | | | | |
|------------------|------------|----|-----|----|-----|----|-----|----|--------|----|-----|----|-----|----|-----|----|
| Source | S1 | | | | S2 | | | | S1 | | | | S2 | | | |
| Test | ADT | KS | CHI | JB | ADT | KS | CHI | JB | ADT | KS | CHI | JB | ADT | KS | CHI | JB |
| T_{sub} 125 Hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 250 Hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 500 Hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 KHz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 KHz | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Δt_1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

4. DISCUSSION

When evaluating the average values of some acoustic criteria at low frequency, according to previous literature [1, 5] the strict application of ISO 3382-1 or the Charter of Ferrara may be a limit, because small subsets of receiver positions are hardly representative of the “average” acoustics of the hall. Strictly speaking, average values over the audience or over all the boxes are representative if and only if the statistical distribution of the data is Gaussian. Thus, normality tests should be applied to determine whether this assumption is verified.

While in previous literature only one normality test is usually applied [6], in the present study different normality tests have been applied to the same data sets, obtaining different results as a function of the different assumptions underlying each test.

The results should be interpreted carefully. Looking at the individual IRs, one could guess that this is due to the different values of the Peak to Noise Ratio (PNR) and Decay Range [9] in the boxes and in the audience. In fact, in the audience the first reflections are well isolated and come from the main surfaces of the hall, while in the boxes they are more distributed in time and come from the interior of the boxes [11]. In this regard, it should be remembered that in Italian historical theatres there is a strong contribution of the first reflection due to the proscenium arch and some surfaces around the audience; in the lower octave bands an additional uncertainty component may come from the used filters [8].

Measurements also confirm that the symmetry along the main axis of the hall is always respected [11].

4. CONCLUSIONS

Following and expanding what is suggested in previous literature a statistical analysis of measured reverberation values has been carried out. While the existing literature is focused on modern concert halls, the present study is focused on historical horseshoe shaped theatres. IRs have been measured at each seat of eight historical Italian theatres.

Different statistical tests have been applied to these data sets, obtaining useful indications about the normality of the underlying statistical distributions in Italian historical theatres.

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