

Building Physics during the Restoration of the Teatro Nuovo in Spoleto

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Abstract - The Teatro Nuovo, the theatre where the famous international “Festival of the Two Worlds” is based, after a full restoration work and functional adaptation, has been returned to the city of Spoleto and its audience. The restoration works of the theatre started in 2003 for improving the safety levels and for adapting the operational functionality of the machines on the stage to the current needs of the show, including the acoustic performances. In particular, the Department of Energetic Engineering, Nuclear and Environmental Control of the University of Bologna collaborated with the Teatro Nuovo from the acoustic point of view. In order to monitor the acoustic performance of the concert hall, two campaigns of acoustic measurements, respectively before and after the restoration works, have been conducted, verifying the conservation of its original acoustical characteristics. The measurements were performed through an omnidirectional loudspeaker, a dummy head and a Soundfield probe. The results of the measurements of every campaign are presented in this article.

Keywords: Acoustical design, Acoustic spatialisation, Room acoustics measurements.

1. Introduction

Evaluating building performance is a central topic to align the building to the overcoming needs and for complying with Energy efficiency legislation [1]. In-situ measurement are of great interest since they help designing scenarios [2] and test the simulated ones [3]. Furthermore, new metrics such as exergy [4] are adopted especially in Research & Development plans for innovative solutions [5] in the field of energy [6], acoustics [7] and comfort [8]. Great attention in the last decade was given to energy involving buildings at different scales, from the single one to urban level [9] but neglecting the main aspects of indoor wellbeing [10] mainly related to thermal insulation layers [11] and acoustic materials used in the ambient [12]. Experimental campaign is crucial to check the effective benefits of the designed solution once become real with a focus on cutting-edge technologies [13] installations, changes in the systems due to the novel components [14], performance outside the building’s boundaries such as emissions [15] or energy exchanges with the Grid [16] and inside the building like the occupants’ behaviour [17]. When the analysis is related to an existing building, its architectural features and its main past and future used must be considered. In the case of a theatre, acoustics is the main building physics matter to study and to check once the renovation is ended [18]. This paper deals with the case study of a theatre in Spoleto, Italy. It is the Teatro Nuovo, erected between 1853 and 1864, based on the plan of the architect Ireneo Oleandri: it was realised starting from the necessity to construct a new theatre, in a central place of the town of Spoleto, which could replace the previous “Ancient theatre”, considered narrow, echoless and filthy.

The building represents a remarkable example of neoclassic architecture and of the nineteenth-century theatre “in Italian style” (see Figure 1), and nowadays it hosts the Festival of the Two Worlds, the Lyric Experimental Theatre and other cultural events. The adaptation and restoration works of the Teatro Nuovo, lasting 3 and half years, have allowed to improve the functionality of the theatre as a whole, to adjust the parts not in compliance with norms regarding the conditions of emergency of the public and of the structure. The design and the modelling part had to guarantee a correct use of the structures in the respect of the original characteristics of the architecture, to adapt the operation of the stage machines to current needs of the show and to enhance the levels of comfort for the public, including the acoustics. Here the link to be verified between foreseen performance and actual ones after restoration is important [19]. The new adjustments requires a deep investigation on the energy supply even considering the option to leave the terminals once already part of the listed interior design and, therefore, not to be modified [20]. Anyway, a detail will be given only to acoustics.



Fig. 1: Front of the Teatro Nuovo.

The works allowed to consolidate the wooden structures of the boxes, to improve the conditions of emergency for the workers and the public through the adaptation of the parapets in the boxes and to restore the pictorial and plastic decorations of the “Show Hall”, of the “XVII September Hall”. Referring to the façades, a reconstruction of the flooring in the arcade and in the entrance halls occurred. Since the restoration works required a special care both from the conservation of the original characteristics of the architecture of the “Show Hall” point of view and of its acoustic functioning, the Umbria Region commissioned the Department of Energetic Engineering, Nuclear and Environmental Control of the University of Bologna the acoustic consultancy since its experience [21-23]. Before closing the theatre, a first campaign of acoustic measurement has been carried out, and once the Theatre reopened, a second campaign was carried out, in order to control any modification of the acoustic performance. In this article the two campaigns of acoustic measurement, carried out before and after the restoration, are analysed and compared.



Fig. 2: View of the chandelier and the clock of the Teatro Nuovo.

2. Measurements of Acoustical Quality

The measurements were conducted for every positioning the loudspeakers in the stage-proscenium, and microphones in several points in the stage.

For both two campaign of acoustic measurements the following instruments were utilized:

- a dummy head (Sennheiser), which allowed the measurements of binaural parameters, like IACC;
- an equalised, omnidirectional, loudspeaker located in few positions on the stage;
- a Soundfield microphone (MK V) which was added to the dummy head for the measurements of 3dimensional parameters like LE and LF, and also allowed the measurements of mono-aural parameters, like reverberation time, clarity and centre time.

The measurements were conducted by means of a logarithmic sinusoidal sweep, ranging between 40 Hz to 20 kHz. The signals acquired by the microphone were stored in the 20 bits, 96 kHz soundboard (Layla) of the computer, and then post processed in the laboratory.

3. Analysis of Measurements

The Teatro Nuovo consists of a shoe-box shape and four orders of balconies (see Figure 3).

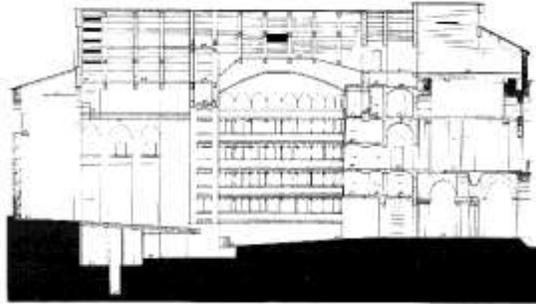


Fig. 3: Longitudinal view of the theatre.

The acoustical measurements were performed, in the first campaign of measurements in 2002, by positioning the sound source in 2 positions and the microphones in 54 positions between the stage and balcony, while in the second campaign in 2007, measurements are carried out by the sound source in 4 positions and the microphones in 66 positions between the stage and balcony. This could allow the opportunity to test innovative materials [24] and to build mathematical models to investigate deeply the acoustic phenomena [25] or simulation tool to check performance [26], even in historical buildings [27].

3.1. Frequency Analysis of Acoustical Parameters

As mentioned, the acoustic parameters were calculated from the omnidirectional (W channel) output of Soundfield microphone, whilst LE and LF were calculated combining the W and Y tracks of the Soundfield. The frequency response of the theatre could be evaluated analysing in the frequency domain the acoustical parameters. All acoustical parameters were calculated both in the stalls and for the balcony for every campaign. In figure 4 a) and b) the histograms in the frequency domain of EDT and T_{20} are depicted, whilst in figure 5 a) and b) the frequency values of C_{50} and C_{80} are reported. Comparing both the Early Decay Time and T_{20} measured in the two campaigns, it is evidence that the theatre presents values rather low of reverberation and gradually reduction of reverberation time up to high frequencies. The Teatro Nuovo resulted a rather dry theatre as many other Italian theatres. Since the optimal values for T_{20} ranges, for the opera, between 1 and 1.5 s, and for symphonic music between 1.8 s and 2.6 s, the measurements highlighted the lyric aptitude of the Teatro Nuovo, especially at medium frequencies. Comparing the values reported in figure 5 a) and b), there is evidence, on the contrary, that the restoration work has modified the indexes of clarity, rather than the reverberation time. In 2002 the values of C_{80} resulted too high, with values for opera houses not acceptable. On the other hand, the values of C_{50} , variable between -2 dB and 2 dB particularly at low and medium frequencies, demonstrated that the theatre is now more appropriate for speech. On the other hand, the measurements conducted in 2007 has revealed that C_{50} , resulted rather high, while the C_{80} , ranging between -2 dB and 2 dB for almost all frequencies, demonstrates that the *Teatro Nuovo* is suitable for musical performances, as previously shown by T_{20} .

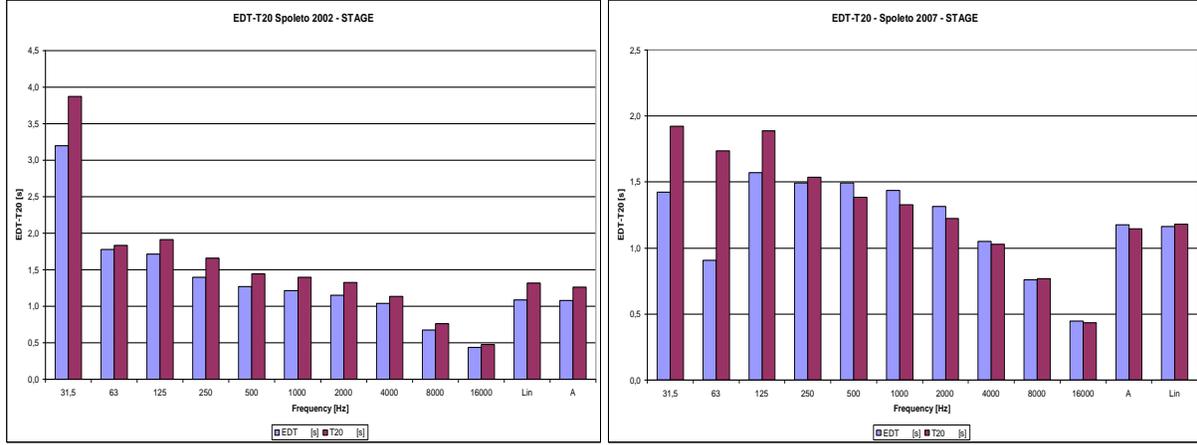


Fig. 4: EDT-T₂₀- Teatro Nuovo 2002-stage (a) and 2007-stage (b).

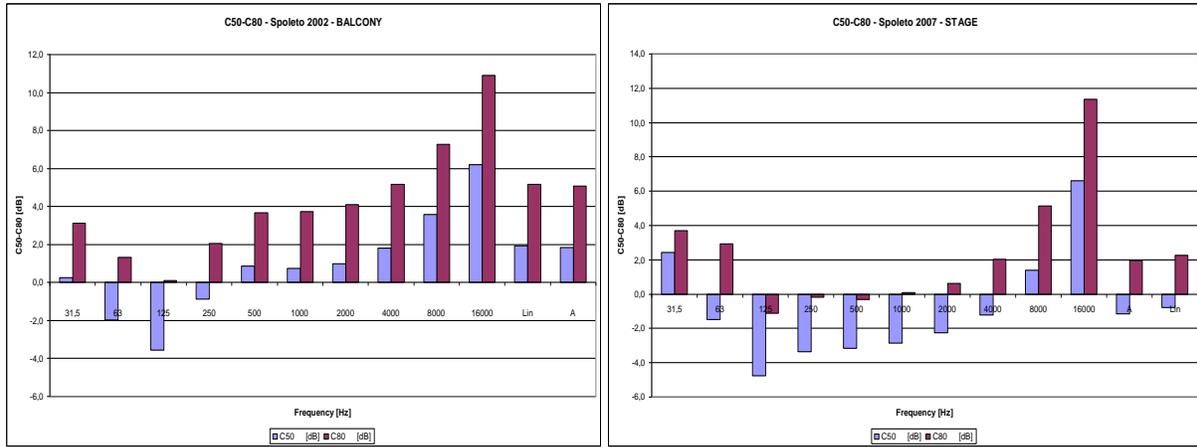


Fig. 5: C₅₀-C₈₀- Teatro Nuovo 2002-stage (a) and 2007-stage (b).

3.1. Frequency Analysis of Acoustical Parameters

From the measurements, the more important spatial acoustical parameters (IACC, LE and LF) were calculated. The Inter Aural Cross-Correlation coefficient (IACC) is defined as [1]:

$$IACC = |\rho(\tau)_{max}|, (\tau \leq 1ms) \quad (1)$$

where:

$$\rho(\tau) = \frac{\phi_{ds}(\tau)}{\sqrt{\phi_d^2(0) \cdot \phi_s^2(\tau)}} \quad (2)$$

The spatial acoustical maps, which describe the distribution inside the theatre, of IACC are reported in Figure 8 for every campaign of acoustic measurement. Considering the spatial distribution of sound energy, the maps of IACC in the Teatro Nuovo, before the restoration (Figure 6a), compared with the maps after the works (Figure 6b), reveals an increasing value of IACC, whose value moved from 0.3 to 0.5.

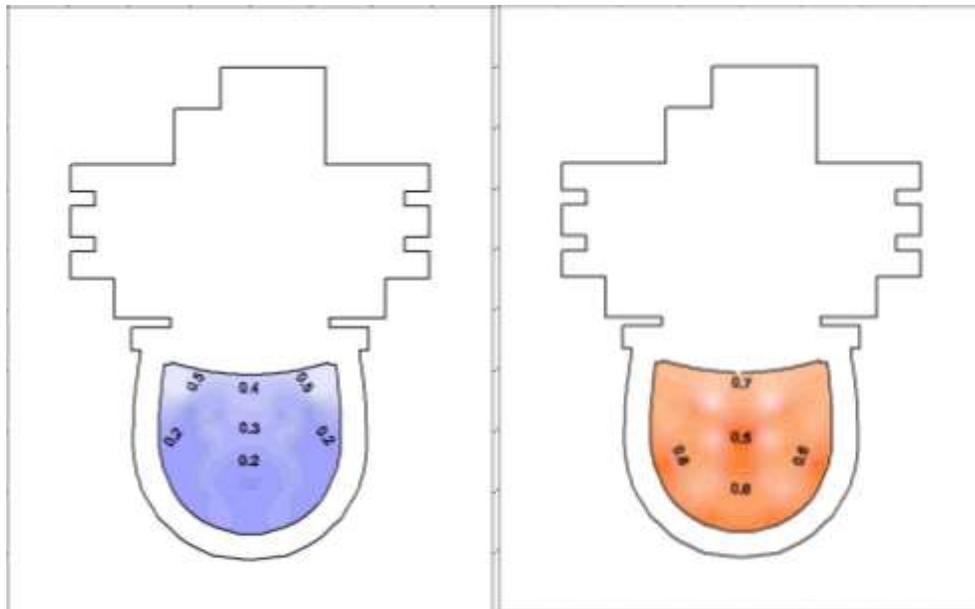


Fig. 6: IACC- Teatro Nuovo 2002-stage (a) and 2007-stage (b).

4. Conclusion

In this work the acoustical properties of Spoleto's *Teatro Nuovo* have been analysed, comparing the two different campaigns of acoustic measurements conducted in 2002 and in 2007. The restoration works of the theatre were necessary to increase the safety of the theatre and to adapt the operational functionality of the machines on the stage to the current needs of the show. The two campaigns of acoustic measurements have been carried out to check the acoustic performance of the theatre, before and after the works. The comparison has shown some slight modification of the acoustic characteristics. The acoustic performances of the theatre are globally enhanced, contributing at good perception of acoustic space, especially for the opera and symphonic music. Today, the *Teatro Nuovo* can, therefore, give again hospitality to Festival of the Two Worlds with a renewed form.

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